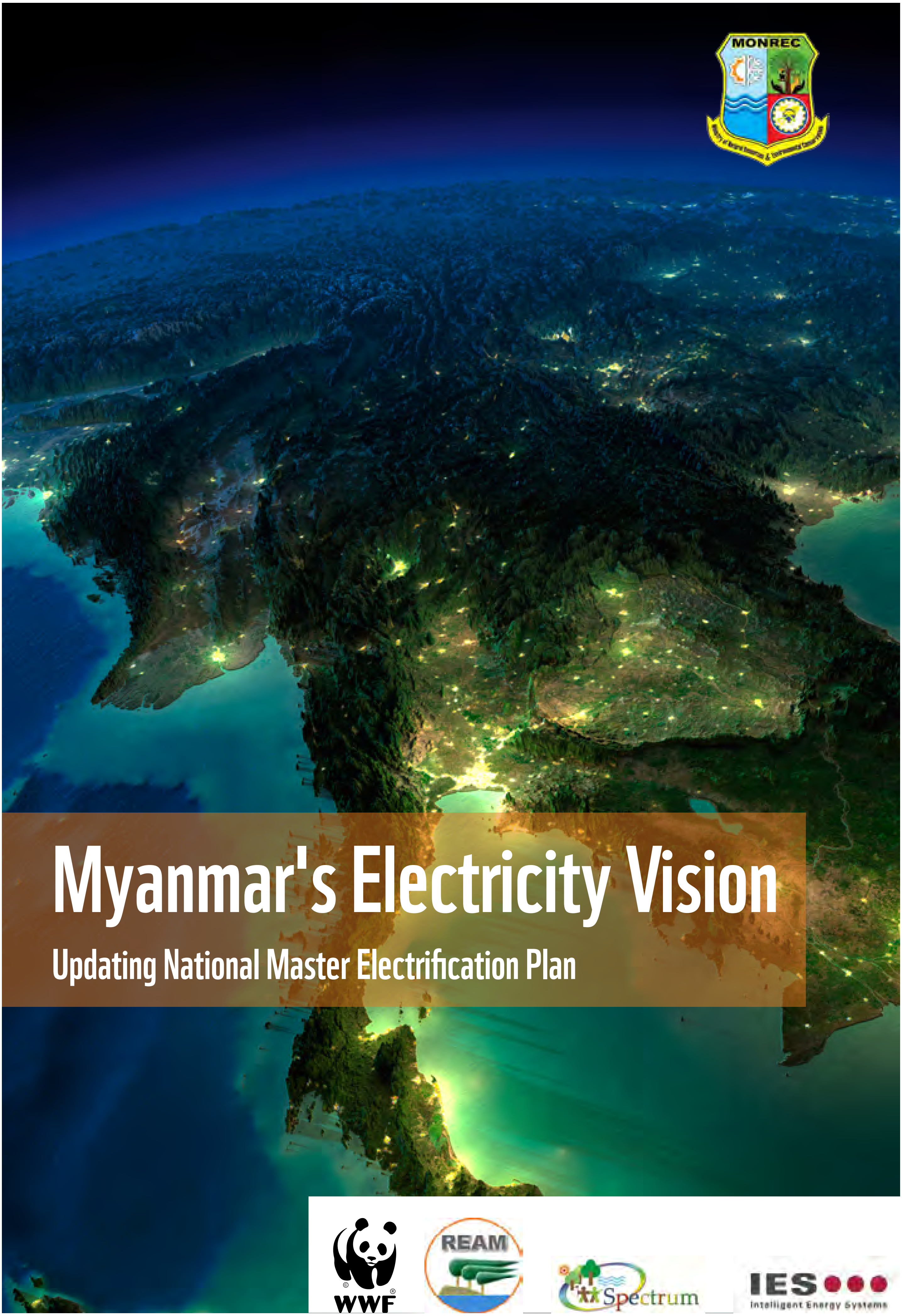

Myanmar's Electricity Vision

Updating National Master Electrification Plan

WWF

WWF is one of the world's largest and most experienced independent conservation organisations, with over 5 million supporters and a global Network active in more than 100 countries.

WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

IES

Intelligent Energy Systems (IES) is an Australian consulting firm established in 1983 to provide advisory services and software solutions to organisations working in the energy industry. IES specialise in taking systematic approaches to solving problems in energy markets that require consideration of energy policy, legislation, economics, finance and engineering. IES has a proven track record in advising government departments, regulators, system and market operators, transmission companies, generators and retailers in the Asia Pacific region, including Australia, the Greater Mekong Sub-region, Philippines, Singapore and elsewhere.

MKE

Mekong Economics Ltd. (MKE) is a leading economic and socio-economic development and commercial consulting firm active in the Greater Mekong sub-region and Asia-Pacific region. MKE has over 20 years of experience in providing specialist services to international development agencies, non-government organizations and corporate clients.

Spectrum

Sustainable Development Knowledge Network is a local initiative working towards the goal of establishing mechanisms to enhance frameworks for "National Development" in Myanmar, via constructive engagement on environment, sustainable development and natural resource management matters. It was founded in 2007. We are passionate about inclusion, involvement and empowerment of people as well as transparency and accountability. Spectrum connects with government, business and communities to inform, empower and educate as an information-sharing network. Spectrum provides resource materials and training, sharing relevant research and case studies, and promotes positive engagement between the government, private sector and society.

REAM

Renewable Energy Association Myanmar (မြန်မာပြန်ပြည့်မြဲစွမ်းအင်အသင်း) was established as an environmental NGO in Myanmar since 1995 and got registration in Myanmar in 2003. REAM conducted series of activities of rural development throughout the country for benefit of poor communities by their participation in implementing projects of fulfilling basic needs of food, water and energy etc. aligned with public educational function. Since 2012 to recent moment, REAM has been involving in Country level policy making process in Energy and Environmental Resources sectors for developmental reform process of the country

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PART A (WWF, SPECTRUM & REAM)

PART B (IES)

FOREWORD

Myanmar , also known to the citizens as the golden land, is blessed with abundant natural resources which provide the nation with protection and benefits. Sunny dry zones in the central, long coastal lines and hilly regions in east and north provides many resources for this golden land to generate electricity.

Smart development is using these resources for the long term good of the people and nowhere is that more critical than in the power sector.

We need more electricity, the question is how we get it. More dams which displace communities and disrupt natures rivers, fossil fuel which pollutes the air we breathe and increases global warming, or wind and solar which are abundant and free?

Sustainable energy will drastically reduce the carbon footprint, prevent environmental and social degradation and create 3-4 times more job opportunities compared to fossil fuel technologies. The most important of all this study proves that the country can go 100% if we want to and it will cost the same.

Decisions made now will determine how Myanmar looks for future generations. We must make the right ones for people and for nature.

Nature protects us and we must protect nature - together we are stronger, together we have a future. Sustainable way, it's the only way.

H. E. U Ohn Winn
Union Minister
Ministry of Natural Resources and
Environmental Conservation

FOREWORD

This could be the year Myanmar takes off. Encouraged by the smooth transition to democracy, investors are pouring into the country. The international community looks forward to being increasingly engaged, not just at the topmost levels of government, but with communities at every level, in every state and region of the country.

Problems remain to be solved. Almost 70 per cent of the population has yet to access reliable and affordable electricity. However, Myanmar has the chance to convert these drawbacks into advantages by avoiding mistakes made by others and catching up with countries that have already forged ahead in harnessing renewable and sustainable energy. Rather than relying on heavily polluting high-carbon fossil fuel power generation, unsustainable hydropower projects or risky and costly nuclear power, Myanmar can focus more on renewable energy sources such as sun, wind, water, geothermal, biomass, and ocean energy.

By seizing the opportunities before it and embracing the best available technologies, Myanmar can take a giant leap into a better future for all its citizens.

About 35 million people do not have access to reliable electricity in Myanmar (IEA, 2014). Myanmar is mainly dependent on hydropower and gas for power generation, and its power development plan relies on large-scale hydropower or coal. But there is a better way. This report shows how tapping into a diverse mix of renewable sources can meet nearly all the country's electricity demand by 2050.

Renewable energy, properly exploited, can achieve a number of objectives: it can significantly reduce the nation's dependence on fossil fuels, accelerate universal access to electricity, ensure stable electricity prices for decades to come, increase job creation, strengthen cooperation with Myanmar's neighbours to optimise electricity consumption and production, and reduce damage to the environment and to society. The use of sustainable power can ensure electricity cost stability and maintain system security – that is, provide enough electricity at all times to make sure the lights don't go out.

Our report will answer some key questions:

- Can Myanmar achieve a secure, sustainable power sector for all by 2050?
- Can Myanmar move away from polluting fossil fuels, nuclear power, and large hydropower?
- Can Myanmar develop an energy-efficient power sector built around clean and inexhaustible renewable energy?

We hope this report will contribute to the debate about our future electricity mix. We strongly believe that renewable energy and energy efficiency will play a major role in Myanmar in the coming years.

Kyaw Thiha
Chairman

Resources and Environmental Conservation Committee
Amotha Hluttaw

FOREWORD

Reliable and sustainable access to electricity in Myanmar is a challenge. Currently only 32% of Myanmar households have access to grid electricity. The rest of the population either has no access or must rely on unreliable or badly maintained diesel micro-grids and small solar systems. Most grid electricity is generated by hydropower and burning fossil fuels. Myanmar must meet its rapidly growing energy needs. The critical question is how.

This comprehensive study proves that renewable energy for Myanmar is not only technically feasible but also economically feasible compared to the so-called “cheap” traditional technologies. The development of Myanmar’s power sector will require multi-billion dollar investment over the next three decades and our analysis shows that a diverse mix of renewable energy, in combination with energy efficiency measures, will be the best solution for the sustainable power development of Myanmar.

Renewable energy goes far beyond the common perception of solar lanterns and solar home systems. Large scale progress can be very fast. Italy installed 9,000 MW of solar power in 2011, almost twice the installed capacity of Myanmar which is currently around 5,000 MW. In 2015, Japan also installed 9,000 MW of solar power within a year.

The first step to renewable energy deployment is acceptance and it is usual for there to be concerns about new technologies. It has been recorded that grid operators are concerned about solar and wind power being fed into the grid, concerns also seen in Germany and Ireland but today both countries have a high share (31% and 25%

respectively) of renewable energy in their generation mix. Recent practices of grid-interconnection in developing countries as Sri Lanka, Nepal and Indonesia are also strong, providing promising examples of technological, regulatory and financial management from which Myanmar can learn.

Myanmar must shape its future sustainably. To do so the right decisions must be made now. The “traditional” approach will repeat the mistakes of its neighbors, while Myanmar has the opportunity to leapfrog to renewable energy technologies. Recent developments in the telecommunication sector have shown that both decision makers and the public are willing to make such a leap, why should this not also occur in the power sector?

Developing a vision is not an end goal, but rather the first step of systematic solution planning. We are looking forward to supporting sustainable power sector development in Myanmar.

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One regional report and five country reports

The Power Sector Vision has been sub-divided as follows: there is a report for each of the countries concerned, and one regional report. The regional report presents a summary of the national reports, and discusses regional power sector topics such as grid interconnection.

Defining renewable energy, energy efficiency and sustainable energy

"Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly or indirectly from the sun, or from heat generated deep within the earth. Included in the definition is energy generated from solar, wind, biomass, geothermal, hydropower and ocean resources, and biofuels and hydrogen derived from renewable resources" (IEA, n.d.).

"Energy efficiency is a way of managing and restraining the growth in energy consumption. Something is more energy-efficient if it delivers more services for the same energy input, or for less energy." For instance, when an LED bulb uses less energy than an incandescent bulb to produce the same amount of light, the LED is more energy-efficient" (IEA, 2016).

"Renewable" does not necessarily mean "sustainable". The location, design, planning, development, construction and operation of power plants and their energy sources (e.g. biomass) will have a strong impact on the sustainability of the project. Special additional caution is recommended for hydropower and biomass projects, which can have severe social and environmental impacts.

Initiatives exist to improve the sustainability of these energy sources. Among those, the World Commission on Dams (WCD) has provided a great deal of relevant information on hydropower. Building on the WCD principles, the Hydropower Sustainability Assessment Protocol promotes and guides more sustainable hydropower projects[1], and the Roundtable on Sustainable Biomaterials is an independent and global multi-stakeholder coalition which works to promote the sustainability of biomaterials[2]. Their certification system is based on sustainability standards that encompass environmental, social and economic principles and criteria.

But it's important to remember that selecting sustainability will not solve every problem. Much remains to be done to maximise the use of wind, solar, and geothermal energy and to use these resources as efficiently as possible.

1. http://www.hydrosustainability.org/
2. http://rsb.org/

A MOVE TOWARD MORE SUSTAINABLE ENERGY IS DESIRABLE

As it stands poised for rapid development, how will Myanmar procure the energy it needs? Should it follow the path of many developed countries and burn fossil fuels, or import costly nuclear power stations? Or should it make use of its abundant potential for renewable resources? Abundant sunshine (particularly in the central dry zone), a 1760 mile-long coastal region with strong wind potential, and growing agricultural, livestock and forestry activity could help make Myanmar one of the world's leading countries of renewable and sustainable energy.

The time to act is now. Only 32 per cent of Myanmar households (United Nation Funds for Population Activities, 2015) have access to grid electricity, while the rest of the population either has no access or must rely on unreliable or badly maintained diesel micro-grids and small solar systems. The absence of standards or maintenance means that these sources are currently erratic. Most electricity is generated by hydropower resources and fossil fuels (Ministry of Electrical Power, 2015). The outgoing government has understandably sought to meet growing energy needs with low-cost investments. The Myanmar Energy Master Plan places great emphasis on deriving energy from coal-fired power plants and big dams, despite the long-term risks and environmental damage associated with these methods. It is precisely because Myanmar has been left so far behind that it now has the chance to leapfrog the fossil fuel-based electricity era that started over 130 years ago and embrace the renewable energy era. 2016 is a critical year with the transition to a new government. There are several reasons to gradually move away from fossil fuel technologies and to embrace renewable and more sustainable energy.

68 PER CENT OF THE POPULATION HAS NO ACCESS TO RELIABLE ELECTRICITY IN MYANMAR

Growing up in a home without power and light, a child's chances of receiving a good education and finding a good job are drastically reduced. Renewable energy sources offer the chance to transform the quality of life and improve economic prospects for millions. Typically, wind projects and solar photovoltaic require less time to build than fossil-based, large-scale hydro, or nuclear-power plants. Building a solar PV project of 1MW (Tritec Group, 2014) can take less than a month, compared to three or four years for fossil-fuel plants and even longer (at least six years) for nuclear power plants (EIA, 2015). Solar and wind projects enable the rapid increase in generation capacity; solar PV, wind and pico hydro are also more modular, enabling people who live in very remote areas to benefit from distributed electricity production. Recent technology has made distributed solar PV cheaper and more efficient than diesel generators (Bloomberg New Energy Finance, 2011) together with pico hydropower and biomass gasifiers.

HYDROPOWER CAN HAVE SEVERE SOCIAL AND ENVIRONMENTAL IMPACTS

Whereas sustainable hydropower could potentially boost economies and help provide energy security, concerns have intensified over the potential cumulative impacts of proposed dams on the environment, fisheries, and people's livelihoods.

"The construction of the large dams required for the production of hydropower causes major environmental harm. For this reason, we will generate electricity from existing hydropower projects, and repair and maintain the existing dams to enable greater efficiency."

National League for Democracy (2015)

Damming the rivers:

- impacts the rivers natural hydrological flows, affecting other users of water resources and ecosystems
- blocks fish migration
- blocks sediment and nutrient transfer that causes river bed incision and associated lowering of water tables, river bank, subsidence of delta and coastal erosion as well as reduction of agriculture and aquaculture yields, increasing salt intrusion, affecting ecosystems and biodiversity conservation
- may require tens of thousands of people to relocate because their homes and land will be flooded
- may impact millions more through changes to water quality, access to river, and other impacts during construction and operation

The example coming from the Mekong River is striking: the risk is that fish populations will fall and some species may vanish. The region's fisheries industry, integral to the livelihoods of 60 million people, may even collapse. "The combined effects of dams already built on tributaries and the loss of floodplains to agriculture is expected to reduce fish catch by 150,000 to 480,000 tonnes between 2000 and 2015" (ICEM, 2010)). For the Lower Mekong alone the fisheries (both wild capture and aquaculture) have been valued at US$17 billion a year (Mekong River Commission, 2015)

CLIMATE CHANGE IS ALREADY A REALITY

Even if fossil fuel supplies were infinite, we would have another compelling reason to switch to renewable energy: climate change. Climate change compounds existing and projected threats, affecting the region’s people, biodiversity, and natural resources. This is likely to have cascading effects: for example, water scarcity leading to reduced agricultural productivity, leading to food scarcity, unemployment, and poverty. In all countries, climate change complicates existing problems. The city of Bangkok is sinking by 5-10 mm each year. Land subsidence and groundwater extraction combined with sea level rise could leave Bangkok under 50-100 cm of water by 2025 (UNEP, 2009). Similarly, the sinking and shrinking of the Mekong and Ayeyarwaddy deltas caused by the trapping effect of dams reservoirs, sand mining, unsustainable ground water extraction, and destruction of the mangrove will be exacerbated by increased extreme weather events and sea level rise.

Across the Greater Mekong Sub-region, temperatures are rising and have risen by 0.5 to 1.5°C in the past 50 years. While rainy seasons may contract over parts of the region, overall rainfall is expected to rise. This means more intense rain events when they occur (WWF, 2009). To avoid even more devastating consequences, scientists and over 100 vulnerable countries agree that we must keep eventual global warming below 1.5°C compared to pre-Industrial temperatures (Tschakert, 2015). To have a chance of doing that, global greenhouse gas emissions need to start falling within the next five years, and we need to cut them by at least 80 per cent globally by 2050 (from 1990 levels) – and even further beyond that date.

WORLD'S SECOND MOST VULNERABLE COUNTRY TO CLIMATE CHANGE

People in Myanmar suffer greatly from floods, drought, landslides, the drying of lakes and rivers, extremes of heat and other effects of climate change. Myanmar is the second most vulnerable country in the world to the harmful effects of climate change (Global Climate Risk, 2015), and its people are already very well aware of the often devastating, even life-threatening, results. (Horton et al, 2015).

These harmful effects are already a reality, and the changes are observable and measurable, including: (Myanmar Ministry of Environmental Conservation and Forestry, 2012);

- Temperature increases (approximately 0.08°C per decade) in the northern and central regions;
- Fluctuation of total rainfall;
- Changes in south-west monsoon period and intensity; and
- Occurrence and severity of extreme weather events has increased (e.g. cyclones, flood/storm surges, intense rains, and drought).

There is a direct link between these harmful extreme-weather phenomena and power generation, or, more specifically, power generation through the burning of fossil fuels. The global energy sector is responsible for around two-thirds of global greenhouse gas emissions, an amount that is increasing at a faster rate than for any other sector. The most carbon-intensive fuel and the single largest source of global greenhouse gas emissions is coal. Embracing renewable energy, along with the adoption of ambitious energy-saving measures, is the best way to achieve the rapid reduction in the rate of emissions that could help mitigate some of these effects.

OIL, GAS AND COAL ARE UNEVENLY SPREAD IN THE REGION AND THEIR VARIABLE PRICES ARE DIFFICULT TO PREDICT

Supplies of oil and gas are set to decline while our energy demands continue to increase. It is clear that our reliance on fossil fuels cannot continue indefinitely. Unpredictable and volatile historical prices and drastic changes over the past three years make it difficult to foresee the financial viability of fossil fuel power plants over their lifetime, since they face competition of renewable energy plants with predictable and decreasing.

FOSSIL FUELS ALSO HAVE IMPACTS ON THE LOCAL COMMUNITIES AND THE BROADER ENVIRONMENT

Consider coal power plants: lifetime impacts of a typical 550-MW supercritical coal plant with pollution controls are not negligible. 150 million tonnes of CO_2; 470,000 tonnes of methane; 7800 kg of lead; 760 kg of mercury; 54,000 tonnes NO_x; 64,000 tonnes SO_x; 12,000 tonnes particulates; 4,000 tonnes of CO; 15,000 kg of N_2O; 440,000 kg NH_3; 24,000 kg of SF_6; withdraws 420 million m^3 of water from mostly freshwater sources; consumes 220 million m^3 of water; discharges 206 million m^3 of wastewater back into rivers[1] (US Department of Energy, 2010; EndCoal.org, no date). The costs of externalities associated with coal-fired generation in the US have been estimated at around 18c per kilowatt hour (Epstein et al, 2011). A recent report (Koplitz et al., 2015) indicates that existing coal plants in Vietnam cause an estimated 4,300 premature deaths every year. If new projects under development are realised, this number could rise to 25,000 premature deaths per year.

In Thailand, air pollution from coal-fired power plants has been blamed for more than 1,500 premature deaths in 2011. Strokes, ischemic heart disease, lung cancer, other cardiovascular and respiratory diseases in adults and children have also been linked to the burning of coal (Greenpeace, 2015).

In Myanmar, NGOs have raised concerns regarding the Tigyit coal power station in Pinlaung township, southern Shan State. "Two nearby villages of Lai Khar and Taung Pola were forced to relocate for the project and over 500 acres of farmlands have been confiscated. Farming families facing eviction and loss of lands are going hungry and have turned to cutting down trees to sell for firewood or migrated in order to survive. Explosions from the mine have destroyed local pagodas. Air and water pollution is threatening the agriculture and health of nearly 12,000 people that live within a five mile radius of the project who may eventually have to move out. Currently 50 per cent of the local population is suffering from skin rashes. The Pa-Oh Youth Organization and Kyoju Action Network have been monitoring the project since February 2010 and urges the companies and government to suspend operations pending full environment, social and health impact assessments. The organization also urges local communities not to sign documents without understanding them and to oppose corruption and exploitation which harms the communities' livelihoods and natural resources." (PYO, 2011)

One should also keep in mind that pollution control mechanisms on coal power plants increase the electricity costs: they can raise the cost of generation to US$0.09/kWh (Endcoal.org, no date), thereby making coal based electricity more expensive than many solar and wind parks.

1. A 0.70 plant capacity factor and a 50-year lifespan are assumed

NUCLEAR IS RISKY

For some, nuclear power is seen to be a part of the solution to the energy crisis. It produces large-scale electricity with low carbon emissions – although mining and enriching uranium is very energy intensive.

But we cannot escape the reality that nuclear fission produces dangerous waste that remains highly toxic for thousands of years – and there is nowhere in the world where it can be safely stored. The United States alone has accumulated more than 50,000 tonnes of radioactive waste that it has not yet disposed of securely. According to the US Environmental Protection Agency (no date), it will be 10,000 years or even longer before it no longer poses a threat to public health.

Equally troubling, the materials and technology needed for nuclear energy can also be used to produce nuclear weapons. In a politically unstable world, spreading nuclear capability is a dangerous course to take, not least because every nuclear power station is a potential terrorist target.

History has shown that nuclear accidents do happen. The most famous are Three Mile Island (Unit 2 reactor, near Middletown, Pa., partially melted down in 1979), due to a combination of personnel error, design deficiencies, and component failures (United States Nuclear Regulatory Commission, 2014a); Chernobyl, Ukraine in 1986 (a surge of power during a reactor systems test destroyed Unit 4 of the nuclear power station) (United States Nuclear Regulatory Commission, 2014b); and Fukushima in 2011 where a tsunami hit the site's reactors (United States Nuclear Regulatory Commission, 2014c); these accidents, with the exception of Three Miles Island, resulted in very significant health and environmental impacts. Such disasters also cause huge economic impacts that have to be met by government, i.e. the tax payers, since the responsible utilities, whether government owned or not, are unable to cover the expenses.

When all costs are taken into account, including decommissioning, nuclear power becomes an extremely expensive option, as is being illustrated by the current British project at Hinkley Point[1]. Nuclear power plants under construction (European Pressurised Reactors) in France and Finland have seen their projected costs soaring and deadlines long since overrun. Construction began at Olkiluoto 3 in 2005, in Finland, and is not expected to be completed before 2018, nine years late. The estimated cost has risen from US$3.6 billion to US$9.5 billion. The company in charge of the project, Areva has already made provision for a US$3.0 billion write-down on the project, with further losses expected; FTVO and Areva/Siemens are locked in a US$10 billion legal battle over the cost overruns (Ecologist, 2015; New York Times, 2015); in Flamanville, France, the reactor was ordered in 2006 for a price of US$3.7 billion and was expected to start generating electricity in 2012; completion is now scheduled for 2018 and costs are assessed at US$11.85 billion (Ecologist, 2015; Reuters, 2015a).

Before pouring billions into creating a new generation of nuclear power stations, we need to ask whether that money would be better invested in other, sustainable energy technologies. The cost overruns and accidents in countries with extensive experience in nuclear power should highlight the risk exposure of countries with little nuclear energy experience and low existing capacity to such risks.

1. The Government agreed to pay EDF a guaranteed a price of £92.50 per MWh over a 35-year period. The strike price is fully indexed to inflation through the Consumer Price Index. This is more expensive than several solar and wind projects already today.

INDUSTRIAL GROWTH ANDJOB CREATION

Energy derived from the sun, the wind, the Earth's heat, biomass, water and the sea has the potential to meet our electricity needs many times over (WWF, 2011), even allowing for fluctuations in supply and demand. We can also greatly reduce the amount of energy we need through simple measures like insulating buildings against heat or reusing and recycling materials. In this region, where energy demand is still expected to grow rapidly, energy efficiency has great potential to mitigate a significant share of this growth.

Around the world, people are taking steps in the right direction. In 2015, the world invested US$329 billion in renewable energy, up by 4 per cent compared to 2014 and this was higher than investment in conventional generation (Bloomberg, 2016b). In 2015, solar PV marked another record year for growth, with an estimated 57 GW installed for a total global capacity of about 234 GW (Bloomberg, 2016a). That is the equivalent of over one billion installed solar modules of 200W. The installed wind capacity has increased by 64GW to a total of 434GW by the end of 2015 (Bloomberg, 2016a). Last year, renewables were responsible for about 7.7 million jobs globally (IRENA, 2015a).

Solar photovoltaic (PV) power has seen its cost plunge, making the technology extremely competitive. The latest examples come from Dubai, where a 260 MW plant will sell solar electricity at US$0.058 per kilowatt-hour (US$/kWh). This is due to learning curves and cost reductions across the supply chain, including PV cell costs (Figure 1).

Figure 1 Price of silicon PV cells (Bloomberg New Energy Finance and pv.energytrend.com, no date)

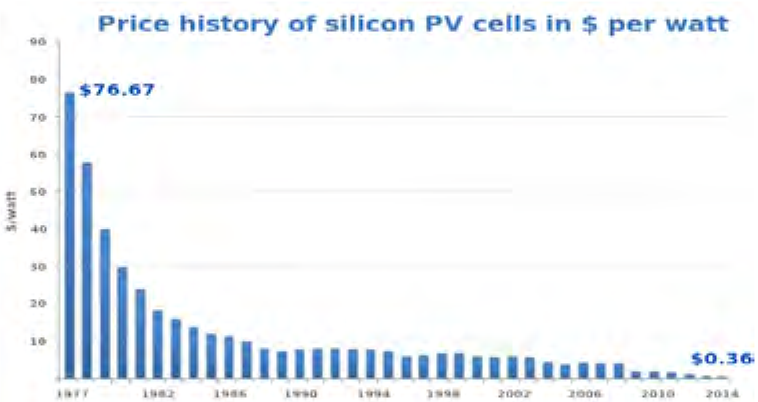
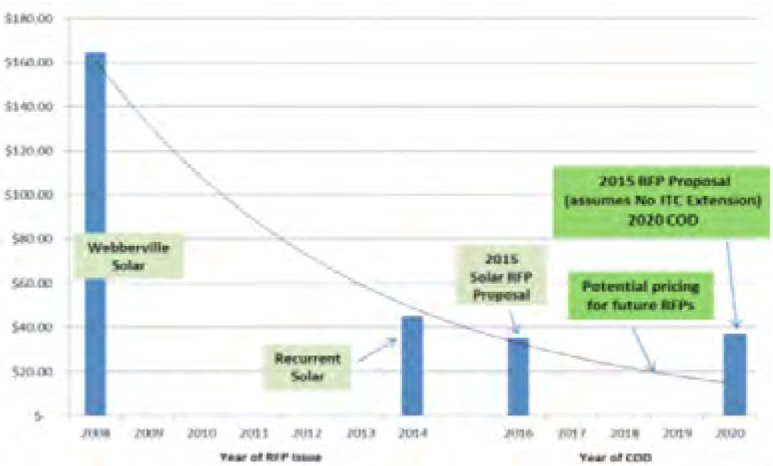


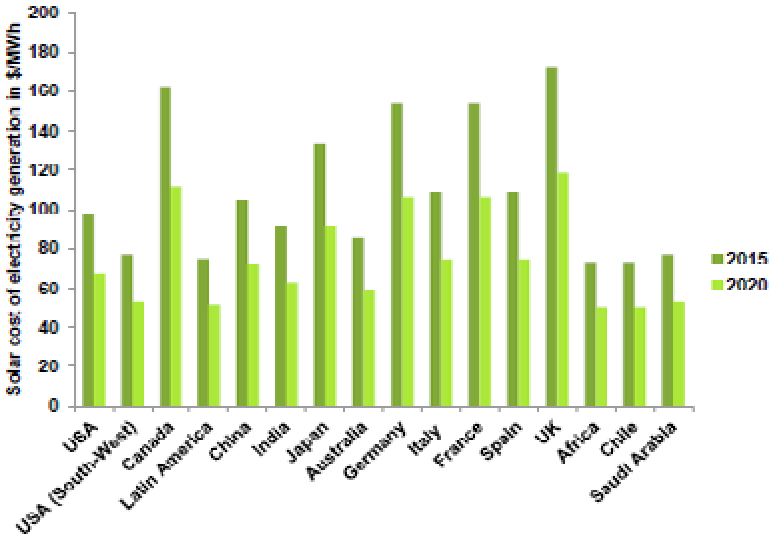
Figure 2. Projected solar PV cost in Austin, Texas (Clean Technica, 2015)



More recently in Austin, Texas, project proposals were offering solar electricity at less than US$0.04/kWh with support from a federal income tax credit. These cost reductions have led Austin Energy to believe that large scale solar PV prices may come down to below US$0.02/kWh in 2020 provided the income tax credit continues. Without the income tax credit, costs could still be lower than US$0.04/kWh (Figure 2).

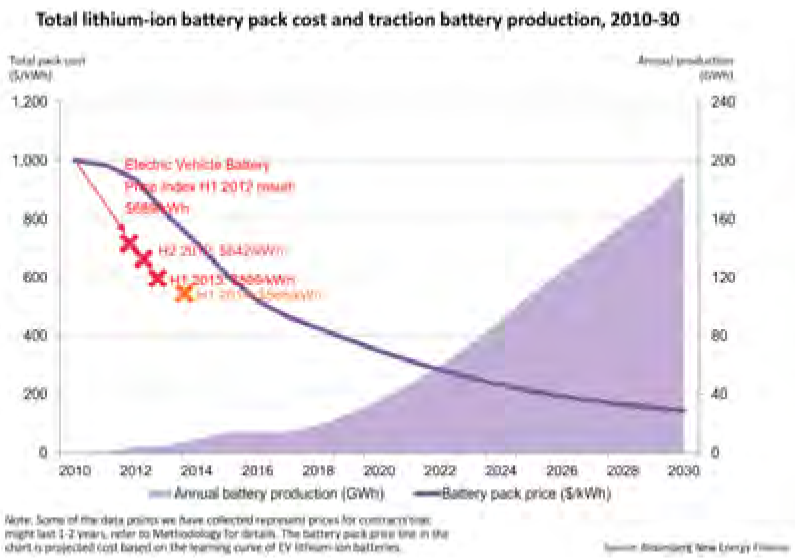
City Research (2015) summarises levelised cost of electricity (LCOE) of solar PV (today and what is expected in 2020 in Figure 3:

Figure 3 Solar PV LCOE (City Research, 2015)



In the New Energy Outlook 2015 report, Bloomberg New Energy Finance said wind is already the cheapest new form of energy capacity in Europe, Australia and Brazil. By 2026, it will be the "least-cost option almost universally". In many countries, individual wind projects are consistently delivering electricity for US$0.05 kWh without financial support. These solar and wind costs compare to a range of US$0.045 to 0.14/kWh or even higher for fossil-fuel power plants (IRENA, 2015b). In fact, this year in India, solar PV could be on par with coal, with major ramifications for coal projects such as those in the Galilee Basin[1]; Deutsche Bank researchers even expect that solar PV could represent 25per cent of total electric capacity in India by 2022 (Reneweconomy, 2015).

Figure 4 Battery costs (Bloomberg New Energy Finance, no date)



1. Latest reports are that Adani, the Indian investor in Australia's huge Galilee Basin coalmine project, has put the project on hold due to current low commodity prices (Reneweconomy, 2016)

Distributed electricity from renewables has also become more affordable: with decreasing solar PV prices and decreasing battery prices (Figure 4). Deutsche Bank recently called solar and batteries transformational (Reneweconomy, 2015), and a UBS study recently showed that solar and batteries are already cost effective in Australia (Reneweconomy, 2014). While currently very low fossil fuel prices may moderate some of these trends the direction is clear: increasingly, new investment will be in sustainable renewable generation rather than in fossil fuel generation.

The Brazilian wind sector provides interesting insights on technology costs in countries starting recently with renewables: capacity auctions in 2009 resulted in projects selling wind energy at about US$0.1/kWh, but the price progressively decreased at each subsequent auction, to result in a price in 2011 of US$0.07/kWh and US$0.052/kWh in 2014 (ABEEólica, 2015).

Projections show conclusively that within a few years, wind and solar electricity will be competing with fossil fuel power plants in the countries of the Mekong region (including coal) while providing price certainty for the next 20-25 years without causing pollution. These countries could join the group of countries that have chosen to modernise their power sector and use modern technologies rather than old fashioned polluting power plants. These quickly decreasing renewable energy prices also mean that any new long term power project based on coal, gas, large hydro or nuclear may be a stranded economic asset in the next 10 or 15 years. Several companies are realising this and are now divesting from coal, gas, oil, and nuclear.

Some countries are leading in renewable energy development (Table 1): Denmark is now producing 40 per cent of its electricity needs with wind energy. Wind power also met more than 30 per cent of electricity demand in Scotland and 20 per cent in Nicaragua, Portugal, and Spain.

Table 1 share of wind in electricity production

Country/Region	Share of wind in electricity production
Denmark	42%
Scotland	>30%
Nicaragua	>20%
Portugal	>20%
Spain	>20%

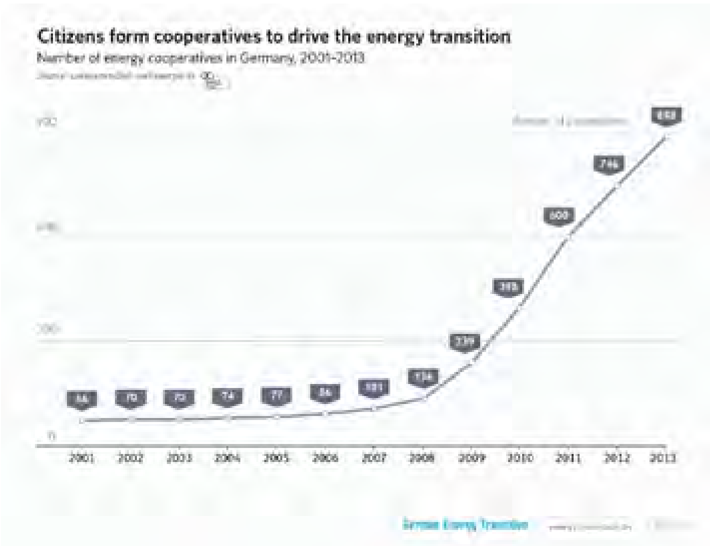
Solar PV reaches nearly 8 per cent of the electricity supply in some European countries: 7.9 per cent in Italy; 7.6 per cent in Greece; 7 per cent in Germany. It is not uncommon to see solar PV projects of over 200MW in countries like China or India. 100 per cent renewable energy and electricity goals are being explored and deployed at the national level in countries such as Cabo Verde, Costa Rica, and Denmark (REN21, 2015).

Germany is an interesting case, with serious electricity production from solar PV, wind, biomass and hydropower. The following table summarises how the different technologies together contributed to 31 per cent of the electricity production in the country during the first half of 2015 (Fraunhofer ISE, 2015).

Renewable electricity production in Germany (TWh) during the first half of 2015		
18.5	TWh	pv
40.5	TWh	wind
23.4	TWh	biomass
11.9	TWh	hydro

There are several interesting developments supporting this energy transition in Germany. A significant change is the contribution from people to this transition, as highlighted by the increasing amount of cooperatives active in the energy sector in Germany (Figure 5).

Figure 5 Renewable Energy Cooperatives (energytransition.de, 2014)



In parts of Asia, the renewable electricity sector is moving fast as well: China and Japan were the top two solar PV markets in 2014 in the world; the Philippines and Indonesia are the second and third largest geothermal power generators in the world, respectively; and South Korea leads in tidal barrage energy. China has installed over 80 per cent the world's solar water heater (SWH) capacity in recent years and currently hosts around two thirds of the global total (REN21, 2015).

But in Myanmar, the pace of change towards renewable energy is slow. Government subsidies and private investments in fossil fuels still vastly outweigh those in renewable energy and energy efficiency, even though the latter would give a far greater long-term return. Many building and factory designs follow old-fashioned, energy-inefficient designs locking in energy inefficiency such as air conditioning for decades to come. Lack of awareness, training, regulation, incentives, and financial mechanisms for energy efficiency and renewables is stifling the much needed development of these industries.

100 PER CENT POSSIBLE

The Sustainable Energy Scenario (SES), which forms the second part of this report, is the most ambitious and detailed analysis of its kind to date in the region. It demonstrates that it is technically feasible to supply everyone in 2050 with the electricity they need, with 100 per cent of this coming from renewable sources. Hydropower with dams would not produce more than 14 per cent of the electricity we need, thereby keeping future hydro impacts in check. Such scenario would reduce carbon emissions (CO2eq) by about 75 million tonnes per year compared to BAU[1]. An Advanced Sustainable Energy Scenario (ASES), with more optimistic assumptions about renewable energy cost decreases and other technological advancements, produces a 100 per cent renewable energy based power sector by 2038.

Despite the fact that the task ahead is, of course, raising major challenges, the scenario IES has mapped out is practically possible. It is based only on the technologies the world already has at its disposal, and is realistic about the rate at which these can be brought up to scale. Although significant investment will be required, the economic outlay is reasonable. Cumulative investments in power plants and energy efficiency are not higher in the Sustainable Energy Scenario (SES) than in the Business as Usual Scenario (BAU). However, cumulative operating costs (including fuel costs) are much lower in the SES than in the BAU and in fact, the Myanmar economy benefits economically from the energy transition. Year-on-year net investments in the BAU and SES represent between 2 and 3 per cent of GDP per year respectively, from now until 2050. The SES accounts for projected increases in population and increased economic wealth – it does not demand radical changes to the way we live.

The scenarios detailed by IES for this report are not the only solution, nor are they intended to be a prescriptive plan. But in presenting the scenarios, we aim to show that a fully renewable energy future is not an unattainable utopia. It is technically and economically possible, and there are concrete steps we can take – starting right now – toward achieving it.

1. Carbon emission reduction calculations have not taken into account dam emissions or biomass emissions, which can be significant depending on project design and management practices.

THE SUSTAINABLE ENERGY SCENARIO (SES) IN A NUTSHELL

In 2050, electricity demand will be sevent to eight times as high as it is today in Myanmar. It is, however, about 30 per cent lower than what would happen in BAU. Although population and economy continue to rise as predicted, ambitious energy-saving measures allow us to do more with less. Industry uses more recycled and energy-efficient materials, buildings are constructed or upgraded to need minimal energy for heating and cooling, and there is a shift to more efficient forms of transport.

All people have access to electricity by 2030, 70 per cent of the households through grid connected and 30 per cent through off-grid solutions. Wind, solar photovoltaic (PV), concentrating solar power (CSP), biomass, and to a lesser degree hydropower are the main sources of electricity. Some gas remains in the system up to 2042).

Because supplies of wind and solar photovoltaic power vary, "smart" electricity grids have been developed to store and deliver energy more efficiently, with pump and battery storage. About 54 per cent of the electricity comes from variable sources (solar PV, wind, run of the river hydro) while the rest comes from less variable sources, such as biomass, CSP with storage, geothermal and hydropower dams. Seasonality still affects hydro and biomass, though.

Due to its environmental and social impacts, the contribution of hydropower is kept to a minimum. This means that minimal large hydro is added to the mix beyond what is already being built or in final development plans today. Micro-hydro is included in the run of the river plants, representing in total about 4 per cent of the generation mix.

Solid biomass and biogas electricity are used carefully and provide about 17 per cent of the total electricity mix. According to ADB (2015) and own calculations there are 130 million tonnes of agriculture residues and 24 million tonnes of dry matter from livestock available yearly for biomass and biogas production purposes in the Greater Mekong region. This potential is assumed to grow in line with agriculture growth projections. The SES scenario uses maximum 75 per cent of this potential year on year until 2050. Around 2035, during the peak of biomass consumption in SES, an additional 12 million tonnes of biomass has to be found. This excess need goes down to nearly zero in 2050. In order to fulfil this additional need, it is expected that forestry residues become available, and that biomass that is used today for cooking is being freed up (within sustainable limits) for electricity production. If any additional bioenergy plantations are required, careful land-use planning and better international cooperation and governance are essential to ensure we do this without threatening food and water supplies or biodiversity, or increasing atmospheric carbon. Human waste has not been included in these calculations. In fact, human waste can be collected through sewage systems and can be used to produce biogas. In the Greater Mekong region, our calculations suggest that human waste biogas could satisfy nearly half of all the scenario's bioenergy needs, although estimates vary widely. Exploiting this potential should be a priority .

By 2050, we save approximately US$2.7 billion per year through energy efficiency and reduced fuel costs compared to a ‘business-as-usual’ scenario. But increases in capital expenditure are needed first – to install renewable energy-generating capacity, modernize electricity grids, transform goods and public transport and improve the energy efficiency of our existing buildings. Our investments pay off very quickly, as the savings outweigh the costs. If oil prices rise faster than predicted, and if we factor in the costs of climate change and the impact of fossil fuels on public health, the economic benefits would be much higher still.

THE ADVANCED SUSTAINABLE ENERGY SCENARIO (ASES) IN A NUTSHELL

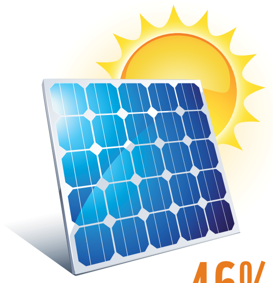
The ASES is based on bolder assumptions regarding technology cost decreases, energy efficiency, demand response, electrification of transport etc. As a result, the power sector becomes entirely fossil and nuclear free by 2038. Solar PV and wind play a bigger role than in SES, as well as battery storage, and ocean energy enters the technology mix. Investments are slightly over 4 per cent higher than in SES, but the fuel costs are reduced even further and there is no significant difference in annual net costs between ASES and SES. While it is relatively obvious that solar and wind capital costs will decrease, it is more difficult to assess precisely how quickly. Predicting the cost of fossil fuels is also difficult. Having two scenarios, SES and ASES, to compare with BAU, enables us to better understand the implications of societal and technological choices. The SES will be discussed further below. The ASES is described in part B of this report.

THE ENERGY MIX AND THE TECHNOLOGIES

At the moment, about 68 per cent of the Myanmar's electricity comes from large-scale hydro and 32 per cent from fossil fuels (oil, gas and coal) (Ministry of Electrical Power, 2015). Under the SES and ASES, fossil fuels are entirely phased out by 2043 and 2038 respectively, to be replaced with a varied mixture of renewable energy sources. However, not all renewable energy sources are sustainable. Without strict sustainability safeguards, hydropower and biomass power can have significant environmental and social impacts. Even solar, wind or geothermal plants need to be properly planned to avoid impacts, but in general impacts are low. For these reasons, this scenario favours solar, wind and geothermal power whenever possible.

The SES and ASES scenarios take into account each resource's potential although it limits the use of dams and biomass due to the potential negative impacts of those technologies, and due to the need to keep biomass for other purposes; the scenario takes into account GDP growth rates, and other constraints and opportunities such as availability of grids, variability of wind and solar sources, economic aspects. Technological breakthroughs, market forces and geographic location will all influence the way renewable energies develop and are deployed, so the final energy breakdown could well look very different.

SOLAR ENERGY



The sun provides an effectively unlimited supply of energy that we can use to generate electricity and heat. At the moment, solar energy technology contributes very little of the total electricity supply in Myanmar with the exception of small household systems in remote areas and larger solar power projects are yet to be implemented. This proportion can grow fast: in the SES, solar energy supplies around 46 per cent of our total electricity by 2050.

Solar energy provides light, heat and electricity.

Photovoltaic (PV) cells, which convert sunlight directly into electricity, can be integrated into devices (solar-powered calculators have been around since the 1970s) or buildings, or installed on exposed areas such as roofs. Solar PV can be grid-connected, but can also generate power in rural areas, islands and other remote places “off-grid”. In the SES, solar PV would contribute about 33per cent of all electricity needs in Myanmar. We estimate that this would require less than 0.03 per cent of the region’s total land mass, or the equivalent of less than half Yangon’s land area[1]. Since many of these solar modules will be installed on existing buildings, the additional land need for solar PV is even lower.

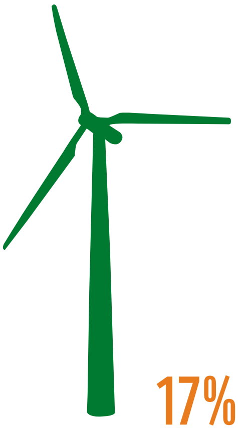
Concentrating solar power (CSP) uses mirrors or lenses to focus the sun’s rays onto a small area – for example to heat water, which can be used to generate electricity via a steam turbine or for direct heat. The same principle can be used on a small scale to cook food or boil water. **Solar thermal collectors**, which absorb heat from the sun, already provide hot water to thousands of households in the region and enable households to reduce their electricity or gas bill.

One obvious challenge in adopting high levels of solar power in the generation mix is that supply varies. Photovoltaic cells do not function after dark – although most electricity is consumed in daylight hours – and are less effective on cloudy days. Solar electricity can be combined with other renewable electricity sources, however, to reduce the impacts of this variability. Moreover, energy storage is improving: CSP systems that can store energy in the form of heat (which can then be used to generate electricity) for up to 15 hours exist (CSP Today, no date)[2]. In the SES, CSP would contribute about 13 per cent of all electricity needs in Myanmar.

1. Assumptions: Maximum irradiance 1000W/sqm; 15per cent module efficiency; 20per cent derating for roads, shadow reduction, service stations etc.
2. The 20 megawatt GemaSolar power tower in Spain designed by SENER has 15 hours of full-load storage.

WIND ENERGY

Feasibility studies have already been conducted for the construction of wind-powered electricity generating plants, in 30 sites in the east and the west of the country (Ministry of Electrical Power, 2015). Although wind power has as yet made no contribution in Myanmar, this could change: in Denmark, wind already accounts for 42 per cent of the country's electricity production. In Jutland and on Funen, two Danish regions, wind power supplied more electricity than the total region's consumption during 1,460 hours of the year (ENERGINET.DK, 2016). Offshore wind, also possible in the region, is less variable, and turbines can be bigger. In the SES, onshore wind could meet 17 per cent of the nation's electricity needs by 2050. However, the total potential is much larger in the region, especially if offshore wind is taken into account (ADB, 2015).



17%

OF ENERGY MIX

Although wind farms take up large areas and have a visible effect on the landscape, their environmental impact is minimal if they are planned sensitively. When turbines are sited on farmland, almost all of the land can still be used for grazing or crops. Unlike fossil fuel and nuclear power plants, wind farms don't need any water for cooling. Offshore wind developments need to be sensitively planned to minimise the impact on marine life and birds, and more research is needed in this area. Floating turbines, which would have less impact on the seabed and could be sited in deep water, are under development already. Two pilot projects are planned, in Scotland (30MW) and Portugal (25MW) (Reuters, 2015b).

OCEAN POWER

1%

OF ENERGY MIX

The motion of the ocean, through waves, tides and currents, salinity and thermal gradients provides a potentially vast and reliable source of energy – but there are significant challenges in converting it into electricity. These are relatively new technologies, although tidal plants have been operating since the 70s, like the La Rance 240MW plant in France. More recently, the Sihwa Lake Tidal Power Station of 254MW was commissioned in South Korea. Costs are still quite high with an LCOE for tidal systems between US$32c/kWh and US$37c/kWh and for wave between US$41c/kWh and US$52c/kWh at 12 per cent discount rate (SI Ocean, 2013).

Myanmar has sites with some of the largest tidal range in South East Asia which are suitable for economic electricity generation (United Kingdom Hydrography Office, 2011). Large amplitude tidal ranges are associated with strong tidal currents, e.g. on the Yangon river (Myanmar Ministry of Transport, 2013). The country would also have 5-10 kW/m annual mean exploitable wave energy resource (Reguedo, 2011). Viet Nam has total exploitable tidal energy of 1,753 GWh/year for a 5.5 GW exploitable capacity (Pham, 2013). However, there are not yet many data available to calculate the real potential for these technologies in the Greater Mekong region.

Recognising this constraint, the SES assumes that ocean power accounts for less than 1 per cent of the country’s electricity supply by 2050.

Wave and tidal power installations could affect the local marine environment, as well as maritime industries such as shipping and fishing and coastal communities. It is critical that appropriate sites are selected and technologies developed that minimize any negative impacts.

GEOTHERMAL ENERGY

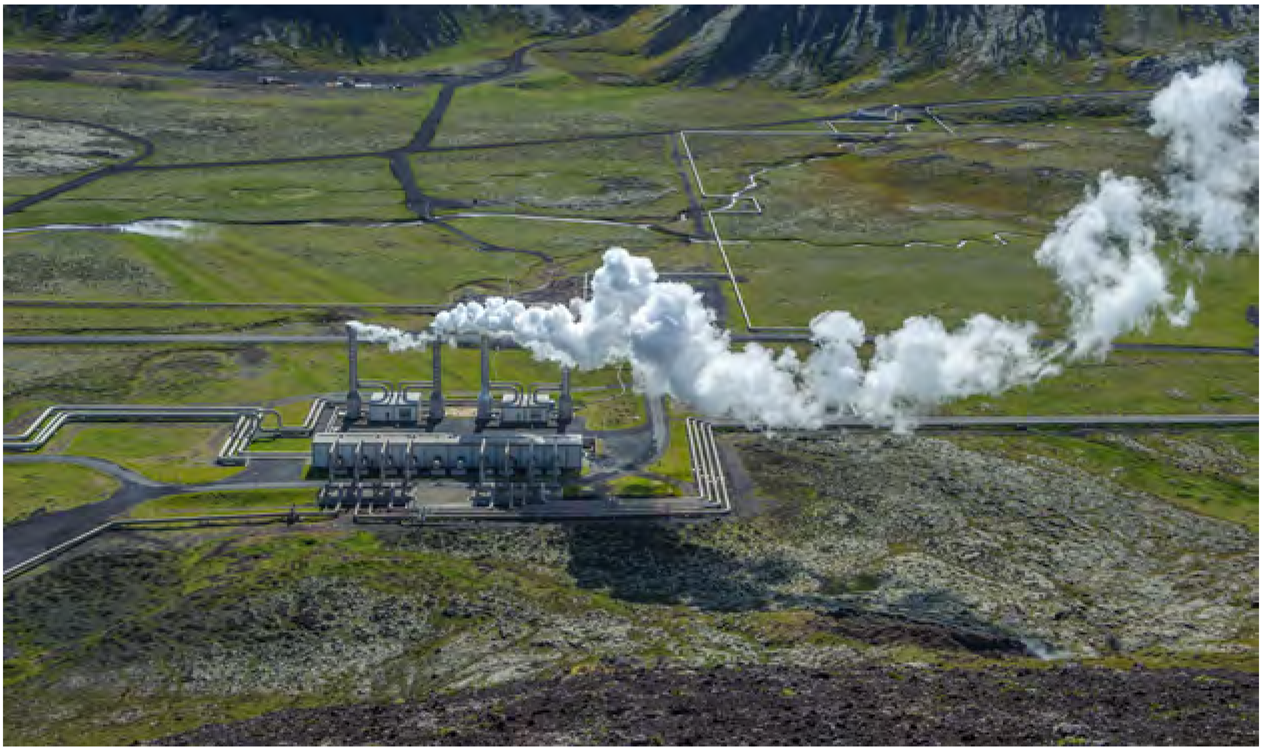
1%

OF ENERGY MIX

The ancient Romans used the heat from beneath the Earth's crust to heat buildings and water, but only relatively recently have we begun to rediscover its potential. When temperatures are high enough, geothermal energy can be used to generate electricity and local heating, including high-temperature heat for industrial processes. Unlike wind or solar power, which vary with the weather, geothermal energy provides a constant supply of electricity. Iceland already gets a quarter of its electricity and almost all of its heating from its molten "basement". In the Philippines, geothermal plants generate 14 per cent of total electricity (Bertani, 2015). In Myanmar, the SES suggests a bit over 1 per cent of geothermal electricity production by 2050.

Exploiting geothermal resources will undoubtedly affect the land and the people who live in the surrounding area. Geothermal steam or hot water used for generating electricity contains toxic compounds, but "closed loop" systems can prevent these from escaping. If sites are well chosen and systems are in place to control emissions, they have little negative environmental impact. In fact, because geothermal plants need healthy water catchment areas, they may actually strengthen efforts to conserve surrounding ecosystems[1].

WWF's "Ring of Fire" programme is supporting Indonesia, the Philippines, Malaysia and Papua New Guinea to develop their geothermal potential in a sustainable way. The programme's vision is to increase the countries' geothermal capacity threefold by 2020, through green geothermal investment in the range of €18–40 billion. It will create 450,000 extra jobs compared to coal by 2015 and 900,000 by 2020.



1. See for instance Geothermal Projects in National Parks in the Philippines: The Case of the Mt. Apo Geothermal Project (Dolor, 2006)

HYDROPOWER

14%

OF ENERGY MIX

Hydropower is currently the nation's largest renewable power source, providing 68 per cent of all electricity (Ministry of Electrical Power, 2015). Large-scale hydropower dams store water in a reservoir behind a dam, then regulate the flow according to electricity demand. Hydropower can provide a relatively reliable source of power on demand, helping to balance intermittent sources like wind and solar PV. In fact, solar PV and wind can also help balance the variability of hydro, since its output is reduced during the dry season, while solar output increases during the dry season.

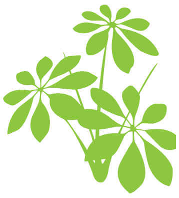
However, with the exception of pico or micro-hydropower, hydropower can have severe environmental and social impacts. By changing water flow downstream, dams threaten freshwater ecosystems and the livelihoods of millions of people who depend on fisheries, wetlands, and regular deposits of sediment for agriculture. They fragment habitats and cut fish off from their spawning grounds. Creating reservoirs means flooding large areas of land: 40-80 million people worldwide have been displaced as a result of hydroelectric schemes (International Rivers, 2008). In fact, the fact that current hydropower projects are included in the SES does not mean that WWF or its partners condone any specific existing dam. But since they have been built, they are part of the suggested power mix in the SES. It may well be that some of those dams will be decommissioned early to make way for more sustainable solutions.

The SES reflects these concerns by reducing the increase in hydropower compared to current business as usual plans. Hydropower would provide 14 per cent of our electricity in the region in 2050, representing an increase in capacity of about 3GW compared to today. 2 GW of run-of-the-river[1] schemes is included as well. New hydropower schemes would need to respect stringent environmental sustainability and human rights criteria, and minimize any negative impacts on river flows and freshwater habitats. A separate report (Grill and Lehner, 2016) presents an analysis of the indicators 'degree of hydrological flow regulation' and 'degree of river fragmentation' caused by hydro dam scenarios.

1. Hydro without dams or reservoirs

BIOENERGY

Energy from biomass – materials derived from living or recently living organisms, such as plant materials or animal waste – comes from a large range of sources and is used in many different ways. Wood and charcoal have traditionally provided the main source of fuel for cooking and heating for millions of people in the Mekong region. Agricultural waste such as rice husk has been used for energy purposes, for instance in briquettes or pellets to replace charcoal, or in biogasifiers to produce electricity. More recently, biofuels have begun to replace some fossil fuels in vehicles.



17%
OF ENERGY MIX

In principle, biomass is a renewable resource – it's possible to grow new plants to replace the ones we use. Greenhouse gas emissions are lower than from fossil fuels, provided there is enough regrowth to absorb the carbon dioxide released and good management practices are applied. Bioenergy also has potential to provide sustainable livelihoods for millions of people. However, if produced unsustainably, its environmental and social impacts can be devastating. We need comprehensive policies to ensure bioenergy is produced to the highest standards.

The SES tries to favour alternative non-biomass renewable electricity resources wherever possible, as bioenergy competes with several other energy and non-energy uses: examples include liquid biofuels for aviation, shipping and long-haul trucking; charcoal for cooking; some industrial processes, such as steel manufacturing. In Myanmar, the SES suggests that 17 per cent of electricity would come from biomass in 2050.

A significant proportion of the biomass electricity needs in the SES is derived from products that sometimes go to waste. These include some plant residues from agriculture and food processing; sawdust and residues from forestry and wood processing; manure; and municipal waste. Using these resources up to a sustainable level has other environmental benefits – cutting methane emissions and water pollution from animal slurry or reducing the need for landfill. But part of these residues need to be left in the field for nutrient recycling. In fact, the biomass needed to fulfil the electricity needs outlined in the SES for the entire Mekong region would amount to 154 million tonnes, agriculture residues and livestock waste combined. This represents maximum 75per cent per cent of the total amount of agriculture residues and livestock waste available each year. An additional 12 million tonnes would come from forestry residues, dedicated biomass plantations or biomass that is freed up through reduction of wood needs for cooking in the region.

A possible long-term alternative source of high-density fuel is algae. Algae can be grown in vats of saltwater or wastewater on land not suitable for agriculture. Large-scale cultivation of algae for biofuel is currently in development. Algae have not been included in this study due to lack of data. However, they may well contribute to the future energy mix. In WWF's global energy study, *The Energy Report* (WWF, 2011), algae were contributing a bit less than 20 per cent of the total biomass used in the energy sector.

CHALLENGES AND RECOMMENDATIONS

The IES analysis shows that the region can technically meet its electricity needs from renewable sources by 2050. But it throws up some challenges – and not just technical ones. The social, environmental, economic and political issues this report raises are equally important.

On the technical side, key factors will enable the region to meet its energy needs from renewable sources. We need to rationalise demand by improving energy efficiency, and by reducing wasteful use of energy. Because electricity and heat are the forms of energy most readily generated by renewables, we need to maximize the use of electricity and direct heat and minimise the use of liquid and solid fuels, with improvements to electricity grids[1] to support this. We need to optimise the use of resources at regional level and exchange electricity. And with current technological developments, we should seriously consider distributed electricity systems at a significant level.

A sustainable energy future must be an equitable one. Its impact on people and nature will greatly depend on the way we use our land, seas and water resources.

Moving to a renewable future will mean rethinking our current finance systems. It will also require innovation.

Local, national and regional governance will need to be greatly strengthened to secure an equitable energy future. We need regional cooperation and collaboration.

These challenges are outlined on the following pages. Additional high level recommendations can be found in the regional report.

1. Whether at the large scale, small scale (micro-grids) or meso-grid level (DNV-GL, 2014)

ENERGY CONSERVATION

How can we do more while using less energy?

Under the SES electricity demand in 2050 is 30 per cent lower than the “business as usual” scenario. It still represents eight times the current consumption. These improvements come from using energy as efficiently as possible. We do assume that, over the next 20 to 35 years, Myanmar will reach an energy efficiency level similar to South Korea, Hong Kong, Japan, or Singapore, depending on the economic sector. In fact, it may well be that we still overestimate future electricity demand in our scenarios, since new more energy efficient technologies will become available over time.

Energy conservation is one of the prerequisites of a future powered by renewables – we will not be able to meet the needs of our people if we continue to use it as wastefully as we do today.

In every sector, solutions already exist that can deliver the massive energy savings we need. The challenge is to roll them out as soon as possible. But the challenge is not only about technologies being available. It is also to ensure energy is used wisely. For example, air conditioning is often programmed at very low temperatures, even 16⁰ Celsius, overlooking elementary and very low energy measures to protect rooms from heat (shades, insulation, adequate ventilation and air circulation etc.).

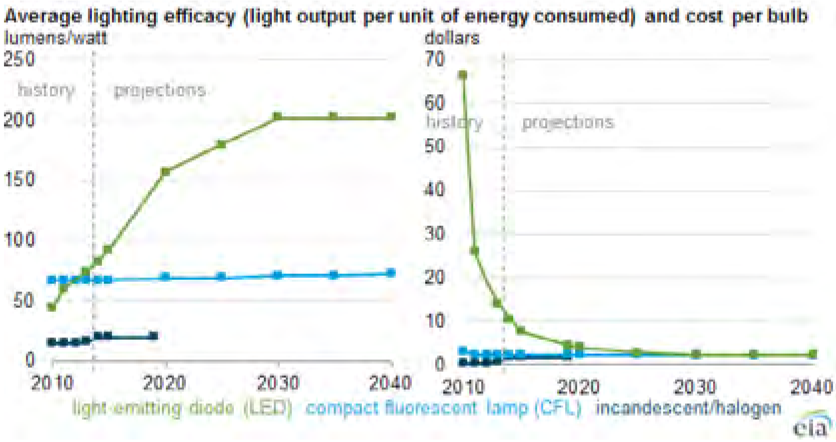
In manufacturing, using recycled materials greatly reduces energy consumption. For example, making new products from recovered aluminium instead of primary aluminium cuts total energy use by more than two-thirds. Stocks of materials that take a lot of energy to produce, such as glass, steel and aluminium, have grown over the past decades, making recycling and reusing materials increasingly viable. Finding alternatives to materials that take the most energy to produce, such as cement and steel, will mean further energy savings.

Product design also has considerable implications for energy use. Making cars with lighter (although not weaker) frames, for example, reduces both the need for energy-intensive steel in manufacturing and their fuel consumption. Electric vehicles are inherently more energy efficient than vehicles with internal combustion engines, even if the electricity comes from combustion-based power plants. The efficiency of energy-hungry appliances like fridges, washing machines and ovens is improving all the time. Considering life cycle costs, and avoiding “disposable manufacturing strategies” for goods is critical. Policy rulings on energy efficiency standards for goods, will have enormous impact given appliance technology improvements.

The world already has the architectural and construction expertise to create buildings that require almost no conventional energy for day-lighting, heating or cooling, through airtight construction, heat pumps and sunlight. With built-in energy generation systems, such as solar PV, they can even produce more energy than they use.

At the same time, we need to radically improve the energy efficiency of our existing buildings. We could reduce heating and cooling needs by insulating walls, roofs and ground floors, replacing old windows and installing ventilation systems. Local solar thermal systems and heat pumps would fulfil the remaining heating, cooling and hot water needs. Lighting efficiency is an obvious example of quick efficiency gains (Figure 6).

Figure 6 Lighting efficiency (EIA, 2014)



The transport sector could transition quickly towards reliance on electricity, with significant supply and storage implications for the electricity sector. While the further development of trains, preferably electric, is a necessity, car transport is about to be transformed through technology and social change. Several manufacturers are selling or actively developing electric models, including less conventional companies such as Google and allegedly Apple. Toyota has recently announced that their fleet would emit nearly zero carbon by 2050 (BBC, 2015) and Volkswagen has made similar announcements after the emission scandal that hit the car manufacturer. This can not only change the way we use and energise our cars, but it also represents a huge opportunity to store electricity and affect grids and home electricity systems. At the same time, new car sharing and personal mobility initiatives like Uber combine the use of smart phones, electronic payment and cars in order to provide mobility services. If this is combined with driverless cars such as the ones developed currently by various companies, it means that owning a car in the city may be a thing of the past very soon.

The more energy we save, the easier the task of moving to a renewable energy future will become. It's one area where everyone can play a part.

WHAT NOW?

- We must introduce legally binding minimum efficiency standards for all products that consume energy, including buildings, along the lines of the Japanese "Top Runner" scheme and the European EcoDesign requirements. Governments, companies and experts will need to agree on the standards, which should be monitored and strengthened over time. The Myanmar government could take such steps as it reviews the draft of the *National Energy Efficiency & Conservation Policy, Strategy and Roadmap for Myanmar* (United Nations Framework Convention on Climate Change, 2015), to be finalised in 2016.

- Energy conservation should be built into every stage of product design. Wherever possible we should use energy-efficient, highly-durable and recyclable materials. Alternatives to materials like cement, steel and plastic that take a lot of energy to produce should be a focus for research and development. We should adopt a "cradle to cradle" design philosophy, where all of a product's components can be reused or recycled once it reaches the end of its life.

- For the rural cooking energy sector, Myanmar still relies heavily on solid fuels, management of wood dryness and fuel stove efficiency will remain important for perhaps 20-25 years. Solid fuel storage, management and stove efficiency remain only partially addressed. Scenarios using electric cooking as a replacement of wood as a renewable, sustainable cooking fuel need further evaluation and review in light of the overall planning decisions.

We need strict energy-efficiency criteria for all new buildings, aiming toward near-zero energy use. Retrofitting rates must increase fast to improve the energy efficiency of existing buildings. Governments must provide legislation and incentives to enable this.

- Substantial investment is needed in public transport to provide convenient and affordable energy-efficient alternatives to private cars. We particularly need to improve rail infrastructure: high-speed electric trains, powered by electricity from renewable sources, should replace air travel over distances of 1000km or less, and a greater proportion of freight should be delivered by rail. In cities, car sharing systems should become the norm. Smart applications enable to do this comfortably and efficiently today.

- In the industry sector, mandatory periodical energy audits for establishments consuming over 300 toe per year; technical assistance in examining energy efficiency measures at the level of industrial processes and installations (boilers, compressed air engines, cold production, etc.); prior consultation obligation (evaluation of the project's energy efficiency by an approved certification) for new industrial projects consuming more than 600 toe a year are measures that can help improve energy efficiency.

- Individuals, businesses, communities and nations all need to be more aware of the energy they use, and try to save energy wherever possible. Driving more slowly and smoothly, buying energy-efficient appliances and switching them off when not in use, turning down heating and air conditioning, and increased reusing and recycling are just some ways to make a contribution. Education should start at the school level and through media. The negawatt approach provides a good example of how to systematically approach energy efficiency.

- Consumers and retailers can put pressure on manufacturers to be more energy efficient through their buying choices. WWF has helped to develop www.topten.info, an online search tool that identifies the most energy-efficient appliances on the market in several countries. Discerning buyers can compare energy-efficiency ratings for a growing number of items, including cars and vans, household appliances, office equipment, lighting, water heaters and air conditioning.


Misss

THE NEGAWATT APPROACH

Definition: Negawatts represent non-consumed energy thanks to a more efficient and waste-conscious use of energy. Concept: consuming better instead of producing more. This common sense approach facilitates the discovery of a new, hidden but huge resource.

The “production” potential of negawatts is higher than half of the current world production of energy with currently available and reliable solutions offering numerous related benefits: absence of pollution, decentralisation, creation of jobs, responsibility, solidarity, peace, etc.

The “NegaWatt approach” can be broken down into 3 phases:

1. Cutting energy waste at all levels of organisation in our society and in our individual behaviour to eliminate careless and expensive waste;
2. Improving the energy efficiency of our buildings, means of transport and all the equipment that we use in order to reduce losses, make better use of energy and increase possibilities;
3. Finally, production using renewable energy sources, which have low impact on our environment.

Benefits: Breaking with the practice of risks and inequality means a fourfold or fivefold reduction (“Factor 4 or 5”) in our greenhouse gas emissions, eliminating our waste and accelerating our transition to energy efficiency and renewable energy.

Negawatts therefore characterise non-consumed energy thanks to a more efficient and waste-conscious approach to energy use. This new approach gives priority to reducing our energy needs, without affecting the quality of life: better consuming instead of producing more.

(Association Negawatt, no date)

RENEWABLES, ELECTRIFICATION, GRIDS AND STORAGE

Renewable sources could provide unlimited power, but how do we switch onto them?

The SES depends heavily on increasingly using electrical power, instead of solid, gaseous and liquid fuels. Using more renewable electricity presents several challenges. Firstly, of course, we need to generate it. That will mean massively increasing our capacity for producing power from the renewable resources with the least environmental impact – through wind, solar, biomass and geothermal power technologies in particular. We will need to combine large-scale renewable power plants with distributed power systems, using for instance solar PV connected to the grid, or off-grid or as part of small and meso-grids.

We are going to need investment to extend and modernize electricity grids to cope with increased loads and different energy sources. We need to transmit power efficiently from onshore and offshore wind turbines, solar parks, biomass plants or remote geothermal plants to factories and urban centres – while minimizing the impact of new power lines or subterranean cables. Efficient regional networks will also help to balance variable renewable sources from different regions. In fact, electricity exchange of this kind is already happening: Norway stores excess Danish wind power production in its dams during windy periods, and exports electricity to Denmark during less windy days.

Capacity markets and demand response also help to improve the efficiency of the power sector (see private sector section).

While solar and wind have the potential to supply an effectively unlimited amount of power, this is constrained by the capacity of electricity grids to deliver it. Our existing grid infrastructure can only manage a limited amount of these variable, supply-driven sources. Grids, whether at large, regional or local scale, need to keep electrical voltage and frequency steady to avoid dangerous power surges, and they need the capacity to meet peaks in demand. Today, we keep some power stations, notably coal and hydropower, working around the clock to provide a permanent supply of electricity (or "base load"). These power stations cannot simply be switched off when renewable energy supplies are high, meaning energy can go to waste.

SES estimates that Myanmar networks could accommodate at least 54 per cent of total electricity from variable sources over the coming decades through improvements in technology and grid management. The other 46 per cent would come from less variable sources: biomass, CSP with storage, hydropower and a little bit of geothermal electricity and ocean power. Some of the most important solutions to manage the grid include demand-response measures; pumped storage in hydropower dams; battery storage; hydrogen; heating storage (e.g. CSP with molten salt) and cooling storage (e.g. ice storage for cooling processes).

The combination of large ("super") and "smart" grids holds the key. Power companies and consumers will get information on energy supply, and price, to help manage demand. Put simply, it will be cheaper to run your washing machine when the wind's blowing or the sun's shining. Households, offices or factories would program smart meters to operate certain appliances or processes automatically when power supplies are plentiful. We could also take advantage of times when supply outstrips demand to charge car batteries and to generate hydrogen fuel.

DISTRIBUTED OR CENTRALISED ELECTRICITY PRODUCTION?

In Myanmar, a large portion of the population is not yet connected to the main grid. Sometimes, there is no centralised grid but rather a series of unconnected regional grids. Discussions are taking place globally and in the region around the optimal way to supply electricity to consumers, whether large or small. With rapidly decreasing solar and battery costs, it is no longer clear-cut that extending a centralised grid will be more cost-effective than investing in a mixture of renewable generation sources off-grid, with storage, either standalone or as part of micro, mini and meso-grids. Lithium-ion storage median price is forecast to decline by 47 er cent in the next 5 years, based on a survey of industry experts (Rocky Mountain Institute, 2016). What's more, batteries will not be dedicated to a single use. One can easily imagine that electric car batteries can also be connected to a household's grid, and in that way contribute to distributed storage and grid management.

It is also no longer clear-cut that substantial electricity off take and higher levels of utility (higher power needs) will only be possible through a centralised grid. Solar home systems will become more sophisticated and capable in combination with deep efficiency, and allow for more comfort (e.g. with DC televisions, small efficient fridges etc.). Micro and mini-grids will also improve, enabling large, industrial and small consumers to connect to distributed power solutions. These new types of grids can also be planned in a way that will allow formation of larger grids over time, should this become desirable. Micro and mini-grids could be connected up over the years, creating meso-grids which would complement existing national grid infrastructure but at lower cost than significant new investment in high voltage transmission infrastructure. Such an approach enables a more rapid satisfaction of local electricity needs, while avoiding the development of a full electricity grid at the national level from the outset.

With increasing capabilities for distributed renewable generation, and the possibility that battery based solar becomes cheaper than the grid in coming years to decades, it would be prudent to consider all options and not focus solely on centralised grid, which is investment heavy, shows little flexibility over time and locks in investment for the next half century, regardless of its use over time. It is useful to keep in mind that, in some countries like Australia, there is already an economic case in some locations to disconnect from the grid and use solar plus storage.

The electricity networks that power our world are one of the great engineering feats of the 20th century. The work we need to do to modernize them or to replace them over the coming decades will be one of the great feats of the 21st.

WHAT NOW?

- The government could consider revising the Energy Master Plan launched in January 2016 to increase the role to be played by sustainable and renewable energy, and improve the ratio of centralised versus more distributed power generation options. Integrating Myanmar's Energy Master Plan and Intended Nationally Determined Contribution would help the country achieve important goals in reducing CO_2 emissions.

- Large-scale and distributed renewable power generation need to be built urgently, to forestall overinvestment in a new generation of costly and ultimately unsustainable fossil fuel power plants, mega dams and grid infrastructure that could lock in a high emissions intensity economy over decades.

- A regulatory framework for renewable energy is required. This framework should include a system to award licences for RE projects, national grid connection rules and a tariff system. Such a system could be based on any of several existing schemes around the world, such as feed-in tariffs, net metering, auctioning, reverse auctioning etc., bearing in mind that some schemes are more adapted for large-scale production and some are more appropriate for distributed systems. Project applications, the process by which they are approved, the issuance of licence and registration, the calculation and imposition of taxes and duties (including exemption and relief) and tariff setting should be clearly stated and easily available for public access. In addition, business security (or the right to sell) for the power producers should be clearly defined (e.g. when the national grid expands to a certain region, local IPPs should have the right to sign Power Purchase Agreements (PPAs)).

- Feed-in tariffs and net metering are crucial to encourage large and small electricity consumers to invest in renewable energy. Many countries have successfully implemented feed-in tariff and/or net metering in their electricity sector (e.g. Thailand, India, China and the Philippines). Feed-in tariffs should also be adjusted to the needs of Small Power Producers (SPP) and Very Small Power Producers (VSPP) in order to allow them to sell directly the electricity thus generated to the grid without a power purchase agreement.

- Planning of renewable energy zones helps the private sector access land for projects. The governments can also announce plans for future grid connections for RE projects, and let companies apply for grid capacity. The new grid connections can then be planned based on firm grid capacity demand, thereby ensuring sufficient grid capacity and optimal grid connection use.

- The rapid development of the country and the transition to a new government are likely to bring more investment in the electricity sector (Greacen, 2014). PPAs allocated on a case-by-case basis would overwhelm MOEP's department in charge. Instead, standardised PPAs with a legal contract template, a price and duration determined for instance through reverse auctions, would not require protracted negotiations. Standardisation should also consider establishing a clear separation between the power purchased by the national grid or the other utilities (i.e. regional grid) and the option for large consumers to sign PPAs directly with electricity producers.

- An institutional framework should provide an arbitral mechanism between the national operator and private operators in case of a dispute, especially in the case of disagreements regarding the interpretation and application of regulations.

- Electrification plans should not automatically consider central grid expansion as the best solution. Distributed solutions, which can be built rapidly and respond in a modular way to growing demand, can be more cost effective.

- Standards and guidelines for existing and new mini and micro-grids are necessary. There are many mini and micro-grids in Myanmar privately operated by SPPs and VSPPs in various part of the country. However, these are often poorly set up due to lack of guidelines and regulations. The standardization shall cover technical, regulatory as well as economic and social aspects. Myanmar has almost 70per cent of the population who do not have access to on-grid electricity and this standardization will pave the way for reliable and affordable electricity.

- Technical guidelines and regulations governing the grid system infrastructure and the quality of the electricity produced should be implemented, as multiple IPPs, SPPs and VSPPs can be expected to emerge in the near future (Greacen, 2014). High-quality electricity enables the smooth operation of industrial activities, and the provision of stable and reliable power in the residential sector also means that household appliances will last longer and devices such as voltage stabilizers would no longer be necessary.

- Countries need to work together to extend electricity networks to bring power from centres of production to centres of consumption as efficiently as possible. International networks will help meet demand by balancing variable power sources (such as solar PV and wind), supported by constant sources (geothermal, stored CSP, hydro, biomass).

- We need urgent investment into smart grids to help manage energy demand and allow for a significantly higher proportion of electricity to come from variable and decentralized sources. This will help energy companies to balance supply and demand more efficiently, and enable consumers to make more informed choices about their electricity use.

- Electricity pricing regulation should be reviewed to discourage waste while still allowing poorer people access to electricity at certain prices. Currently, the social tariff of 35MMK extends to 100kWh per month, so that most people are subsidized for their entire consumption, though many can afford to pay more. The second tariff layer of 50MKK is also too low. This subsidy depletes government resources without encouraging wealthier families to save energy. Air conditioners are often run with windows open! Electricity should remain affordable, but low prices should not reward wasteful consumption. Better-off families that pay higher rates can help to cross-subsidise the electrification of poorer communities. Below is an example of electricity tariffs in Sri Lanka[1].

1. Exchange rate of 1 US$ – 143.93 LKR, http://www.xe.com/currencyconverter/convert/?Amount=1&From=US$&To=LKR, 24 February 2016

By Sri Lanka's Electricity Act 2009, the Public Utilities Commission set electrical tariffs and charges for the domestic residential sector in the form of Incremental Block Tariffs (PUCSL, 2009)				
Tariff Category Domestic (30 day period)	Unit Charge (per kWh)		Fixed Charge (LKR/kWh)	
	LKR	US$	LKR	US$
Up to 30 units	3.00	0.02	60.00	0.42
31 to 60 units	4.70	0.03	90.00	0.63
61 to 90 units	7.50	0.05	120.00	0.83
91 to 180 units	16.00	0.11	180.00	1.25
181 to 600 units	25.00	0.17	240.00	1.67
Above 600 units	30.00	0.21	240.00	1.67

- Different tariffs could be applied based on time of day (day/night or more sophisticated hourly based tariffs). This would help discourage consumption when there is high demand or low supply, while encouraging consumption when demand is low and production high. This is particularly important when a lot of variable power is used. n fact, many countries in the world apply day/night electricity tariff rates for electricity (e.g. India) and some countries also apply different tariffs depending on time of day (e.g. Australia).

Off-peak Electricity

Off-peak electricity is the different set of tariffs set for usage during specific times. This tariff is normally set at lower or discounted rates for households and businesses during periods of low electricity consumption, to avoid strain on electricity networks. Off-peak times are usually at night and/or weekend; however, they may vary according to country, location and type of meter. (Energy Australia, 2016)

- By 2050, all cars, vans and trains globally should run on electricity. We need legislation, investment and incentives to encourage manufacturers and consumers to switch to electric cars. Improvements in battery technology could even allow us to run electric trucks, and possibly even ships. This is a long-term aim, but research and development is needed now.

ELECTRICITY EXCHANGE BETWEEN COUNTRIES AND POWER SECTOR STRATEGIES

Various countries in the Mekong region consider electricity as an export product. Laos exports a large part of its hydropower production to Thailand. Myanmar is considered as having an important potential for exports as well.

Electricity exchanges between countries should therefore be encouraged as long as they do not have negative social, economic and environmental impacts. They allow integration of more variable power in the grids. Solar, wind and hydropower can be combined. Hydro can offer pumped storage during sunny or windy days in parts of the Mekong, and this reserve hydro capacity can then be used during rainy and windless days. This can happen on various time frames, from an hourly basis, to a seasonal basis.

By 2025, large solar and wind farms will compete at prices which are likely to be lower than the production cost of large hydro or coal power plants. This means that countries that were importing hydro or coal power might look to renegotiate or even not renew their PPAs, since they would produce more solar or wind electricity at home or would be able to sign PPAs with wind or solar parks that would be cheaper than the hydro or coal PPAs. It will therefore be important to consider very carefully the construction of large coal or hydropower plants with payback periods of over 10 years.

This would lead to risk of stranded assets in the region: diesel, hydro, gas or coal power plants where the break-even has not yet happened but the assets are priced out of the market. This is already happening to some extent with a series of gas and coal power plants in Europe. Countries that are planning their power sector on the basis of coal and/or large scale hydro might see their electricity markets becoming more expensive than other countries, losing out in terms of competitiveness and environmental reputation. This should be kept in mind when developing the grid, preparing master plans and power sector strategies.

WHAT NOW?

- A careful assessment of the financial viability of electricity export strategies based on various power sector scenarios of the exporting and importing countries would help mitigate a part of the stranded asset risk

- A diversification of power plant technologies, integrating more wind and solar technologies in the mix, would reduce the technology risk by providing more complementarity between the technologies (it does not help to offer only hydropower production to the regional mix during the dry season)

- A regional discussion between grid operators based on credible projections regarding different renewable energy technologies would help identify where grid improvements are necessary to optimise electricity exchange between countries

LAND USE

We need large areas of land to meet our energy needs. What can we do to limit the impact on people and nature?

Sustainability means living within the capacity of humanity's one and only planet and the limited amount of land and sea available without jeopardising the ability of future generations to do the same. We need space for buildings and infrastructure, land to grow food and fibres and raise livestock, forests for timber and paper, seas for food and leisure. More importantly, we need to leave space for nature! We need healthy ecosystems to supply our natural resources, provide clean air and water, regulate our climate, pollinate our crops, keep our soils and seas productive, prevent flooding, and much more. The way we use our land and sea and planning for this is key to securing a renewable energy future, and perhaps one of the hardest challenges we face.

Over the coming decades, we will need to develop an extensive renewable energy infrastructure, and it will be essential that we put the right technologies in the right places. Solar farms, for example, can make use of unproductive areas and roofs of existing buildings or parking areas in urban areas. Geothermal fields are often found in unspoilt areas, so we need to choose sites carefully to minimize the environmental and social impact, and make sure surrounding areas are well protected. We need to assess all new hydropower plants especially rigorously, and choose sites for offshore wind and ocean power carefully to minimize the impact on marine life. We also need to carefully plan the routes of the long-distance, high-voltage power lines and undersea cables we will need to transmit electricity from new production centres. Regarding bioenergy production we need to consider the rights of local communities, including indigenous people, the movements of migratory species, the effect on water supplies, the type of infrastructure and governance systems in place, and a host of other constraints. All energy projects need to reflect community Free Prior and Informed Consent (FPIC).

WHAT NOW?

- All large-scale energy infrastructure developments must satisfy independent, in-depth social and environmental impact assessments. They should also meet – or exceed – the best social and environmental management practices and performance standards. The Gold Standard for best practice in projects delivering carbon credits provides a good example. For hydropower, WWF has participated in the development of the International Hydropower Association Sustainability Guidelines.

- We need to carefully analyse, country by country, what land and water is available for bioenergy, taking social, environmental and economic issues into account. An important future source of biomass could come from the biomass currently used for fuel wood and charcoal. If we accept that everybody should have access to electricity by 2030, in accordance to the UN Sustainable Energy for All target, then it is not impossible to imagine that, by 2050, a much smaller percentage of people in Myanmar will depend on biomass for cooking. A sustainable part of this biomass could be used for other purposes, such as electricity production.

- Forestry companies, governments and conservationists need to identify areas of idle land (forests that have been cleared already but are no longer in use) where it may be possible to increase yields of biomass with the least impact on biodiversity. South East Asia, Russia and the Americas hold the most potential. WWF is supporting the Responsible Cultivation Area concept, which aims to identify land where production could expand without unacceptable biodiversity, carbon or social impacts. We are also helping to identify areas that should be maintained as natural ecosytems and primarily managed for conservation purposes through schemes such as the High Conservation Value Framework.

- Large scale bioenergy production has to be based on binding sustainability criteria, with strong legal controls – binding legislation and strict enforcement – at national and international levels. Voluntary standards and certification schemes, along the lines of the Forest Stewardship Council, the Roundtable on Sustainable Biomaterials and Bonsucro, also have a role to play.

- As individuals, we need to make more considered choices about the food we eat, the transport we use and other lifestyle factors that influence global land use. Plant based diets require much less land than meat based diets. Public policy should help to guide these choices.

FINANCE

Renewable energy makes long-term economic sense, but how do we raise the capital needed?

Energy efficiency and renewable energy share a similar financial barrier. Upfront investments in capital are most often higher than less efficient or non-renewable technologies. This higher capital cost is compensated by energy savings in the case of energy efficiency and by lower operating costs in the case of renewable energy that do not require raw energy sources[1]. This is confirmed by the SES, where the yearly net costs very quickly become lower than the BAU yearly net costs. The investment pays off handsomely. By 2050, we will be saving nearly US$2.7 billion every year, according to the SES compared to a business-as-usual scenario. And that's purely the financial savings that come from reduced operating costs. It doesn't take account of the costs we could incur from climate change– up to one-fifth of global GDP, according to the Stern Review (Stern, 2007) – if we don't radically reduce our greenhouse gas emissions by moving to a renewable energy supply. Nor does it include the added value of the millions of jobs created or the health and social benefits, such as better air quality and more leisure time.

But we will need to invest significant capital before we start seeing these returns. Large sums will be needed to install renewable energy-generating capacity on a massive scale, to modernize electricity grids, transform public transport infrastructure and improve the energy efficiency of our existing buildings. Upfront costs are likely to be higher than for a conventional power sector, but there will be international sources of support for opting for a greener development pathway. Climate finance can leverage private sector investment to achieve significant (sustainable) renewable energy investment if there are quality projects which meet IFIs' governance requirements. In particular, the Green Climate Fund "is a global initiative to respond to climate change by investing into low-emission and climate-resilient development. It was established by 194 governments to limit or reduce greenhouse gas emissions in developing countries, and to help adapt vulnerable societies to the unavoidable impacts of climate change. Given the urgency and seriousness of the challenge, the Fund is mandated to make an ambitious contribution to the united global response to climate change" (United Nations, 2016). The fund will offer a wide variety of financial products to support, amongst others, renewable energy and energy efficiency projects.

Net expenditure will need to continue to grow until 2050 to around US$120 billion a year but will not rise above five per cent of the Greater Mekong region's GDP. This remains lower than the net cost of the BAU scenario, which peaks at 6 per cent of GDP. At the same time, energy savings and reduced fuel costs mean operating expenditure will soon start to fall. The savings outweigh the costs very quickly, after a few years depending on the country.

Unfortunately, our current financial system is not suited to taking the long view. Investors expect a return within a couple of years. New power developments cannot be left entirely to the free market as long as it's sometimes cheaper to build a coal or gas power station than a wind farm or solar array, especially in terms of CAPEX. We need new financing models, such as public-private partnerships with shared risks, to encourage long-term investment in renewables and energy efficiency. Legislation and stable political frameworks will also help to stimulate investment.

This need for upfront capital is not only a problem for governments and utilities but also for households wanting to invest in solar technologies. Attracting local and foreign investors and lenders to the renewable energy and energy efficiency markets requires stable and ambitious policies creating an enabling framework. It has been demonstrated in several countries, for instance Tunisia, Bangladesh, Germany or the US, that this enabling environment can start a very rapid development of renewables and efficiency. At household level, very often, solar is already economically interesting, but some

1. Biomass is an exception

financial barriers are making it difficult to act. Some creative programmes have been very successful in other countries and could be adapted to the country needs. In Tunisia, PROSOL is a savvy mix of government subsidies and bank loans that enable middle-class citizens to invest in solar thermal or PV (Climate Policy Initiative, 2012); Mosaic is crowdsourcing investors who invest in solar PV on other people's roofs in the US (Mosaic, 2015); Solease is leasing solar PV on people's roofs in Europe (Climate-KIC, 2015). Grameen Shakti provides soft loans for solar home systems in Bangladesh (Grameen Shakti, 2009).

But this sort of support for renewable energy needs to be compared with direct and indirect subsidies for electricity and fossil fuels. These subsidies provide affordable fuel and electricity for people and industry but are weighing heavily on countries' budgets. Reducing these subsidies for electricity while maintaining some social tariffs would reduce the burden on public budgets and higher electricity prices would make energy efficiency and renewable energy financially more attractive. Subsidies to the fossil fuel sector could be redirected to renewable energy and energy efficiency programme, providing long term benefits for the countries' people and industries.

While many governments are cutting public spending, investing in renewable energy could help stimulate economic growth, creating many "green collar" jobs. Today, 7.7 million jobs have been created in the renewable energy industry (IRENA, 2015a). Energy efficiency savings, especially in industry, can also help spur economic competitiveness and innovation.

The economic arguments in favour of moving toward a fully renewable energy supply are persuasive. When we also take into account the environmental and social costs and benefits, the case is unbeatable. Subsidies for fossil fuel options should be revised and positive investment for long term sustainable options should receive more incentive for establishment. The challenge now is to overcome the clamour for short-term profits and recognize the long-term opportunities.

WHAT NOW?

- We urgently need to create a level playing field for sustainable renewable energy and energy efficiency – or, better, one tilted in its favour to reflect the potential long-term benefits. Feed-in tariffs, net metering, renewable electricity auctions and reverse auctions should be extended. We need to end direct and hidden subsidies to the fossil fuel sector, but without increasing energy prices for the poorest.
- Increasing taxes on products and cars that use more energy will help to steer demand toward more efficient alternatives. VAT and import taxes should be waived for sustainable energy technologies.
- We need ambitious cap-and-trade or carbon tax regimes, nationally and internationally, that cover all large polluters, such as coal-fired power stations and energy-intensive industries. Setting a high price on carbon will help to encourage investment in renewable energy and energy efficiency, as well as reducing emissions.
- Global climate negotiations have provided finance and technology opportunities to help developing countries build their capacity for generating renewable energy and improve energy efficiency. It is now up to the governments, the private sector and other organisations in the Greater Mekong region to prepare plans and claim a substantial part of this financial support.
- People should install any effective micro-generation and energy-efficiency measures they can afford in their own home, business or community, assuming these make environmental and economic sense. Governments, energy companies and entrepreneurs can encourage this. Banks can offer low interest rates for energy efficiency and renewable energy projects, backed by international support mechanisms for instance.
- Investors should divest from fossil fuel and nuclear firms, and buy shares in renewable energy and efficiency-related companies. Anyone with savings can help to tip the balance by choosing banks, pension providers or trust funds that favour renewables.
- Politicians need to clearly support renewable energy and energy efficiency, and create supportive legislation to build investor confidence. Political parties need to reassure investors that broad energy policies will survive a change of government. National legislation needs to overcome the bias towards the energy status quo, through measures such as legally binding energy-efficiency standards.
- Energy service companies could have access to lines of credit to make energy efficiency investments (so-called third-party financing) in the industrial, buildings and service sectors. They are remunerated on the basis of the savings achieved. The ESCOs can also offer energy performance contracts (EPCs).

INNOVATION

What advances will make our renewable energy vision a reality?

The power sector scenario mapped out in the second part of this report is ambitious – but it is grounded firmly in what exists today. Only technologies and processes which are already proven are included. These are sure to be refined and improved in the years ahead, but the report is cautious in estimating their growth potential. This means we have an opportunity to improve on the IES scenario – to increase from about 90 to 100 per cent renewable electricity, and to reduce the need for hydropower and biomass as this puts pressure on food and water supplies, communities and the natural world.

After 2030 smart energy grids that are capable of managing demand and accommodating a much larger proportion of variable electricity have a vital role to play, and will be an important area for R&D. Already mobile technology offers more immediate feedback possibilities for transmission efficiency monitoring. Smart appliances that respond to varying electricity supplies will complement this.

Improving ways of storing electricity generated by wind and solar is another important focus. Several solutions are already in use. Solar power can be stored as heat or cold. Lower cost storage options, at a home, business or basin basis are rapidly becoming available. This presents another challenge to the “spinning reserve” models which underpinned previous generation planning. Technology has provided us many more options – we need to think hard how to use them best.

Hydrogen could also have a major role to play in industry and transport. Hydrogen is the ultimate renewable fuel: the raw material is water, and water vapour is the only emission. It produces energy either through direct combustion or in fuel cells, and is easily produced through electrolysis, which can be powered by renewable electricity at times of high supply or low demand. However, major challenges remain in storing and transporting it. Intensive R&D into hydrogen could have a major impact on the future energy balance.

Technology moves fast. Just 50 years after the Wright Brothers made their first flight, jet planes were carrying passengers from London to Johannesburg. Tim Berners-Lee wrote the first World Wide Web page in 1991: there are now over 3 billion web users and an immeasurable number of web pages. Tablets have already overtaken the sales of laptop computers in the incredibly short space of 6 years. Given the right political and economic support, human ingenuity will allow us to realize our vision of a 100 per cent renewable electricity supply by 2050. This is also why we developed a third scenario: the advanced sustainable energy scenario (ASES). With this scenario we try to understand what would happen if these technology improvements happen more rapidly than expected.

WHAT NOW?

- We need to radically increase investments in researching, developing and commercializing technologies that will enable the world to move toward a 100 per cent renewable energy supply. These include energy-efficient materials, design and production processes, electric transport, renewable energy generation, smart grids and alternative fuels.
- At the same time, we should stop pursuing ideas that will lock the world into an unsustainable energy supply, particularly techniques for extracting unconventional fossil fuels.
- National policies for renewable energy innovations are often fragmented or simply non-existent. Governments need to introduce supportive policies, in close collaboration with representatives from industry and finance.
- We need to educate, train and support the scientists, engineers and other skilled workers who will invent, design, build and maintain our new energy infrastructure. We also need to support entrepreneurs and innovative companies with ideas to help us move toward a renewable energy future.

THE ROLE OF THE PRIVATE SECTOR

Unreliable and low-quality electricity is holding back Myanmar's private sector, crippling productivity and damaging equipment. When factories are forced to resort to diesel generators, this not only increases costs, but also harms the health of employees and nearby communities. Switching from grid to diesel in case of power cuts takes time and disrupts the continuity of assembly line/streamlined processes. Companies operating in semi-urban and rural areas where grid electricity is limited have significantly higher operating and maintenance costs.

Companies are interested in electricity supply security. A power cut represents an economic loss. Analyses from blackouts in the United States show that a 30-minute power cut results in an average loss of US$15,709 for medium and large industrial companies, and nearly US$94,000 for an eight-hour interruption. Even short blackouts – which occur several times a year in the US – add up to an annual estimated economic loss of between US$104 and US$164 billion (Allianz, no date). Renewable energy systems and energy efficiency or demand side management can provide energy security to companies, by helping them to satisfy their power needs in a hybrid way – combining on-grid and distributed solutions.

Companies are interested in stable electricity prices. Power purchase agreements (PPAs) with wind power plants or solar parks guarantee stable prices for the next 20 to 25 years, since these electricity plants do not depend on raw material prices, unlike diesel, coal or gas power plants. Several companies, including IKEA, Google, Apple and Coca Cola are heavily investing in renewable energy, be it through PPAs or their own renewable energy infrastructure. The private sector in Myanmar is showing increasing interest in sourcing electricity through renewables such as solar, mini-hydro and biomass. International and domestic companies alike are exploring options to source renewable energy, particularly through solar and biomass.

Companies are also concerned about their reputation. Most famous companies want to operate in a clean way. This includes the sourcing of electricity. Several companies have made commitments to source 100 per cent of their energy from renewables. These include These are Adobe, Alstria, Autodesk, Aviva, Biogen, BMW Group, BROAD Group, BT Group, Coca-Cola Enterprises, Commerzbank, DSM, Elion Resources Group, Elopak, Formula E, Givaudan, Goldman Sachs, Google, H&M, IKEA Group, Infosys, ING, International Flavors & Fragrances Inc.(IFF), J. Safra Sarasin, Johnson & Johnson, Kingspan, KPN, La Poste, Land Securities, Some companies have already started relocating in order to have access to clean, renewable electricity sources. Countries that offer clean electricity available on the grid, or that provide the right enabling framework for companies to invest in renewable energy

Marks & Spencer, Mars Incorporated, Microsoft, Nestlé, Nike, Inc., Nordea Bank AB, Novo Nordisk, Pearson PLC, Philips, Procter & Gamble, Proximus, RELX Group, Salesforce, SAP, SGS, Starbucks, Steelcase, Swiss Post, Swiss Re, UBS, Unilever, Vaisala, Voya Financial, Walmart and YOOX Group (The Climate Group, 2016). Some companies have already started relocating in order to have access to clean, renewable electricity sources. Countries that offer clean electricity available on the grid, or that provide the right enabling framework for companies to invest in renewable energy and energy efficiency will attract companies.

Companies may also be interested in providing flexibility to the grid operators. Every electricity consumer can agree to give up some of its power access at specified times in order to provide flexibility to power companies and grid operators. A surge in demand can then be mitigated by curtailing some consumers rather than calling upon additional power plants, usually called "spinning reserve". Aggregators can form the interim party between consumers and the grid operators or power companies. In other words, the capacity market will provide an insurance policy against the possibility of blackouts by providing financial incentives to ensure we have enough reliable electricity capacity to meet demand. These challenges include policy inconsistencies, limited financing options, the persistence of subsidies on hydrocarbons, and lack of access to a streamlined PPA process.

In the United States businesses and homeowners earned over US$2 billion in direct revenues from demand response measures in 2012; 29.5GW of capacity was made available by these players to the electricity market to provide more flexibility to the grid, lowering the number of peaking plants and increasing efficiency (Smart Energy Demand Coalition, no date).

WHAT NOW?

- Provide the right enabling framework for companies to invest in renewable energy and energy efficiency: in Myanmar, most of the time policies are lacking and several barriers prevent companies from investing in renewable energy and energy efficiency.

- The private sector can do more to help break down these barriers to help achieve better energy security and a brighter future. Helping Myanmar achieve its goal of sustainable development will also create a better business environment beneficial to all.

- Provide the right framework for the organisation of capacity markets. Here are some recommendations taken from the Department of Energy and Climate Change, United Kingdom (2012). Forecast of future peak demand will be made; the total amount of capacity needed to ensure security of supply will be contracted through a competitive central auction a number of years ahead; providers of capacity successful in the auction will enter into capacity agreements, committing to provide electricity when needed in the delivery year (in return for a steady capacity payment) or face penalties; providers of capacity able to enter the auction will include existing providers and new providers, to incentivise extra investment now and in the future and to incentivise good repair and maintenance practices; and the costs of the capacity payments will be shared between electricity suppliers in the delivery year.

- Ensure a sustainable electricity grid mix to attract companies that are serious about their environmental performance and worried about unstable electricity prices.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WHERE DOES THIS TAKE US?

COP21, in December 2015, in Paris, confirmed the global willingness for avoiding addressing catastrophic climate change. That the world faces an energy crisis is beyond doubt. A lack of access to energy is one of the main causes of poverty. There's a pressing need to secure a sustainable energy supply as demand for fossil fuels and hydropower outstrips environmentally and economically sustainable supply.

We – individuals, communities, businesses, investors, politicians – must act immediately, and boldly. Half-hearted solutions are not enough. We must aim for a fully renewable and sustainable energy supply as a matter of urgency.

It is possible. The second part of this report lays out, in unprecedented detail, one way that we can do this. It isn't the definitive solution, and it isn't perfect: as we've seen, it raises many challenges and difficult questions. The modelling shows that solutions are at hand. The scenarios are presented to catalyse debate and to spur the region to action.

We now need to respond to the issues it raises. We need to take it further. But most of all, we need to act on it – each and every one of us. Starting today.


Renewable
It's doable

PART B: IES SCENARIOS

Disclaimer

This report has been prepared by Intelligent Energy Systems Pty Ltd (IES) and Mekong Economics (MKE) in relation to provision of services to World Wide Fund for Nature (WWF). This report is supplied in good faith and reflects the knowledge, expertise and experience of IES and MKE. In conducting the research and analysis for this report IES and MKE has endeavoured to use what it considers is the best information available at the date of publication. IES and MKE make no representations or warranties as to the accuracy of the assumptions or estimates on which the forecasts and calculations are based.

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Acronyms

AD	Anaerobic Digestion
ADB	Asian Development Bank
ASEAN	Association of Southeast Asian Nations
ASES	Advanced Sustainable Energy Sector
BAU	Business As Usual
BCM / Bcm	Billion Cubic Metres
BNEF	Bloomberg New Energy Finance
BOT	Build-Operate-Transfer
BP	British Petroleum
BTU / Btu	British Thermal Unit
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CNPC	China National Petroleum Corporation
COD	Commercial Operations Date
CSP	Concentrated Solar Power
DNI	Direct Normal Irradiation
DTU	Technical University of Denmark
EE	Energy Efficiency
EGAT	Electricity Generation Authority of Thailand
EIA	Energy Information Administration
FOB	Free on Board
FOM	Fixed Operating and Maintenance
GDP	Gross Domestic Product
GHI	Global Horizontal Irradiance
GMS	Greater Mekong Subregion
GT	Gas Turbine
HV	High Voltage
ICT	Information and Communication Technology
IEA	International Energy Agency
IES	Intelligent Energy Systems Pty Ltd
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
JV	Joint Venture

JVA	Joint Venture Agreement
KOGAS	Korean Gas Corporation
LCOE	Overall Levelised Cost of Electricity
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MEPE	Myanmar Electric Power Enterprise
MERRA	Modern Era-Retrospective Analysis
MKE	Mekong Economics
MMcfd	Million Cubic Feet Per Day
MOA	Memorandum of Agreement
MOAI	Ministry of Agriculture and Irrigation
MOE	Ministry of Energy
MOEP	Ministry of Electric Power
MOGE	Myanmar Oil and Gas Enterprise
MOM	Ministry of Mines
MOST	Ministry of Science and Technology
MOU	Memorandum of Understanding
MTU	Mandalay Technological University
MV	Medium Voltage
NASA	National Aeronautics and Space Administration (the United States)
NEDO	New Energy and Industrial Technology Development Organisation (Japan)
NPV	Net Present Value
NREL	National Renewable Energy Laboratory (the United States)
OECD	Organisation for Economic Co-operation and Development
ONGC	Oil and Natural Gas Corporation (India)
OPEC	Organisation of the Petroleum Exporting Countries
OPEX	Operational Expenditure
PDR	People’s Democratic Republic (of Laos)
PRC	People’s Republic of China
PTT	Petroleum Authority of Thailand
PTTEP	PTT Exploration and Production
PV	Photovoltaic
RE	Renewable Energy
ROR	Run of River
RPR	Reserves to Production Ratio
SCADA/EMS	Supervisory Control and Data Acquisition/Energy Management System
SES	Sustainable Energy Sector
SWERA	Solar and Wind Energy Resource Assessment

SWH	Solar Water Heating
TCF / Tcf	Trillion Cubic Feet
UN	United Nations
US$	United States Dollar
VOM	Variable Operating and Maintenance
WEO	World Energy Outlook
WWF	World Wide Fund for Nature
WWF-GMPO	WWF – Greater Mekong Programme Office

Table of Contents

1 Introduction

Intelligent Energy Systems Pty Ltd ("IES") and Mekong Economics ("MKE") have been retained by WWF – Greater Mekong Programme Office ("WWF-GMPO") to undertake a project called "Produce a comprehensive report outlining alternatives for power generation in the Greater Mekong Sub-region". This is to develop scenarios for the countries of the Greater Mekong Sub-region (GMS) that are as consistent as possible with WWF's Global Energy Vision to the Power Sectors of all Greater Mekong Subregion countries. The objectives of WWF's vision are: (i) contribute to reduction of global greenhouse emissions (cut by >80% of 1990 levels by 2050); (ii) reduce dependency on unsustainable hydro and nuclear; (iii) enhance energy access; (iv) take advantage of new technologies and solutions; (v) enhance power sector planning frameworks for the region: multi-stakeholder participatory process; and (vi) develop enhancements for energy policy frameworks.

The purpose of this report is to provide detailed country-level descriptions of three scenarios for the Republic of the Union of Myanmar's (Myanmar's) power sector:

- Business as Usual (BAU) power generation development path which is based on current power planning practices, current policy objectives,
- Sustainable Energy Sector (SES) scenario, where measures are taken to maximally deploy renewable energy[1] and energy efficiency measures to achieve a near-100% renewable energy power sector; and
- Advanced Sustainable Energy Sector (ASES) scenario, which assumes a more rapid advancement and deployment of new and renewable technologies as compared to the SES.

It should be noted that all of the scenarios are supported by data, information and our own independent assessments based only on reports and data sources that have been published.

1.1 Report Structure

This report has been structured in the following way:

- Section 2 sets out recent outcomes for Myanmar's electricity industry;
- Section 3 summarises the main development options covering both renewable energy and fossil fuels;
- Section 4 provides a brief summary of the two scenarios that are modelled and a summary of the assumptions common to both of the scenarios;
- Section 5 sets out the key results for the business as usual scenario;
- Section 6 sets out the key results for the sustainable energy sector scenario;
- Section 7 sets out the key results for the advanced sustainable energy sector scenario;
- Section 8 provides comparative analysis of the two scenarios based on the computation of a number of simple metrics that facilitate comparison;
- Section 9 provides analysis into the cost of electricity under the two scenarios; and
- Section 10 provides the main conclusions from the modelling.

The following appendices provide some additional information for the scenarios:

- Appendix A contains the technology cost assumptions that were used;
- Appendix B provides the fuel price projections that were used; and
- Appendix C sets out some information on the methodology used for estimating jobs creation for each scenario.

Note that unless otherwise stated, all currency in the report is Real 2014 United States Dollars (US$).

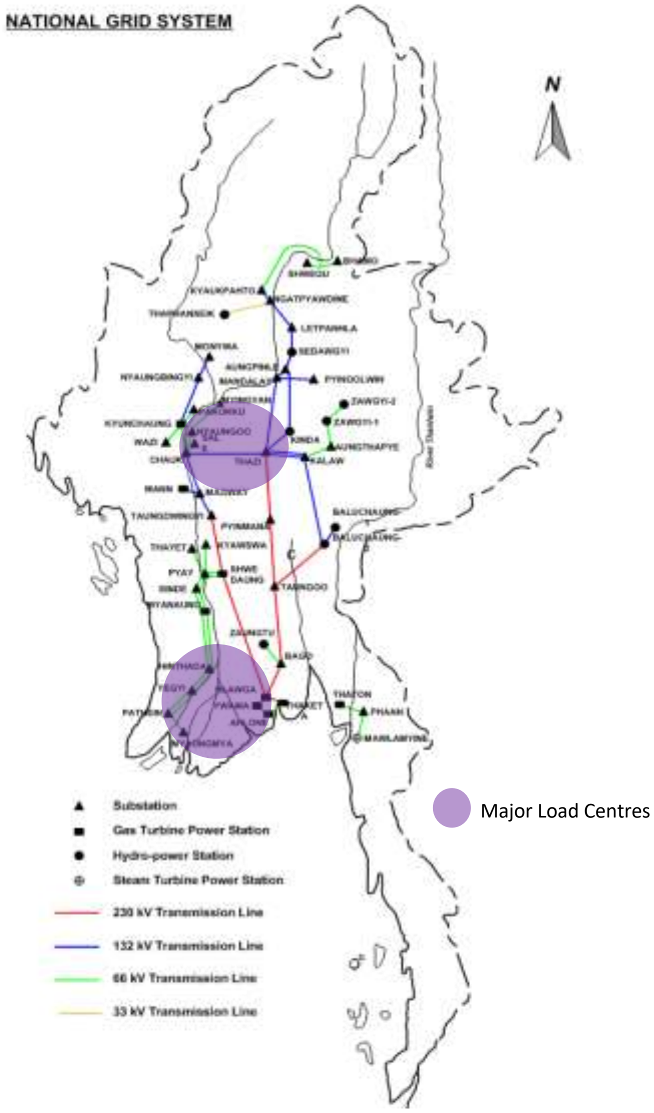
[1] Proposed but not committed fossil fuel based projects are not developed. Committed and existing fossil fuel based projects are retired at the end of their lifetime and not replaced with other fossil fuel projects. A least cost combination of renewable energy generation is developed to meet demand.

2 Background: Myanmar's Electricity Sector

2.1 Power System

A representation of Myanmar's power system is illustrated in Figure 1. The diagram highlights the present statehood of the country's national system in terms of the main generation resources that are used in the power system and their locations within the country. We have also highlighted the main demand centres within the country.

Figure 1 Myanmar Power Generation System (2013)



Before 1960, the generation system consisted mainly of isolated grids supplied by diesel generators and mini-hydropower. The first stage of the first medium-scale hydropower plant, Baluchaung-2 in central-east Myanmar about 420 km north of Yangon, was commissioned in 1960 with an installed capacity of 84 MW. The plant was designed for an annual generation of 595 gigawatt-hours (GWh) to supply Yangon and, from 1963, Mandalay. The second stage was commissioned in 1974, also with 84 MW capacity and providing an additional 595 GWh. During the subsequent 30 years, another eight hydropower plants were built, ranging from 12 MW to 75 MW and totalling 264 MW. In 2005, the 280 MW Paunglaung Hydropower Plant, about 20 km east of the new capital, Nay Pyi Taw, was commissioned. From 2005 to 2011, eight power plants, totalling 1,934 MW, were built. Two large-scale hydropower plants, one partly for export to the PRC (Shewli-1, 600 MW) and the other for domestic supply (Yeywa, 790 MW), were commissioned in 2008 and 2010, respectively. More recently built include Thauk Ye Khat No.2 (120 MW), Dapein No.1 (240 MW), Shwegyin (75 MW), Kyun Chaung (30 MW) and Kyeeon Kyeewa (74 MW).

The first gas-fired power plant, Kyunchaung in central-western Myanmar, was commissioned in 1974 with an installed capacity of 54.3 MW. During the following 30 years up to 2004, another nine gas-fired power plants were commissioned with a total capacity of 714.9 MW. Ywama, the first gas-fired power plant close to Yangon, was commissioned in 1980 with an installed capacity of 36.9 MW. In 2004, two units of 33.4 MW capacity were added. Subsequently, another three gas-fired steam turbine power plants were built in stages surrounding Yangon including Hwlaga (154.2 + 54.55 MW), Thaketa (92 + 53.6 MW) and Ahlone (154.2 + 121 MW).

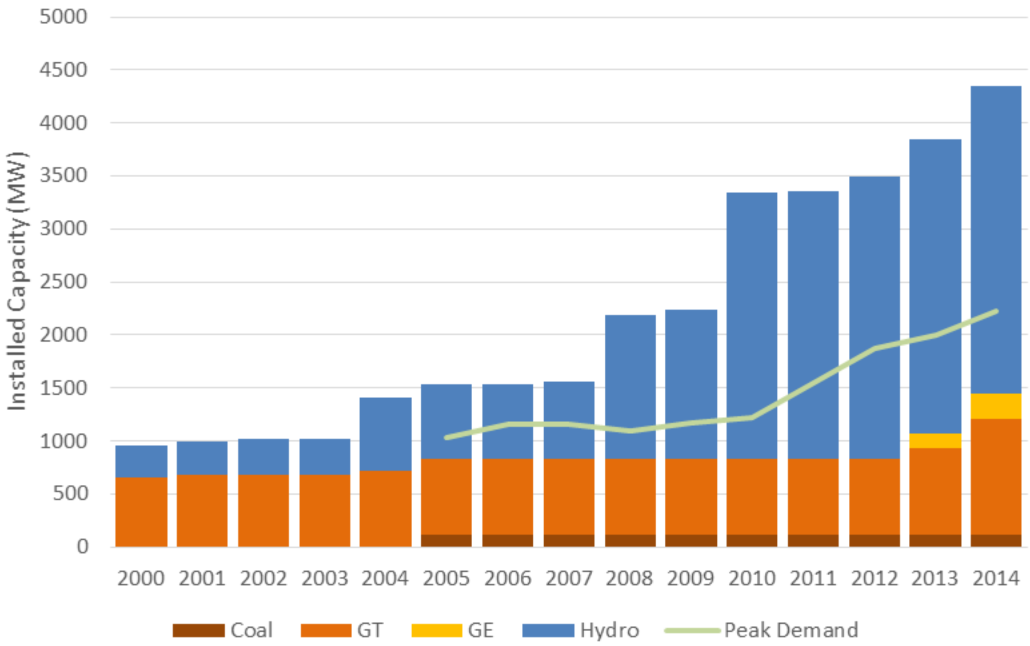
The 120 MW Tigyit power plant in central Myanmar was completed in 2002 in central Myanmar and was the first coal-fired power plant. It generates between 217 GWh/year and 389 GWh/year, corresponding to an average capacity factor of only 31%; to be efficient, it should operate at 75%–80% capacity.

2.2 Installed Capacity

Figure 2 sets out the current profile of installed capacity for the period from 2000 to 2014. By end of 2014, the system's combined installed capacity is 4,456 MW comprising of 3,011 MW hydropower capacity, 1,325 MW gas-fired and 120 MW coal-fired capacities. This capacity mix is illustrated in percentage in Figure 3 showing that hydro as the main power production technology accounts for 67% of the total grid-connected capacity, followed by natural gas at 30%.

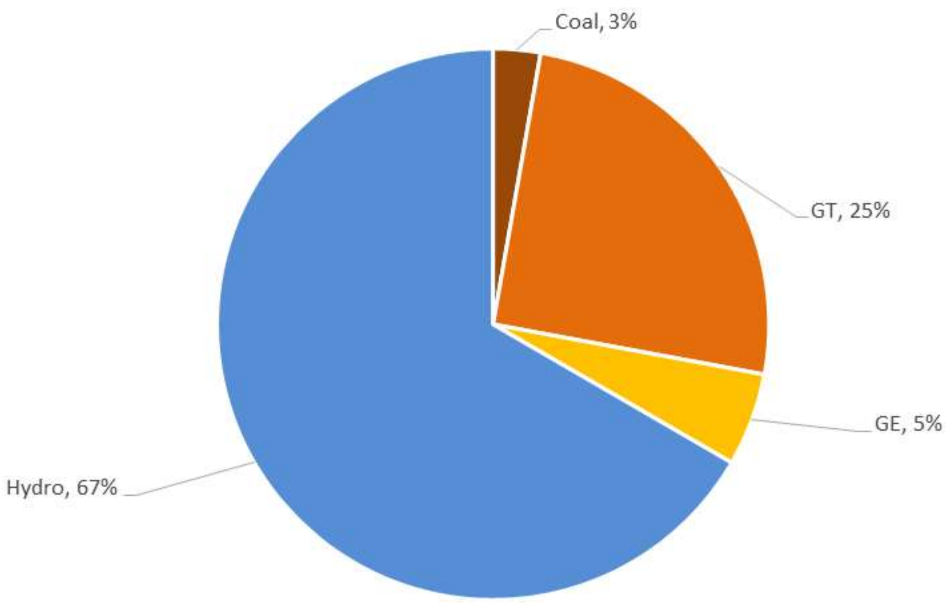
Although power generation and installed capacity have increased considerably over the past few years thanks to several newly commissioned hydro facilities, production capacity underperforms by 40% lower than installed capacity according to the ADB's estimate. Major drawbacks in power generation are largely attributed by low maintenance capacity and lack of additional infrastructure investments. The aging infrastructure coupled with system base load instability leads to frequent power supply shortages, occurring particularly during the summer months.

Figure 2 **Installed Capacity and Average Demand (2000-14)**



Sources: Consultant analysis

Figure 3 **Installed Capacity Share by Generation Type (2014)**

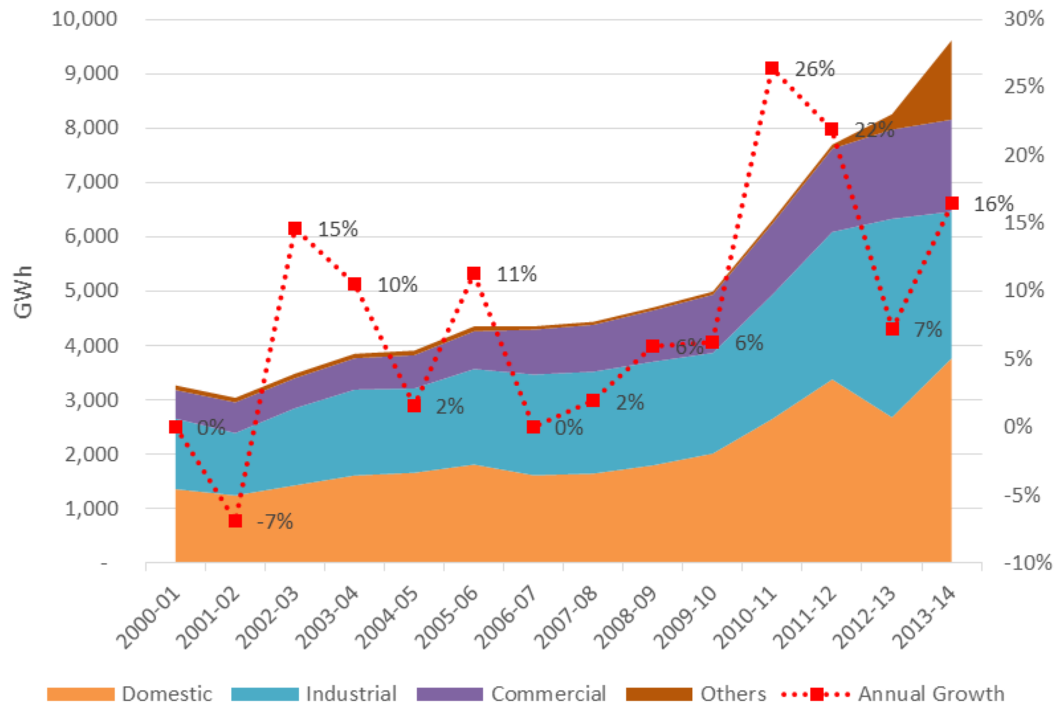


Sources: Consultant analysis

2.3 Electricity Demand

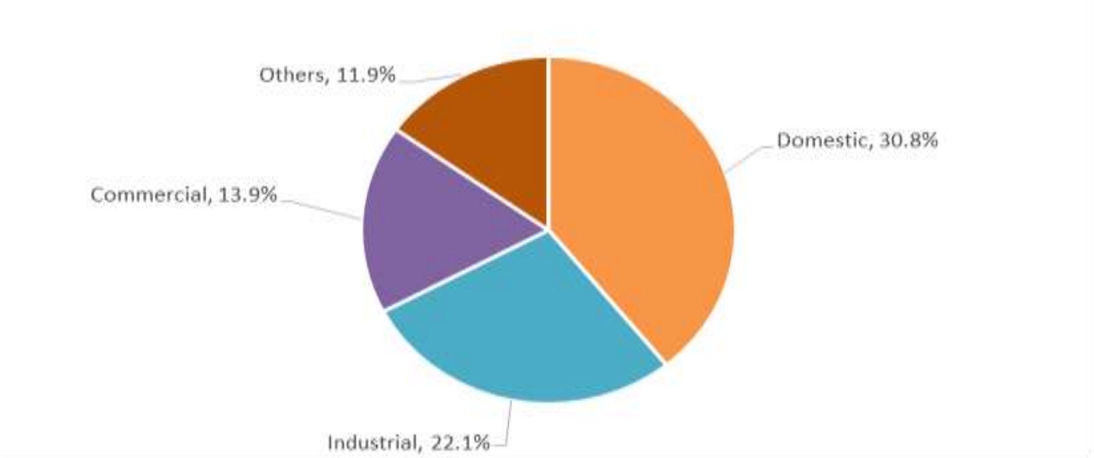
Figure 4 shows Myanmar's final electricity consumption by the end use categories until 2013/14. Electricity consumption has increased significantly in the last five years at an annual average growth rate of 15.7%. Residential (domestic), industrial, and commercial sectors were the three major end users of electricity in descending order, with their shares in the 2013/14 total final consumption being 31%, 22% and 13% respectively – see Figure 5. Industrial demand has been observed to have annual average growth rate in excess of 15% over the last 5 years, with commercial and residential sectors experiencing annual growth rates above 10%.

Figure 4 Electricity Demand by Category (2000-14)



Sources: Consultant analysis

Figure 5 Electricity Demand Shares by Category (2014)

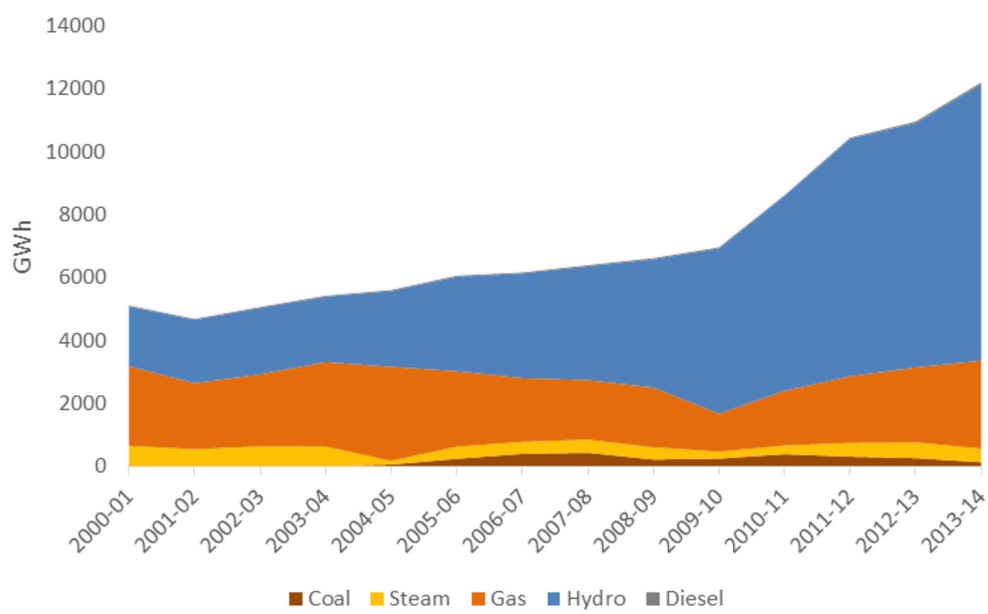


Sources: Consultant analysis

2.4 Generation Supply

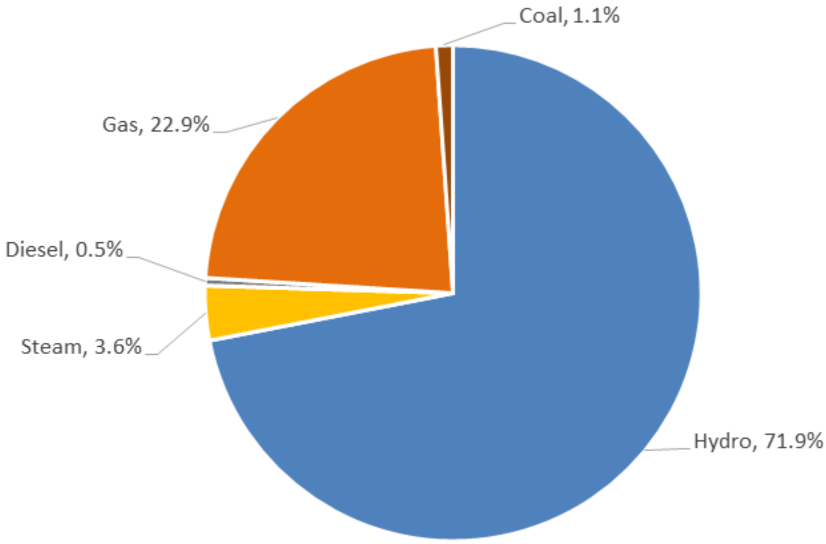
Figure 6 shows historical generation by technology type for the period 2000 to 2014, illustrating how the industry has become more heavily dependent on hydropower with its contribution being around 72% of total electricity supplied. Figure 7 plots the most updated shares in generation. In 2013/14, a total of 12,202 GWh was generated, of which 8,778 GWh was from hydropower, 2,794 GWh from gas-fired turbines and 433 GWh from steam turbines.

Figure 6 Generation by Technology (2000-2014)



Sources: Various

Figure 7 Generation Shares (2013-14)



2.5 Under Construction Generation

Table 1 sets out summary data of the existing and future power generation projects at the end of 2014.

Table 1 Summary of Current Generation Projects (2014)

Development Stage	Numbers of Projects	Installed Capacity, MW
Hydropower		
Existing	24	3,011
Under Construction	7	1,662
Joint Venture Agreement (JVA)	4	12,700
Memorandum of Agreement (MOA)	19	16,970
Memorandum of Understanding (MOU)	12	8,583
Planning / Proposal	4	783
Steam / Gas Fired		
Existing	14	915
Under Construction	12	1,255
JVA		
MOA	2	703
MOU	4	1,899
Planning / Proposal	1	106
Coal Fired		
Existing	2	128
Under Construction		
JVA		
MOA		
MOU	12	10,090
Planning / Proposal	10	8,710
Renewable Energy		
Wind MOU	25	4,032
Solar MOU	4	530
Geothermal MOU	5	200

Source: Consultant analysis based on various sources

3 Development Options for Myanmar's Electricity Sector

Myanmar is endowed with very significant amounts of hydro, solar, wind and biomass. There are also prospects for geothermal. In terms of fossil fuel resources, the country's coal deposits mainly consist of lignite and subbituminous types and are limited in terms of having low calorific value with proven reserves not being sufficient to support large coal power station developments. While Myanmar has significant offshore gas reserves, most produced natural gas is exported to the People's Republic of China (PRC) and Thailand. Further offshore gas is expected to be found, however the quantity and timing remain uncertain. In this section we provide a summary of the main development options for Myanmar's electricity sector, with respect to both fossil fuel and renewable energy options.

3.1 Natural Gas

According to ADB Myanmar Energy Sector Initial Assessment (2012), Myanmar's natural gas reserves have been estimated to be 11.8 trillion cubic feet (Tcf). Offshore gas discoveries have been significant. Two major offshore gas fields, Yadana (5.7 Tcf) and Yetagun (3.16 Tcf), were discovered in the 1990s in the Gulf of Moattama. The two fields have been supplying natural gas to Thailand since 2000, at a rate of about 755 million cubic feet per day (MMcfd) from the Yadana field and 424 MMcfd from the Yetagun field. In 2004, Daewoo International Corporation discovered the new Shwe gas field, off the coast of Sittwe, with estimated reserves of about 5 Tcf. Production from the Shwe field was commenced in 2013, for export to the PRC, through an overland pipeline from Myanmar to Kunming, Yunnan Province. The pipeline will have capacity of about 500 MMcfd, with a possible expansion to 1,200 MMcfd.

The BP statistics in 2014, on the other hand, estimated Myanmar's proved reserves of natural gas to be at some 283.2 billion cubic metres (Bcm) or 10,0 Tcf, representing around 22% of the total proved natural gas reserves of the GMS. Table 2 and Figure 8 summarise proved natural gas reserves for the GMS countries. The figure also shows the reserves to production ratio (RPR)[2]. For Myanmar, the number is relatively low because a number of fields with proven reserves have already been put into production.

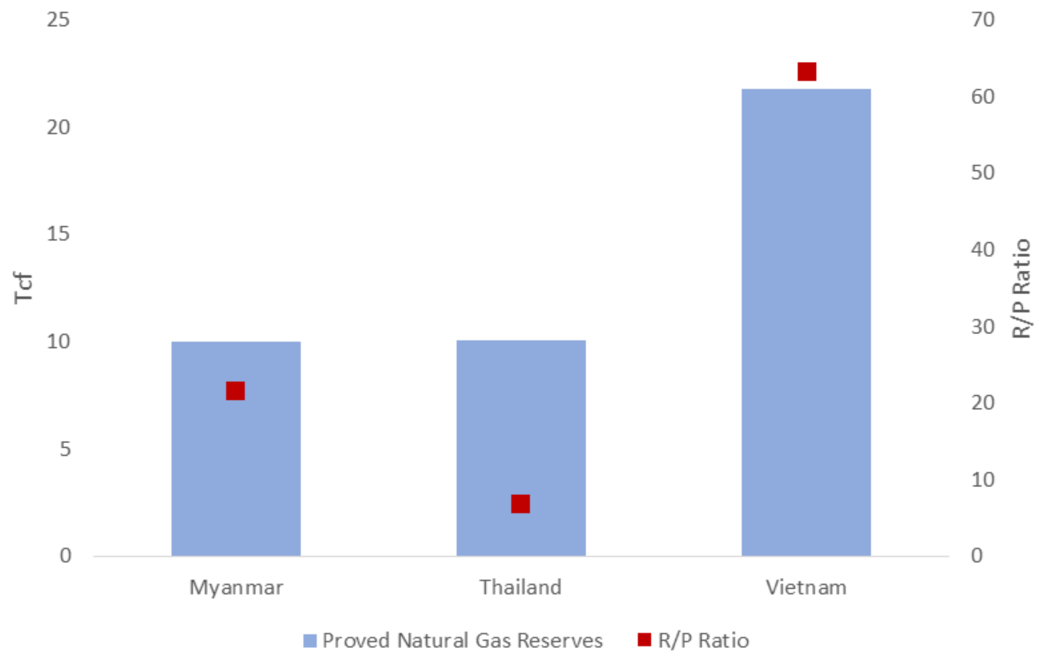
Table 2 Proved Natural Gas Reserves in GMS Countries

	Proved Reserves		RPR
	Bcm	**Tcf**	**Years**
Myanmar	283.2	10.0	21.6
Thailand	284.9	10.1	6.8
Viet Nam	617.1	21.8	63.3

Source: BP Statistics 2014

[2] The RPR is the proved reserves divided by the amount of reserves produced each year and thus a rough measure of how many years until the resource is depleted. Further information: http://en.wikipedia.org/wiki/Reserves-to-production_ratio.

Figure 8 Proved Gas Reserves of GMS Countries



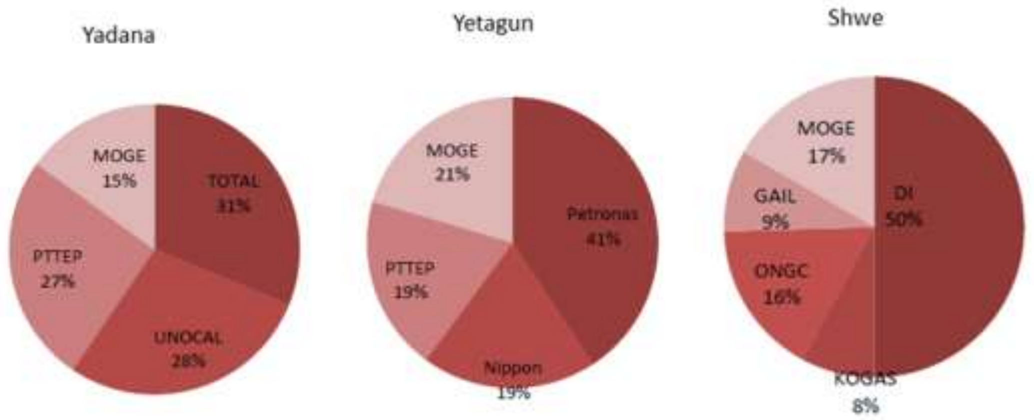
Source: BP Statistics 2014

3.1.1 Natural Gas Production and Exports

Myanmar's oil and gas industry involves the 100 per cent state-owned Myanmar Oil and Gas Enterprise (MOGE), foreign-invested companies and joint ventures between international and domestic firms. MOGE is responsible for natural gas exploration, domestic supply, pipelines construction, and coordination of the production sharing contracts with foreign companies.

Foreign firms are primarily involved in offshore exploration and production. Companies operating in Myanmar's gas sector include Malaysia's Petronas, Thailand's PTT Exploration and Production (PTTEP), TOTAL, Oil and Natural Gas Corporation (ONGC) Videsh, GAIL India, Korean Gas Corporation (KOGAS) and Nippon. The current structure of the production sharing agreements for three major offshore gas fields Yadana, Yetagun and Shwe are shown in Figure 9.

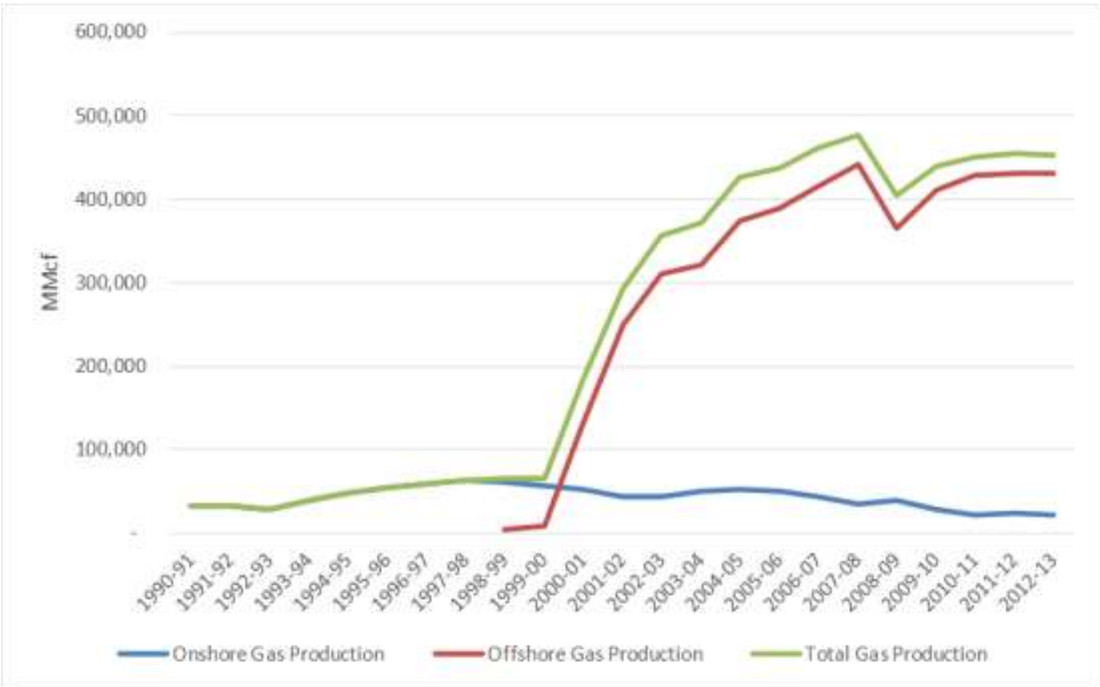
Figure 9 Production Sharing Agreement Structures of Natural Gas Fields in Myanmar



Source: MOGE

Figure 10 plots Myanmar's gas production showing the onshore and offshore production. It demonstrates how offshore production with production from the offshore fields has become a key component of Myanmar's gas sector since the year 2000. Total production in 2012/13 was 453,000 MMcf, more than 90% of which was from the offshore Yadana (57%) and Yetagun (34%) fields; the remainder was from the MOGE-operated onshore fields. Production in Shwe and Zawtika (scheduled to begin in 2014), is anticipated to bring Myanmar's total gas output to roughly 2,200 MMcfd by 2015.

Figure 10 Myanmar Natural Gas Production



Source: MOGE Presentation

Around 80% of natural gas produced in Myanmar is for exports. As of 2012/13, the export volume was 362,000 MMcf and most of it was for Thailand; however, production from Shwe commencing in July 2013 means that China has also become a significant export destination for Myanmar's gas.

Myanmar–People's Republic of China Gas Pipeline Project

In June 2008, the China National Petroleum Corporation (CNPC) signed a memorandum of understanding (MOU) with the Government of Myanmar and a Daewoo-led consortium on the sale and transport of natural gas from the offshore blocks A-1 and A-3. Following signing of the MOU, Daewoo commenced development of the gas fields, targeting 2013 for the start of on-stream production. An Export Gas Sale and Purchase Agreement was signed in December 2008, and includes a provision whereby the gas price would be reviewed quarterly to reflect global trends.

Daewoo, CNPC, and MOGE have agreed on a gas price for Daewoo's Shwe, Shwe Phyu, and Mya fields on Block A-1 and Block A-3 in the Rakhine Basin, offshore of northern Myanmar. Gas from the fields would be sold to the People's Republic of China (PRC) at a rate of about US$7.73 per million British thermal units (MMBtu), inclusive of a tariff of US$1.02 per MMBtu. The contract is valid for a 30-year period and is indexed to the inflation rate in the United States. Concurrently, another consortium of block partners, consisting of Oil and Natural Gas Corporation Videsh, GAIL India, Daewoo, and the Korean Gas Corporation, were reportedly planning to invest approximately US$2.8 billion to develop the fields, with first gas production also scheduled for 2013. The consortium planned to spend a further US$936 million to lay an undersea pipeline to transport the gas to shore.

The export pipeline from Myanmar to China is shown in Figure 11.

Figure 11 Oil and gas export pipelines from Myanmar to China

Source: Reuters International 2013

3.1.2 Natural Gas Use in Electricity Generation

Domestically, Myanmar's electricity sector accounts for around 60% of natural gas consumption. Other major gas users are the government-owned factories (20%), fertiliser plants (7.9%), a compressed natural gas facility (7.2%) and LPG production (0.9%). In absolute terms, the amount of natural gas used for power generation has increased nearly two-fold over the period 2001 – 2013, from 29,066 MMcf to 57,333 MMcf per year.

3.2 Coal Resources

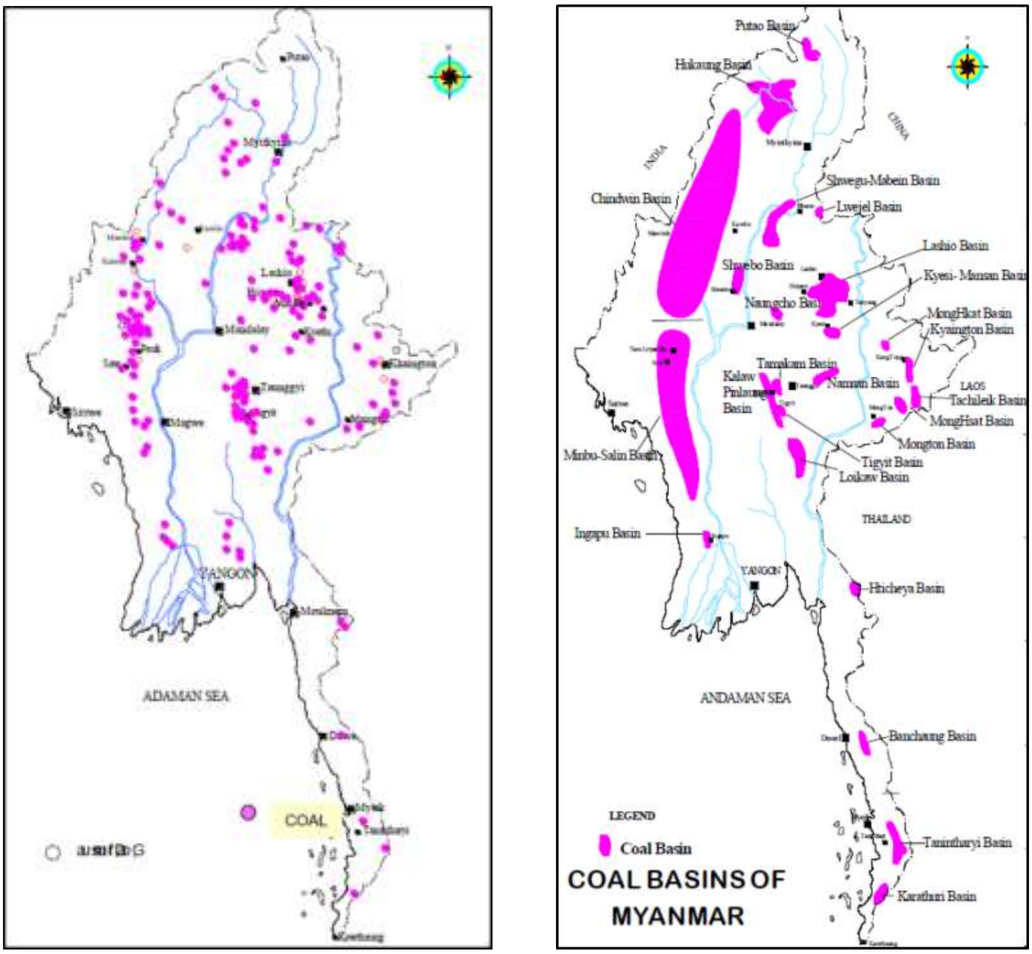
3.2.1 Domestic Coal Reserves

Coal has historically been of minor significance in Myanmar although the country possesses a reserves of coal, albeit of low quality. Serious attempts, even though at smaller scales, to explore coal started in 1965 and since then coal deposits have been found in some 400 locations. There are two main river basins of Chindwin and

Ayeyarwady rivers but sustained explorations found coal in the southern states and intra-mountain basins of the Shan state. Coal deposits are mainly clustered in Kalewa area in Chindwin River valley and Sagaing Region. There are deposits found in Magway, Tanintharyi, Shan State and Ayeyarwady regions. Most of Myanmar's coal resources are graded between lignite to sub-bituminous. Coal found in Shan State tends to be of lower quality (sub-bituminous). The combined reserves in these deposits have been proven to be some 405.89 million tons in various categories.

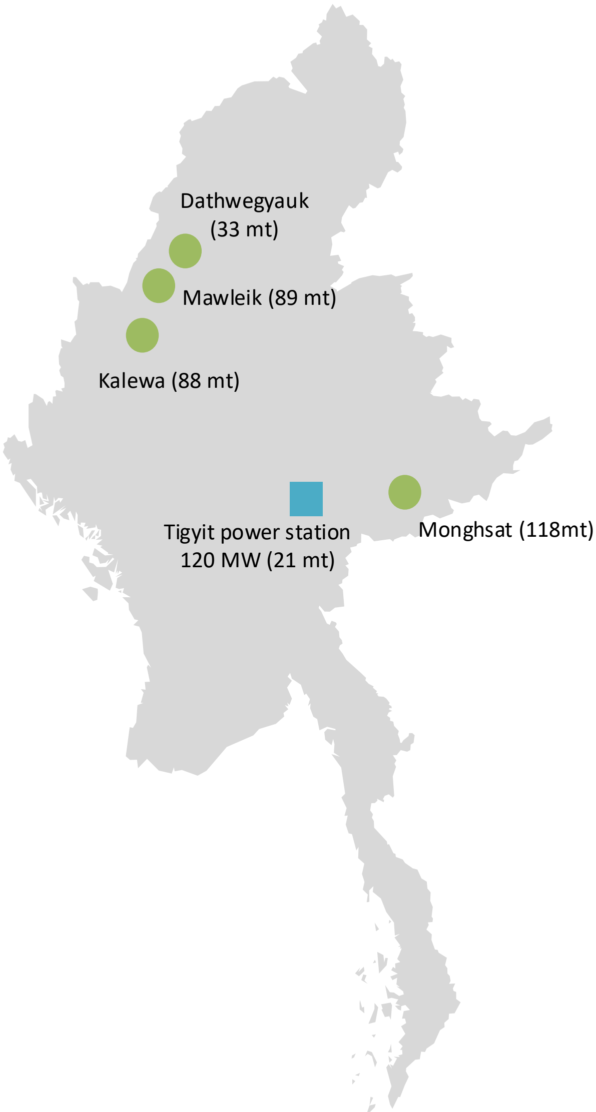
Figure 12 shows the coal occurrences in Myanmar (chart to the left) and the main coal basins (chart to the right). There are some 500 occurrences and over 200 deposits, of which around 34 are considered to warrant some attention in terms of exploitation. Figure 13 shows the location of some large strategic coal mines and deposits. It can be seen that the unexploited reserves are located in remote locations of the country; the locations are at considerable distances from the established rail network. Closer analysis of Myanmar's domestic coal reserves, taking into account factors such as deposit size, and the calorific value suggests that exploitation of domestic coal for power generation would only be feasible on a small scale (fluidised bed for example). This implies that future coal power plants would mainly depend on coal imports.

Figure 12 Coal Deposits and Coal Basins in Myanmar



Source: MOM

Figure 13 Locations of Myanmar's Largest Coal Deposits



3.3 Nuclear Energy

Some studies have been conducted to examine nuclear energy in the country. However, it is considered to be a last-resort option, as Myanmar has solar, wind, biomass, hydro potential and offshore gas reserves that could be explored ahead of nuclear energy.

3.4 Hydro Power

Hydropower is by far the dominant source of electricity in Myanmar, accounting for around 70% of both the capacity mix and annual production. We therefore briefly review the present status of hydro power development in Myanmar as this feeds into our modelling framework.

3.4.1 Hydropower Potential

Various studies have reported Myanmar has huge hydropower potential, estimated to be at 108 GW, from its four main river basins: Ayeyarwaddy, Chindwin,Thanlwin and Sittaung. Myanmar Electric Power Enterprise (MEPE), under the Ministry of Electric Power (MOEP), has so far identified more than 300 locations suitable for hydropower development, with a combined potential capacity of about 46,000 MW. Among these locations there are as many as 92 potential sites for construction of medium to large power plants, each having capacity greater than 10 MW. These hydro sites have been grouped into 60 potential hydro projects including 10 projects that are in various stages of development. Similarly as many as 210 sites of small and medium size sites each have less than 10 MW potential. A total potential installed capacity of 231 MW has been identified. The majority of hydropower potential is located on the eastern side of the country in Kayin State (17 GW potential), Shan State (7 GW potential) and Kayah State (3.9 GW potential).

3.4.2 Existing Hydro Power Plans and Proposed Construction

At the present, over 4,000 MW of hydro power capacity has been developed, representing just a small portion of the identified potential of 46 GW for the country. Run-off-the-river (ROR) type plants such as Baluchaung 1-2, Kyaingtoung and Shweli are combined with 16 storage-type hydro units to meet approximately 70% of the country's total electricity requirements. Most storage-type plants however have limited reservoir sizes and also are energy-constrained owing to their multi-purpose nature. Sedawgyi, Kinda, Thaphanseik, Mone, Yenwe, Khapaung, Kyi-on- Kyiwa are those plants, the generation of which is dependent on the irrigation water availability.

Without a shift in the government strategy, it is expected that hydro will comprise the majority of future capacities added to the national power grid and for exports. Until 2030 and beyond, thirty six projects have been formed to realise the untapped hydro power resources, most of them would be built under a JV/BOT basis by foreign investors and only small portions of the projects would be funded by MOEP and domestic entrepreneurs. Under this scenario, hydropower would be the main contributor to any increase in renewable energy capacity in Myanmar, although large solar projects are expected soon and there are many community scale solar projects that are starting to occur[3].

Small hydropower projects for border area development: Over the past 5 years, some 26 micro and 9 mini-hydropower power projects have been developed by MEPE, with installed capacity ranging from 24 to 5,000 kW. These projects have included border areas, aimed at improving the social and economic conditions of poor rural households and remote communities. These mini-hydropower projects also facilitate cottage industries and enhance agricultural productivity through improved irrigation.

Village-scale hydropower projects range from primitive wooden wheel types to a variety of small modern turbine systems. Research on micro-hydropower plants, led by the Ministry of Science and Technology (MOST), includes the design and construction of different types of turbines and synchronous generators for micro-hydropower plants.

3.4.3 Existing Hydro Power Plants

Table 3 provides the details of the 22 existing hydro power plants with capacity greater than 10 MW. As can be seen, while the combined capacity of the plants is nearly 3,000 MW, the firm capacity is just one third of this amount. This would normally result in actual electricity generation being significantly below the planned energy. In 2013 for example, this was 8,466,138 MWh versus 14,088,800 MWh. The locations of the existing hydro power stations are shown in Figure 14. As illustrated earlier in Figure 2, Myanmar's power system has a significant amount of generation based on hydro.

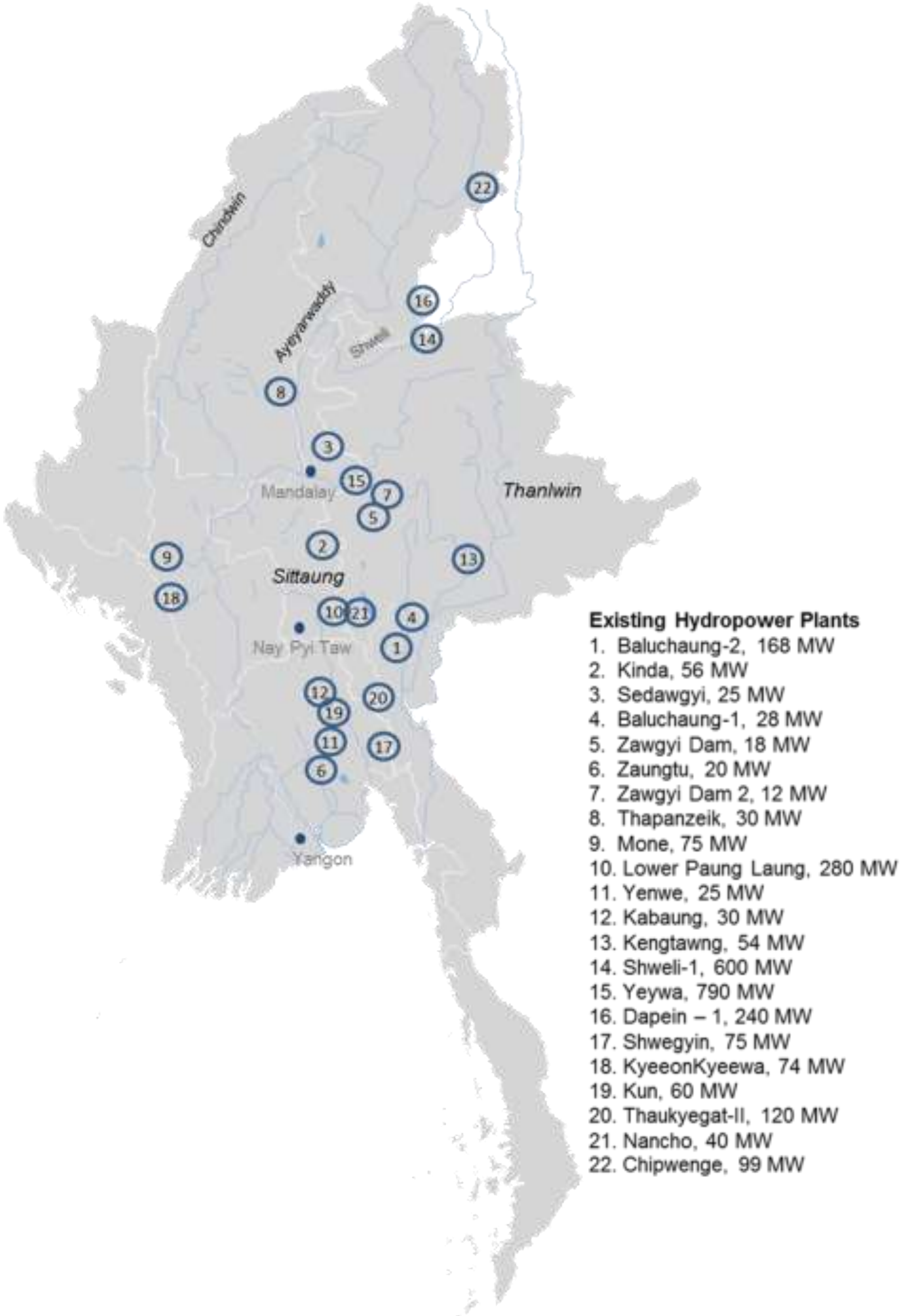
[3] See for example: http://www.mmbiztoday.com/articles/lao-based-firm-build-solar-micro-grids-shan-chin.

Table 3 Myanmar Hydro Power Plants with Capacity Over 10 MW in Operation

No.	Name of Plant	Owner	Capacity (MW)		COD[4]	Location
			Nameplate	Firm		
1	Baluchaung 2	MOEP	168	155	1960/74	Kayah
2	Kinda	MOEP	56	21	1985	Mandalay
3	Sedawgyi	MOEP	25	20	1989	Mandalay
4	Baluchaung-1	MOEP	28	26	1992	Kayah
5	Zawgyi Dam	MOEP	18	4	1995	Shan
6	Zaungtu	MOEP	20	9	2000	Bago
7	Zawgyi Dam 2	MOEP	12	3	2000	Shan
8	Thapanzeik	MOEP	30	13	2002	Sagaing
9	Mone	MOEP	75	38	2004	Magway
10	Lower Paunglaung	MOEP	280	104	2005	Naypyitaw
11	Yenwe	MOEP	25	14	2007	Bago
12	Kabaung	MOEP	30	13	2008	Bago
13	Kengtawng	MOEP	54	43	2009	Shan
14	Shweli-1	JV	600	175	2009	Shan
15	Yeywa	MOEP	790	175	2010	Mandalay
16	Dapein-1	JV	240	30	2011	Kachin
17	Shwegyin	MOEP	75	51	2011	Bago
18	KyeeonKyeewa	MOAI	74	42	2012	Magway
19	Kun	MOEP	60	18	2012	Bago
20	Thauk Ye Khat-2	BOT	120	32	2013	Bago
21	Phyu Chaung	MOEP	40	40	2013	Phyu
22	Baluchaung 3	MOEP	52	52	2013	Kayah
23	Upper Paunglaung	MOEP	140	140	2014	Naypyitaw
24	Namcho	MOEP	40	n/a	2014	Mandalay
25	Chipwenge	BOT	99	n/a	2014	Kachin
Total			**3,151**	**1,218**		

[4] Commercial operations date

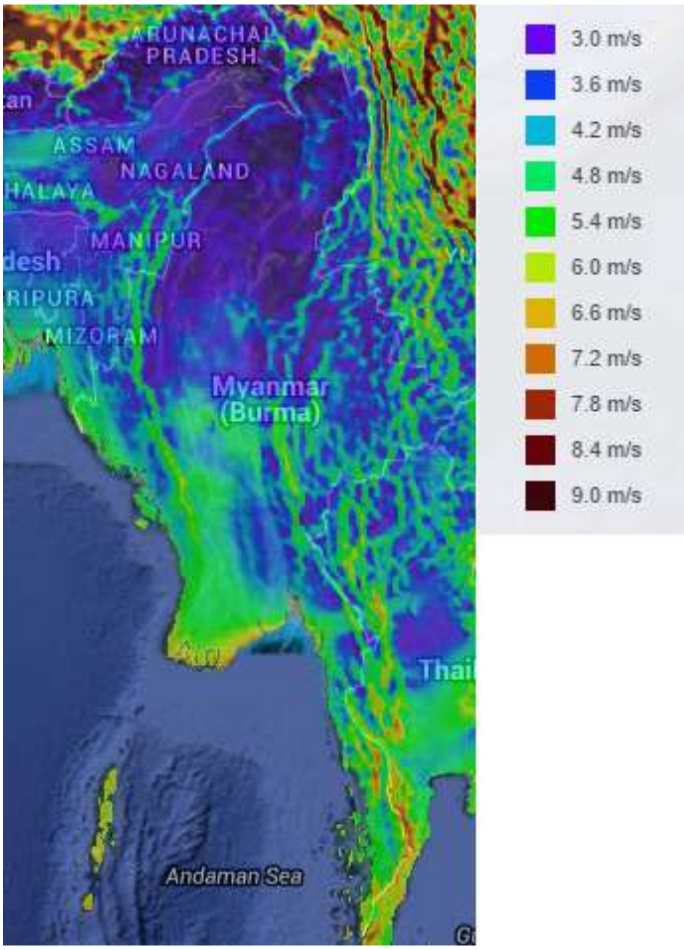
Figure 14 Location of Existing Hydro Plants in Myanmar



3.5 Wind Power

Myanmar has significant potential for wind energy, with reports suggesting some 365 TWh per year[5] could be produced. However, the industry is currently underdeveloped. Due to the initial high cost of wind energy, its development is mostly at the experimental and research phase. The evaluation of wind energy resources using modern systems has been conducted since 1998, led by the Myanmar Scientific and Technological Research Department and the Department of Meteorology and Hydrology. Judging from existing data, the western part of the country appears to have the best potential for harnessing wind power. However, available data on wind energy sources are not sufficient to evaluate suitable sites for the construction of wind turbines. Figure 15 shows Myanmar's wind resource potential based on 3TIER measurements accessed via the IRENA Global Atlas.

Figure 15 3TIER's Global Wind Dataset 5km onshore wind speed at 80m height[6]



Source: IRENA Global Atlas for Renewable Energy (3TIER Global Wind Dataset)

Figure 16 shows the DTU Global Wind Atlas[7] onshore and 30 km offshore wind climate dataset which accounts for high resolution terrain effects for 100 m above ground level. According to the IRENA global atlas description:

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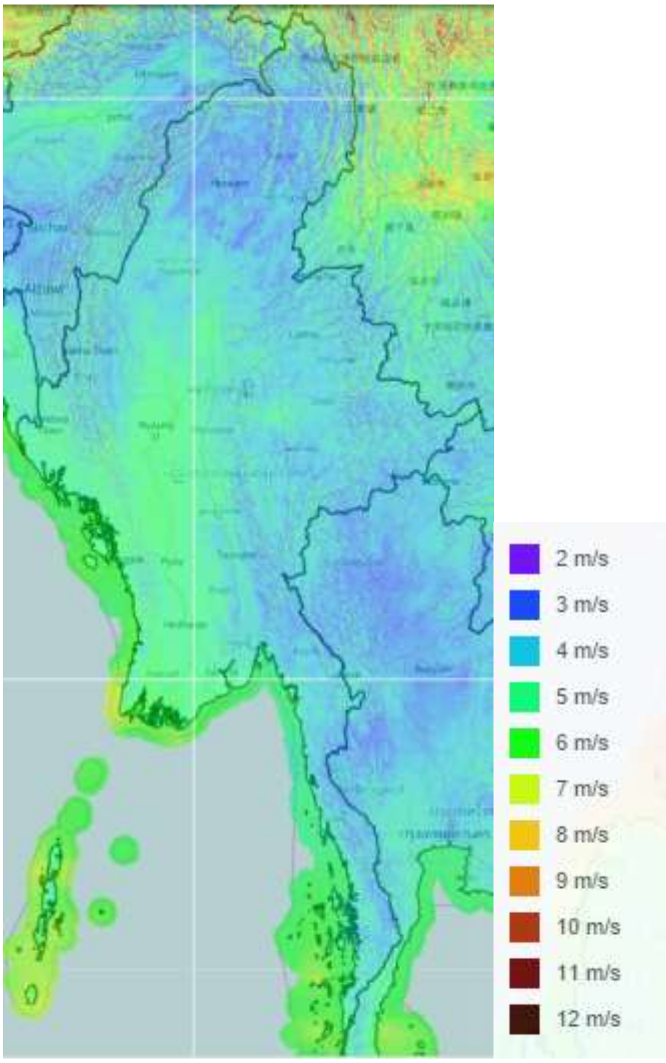
[5] MOEP; http://www.asiatradehub.com/burma/energy6.asp

[6] Average for period 1980.

[7] See: http://globalwindatlas.com/.

"this was produced using microscale modelling in the Wind Atlas Analysis and Application Program and capture small scale spatial variability of winds speeds due to high resolution orography (terrain elevation), surface roughness and surface roughness change effects. The layers shared through the IRENA Global Atlas are served at 1 km spatial resolution. The full Atlas contains data at a higher spatial resolution of 250 m, some of the IRENA Global Atlas tools access this data for aggregated statistics". This is largely consistent with Figure 15 and it also shows offshore potential is quite significant recording measurements in the range from 5 m/s to 7 m/s.

Figure 16 Average Wind Speed 1km at 100 m AGL DTU (2015)



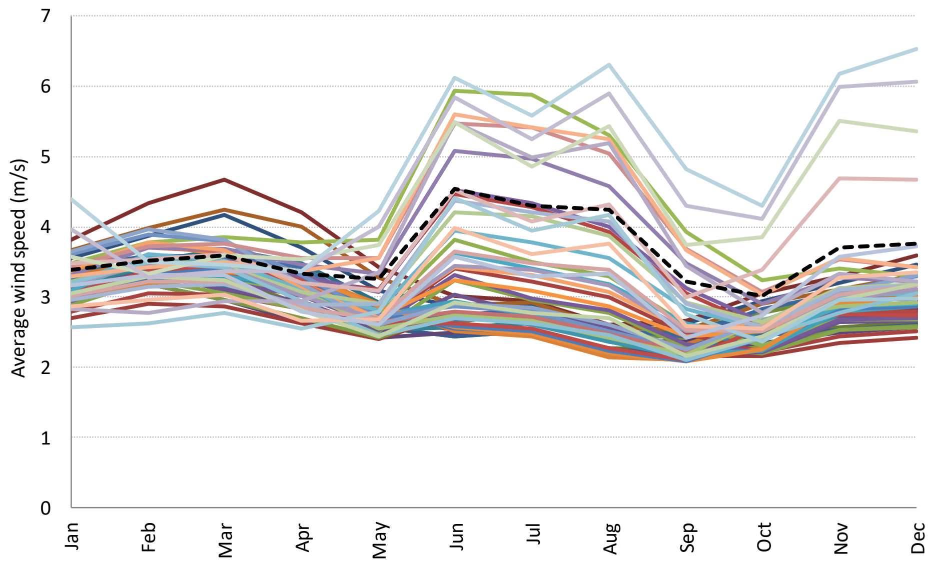
Source: IRENA Global Atlas and Global Wind Atlas (2015)

Other institutions have also conducted research and development on wind energy, including the Department of Physics at Yangon University and the Department of Electric Power (DEP) and MEPE at the MOEP. This research was in cooperation with the New Energy and Industrial Technology Development Organization (NEDO) of Japan, which has constructed meteorological observation stations in Central and Lower Myanmar. Further, NEDO has assisted in installing wind and solar measuring equipment at several sites, to collect data and to conduct feasibility studies for wind-solar power hybrid systems.

Figure 17 shows average monthly wind speed measurements for Myanmar as reported by NASA Atmosphere Science Data Centre for the locations that have the highest average wind speeds throughout the year. This shows that a number of locations in Myanmar record high wind speeds during the periods of May to September and November to December. When these locations are shaded over the map of Myanmar, as illustrated in Figure 18, we can see that in the main the locations are along the coastline of the country. There are also some locations within the central region and in the north. In general, an issue for wind generation in Myanmar is the distance of the locations with the greatest potential from demand centres.

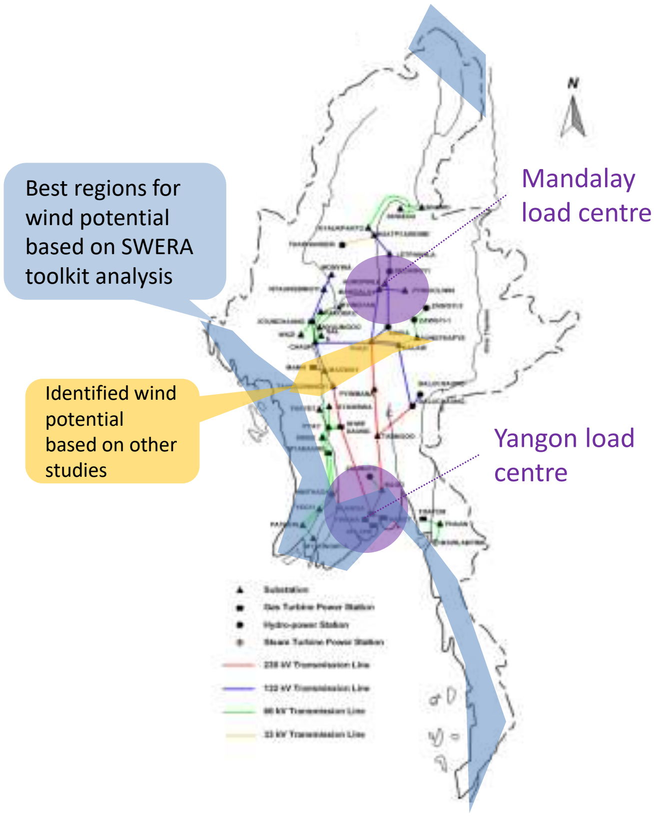
At present, there are four wind turbines are operational in Myanmar, including the 1.2 kW turbine installed at the Technological University in Shwetharlyoug Mountain (Kyaukse) Township, another 1.2 kW turbine at the Government Technical High School (Ahmar) in Ayeyarwaddy region, a 500 kW wind project on the beach (Ngwe Saung) in Ayerwaddy region and a 3 kW wind project at Dattaw Mountain in Kyaukse Township.

Figure 17 Monthly Wind Speeds for Selected Locations in Myanmar



Source: NASA Atmosphere Science Data Centre, obtained via the SWERA Geospatial Toolkit

Figure 18 Locations in Myanmar with Highest Wind Potential

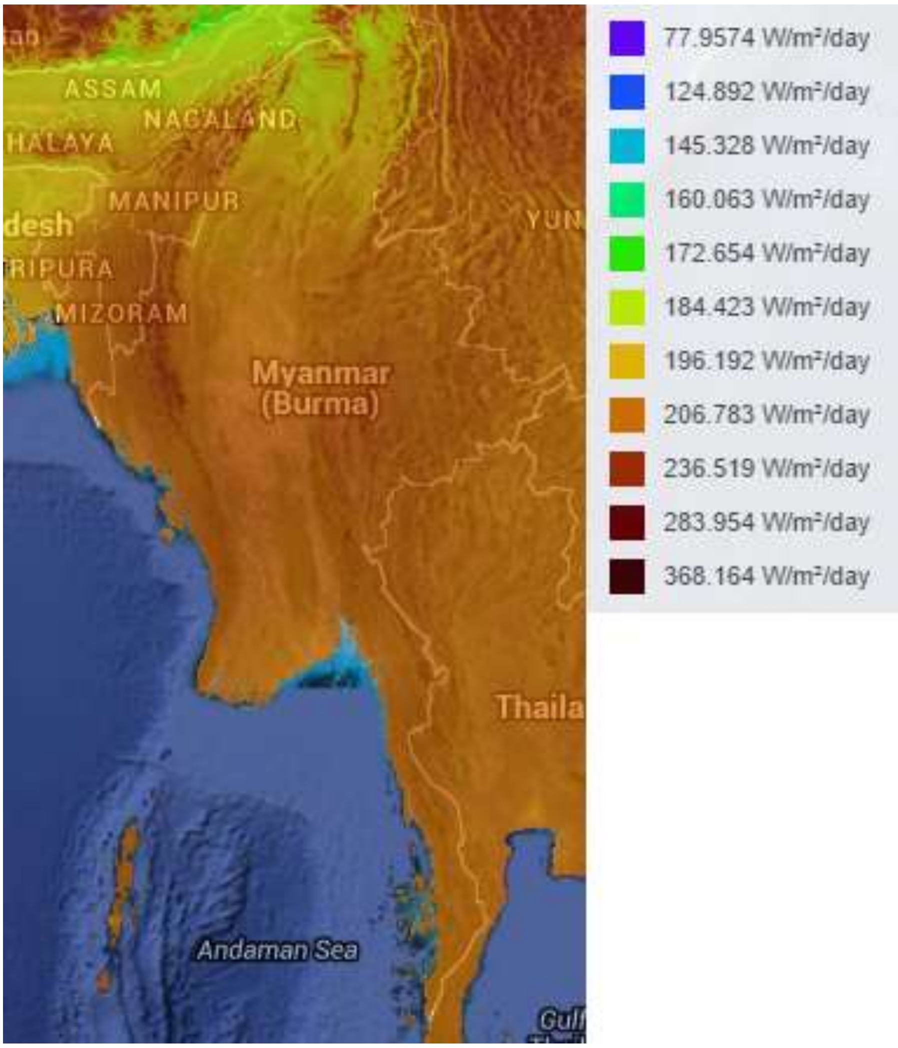


3.6 Solar Energy

As with other South East Asian nations, Myanmar has high solar radiation levels especially in the Central Dry Zone Area (see Figure 19). Potential available solar energy of Myanmar is estimated to be around 52,000 TWh per year[8]. However, similar to wind energy, solar energy in Myanmar is only in an early stage of development.

[8] MOEP; http://www.asiatradehub.com/burma/energy6.asp.

Figure 19 3TIER's Global Solar Dataset (3km in W/m^2) for GHI



Source: IRENA Global Atlas for Renewable Energy (3TIER Global Solar Dataset)

Solar energy is being introduced in a limited manner in some rural areas, through photovoltaic cells to generate electricity for charging batteries and to pump water for irrigation. As an initial step to demonstrate photovoltaic power systems for remote villages, some equipment has been installed under a technical cooperation program with other developing countries.

Stand-alone PV systems are being used for rural electrification in areas that cannot be connected to the national grid, with notable initiatives in schools and universities.

Pilot projects have included the following[9]:

1. "Solar Photovoltaic Battery Charging Community Enterprise," financed by the Energy Services and Income Generating Opportunities for the Poor (Project "ENSIGN"), in collaboration with Yoma Bank and Energy Planning Department of the Ministry of Energy (MOE);

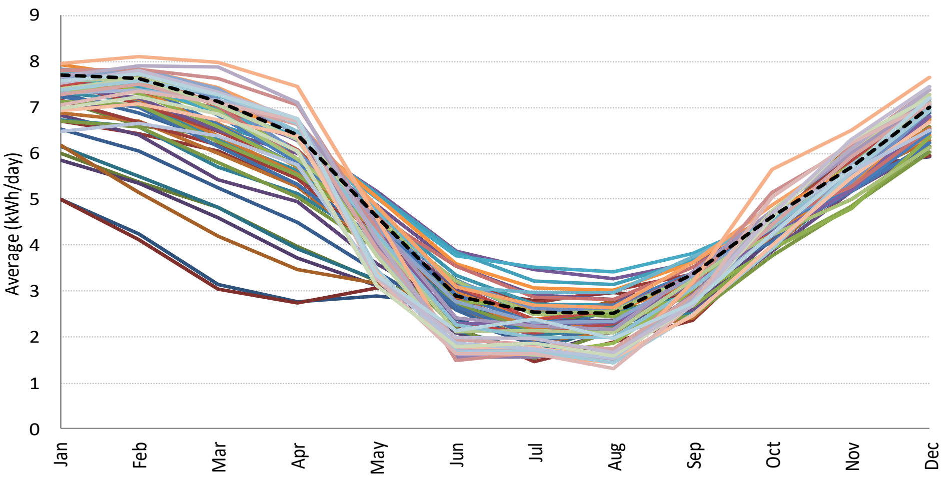
[9] ADB Myanmar Energy Sector Initial Assessment (2012)

2. "Demonstrative Research on a Photovoltaic Power Generation System in Myanmar," in cooperation with NEDO of Japan and the Department of Electric Power of MOEP; and
3. "Solar Power Village Electrification Scheme," with research and development of solar equipment prototypes, supported by the Myanmar Scientific and Technological Research Department and the Department of Physics of the Yangon Technological University.

Research continues on the use of solar power for household purposes (lighting and cooking), for irrigation pumps, and for solar driers for grain and fish. Research has successfully demonstrated the use of solar energy for making salt from seawater. MOST has begun providing electricity to schools and institutes by using solar energy. To help demonstrate the practicality of this initiative, Mandalay Technological University (MTU) has installed 3 kW PV power systems in several MOST technical schools and institutes located in remote areas and without access to the national grid system. For each school, there is enough power to supply 10 computers, one overhead projector, IPSTAR internet equipment, and 10 fluorescent lamps. The solar system used can be applied at minimum cost. MOST plans to install the system throughout the country in technical schools lacking electricity.

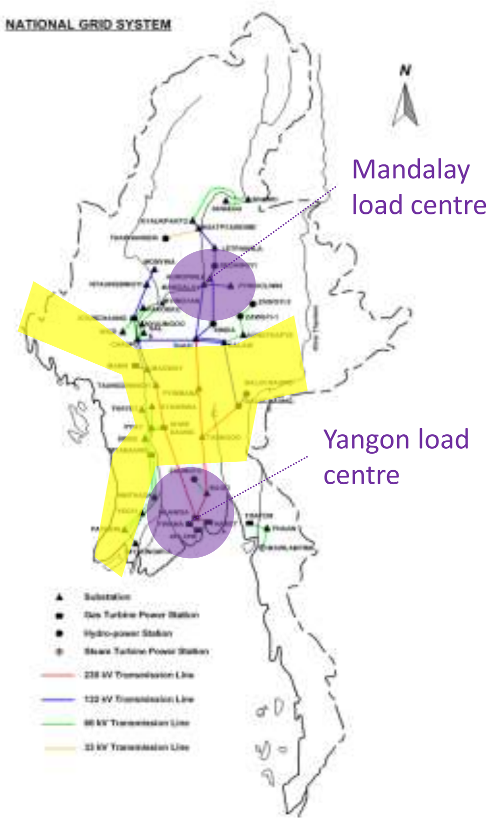
Figure 20 plots the monthly average irradiation levels for a number of selected sights with the highest annual average irradiation levels. The graph shows the monthly variation throughout the year for solar irradiation and hence generation. This also highlights October through to May exhibit excellent solar conditions. The map shading the locations of solar for Myanmar is provided in Figure 21. This also highlights that the greatest potential for solar lies in the central region of the country. Myanmar has excellent potential for largescale integration of solar resources.

Figure 20 Monthly Irradiance Levels for Selected Locations in Myanmar



Source: NASA Atmosphere Science Data Centre, obtained via the SWERA Geospatial Toolkit

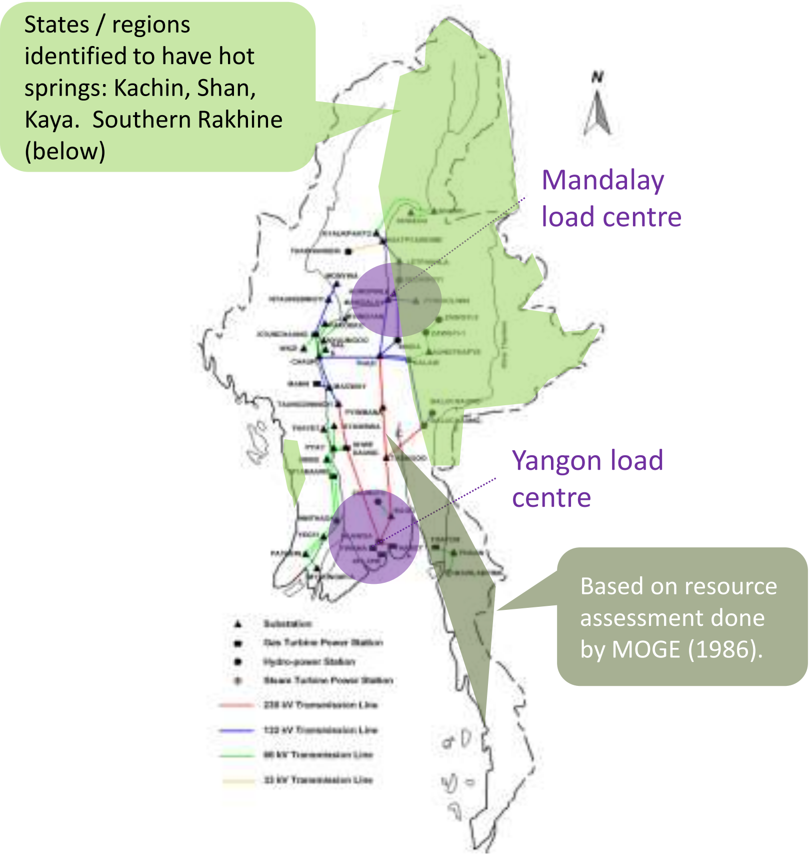
Figure 21 Best DNI Solar Irradiation Locations in Myanmar



3.7 Geothermal Energy

Geothermal energy is also abundant in Myanmar, with considerable potential for commercial development. Ninety-three geothermal locations have been identified throughout the country. Forty-three of these sites are being tested MOGE and MEPE, in cooperation with the Electric Power Development of Japan and Union Oil Company of California and Caithness Resources of the United States. Figure 22 shows the areas where considerable geothermal potential has been identified including Kachin, Shan, and Kayah states, Kayin, Kayah, Mon, Taninthayi, and also the southern part of Rakhine.

Figure 22 Locations in Myanmar with Geothermal Potential



3.8 Biomass

Approximately two-thirds of primary energy in Myanmar is supplied by biomass including fuelwood, charcoal, agriculture residue and animal waste. Fuelwood accounts for more than 90% of biomass-sourced energy, most of which is harvested from natural forests and used in both urban and rural areas. Charcoal, which accounts for 4% - 6% of total fuelwood consumption, is mainly used in urban areas. The annual consumption of fuelwood per household is estimated to be about 2.5 cubic tons (4.5 m3) for rural households and 1.4 cubic tons (2.5 m3) for urban residents[10].

According to MOEP, use of biomass for off-grid electricity production is insignificant, with only 5 MW of capacity currently installed. ADB studies (Renewable Energy Developments and Potential in the Greater Mekong Subregion) suggest total theoretical energy potential from agricultural residues[11] at around 60,000 GWh per annum.

3.9 Biogas

Over the past 10 years, about 152 community-based biogas digesters (plants) have been built, mostly in the central region (Mandalay, Sagaing, and Magway divisions) and in the Northern Shan State. The digesters vary in

[10] ADB Myanmar Energy Sector Initial Assessment (2012)

[11] Rice husks, rice straw, corn cob, cassava stalk, bagasse, sugarcane trash, and oil palm and coconut residues.

capacity (from 25 to 100 cubic meters) and electricity output ranges from 5–25 kW. While the combined output of these digesters is modest, it is enough to serve 172 villages with four hours of electricity per day. The theoretical biogas energy potential is shown in Table 4.

Table 4 Myanmar Biogas Energy Potential

Livestock	2010 Production* (million heads)	Daily Manure Production Factor (kg/animal)	Substrate Quantity (kg/day)	Dry Matter Factor (%)	Total Dry Matter Available (kg/day)	Mean Biogas Yield Factor (m^3/kg dry matter)	Daily Biogas Production (m^3/day)
Buffalo	3.09	8.00	24,720,000	16	3,955,200	0.250	988,800
Cattle	14.02	8.00	112,160,000	16	17,945,600	0.250	4,486,400
Pigs	9.30	2.00	18,600,000	17	3,162,000	4.200	13,280,400
Chicken	153.20	0.08	12,256,000	25	3,064,000	0.575	1,761,800
Total							**20,517,400**

kg = kilogram, m^3 = cubic meter.

Source: Renewable Energy Developments and Potential in Myanmar, ADB, 2015

3.10 Ocean Energy

Myanmar has a vast coastline that is 2,832 km long. There is potential for tidal and ocean current energy given the strong currents and tides along the coast. The first tidal power plant was commissioned in 2007 in Kambalar village. It has a 3 kW turbine and provides electricity to 220 village households. The country is estimated to have wave energy potential between 5 and 10 kW/m[12].

3.11 Renewable Energy Potential and Diversity

In summary, the renewable energy potential for Myanmar is provided in Table 5. The numbers presented here have been drawn from multiple sources and informed by analysis of IRENA Global Atlas data. Figure 23 plots the seasonal variation of renewable energy generation profiles in Myanmar for hydro, wind and solar. This shows that there is very good seasonal diversification across these three forms of renewable energy. The annual maximum solar irradiation is in February and the minimum in July to August. For hydropower, the annual maximum output occurs in October, which is when the reservoirs are filled following the dry season rains (which occur typically in May to June). Wind fluctuations are not as predictable but as illustrated, generation from wind reaches its maximum between July and September and complements hydro and solar resources very well.

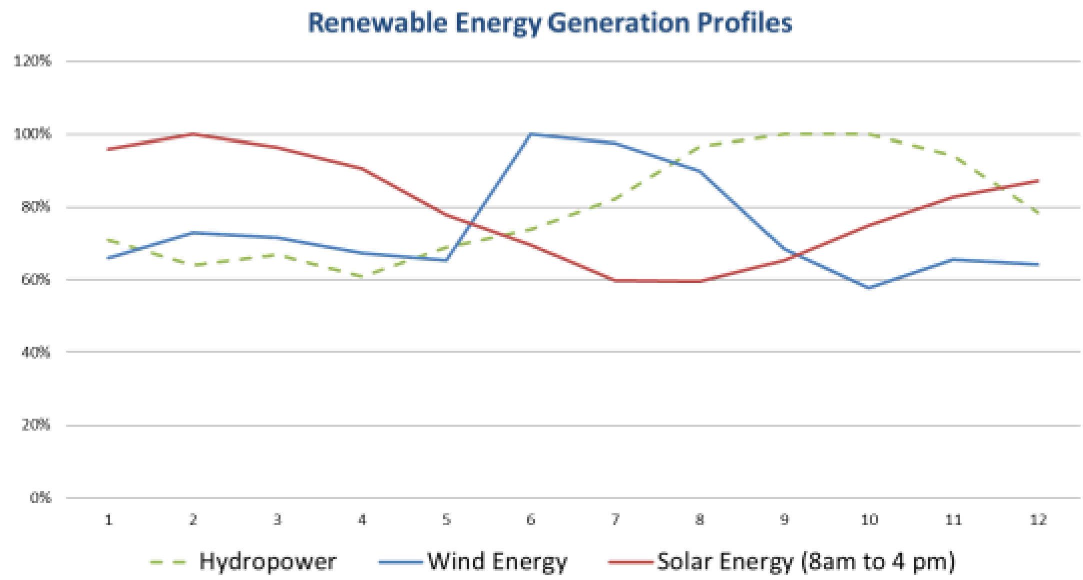
Table 5 Summary of Estimated Renewable Energy Potential (Compiled from Various Sources and Analysis)

Myanmar	Potential (MW)	Source and comments
Hydro (Large)	46,000	See Section 3.4
Hydro (Small)	231	See Section 3.4
Pump Storage	0	Lack of studies available
Solar	26,962 MW	Renewable Energy Developments and Potential in the Greater Mekong Subregion (ADB, 2015)

12 Ocean renewable energy in Southeast Asia: A review (Quirapas, Lin, Abundo, Brahim, Santos, 2014). Note that the unit of measure is kW of installed capacity per metre of coastline.

Wind Onshore	33,829	Renewable Energy Developments and Potential in the Greater Mekong Subregion (ADB, 2015)
Wind Offshore	No information available	Lack of studies available
Biomass	6,899	IES projections based on data from Renewable Energy Developments and Potential in the Greater Mekong Subregion (ADB, 2015)
Biogas	4,741	IES projections based on data from Renewable Energy Developments and Potential in the Greater Mekong Subregion (ADB, 2015)
Geothermal	400	See Section 3.7
Ocean	1,150	Ocean renewable energy in Southeast Asia: A review (2014), based on 5kW/m wave potential, 2300km coastline, 10% efficiency

Figure 23 Seasonal Renewable Energy Generation Profiles



Source: Consultant analysis

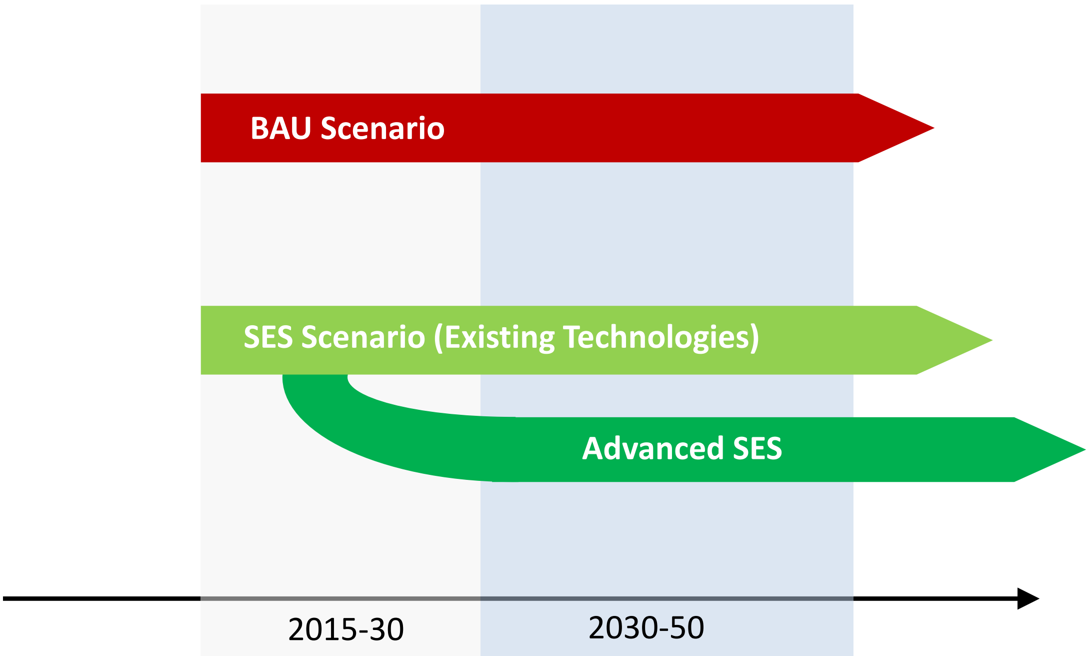
4 Myanmar Development Scenarios

In this section, we provide more detail on the three scenarios for Myanmar's electricity sector that we have modelled: the Business as Usual (BAU), Sustainable Energy Sector (SES), and Advanced SES (ASES) scenarios. We observe the assumptions that are common to all countries within this study for technology costs (section 4.2) and fuel prices (section 4.3). We then set out several Myanmar-specific assumptions including an economic outlook, list of generation projects that were assumed to be committed[13] and comments on the status of power export projects. Further assumptions for each scenario are provided in Section 5, Section 6 and Section 7.

4.1 Scenarios

The three power sector development scenarios (BAU, SES and ASES) for Myanmar's electricity industry are illustrated conceptually in Figure 24.

Figure 24 GMS Power Sector Scenarios



The BAU scenario is characterised by electricity industry developments consistent with the current state of planning within the GMS countries and reflective of growth rates in electricity demand consistent with an IES view of base development, existing renewable energy targets, where relevant, aspirational targets for electrification rates, and energy efficiency gains that are largely consistent with the policies seen in the region.

In contrast, the SES seeks to transition electricity demand towards the best practice benchmarks of other developed countries in terms of energy efficiency, maximise the renewable energy development, cease the development of fossil fuel resources, and make sustainable and prudent use of undeveloped conventional hydro resources. Where relevant, it leverages advances in off-grid technologies to provide access to electricity to remote communities. The SES takes advantage of existing, technically proven and commercially viable renewable energy technologies.

[13] That is, construction is already in progress, the project is near to commissioning or it is in an irreversible / advanced state of the planning process.

Finally the ASES assumes that the power sector is able to more rapidly transit towards a 100% renewable energy technology mix under an assumption that renewable energy is deployed more than in the SES scenario with renewable energy technology costs declining more rapidly compared to BAU and SES scenarios. A brief summary of the main differences between the three scenarios are summarised in Table 6.

Table 6 Brief Summary of Differences between BAU, SES and ASES

Scenario	Demand	Supply
BAU	Demand is forecast to grow in line with historical electricity consumption trends and projected GDP growth rates in a way similar to what is often done in government plans. Electric vehicle uptake is assumed to reach 15% across all cars and motorcycles by 2050.	Generator new entry follows that of power development plans for the country including limited levels of renewable energy.
SES	• Assumes a transition towards energy efficiency benchmark for the industrial sector of Hong Kong[14] and of Singapore for the commercial sector by year 2050. • For the residential sector, it was assumed that residential demand per electrified capita grows to 750 kWh pa by 2050, 38% less than in the BAU. • Demand-response measures assumed to be phased in from 2021 with some 15% of demand being flexible[15] by 2050. • Slower electrification rates for the national grids in Myanmar compared to the BAU, but deployment of off-grid solutions that achieve similar levels of electricity access. • Mini-grids (off-grid networks) are assumed to connect to the national system in the longer-term. • Electric vehicle uptake as per the BAU	• Assumes no further coal and gas new entry beyond what is already understood to be committed. • A modest amount of large scale hydro (between 4,000 to 5,000 MW in total) is deployed in Lao PDR and Myanmar above and beyond what is understood to be committed hydro developments[16]. • Supply is then developed by a least cost combination of renewable generation sources limited by estimates of potential rates of deployment and judgments on when technologies would be feasible for implementation to deliver a power system with the same level of reliability as the BAU. • Technologies used include: solar photovoltaics, biomass, biogas and municipal waste plants, CSP with storage, onshore and offshore wind, utility scale batteries, geothermal and ocean energy. • Transmission limits between regions are upgraded as required to support the GMS as a whole, and a different (approximate) transmission plan to the BAU is allowed to develop.
ASES	The ASES demand assumptions are	ASES supply assumptions are also

[14] Based on our analysis of comparators in Asia, Hong Kong had the lowest energy to GDP intensity for industrial sector while Singapore had the lowest for the commercial sector.

[15] Flexible demand is demand that can be rescheduled at short notice and would be implemented by a variety of smart grid and demand response technologies.

[16] This is important to all countries because the GMS is modelled as an interconnected region with significant conventional baseload capacity retiring around 2030.

Scenario	Demand	Supply
	done as a sensitivity to the SES: • An additional 10% energy efficiency applied to the SES demands (excluding transport). • Flexible demand assumed to reach 25% by 2050. • Uptake of electric vehicles doubled by 2050. • Electrification rates in Myanmar remain constant after solar PV and battery storage reach parity with grid costs.	implemented as a sensitivity to the SES, with the following main differences: • Allow rates of renewable energy deployment to be more rapid as compared to the BAU. • Technology cost reductions are accelerated for renewable energy technologies • Implement a more rapid programme of retirements for fossil fuel based power stations • Energy policy targets of 70% renewable generation by 2030, 90% by 2040 and 100% by 2050 across the region are in place

4.2 Technology Cost Assumptions

Technology capital cost estimates from a variety of sources was collected and normalised onto a consistent and uniform basis and mid-points taken for each technology that is relevant to the GMS region. The data points collated were based on overnight capital costs and are exclusive of fixed operating and maintenance costs, variable operating and maintenance costs and fuel costs. The capital costs are presented in Figure 25 which summarises the cost assumptions used to produce the installed cost comparisons between the technologies for the BAU and SES scenario. For the ASES scenario we have assumed that the technology costs of renewables decline more rapidly with the technology costs shown in Figure 26. Note that all installed costs do not include land, transmission, substations and decommissioning costs and are quoted on a US$ (real 2014) basis.

Comments on the various technologies are discussed below in relation to the BAU and SES technology costs:

- Conventional thermal technology costs are assumed to decrease at a rate of 0.05% pa citing gradual maturation of the technologies with no significant scope for cost improvement.
- Onshore wind costs were based on the current installed prices seen in China and India with future costs decreasing at a rate of 0.6% pa. Future offshore wind costs are also assumed to decrease at a rate of 0.6% pa starting at US$2,900/kW.
- Large and small-scale hydro costs are assumed to increase over time reflecting easy and more cost-efficient hydro opportunities being developed in the first instance. IRENA reported no cost improvements for hydro over the period from 2010 to 2014. Adjustments are made in the case of Lao PDR and Myanmar where significant hydro resources are developed in the BAU case[17].
- Solar PV costs are based on the more mature crystalline silicon technology which accounts for up to 90% of solar PV installations (IRENA, 2015), and forecast to continue to drop (2.3% pa) albeit at a slower pace than in previous years.
- Utility scale battery costs are quoted on a US$/kWh basis, and cost projections based on a report by Deutsche Bank (2015) which took into account several forecasts from Bloomberg New Energy Finance (BNEF), Energy Information Administration (EIA) and Navigant.
- Solar thermal (CSP) capital costs are projected to fall at 2.8% pa on the basis of the IRENA 2015 CSP overall levelised cost of electricity (LCOE) projections. While globally there are many CSP installations in

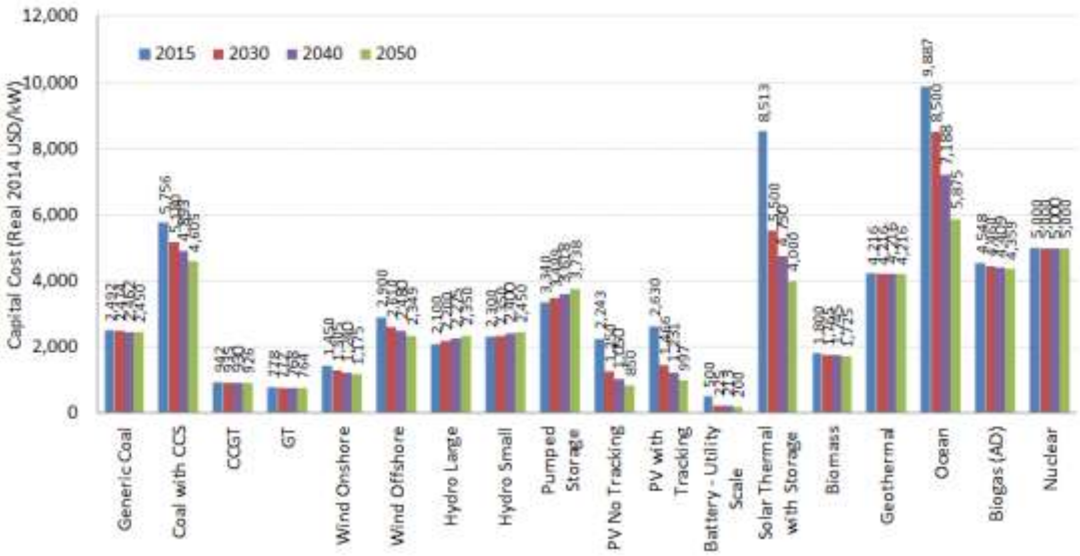
[17] Capital costs for large scale hydro projects are assumed to increase to US$3,000/kW by 2050 consistent with having the most economically feasible hydro resources developed ahead of less economically feasible resources.

place, the technology has not taken off and the cost of CSP technology over the past 5 years has not been observed to have fallen as rapidly as solar PV.

- Biomass capital costs are based on costs observed in the Asia region which are significantly less than those observed in OECD countries. Capital costs were assumed to fall at 0.1% pa. Biogas capital costs were based on anaerobic digestion (AD) and assumed to decline at the same rate as biomass.
- Ocean energy (wave and tidal) technologies were based on learning rates in the 'Ocean Energy: Cost of Energy and Cost Reduction Opportunities' (SI Ocean, 2013) report assuming global installation capacities increase to 20 GW by 2050[18].
- Capital costs are all discounted at 8% pa across all technologies over the project lifetimes. Decommissioning costs were not factored into the study.
- For technologies that run on imported coal and natural gas, we have factored in the additional capital cost of developing import / fuel management infrastructure in the modelling.

For reference, Appendix A tabulates all technology cost assumptions used in the modelling.

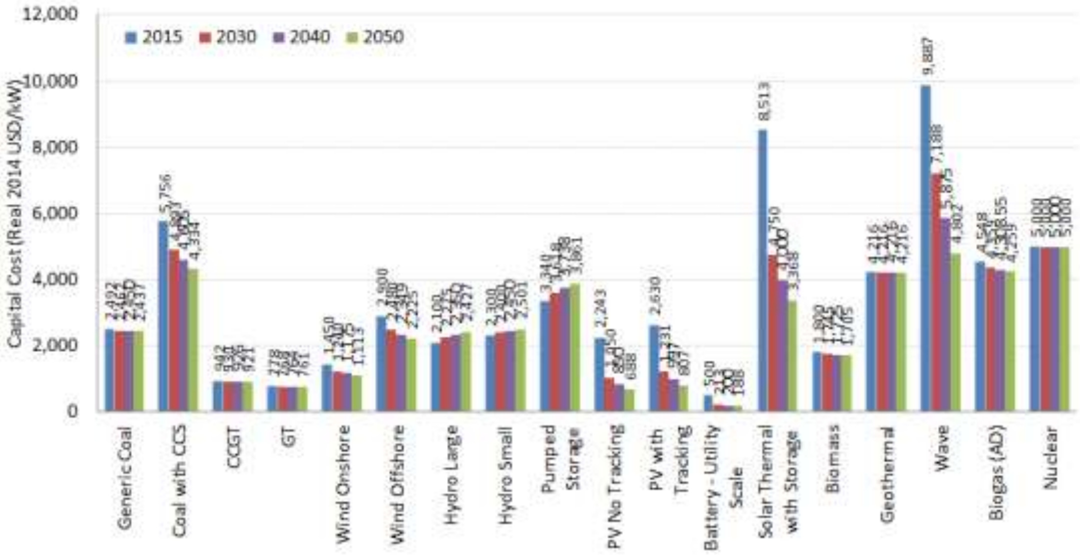
Figure 25 Projected Capital Costs by Technology for BAU and SES



** Battery costs are quoted on a Real 2014 US$/kWh basis.*

[18] Wave and tidal costs are averaged.

Figure 26 Projected Capital Costs by Technology for ASES



** Battery costs are quoted on a Real 2014 US$/kWh basis.*

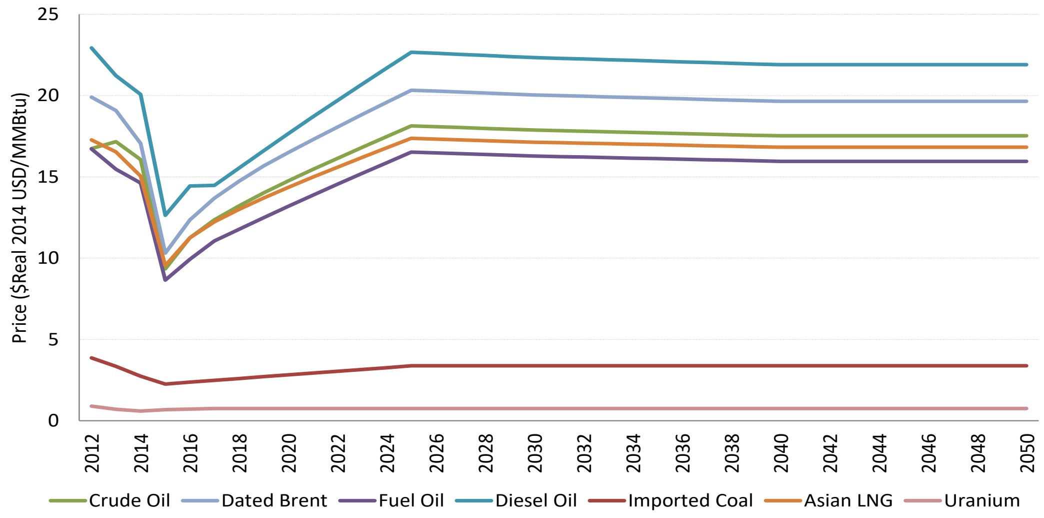
4.3 Fuel Pricing Outlook

IES has developed a global fuel price outlook which is based on short-term contracts traded on global commodity exchanges before reverting towards long-term price forecasts and relationships provided in energy agency reports. A summary of the fuel prices expressed on an energy basis (US$/MMBtu HHV) is presented in Figure 27 below.

The 30% dip from 2014 to 2015 for the various fuels was the result of a continued weakening of global energy demand combined with increased stockpiling of reserves. Brent crude prices fell from US$155/bbl in mid-2014 to US$50/bbl in early 2015. The Organisation of the Petroleum Exporting Countries (OPEC) at the November 2014 meeting did not reduce production causing oil prices to slump. Fuel prices are assumed to return to long-term expectations by 2025. This is presented in Figure 27.

Appendix B tabulates the fuel pricing assumptions that we have used in the modelling presented in this report.

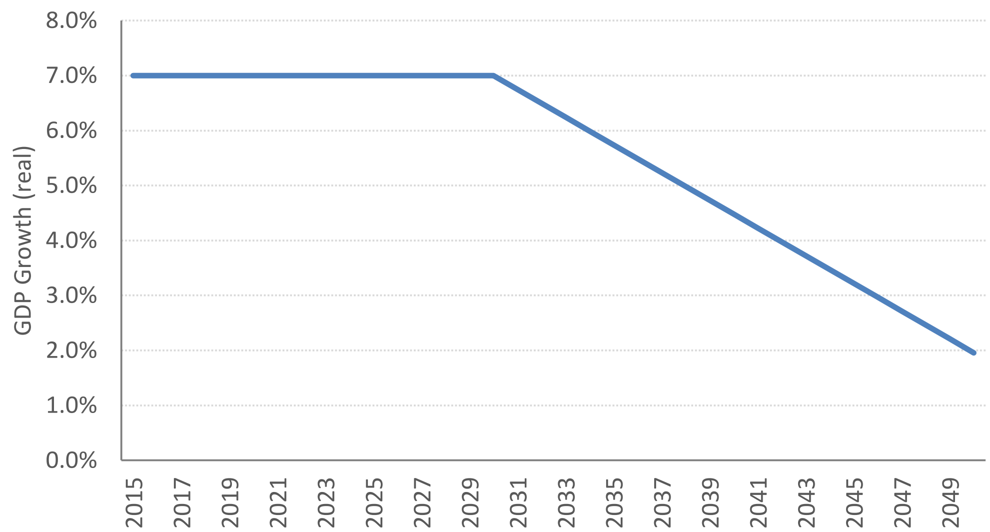
Figure 27 IES Base Case Fuel Price Projections to 2050



4.4 Real GDP Growth Outlook

Real Gross Domestic Product (GDP) growth is assumed to stay relatively high around current GDP growth rates due to the focus on industrialisation in the region. Over time, GDP growth is assumed to decline towards 1.96%[19] pa by 2050 as seen in Figure 28. The trend down is assumed to reflect the economic development cycle of a developing country. This assumption is held consistent in the BAU and SES.

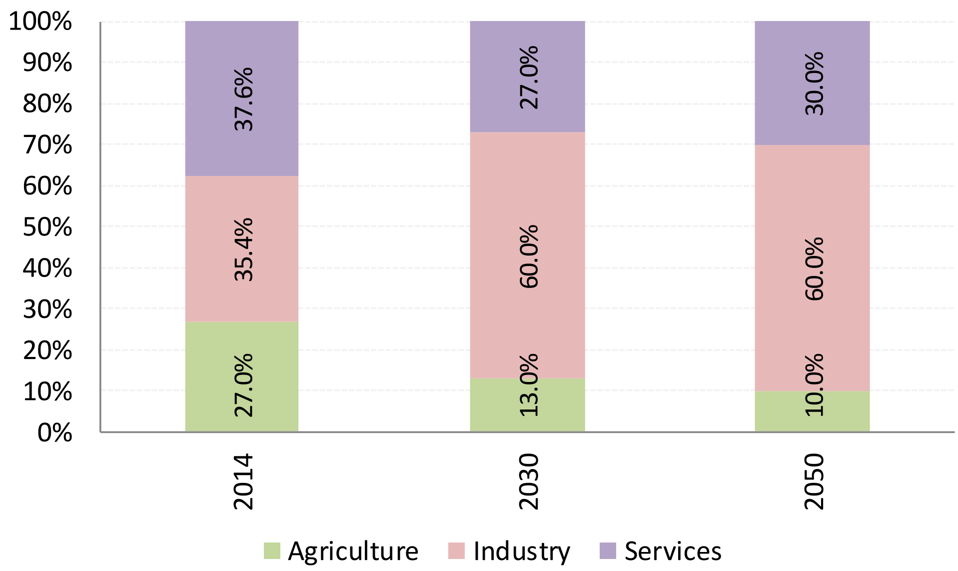
Figure 28 Myanmar GDP Projection



[19] 1.96% reflects the previous 5 year GDP growth of the top 10 GDP countries in the world excluding Brazil, China and Russia.

The GDP composition of Myanmar is weighted towards industry in line with the strategic aspirations of the country. The industry share of GDP in Myanmar is assumed to increase from 35% in 2014 to 60% in 2030. The GDP composition is presented in Figure 29 below. Note that this assumption is held constant in the BAU and SES.

Figure 29 Myanmar GDP Composition



4.5 Population Growth

Population was assumed to grow in line with the UN Medium Fertility scenario and is held constant across all scenarios[20].

4.6 Committed Generation Projects in BAU, SES and ASES Scenarios

Table 7 lists Myanmar's existing plants and the generation projects we assumed to be committed. APR Energy is the 100 MW Kyauske gas-fired generation facility with a short-term contract with the Government, however, we expect it to continue running, or be replaced by another gas-fired plant.

Table 7 Myanmar Committed New Entry Assumptions

Unit	Capacity (MW)	Generation Type	COD[21]
Mawlamyine MPLP(1st)	98	Gas	2015
Thaton GT (W-B)	106	Gas	2015
Myinchan Aggrego	103	Gas	2015
APR Energy	100	Gas	2015
V-Power	50	Gas	2015

[20] UN Department of Economic and Social Affairs, World Population Prospects: The 2012 Revision

[21] Commercial operations date.

Unit	Capacity (MW)	Generation Type	COD[21]
Upper Nam Htwan	3.2	Hydro	2016
Mong Wa	60	Hydro	2016
Thilawa(1)	25	Gas	2016
Shwedaung IPP	70	Gas	2016
Kanbauk GEG	6	Gas	2016
Thilawa(2)	25	Gas	2017
Myinchan IPP	250	Gas	2017
Thahtay	111	Hydro	2018
Upper Keng Tong	51	Hydro	2018
Upper Baluchaung	30.4	Hydro	2018
Tharkayta UREC 1st	115	Gas	2018
Kanbauk GTCC	200	Gas	2018

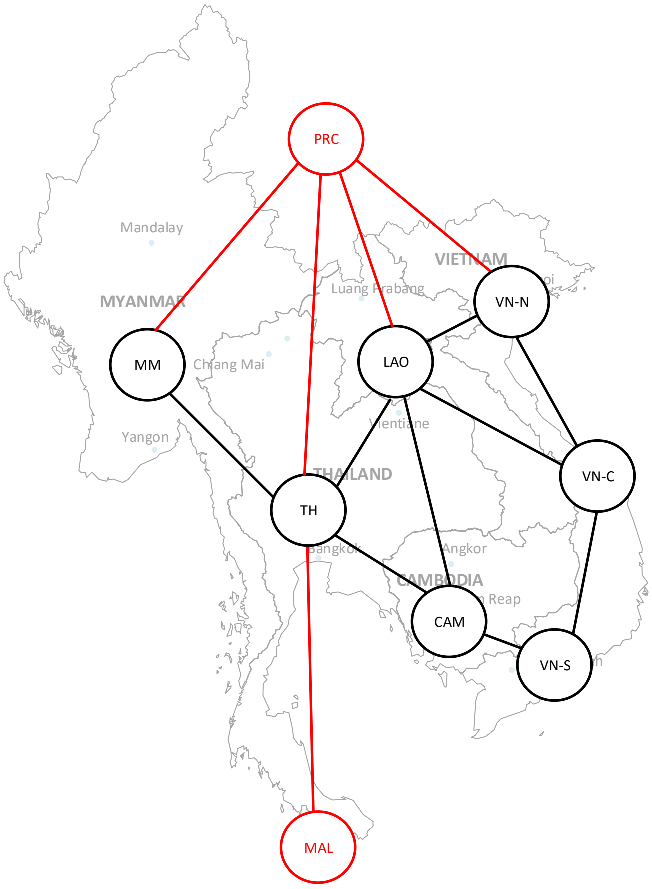
4.7 Transmission System, Imports and Exports

The modelling presented in this report assumes transmission in the GMS becomes more tightly integrated than at present. Given the modelling period is for 35 years, we use a very simple model for the interconnections as illustrated in Figure 30. The figure shows the interconnections in the region as well as to countries outside the region (PRC and Malaysia). Initially not all transmission lines are in place and the power system is modelled as per the status quo. However, over the modelling period the transmission system evolves as needed to provide mutual support between the two regions and to minimise costs. This leads to a different transmission plan in each scenario.

There are some slight differences in the assumptions behind the transmission system enhancements in each scenario as follows:

- In the BAU, it is assumed that transmission developments occur slowly and a tightly integrated regional power system is in place from about 2030, but the power sectors are developed so that there is only a limited level of dependency on imports from neighbouring countries. This is consistent with power sector planning that seeks to not be overly dependent on power imports from neighbouring countries.
- In the SES and ASES, the transmission system evolves from 2025 and we allow the transmission system (based on a simplified model of the region) to expand as needed to optimise the use of a geographically disperse set of renewable energy resources. A consequence of this is that some countries become significant exporters of power while others take advantage of power imports from neighbouring countries. In particular Myanmar and Lao PDR become major power exporters with the beneficiaries being the other GMS countries.

Figure 30 Simple Transmission System Model of GMS



4.8 Technical-Economic Power System Modelling

Technical and economic modelling of the GMS was done in the PROPHET electricity planning and simulation models. It develops a least cost generation based plan and was used to simulate the operation of the GMS region as an integrated power system.

A brief overview of the various aspects is provided below:

- **Planning Module**: The Planning Module of Prophet allows for intertemporal constraints such as energy limits to be preserved when simulating the power system and developments. It also develops a least cost set of new entrants to satisfy demand over the 35 year modelling horizon.
- **Transmission**: The power system was modelled based on the configuration as per Figure 30 with fixed / scheduled flows (red lines) to power systems outside the GMS not being explicitly modelled while power transfers within the GMS countries were optimised as needed to allow supply and demand to balance. This is important with respect to modelling diversity in demand in the different regions and geographical variation in generation patterns from supply-driven renewable energy (solar and wind) and seasonal variation of inflows into the hydro storages (see Figure 30).
- **Economics:** Capital and operating costs relating to generation plants as per the assumptions covered in this report allow the Planning Module to model generation and transmission development in a least cost manner. On top of this, resource constraints had to be formulated to reflect actual limits such as the maximum renewable resource and development rates available to each country.

- **Demand:** Demand profiles were constructed from energy and peak demand forecasts for electricity based on regression models that were developed for each sector of the electricity industry (commercial, industrial, residential, agricultural and transport). The monthly and intraday construction of the profiles were performed in Prophet based on historical data and/or external data sources indicating the seasonal profile of demand for each country.
- **Flexible demand**: was modelled as a MW and GWh/month quantities that can be scheduled as necessary to reduce system costs. This means that demand tends to be shifted from periods when supply and demand would otherwise be tight to other times. The technology for rescheduling demand was assumed to be in place from 2020 in the SES and ASES scenarios.
- **Supply:** The approach taken for modelling generation supply technologies varied according to the technology type. This is discussed further below:
  - *Conventional thermal plant*: is modelled as capacity limited plants, with fuel take or pay contracts applied to generators running on natural gas and where relevant supply constraints put in place – for example, gas supply limits applied to Liquefied Natural Gas (LNG) facilities or offshore gas fields. Examples of such plant include coal, biomass, gas, and diesel generators.
  - *Energy limited plants*: such as large-scale hydros with reservoirs / storages and CSP have monthly energy limits corresponding to seasonal variations in energy inflows. The equivalent capacity factors are based on external reports for hydro and resource data for CSP (see next point).
  - *Supply-driven generation forms*: Seasonal profiles for wind, solar and run of river hydros without reservoirs were developed on an hourly basis. For wind and solar they were derived from monthly resource data collected from a variety of sources including NASA, NREL[22] and accessed via the Solar and Wind Energy Resource Atlas (SWERA) Toolkit and IRENA Global Atlas. Resource amounts were matched against actual generation data for known plants to develop equivalent monthly capacity factors at various high resource pockets in each country. Several traces were built from known generation traces to provide diversification benefits.
  - *Pump Storage and battery storage*: these are modelled in a similar way to flexible demand in that demand can be shifted with a capacity and energy limit but the scheduled demand is stored for generation later with an appropriate energy conversion efficiency (pumped storages assumed to be 70% and battery storage systems at 85%).

[22] DNI and Wind NASA Low Resolution and NREL DI Moderate Resolution data.

5 Business as Usual Scenario

5.1 Business as Usual Scenario

The BAU scenario assumes industry developments consistent with the current state of planning within the GMS countries and reflective of growth rates in electricity demand consistent with an IES view of base development, existing renewable energy targets, where relevant, aspirational targets for electrification rates, and energy efficiency gains that are largely consistent with the policies seen in the region.

5.2 Demand Growth

Myanmar's on-grid electricity demand (including transmission and distribution losses[23]) is plotted in Figure 31. Myanmar's electricity demand is forecast to increase at a rate of 7.1% pa over the 35-year period to 2050 with a slowdown in growth from 2035 as GDP growth converges to that of a developed nation. The electricity growth compared to other GMS countries increases in line with industrialisation and commercialisation of the economy.

The commercial sector is forecast to grow the fastest at 7.7% pa followed by residential at 7.3%, industry at 6.5% and agriculture at 1.0% as the GDP composition shifts towards commerce/services and industry accounting for 30% and 60%, respectively, of GDP by 2050. Residential electricity consumption increases at a high rate driven by growing electrification rates in the urban and rural areas. Myanmar's electricity demand is forecast to reach 149 TWh by 2050 and the transport sector is forecast to hit 9 TWh by 2050 as the number of cars and uptake of electric cars and motorbikes increase towards an uptake rate of 15%.

Peak demand is plotted below in Figure 32 and shows peak demand growing at 6.5% pa to 22.7 GW by 2050. The load factor is assumed to trend towards 75% by 2040 mainly driven by additional industrial loads. Key drivers for demand growth and the demand projections are summarised in Table 8.

[23] Note that unless otherwise stated, all other demand charts and statistics include transmission and distribution losses.

Figure 31 Myanmar Projected Electricity Demand (2015-50, BAU)

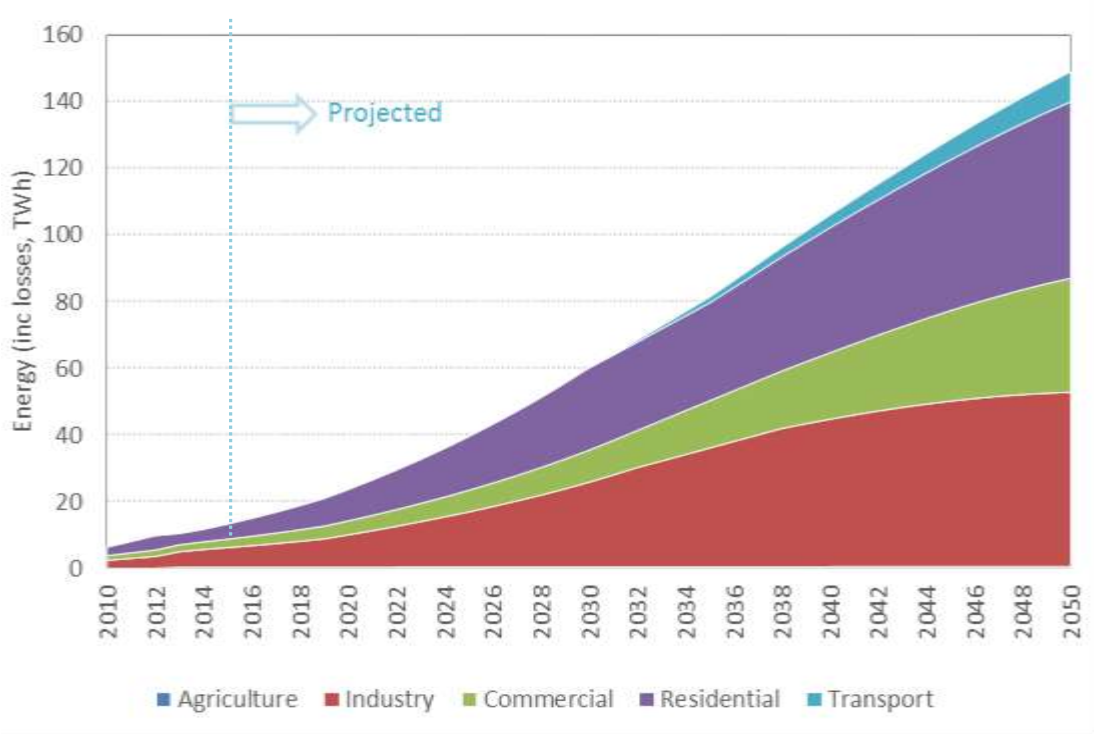


Figure 32 Myanmar Projected peak Demand (MW, BAU)

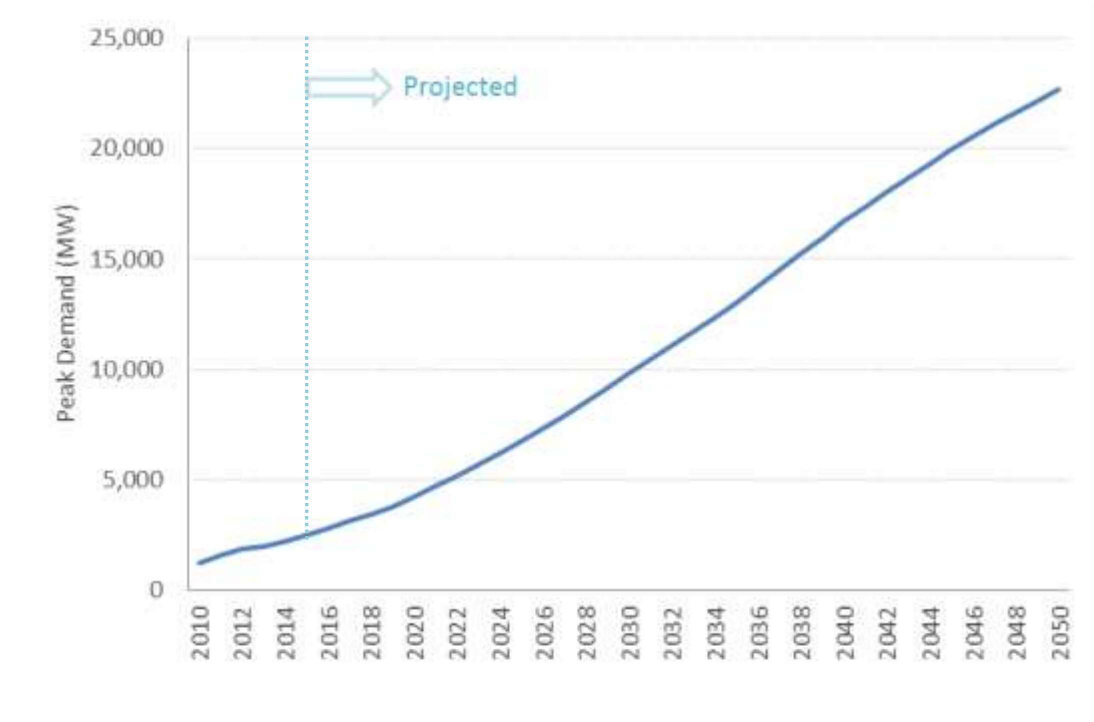


Table 8 Myanmar Demand and Demand Drivers (BAU)

No.	Aspect	2015-30	2030-40	2040-50
1	Demand Growth (pa)	10.8%	5.8%	3.5%
2	GDP Growth (Real, pa)	7.0%	5.6%	3.1%
3	Electrification Rate (Population)	62.6%	97.0%	98.8%
4	Population Growth	0.56%	0.12%	-0.13%
5	Per Capita Consumption (kWh)	421	1,056	1,885
6	Electricity Elasticity*	4.02	2.51	1.79
7	Electricity Intensity (kWh/US$)	0.123	0.181	0.235

** Electricity elasticity is calculated as electricity demand growth divided by the population growth over the same period*

5.3 Installed Capacity Development

The BAU installed capacity (MW) for Myanmar is plotted in Figure 33 and Figure 34 by capacity shares for selected years: 2010, 2015, 2020, 2030, 2040 and 2050. The former shows installed generation capacity by the main generation type categories. We provide corresponding statistics in Table 9 and Table 10. Installed capacity in 2014 increases from 4.5 GW to 34.4 GW with coal and large-scale hydro each increasing to 10 GW dominating the capacity supply by 2050. An additional 1,200 MW of gas-fired generation fills the intermediate and peaking role and smaller investments in solar, biomass and run-of-river hydro help Myanmar diversify the supply mix to 21% renewable capacity (excluding large-scale hydro).

Figure 33 Myanmar Installed Capacity (BAU, MW)

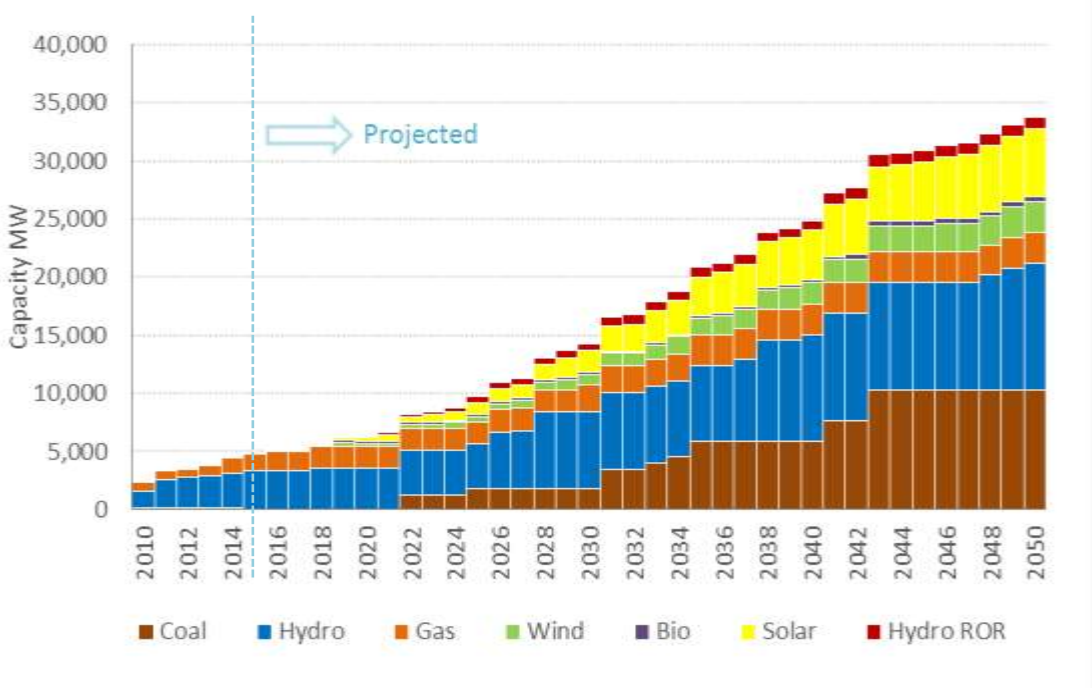


Figure 34 Myanmar Installed Capacity Mix Percentages (BAU, %)

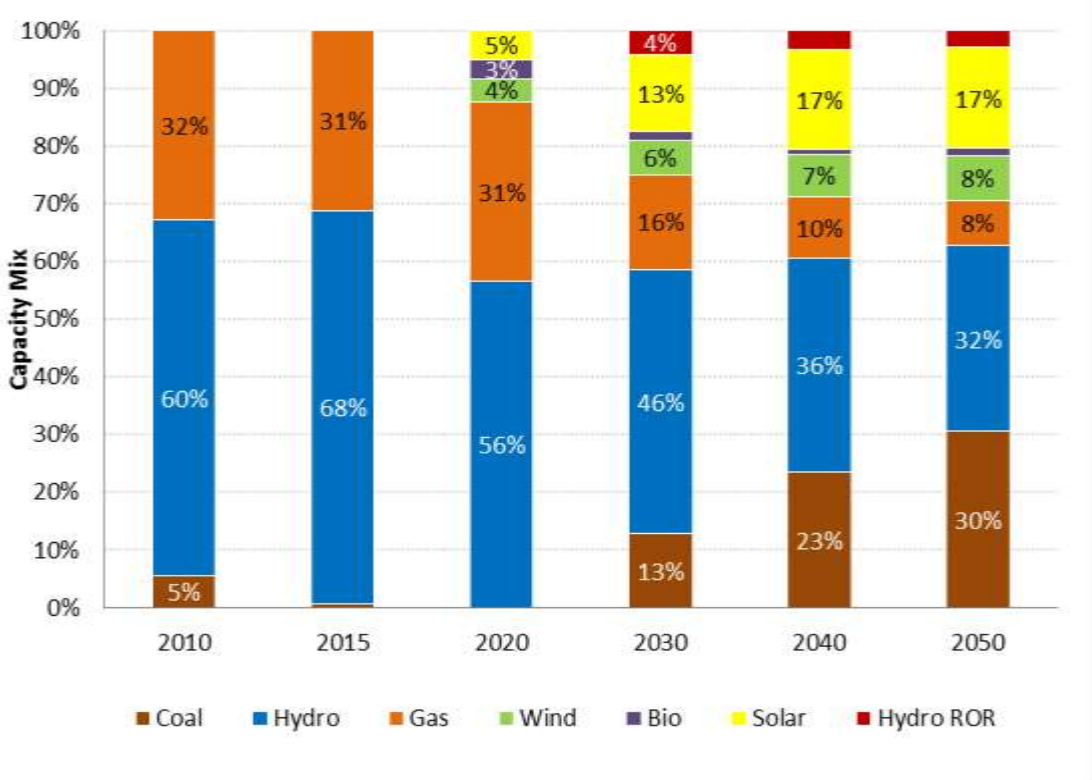


Table 9 Myanmar Capacity by Type (BAU, MW)

Resource	2010	2015	2020	2030	2040	2050
Coal	130	30	0	1,830	5,860	10,300
CCS	0	0	0	0	0	0
Diesel	70	0	0	100	400	600
Fuel Oil	0	0	0	0	0	0
Gas	770	1,490	1,939	2,339	2,638	2,638
Nuclear	0	0	0	0	0	0
Hydro	1,450	3,252	3,508	6,544	9,162	10,882
Onshore Wind	0	0	248	848	1,848	2,648
Offshore Wind	0	0	0	0	0	0
Biomass	0	0	205	205	205	405
Biogas	0	0	0	0	0	0
Solar	0	0	311	1,911	4,311	5,911
CSP	0	0	0	0	0	0
Battery	0	0	0	0	0	0
Hydro ROR	0	0	0	600	800	1,000
Geothermal	0	0	0	0	0	0
Pump Storage	0	0	0	0	0	0
Ocean	0	0	0	0	0	0

Table 10 Myanmar Capacity Share by Type (BAU, %)

Resource	2010	2015	2020	2030	2040	2050
Coal	5%	1%	0%	13%	23%	30%
CCS	0%	0%	0%	0%	0%	0%
Diesel	3%	0%	0%	1%	2%	2%
Fuel Oil	0%	0%	0%	0%	0%	0%
Gas	32%	31%	31%	16%	10%	8%
Nuclear	0%	0%	0%	0%	0%	0%
Hydro	60%	68%	56%	46%	36%	32%
Onshore Wind	0%	0%	4%	6%	7%	8%
Offshore Wind	0%	0%	0%	0%	0%	0%
Biomass	0%	0%	3%	1%	1%	1%
Biogas	0%	0%	0%	0%	0%	0%
Solar	0%	0%	5%	13%	17%	17%
CSP	0%	0%	0%	0%	0%	0%
Battery	0%	0%	0%	0%	0%	0%
Hydro ROR	0%	0%	0%	4%	3%	3%
Geothermal	0%	0%	0%	0%	0%	0%
Pump Storage	0%	0%	0%	0%	0%	0%
Ocean	0%	0%	0%	0%	0%	0%

5.4 Projected Generation Mix

Figure 35 plots the generation mix (on an as generated basis[24]) over time in the BAU case and Figure 36 plots the corresponding percentage shares. Table 11 and Table 12 tabulate the generation data by snapshot year.

Over time, additional generation from new coal-fired generators raises the coal share from 0% in 2015 to 53% by 2050 displacing large-scale hydro as the primary supply technology. The large-scale hydro generation share declines over time but increases in energy terms contributing 83 TWh or 26% of total production by 2050. The gas generation share decreases from 39% in 2015 to approximately 6% by 2050 as other technologies are brought into the mix.

As new renewable capacity comes online, the generation share slowly picks up from 0% in 2015 to around 15% by 2050. Biomass accounts for 2%, solar PV 7% and wind 4% of the system total.

[24] Unless otherwise stated, all generation charts and statistics in this report are presented on an "as generated" basis, meaning that generation to cover generator's auxiliary consumption accounted for.

Figure 35 Myanmar Generation Mix (BAU, GWh)

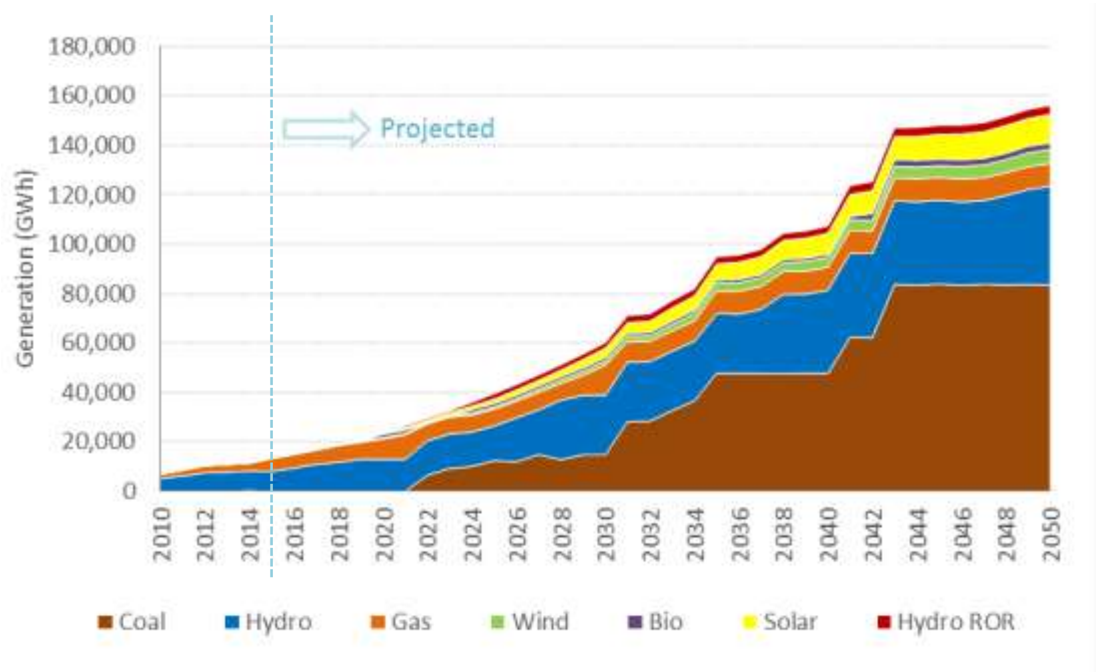


Figure 36 Myanmar Generation Mix Percentages (BAU, %)

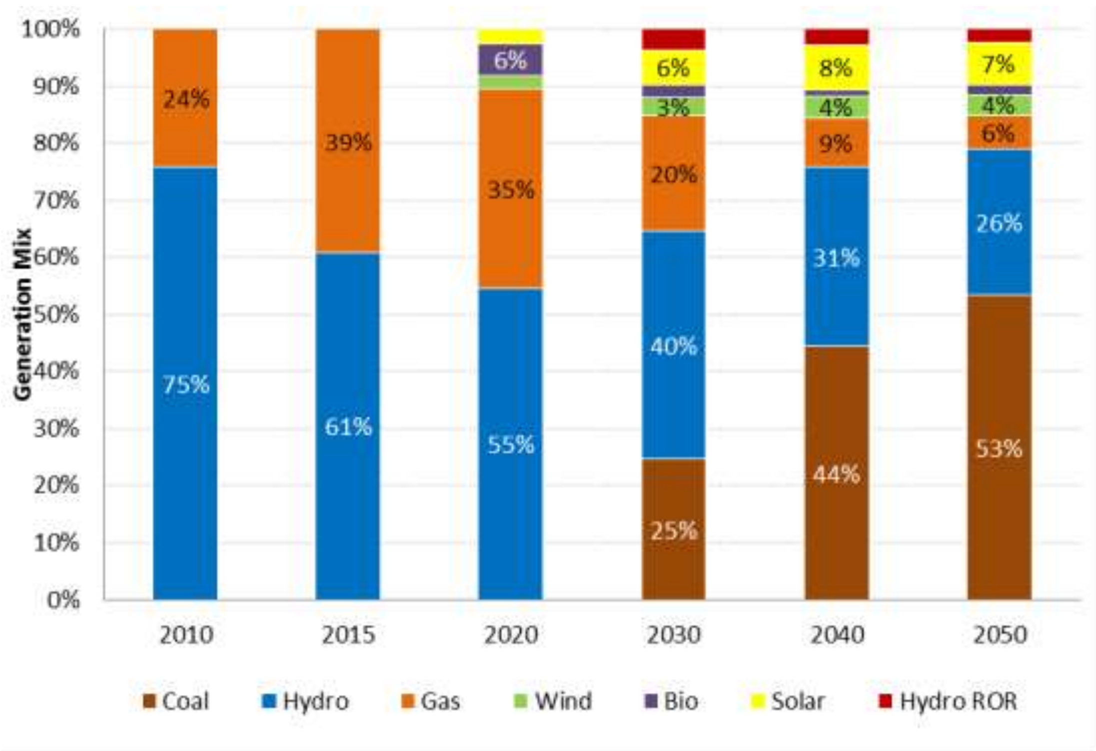


Table 11 Myanmar Generation by Type (BAU, GWh)

Generation	2010	2015	2020	2030	2040	2050
Coal	0	0	0	13,062	47,066	83,529
CCS	0	0	0	0	0	0
Diesel	30	0	0	0	0	0
Fuel Oil	0	0	0	0	0	0
Gas	1,678	5,233	8,280	12,161	9,255	9,255
Nuclear	0	0	0	0	0	0
Hydro	5,263	8,099	12,905	24,075	33,707	40,036
Onshore Wind	0	0	526	1,808	3,951	5,641
Offshore Wind	0	0	0	0	0	0
Biomass	0	0	1,353	1,349	1,353	2,663
Biogas	0	0	0	0	0	0
Solar	0	0	609	3,733	8,450	11,547
CSP	0	0	0	0	0	0
Hydro ROR	0	0	0	2,207	2,962	3,679
Geothermal	0	0	0	0	0	0
Pump Storage	0	0	0	0	0	0
Ocean	0	0	0	0	0	0

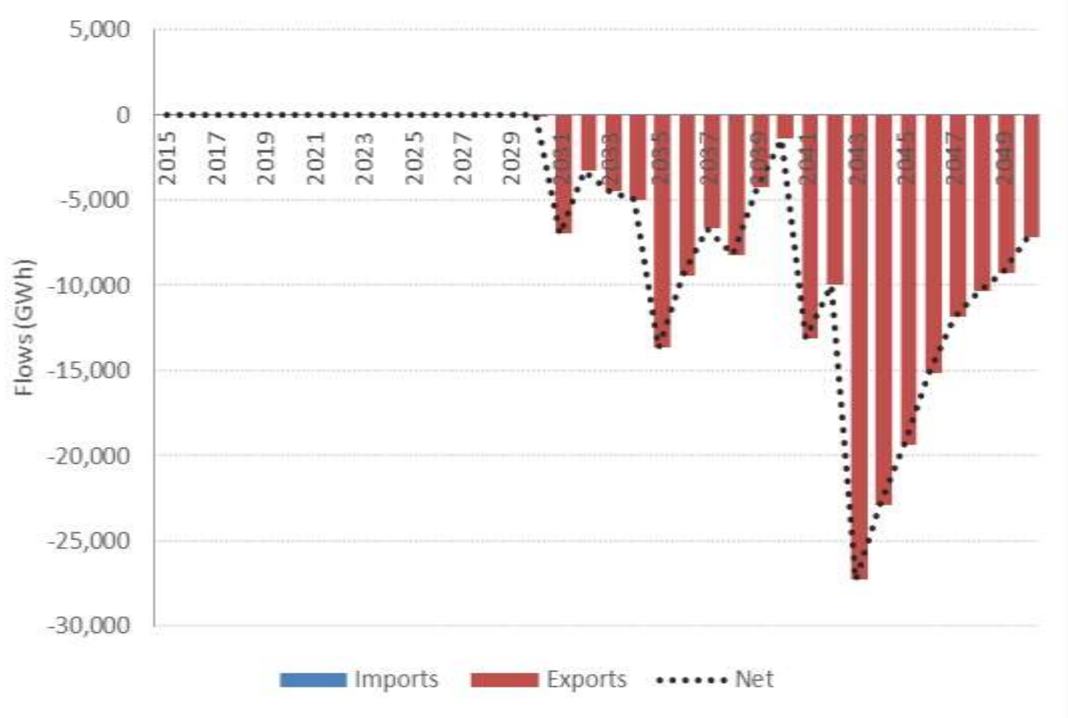
Table 12 Myanmar Generation share by Type (BAU, %)

Generation	2010	2015	2020	2030	2040	2050
Coal	0%	0%	0%	22%	44%	53%
CCS	0%	0%	0%	0%	0%	0%
Diesel	0%	0%	0%	0%	0%	0%
Fuel Oil	0%	0%	0%	0%	0%	0%
Gas	24%	39%	35%	21%	9%	6%
Nuclear	0%	0%	0%	0%	0%	0%
Hydro	75%	61%	55%	41%	32%	26%
Onshore Wind	0%	0%	2%	3%	4%	4%
Offshore Wind	0%	0%	0%	0%	0%	0%
Biomass	0%	0%	6%	2%	1%	2%
Biogas	0%	0%	0%	0%	0%	0%
Solar	0%	0%	3%	6%	8%	7%
CSP	0%	0%	0%	0%	0%	0%
Hydro ROR	0%	0%	0%	0%	0%	0%
Geothermal	0%	0%	0%	4%	3%	2%
Pump Storage	0%	0%	0%	0%	0%	0%
Ocean	0%	0%	0%	0%	0%	0%

5.5 Grid to Grid Power Flows

Figure 37 plots the imports and exports in the BAU with the dotted line representing the net interchange. Overall flows in the BAU are zero up to 2031 when exports out of Myanmar start to increase up to 25,000 GWh with transmission capability developed between Myanmar and Thailand. The flows between the countries occur primarily because of the relative generation cost differences with Thailand relying heavily on gas-fired generation.

Figure 37 Myanmar Imports and Exports (BAU)



5.6 Generation Fleet Structure

Figure 38 shows the installed generation capacity by the main categories of generation: thermal, renewable and large-scale hydro, in order to provide greater insight into the basic structure of installed capacity under the BAU. This highlights that Myanmar's BAU projection is as anticipated heavily dominated by fossil-fuel based generation and large-scale hydro projects. Figure 39 shows the on-grid composition of generation by major categories of generation: thermal, large hydro and renewable and reflects the installed capacity trends with coal dominating the generation outlook due to its much higher capacity factor relative to large-scale hydro and renewables.

Figure 38 Myanmar Installed Capacity by Generation Type (BAU, MW)

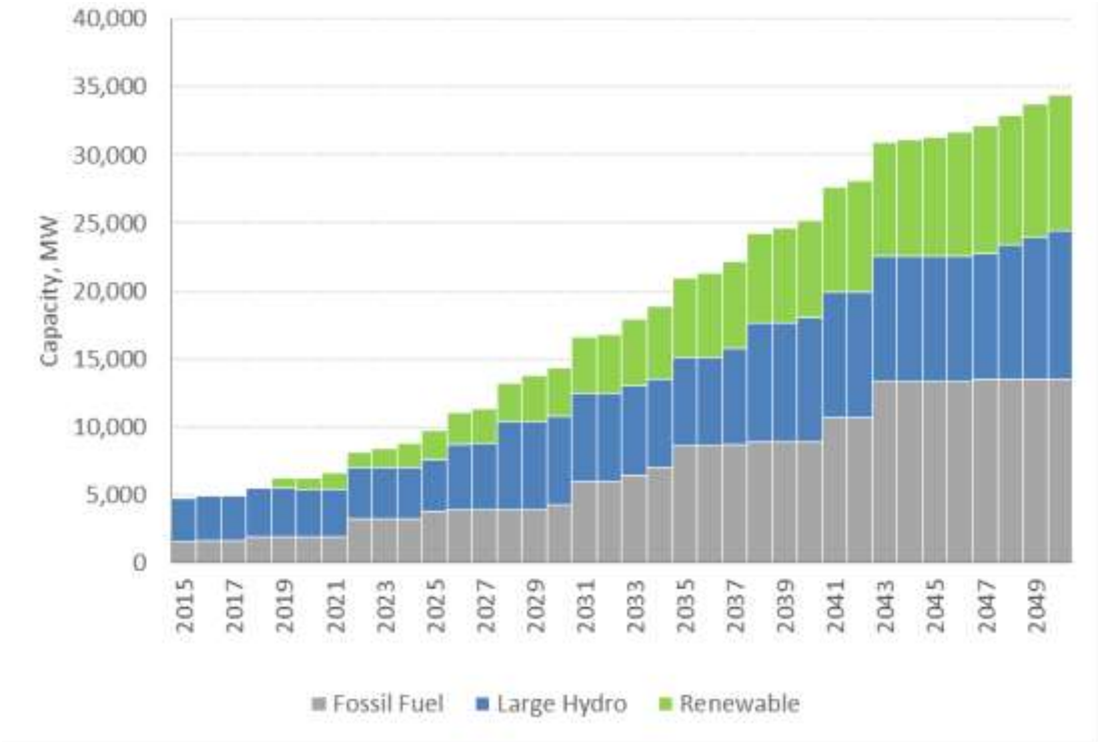
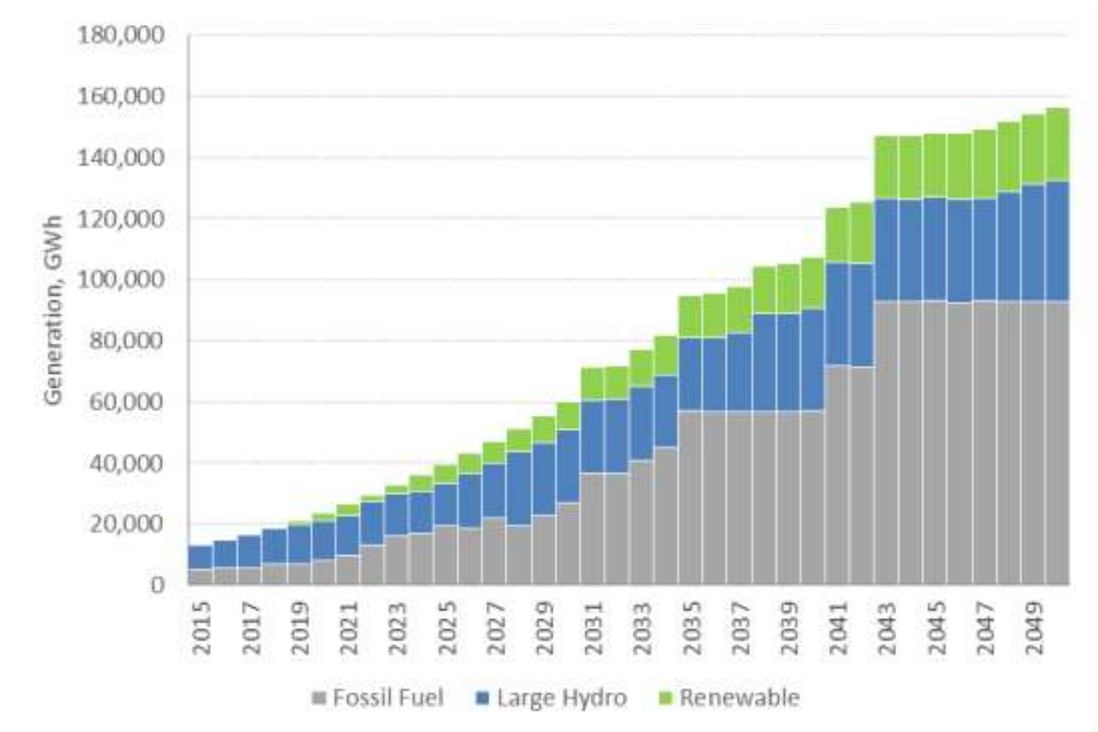
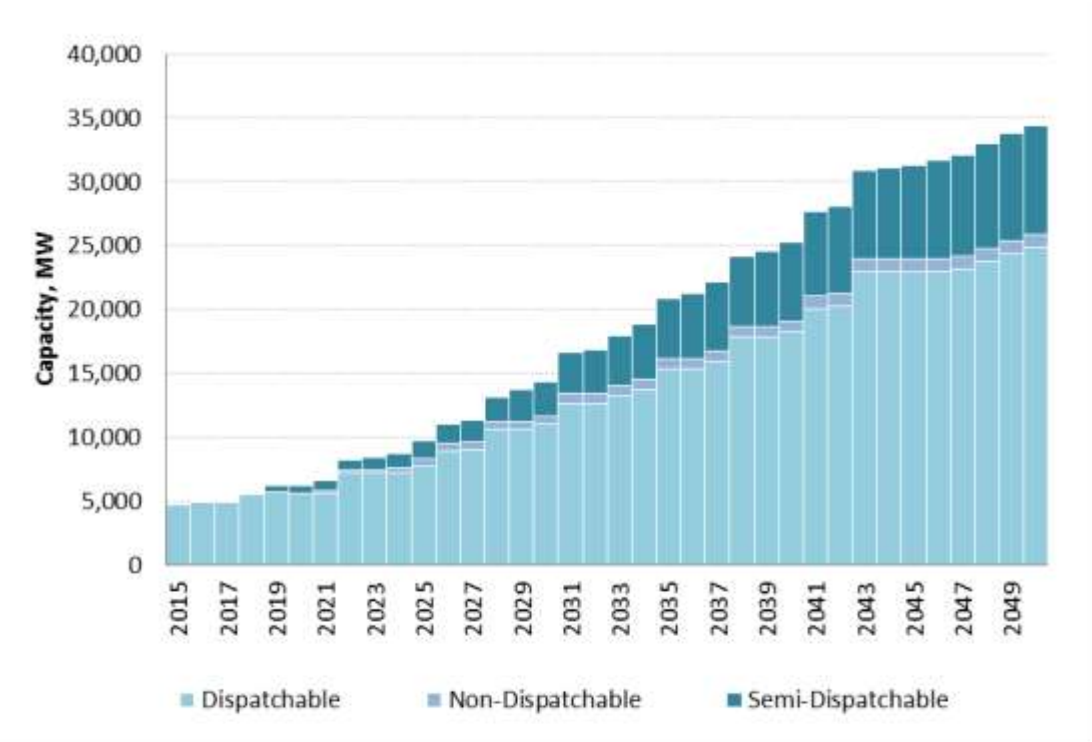


Figure 39 Myanmar Generation Mix by Generation Type (BAU, GWh)



To facilitate later comparison with the SES, Figure 40 plots installed capacity with capacity being distinguished between the following basic categories: (1) dispatchable capacity, (2) non-dispatchable capacity; and (3) semi-dispatchable capacity[25]. This provides some insight into the operational flexibility of the generation fleet to match demand uncertainty. The dispatchable category relates to generation that can be controlled and dispatched at short notice to ramp up or down, non-dispatchable means that the generation is not able to respond readily to dispatch instructions while the semi-dispatchable category means that the resource can respond within limits, and in particular is capable of being backed off should the need arise to for example, avoid overloading the network or "spill" energy in the event that an over generation situation emerges; solar photovoltaics and windfarms with appropriately installed control systems can be classified in this category. In the BAU, over time, as renewable generation trends towards 29% of the total installed capacity by 2050, the dispatchable percentage declines to 72% although this still suggests a high level of dispatch control.

Figure 40 Myanmar Installed Capacity by Dispatch Status (BAU, MW)

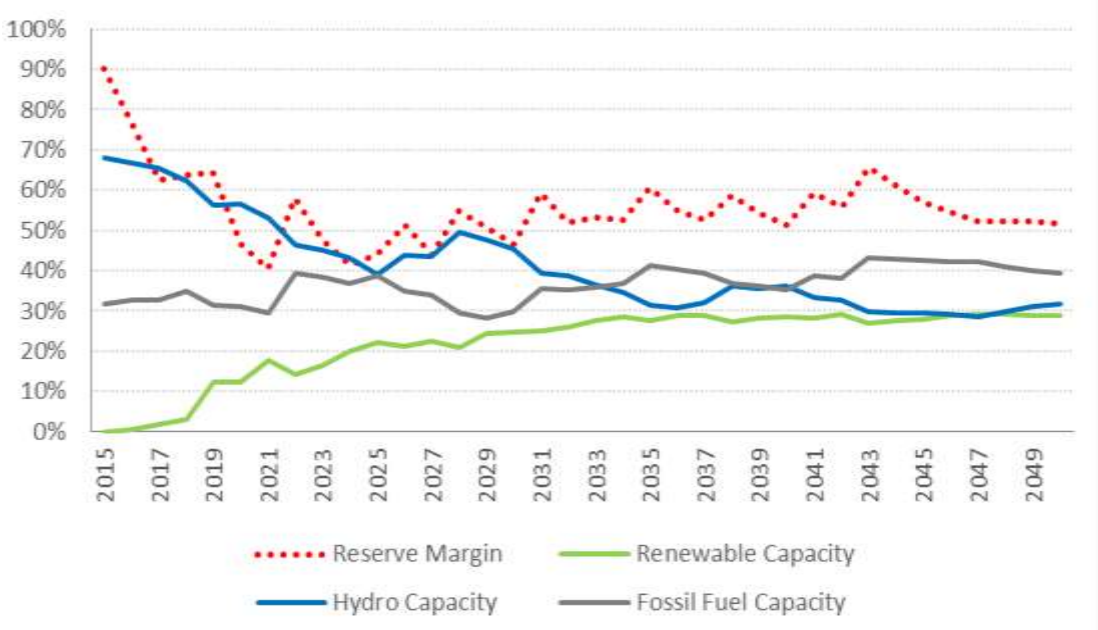


5.7 Reserve Margin and Generation Trends

Figure 41 plots the reserve margin based on nameplate capacity and annual peak demand. The Myanmar reserve margin in the BAU declines to 40% as the system adjusts to newly constructed projects then trends to 52% by 2050 as renewables are added to the system on top of conventional technologies that developed to meet reserve requirements.

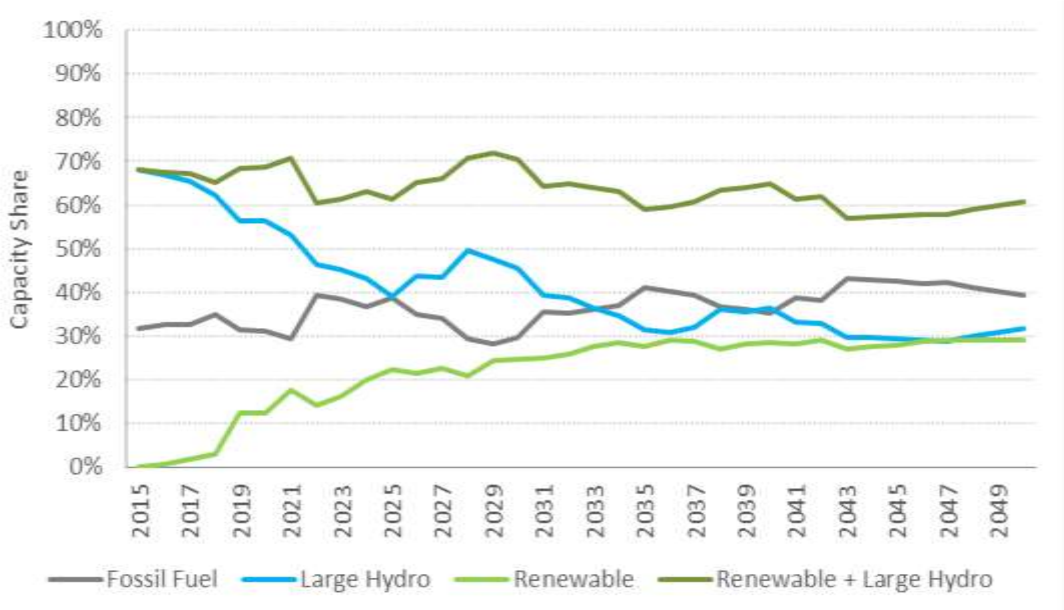
[25] Wind and solar is classified as semi-dispatchable, geothermal and hydro run-of-river is classified as non-dispatchable and all other technologies are classified as dispatchable.

Figure 41 Myanmar Reserve Margin (BAU)



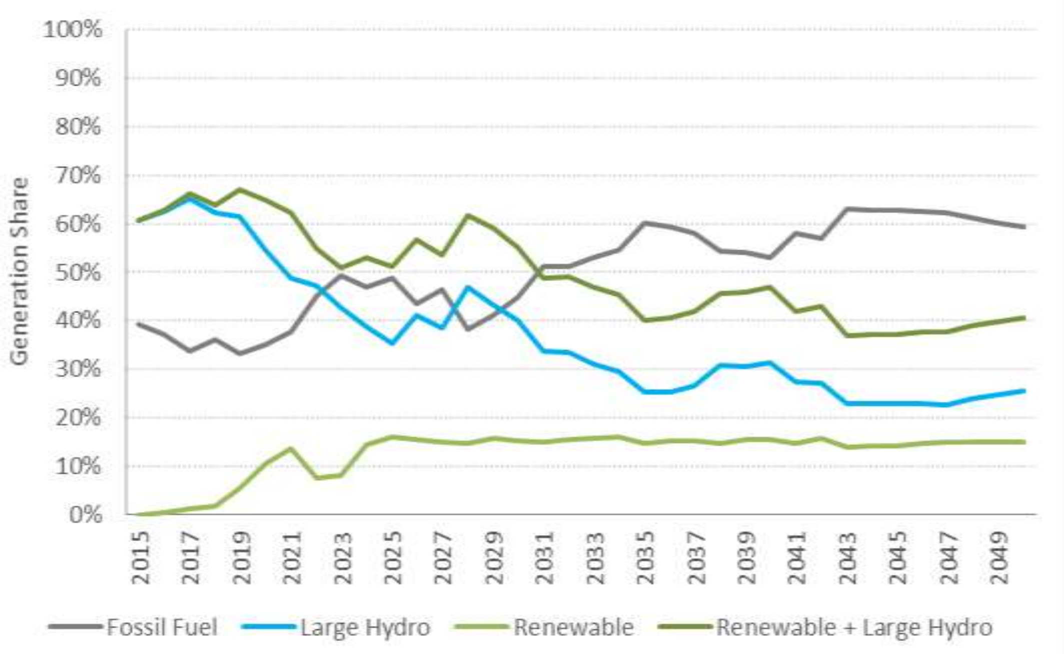
To obtain a better understanding of the broad mix of generation capacity and generation mix, Figure 42 and Figure 43 show shares in installed capacity and in generation grouped by the main categories of generator: thermal, large hydro, renewable energy (RE) and large hydro plus renewable energy.

Figure 42 Myanmar Capacity Shares by Generation Type (BAU)



Thermal-based generation share increases as coal and gas capacity is added to the system growing to 59% by 2050. Renewable generation reaches 15% of total generation and 41% including large-scale hydro.

Figure 43 Myanmar Generation Shares by Generation Type (BAU)



5.8 Electrification and Off-Grid

In the BAU, Myanmar's central grid-based electrification rate for its urban and rural population is assumed to reach close to 100% by 2030 in the BAU.

6 Sustainable Energy Sector Scenario

6.1 Sustainable Energy Sector Scenario

The SES seeks to transition electricity demand towards the best practice benchmarks of other developed countries in terms of energy efficiency, maximise the renewable energy development, cease the development of fossil fuel resources, and make sustainable and prudent use of undeveloped conventional hydro resources. Where relevant, it leverages advances in off-grid technologies to provide access to electricity to remote communities. The SES takes advantage of existing, technically proven and commercially viable renewable energy technologies.

6.2 Demand Growth

Figure 44 plots Myanmar's forecast energy consumption from 2015 to 2050 with the BAU energy trajectory charted as a comparison. The significant savings are due to additional energy efficiency assumptions relating to the various sectors achieving energy intensity benchmarks of comparable developed countries in Asia[26]. The SES demand grows at a slower rate of 6.2% pa over the period to 2050 with the commercial sector growing at 6.2% pa, industry growing at 6.3% pa and the residential sector growing at 5.6% pa. Uptake of electric transport options occurs from 2031 onwards and grows to 9 TWh accounting for 8.5% of total demand by 2050, or 15% of all vehicles. Off-grid demand growing up to 1,300 GWh in 2030 and dropping to 716 GWh by 2050 is driven by granting off-grid access to non-electrified households in the interim as electrification follows. The off-grid demand is relatively small as it reflects off-grid per capita demand that is much lower than grid connected demands and only reflects demand that is supported by off-grid generation as opposed to potential off-grid demand.

Figure 45 plots the peak demand of Myanmar. The firm blue line represents peak demand in Myanmar without any demand side management impacts. Demand side management reflects demand responses (excluding technology enabling responses such as battery storage) to tight supply and network conditions. This is assumed to grow to as much as 10% of demand across all sectors by 2050. The load factor associated with the SES is also assumed to reach 80% (compared to 75% under the BAU case) by 2050 as a further consequence of enhanced demand side management measures relative to the BAU.

Key drivers for demand growth and the demand projections are summarised in Table 12.

[26] Myanmar's industrial intensity was trended towards levels commensurate with Hong Kong (2014) which was the lowest in a basket of comparable economies.

Figure 44 Myanmar Projected Electricity Demand (2015-2050, SES)

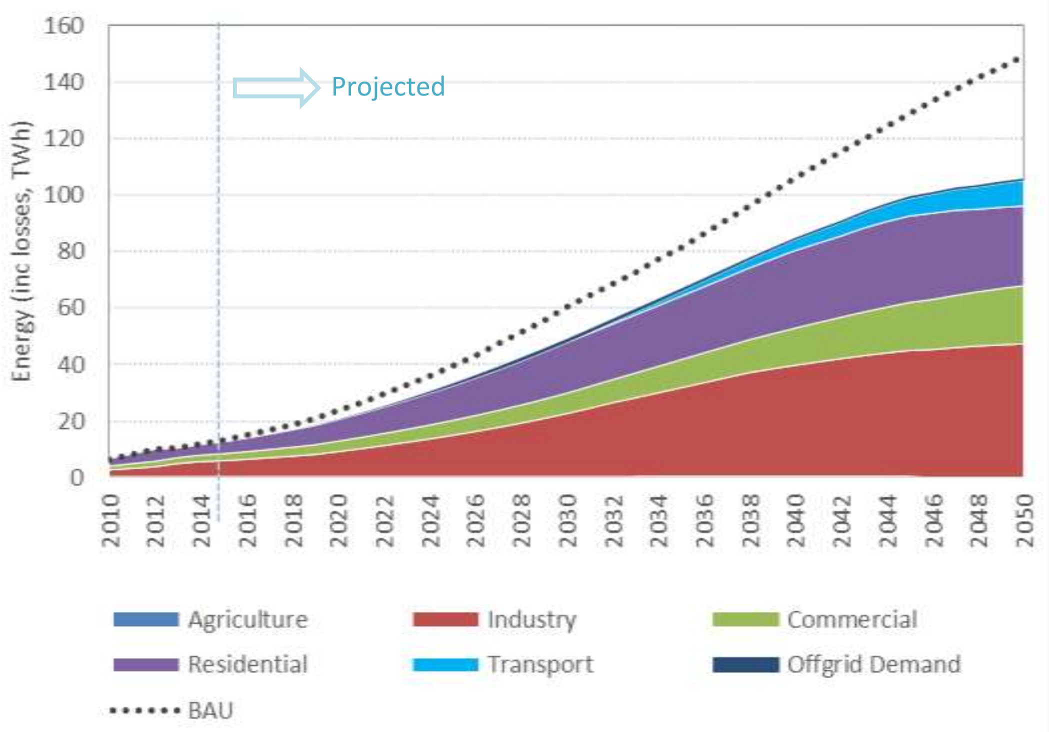


Figure 45 Myanmar Projected Electricity Demand (SES, MW)

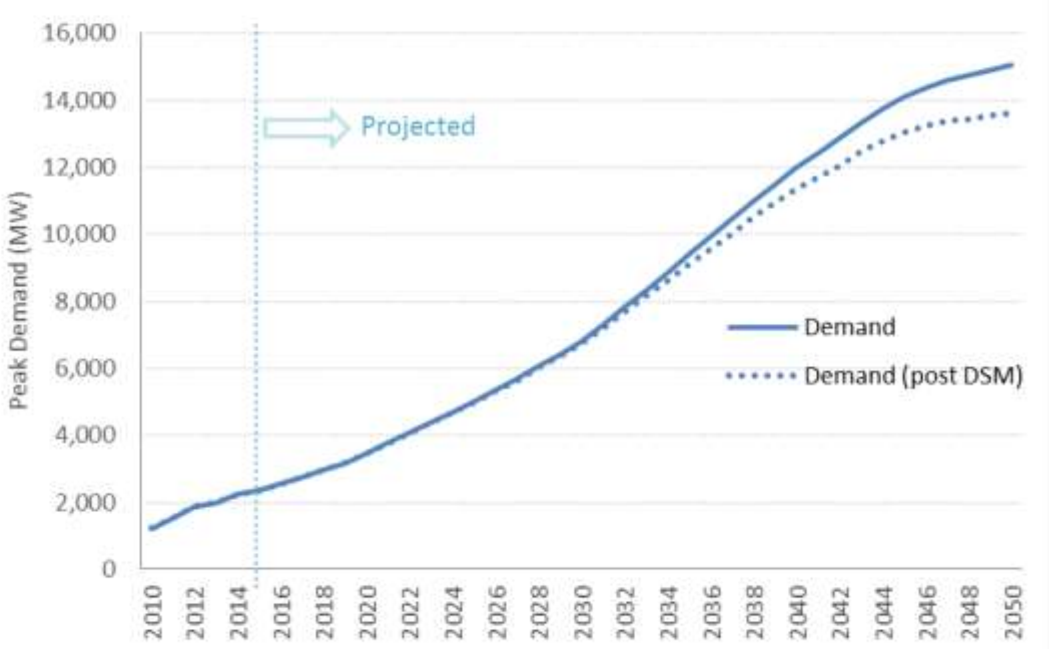


Table 13 Myanmar Demand and Demand Drivers (SES)

No.	Aspect	2015-30	2030-40	2040-50
1	Demand Growth (pa)	9.3%	5.8%	2.3%
2	GDP Growth (Real, pa)	7.0%	5.6%	3.1%
3	Central grid-based electrification Rate (Population)	49.3%	78.4%	84.5%
4	Population Growth	0.56%	0.12%	-0.13%
5	Per Capita Consumption (kWh)	365	839	1,496
6	Electricity Elasticity*	3.48	2.30	1.78
7	Electricity Intensity (kWh/US$)	0.106	0.144	0.186

** Electricity elasticity is calculated as electricity demand growth divided by the population growth over the same period*

6.3 Installed Capacity Development

Figure 46 plots the installed capacity developments under the SES and Figure 47 plots the corresponding percentage shares. Table 14 and Table 15 provide the statistical details of the installed capacity and capacity shares by type including the estimated 2010 levels.

Committed and existing plants are assumed to come online as per the BAU and are not replaced when retired. Planned and proposed thermal developments are not developed and up to 2,500 MW of large-scale hydro is developed to support renewable technologies as GMS countries target more sustainable energy options and look to renewable technologies to meet future demands. Gas fired-generation in the earlier years is very similar to the BAU due to existing and committed projects but drops off with plant retirements in the late 2030s compared to the 31% share in 2015. Large-hydro penetration also decreases with large-scale hydro considered in the BAU replaced with other renewable energy.

Timing of renewable energy developments are based on the maturity of the technology and ease of deployment. Additional demand in the SES is predominantly met by renewables with 58 GW required to meet 2050 electricity demand from a current capacity base of 0 MW (large-scale and grid connected). Solar PV is to account for 27 GW, biomass 4 GW, CSP 5 GW, and wind energy 13 GW of the total by 2050 with 6 GW of battery storage developed to support significant penetration of solar PV in the Myanmar system. 1 GW of solar PV and battery storage is also deployed to provide interim electricity access. By 2050, renewable generation excluding large-scale hydro accounts for 90% of installed capacity.

Figure 46 Myanmar Installed Capacity by Type (SES, MW)

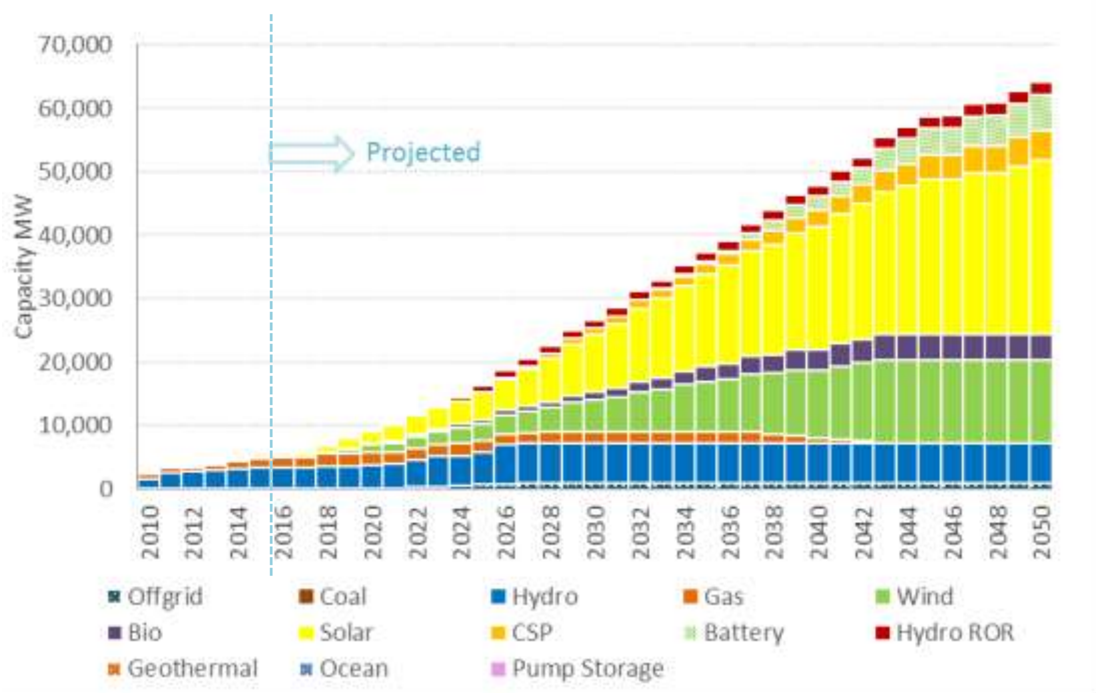


Figure 47 Myanmar Capacity Shares (SES, %)

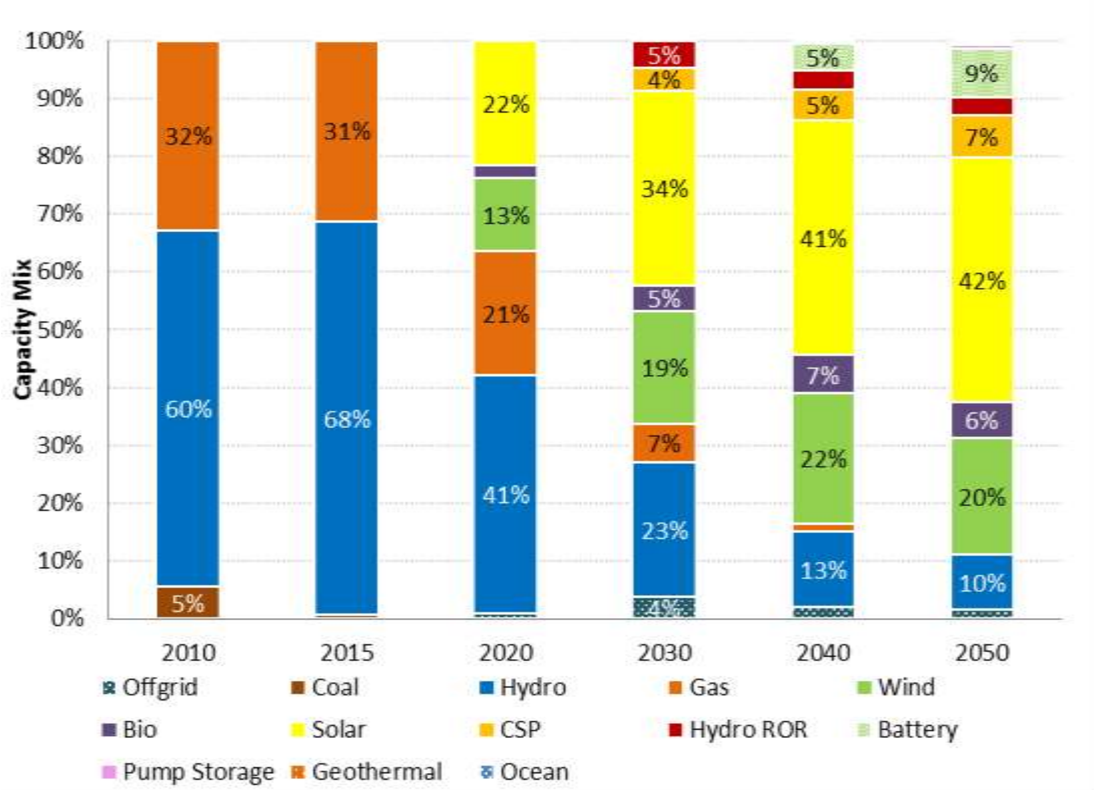


Table 14 Myanmar Capacity by Type (SES, MW)

Resource	2010	2015	2020	2030	2040	2050
Coal	130	30	0	0	0	0
CCS	0	0	0	0	0	0
Diesel	70	0	0	0	0	0
Fuel Oil	0	0	0	0	0	0
Gas	770	1,490	1,939	1,774	691	0
Nuclear	0	0	0	0	0	0
Hydro	1,450	3,252	3,748	6,213	6,213	6,213
Onshore Wind	0	0	1,149	5,149	10,749	13,049
Offshore Wind	0	0	0	0	0	0
Biomass	0	0	205	1,205	3,205	4,005
Biogas	0	0	0	0	0	0
Solar	0	0	1,959	8,959	19,459	27,459
CSP	0	0	0	1,050	2,550	4,800
Battery	0	0	0	0	2,192	5,521
Hydro ROR	0	0	0	1,200	1,600	2,000
Geothermal	0	0	0	50	250	350
Pump Storage	0	0	0	0	0	300
Ocean	0	0	0	0	50	200
Off-grid	0	2	87	1,001	1,008	1,008

Table 15 Myanmar Capacity Share by Type (SES, %)

Resource	2010	2015	2020	2030	2040	2050
Coal	5%	1%	0%	0%	0%	0%
CCS	0%	0%	0%	0%	0%	0%
Diesel	3%	0%	0%	0%	0%	0%
Fuel Oil	0%	0%	0%	0%	0%	0%
Gas	32%	31%	21%	7%	1%	0%
Nuclear	0%	0%	0%	0%	0%	0%
Hydro	60%	68%	41%	23%	13%	10%
Onshore Wind	0%	0%	13%	19%	22%	20%
Offshore Wind	0%	0%	0%	0%	0%	0%
Biomass	0%	0%	2%	5%	7%	6%
Biogas	0%	0%	0%	0%	0%	0%
Solar	0%	0%	22%	34%	41%	42%
CSP	0%	0%	0%	4%	5%	7%
Battery	0%	0%	0%	0%	5%	9%
Hydro ROR	0%	0%	0%	5%	3%	3%
Geothermal	0%	0%	0%	0%	1%	1%
Pump Storage	0%	0%	0%	0%	0%	0%
Ocean	0%	0%	0%	0%	0%	0%
Off-grid	0%	0%	1%	4%	2%	2%

6.4 Projected Generation Mix

Grid generation is plotted in Figure 48 and Figure 49[27]. The corresponding statistics for snapshot years are provided in Table 17 and Table 18. Myanmar's generation mix in the earlier years to 2020 is similar to the BAU case as committed new entry is commissioned. Biomass generation grows to 27TWh by 2050 accounting for 17% of generation with CSP contributing 13%, solar PV and wind accounting for 33% and 17% respectively. By 2050 renewable technology (excluding large-scale hydro) generates 85% (or 100% including large-scale hydro) of total power requirements in the country coinciding with the retirements of older gas and coal plants.

[27] Battery storage is not included as storage technologies are generation neutral.

Figure 48 Myanmar Generation Mix (SES, GWh)

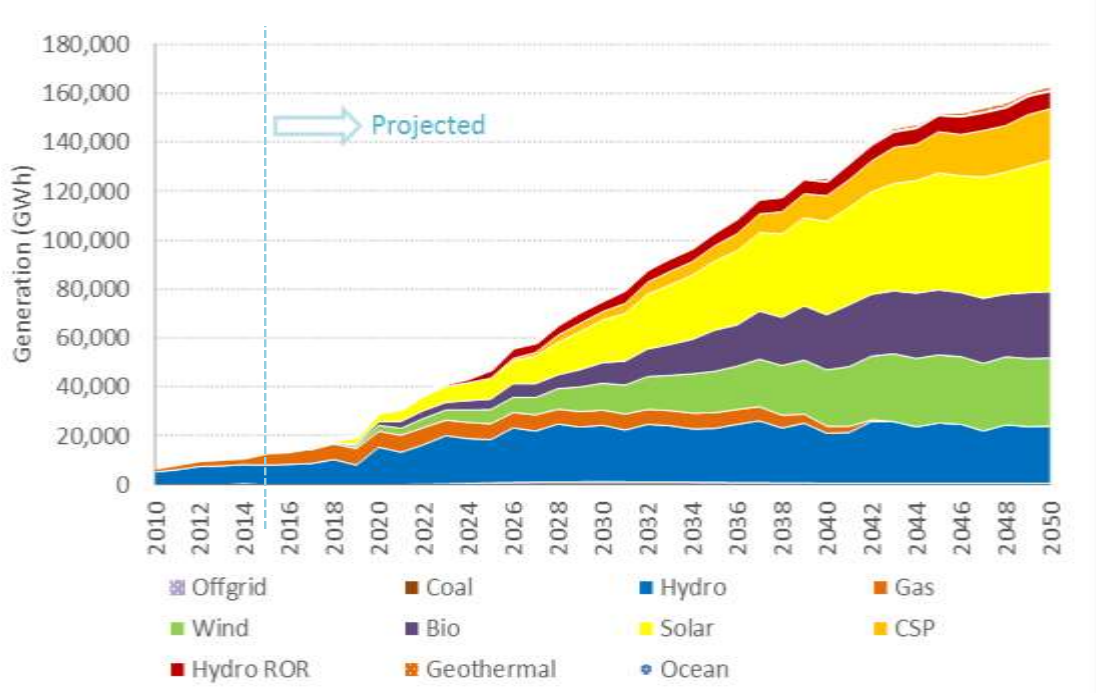


Figure 49 Myanmar Generation Share (SES, %)

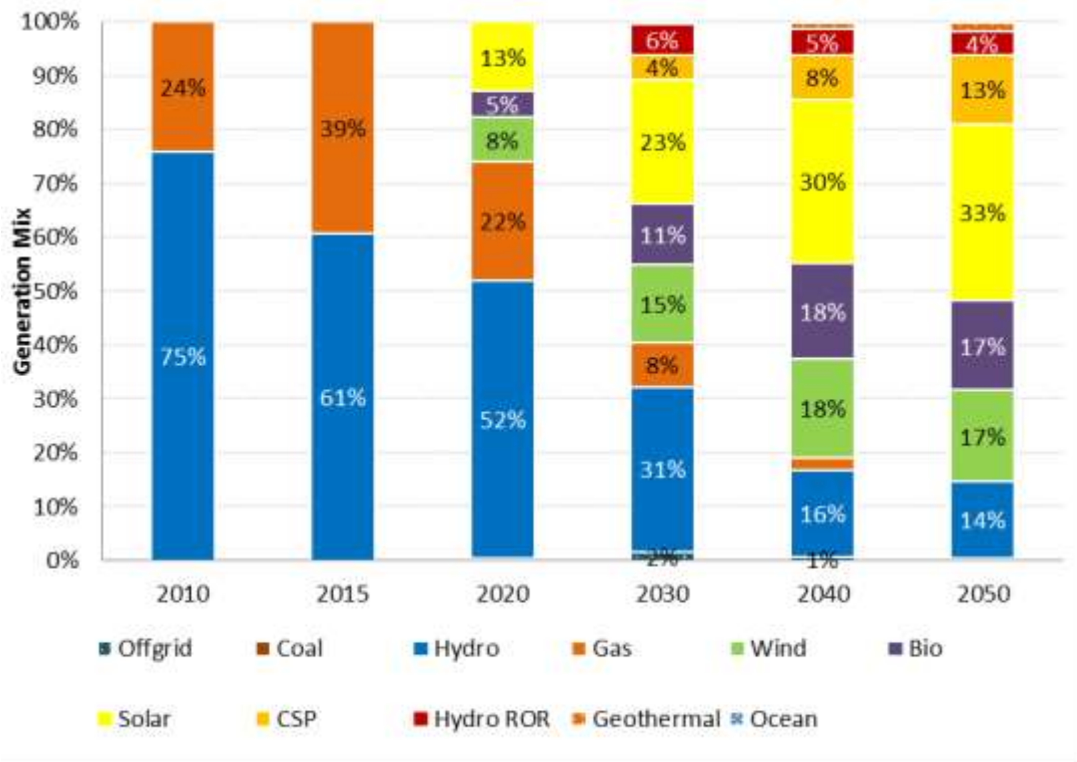


Table 16 Myanmar Generation by Fuel (SES, GWh)

Generation	2010	2015	2020	2030	2040	2050
Coal	0	0	0	0	0	0
CCS	0	0	0	0	0	0
Diesel	30	0	0	0	0	0
Fuel Oil	0	0	0	0	0	0
Gas	1,678	5,233	6,502	6,174	2,923	0
Nuclear	0	0	0	0	0	0
Hydro	5,263	8,099	15,308	23,125	20,402	23,362
Onshore Wind	0	0	2,435	10,980	22,981	27,800
Offshore Wind	0	0	0	0	0	0
Biomass	0	0	1,441	8,445	22,522	27,187
Biogas	0	0	0	0	0	0
Solar	0	0	3,836	17,501	38,141	53,640
CSP	0	0	0	3,381	10,525	21,085
Battery	0	0	0	0	0	0
Hydro ROR	0	0	0	4,415	5,925	7,358
Geothermal	0	0	0	333	1,651	2,304
Pump Storage	0	0	0	0	0	317
Ocean	0	0	0	0	132	526
Off-grid	0	2	112	1,268	725	716

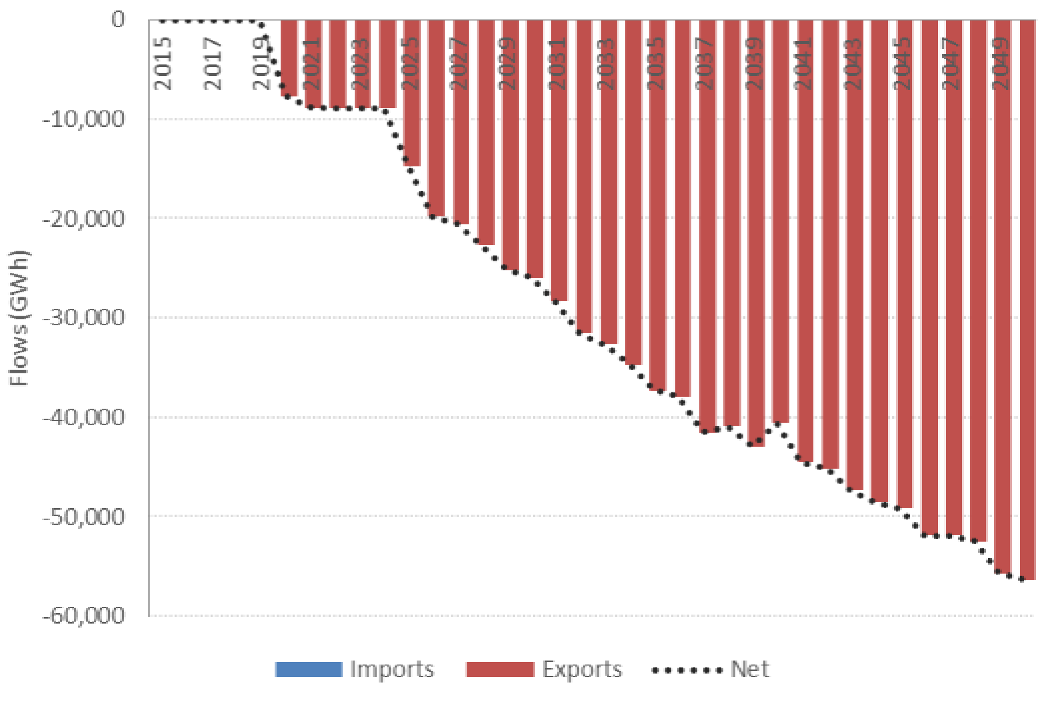
Table 17 Myanmar Generation Share by Fuel (SES, %)

Generation	2010	2015	2020	2030	2040	2050
Coal	0%	0%	0%	0%	0%	0%
CCS	0%	0%	0%	0%	0%	0%
Diesel	0%	0%	0%	0%	0%	0%
Fuel Oil	0%	0%	0%	0%	0%	0%
Gas	24%	39%	22%	8%	2%	0%
Nuclear	0%	0%	0%	0%	0%	0%
Hydro	75%	61%	52%	31%	16%	14%
Onshore Wind	0%	0%	8%	15%	18%	17%
Offshore Wind	0%	0%	0%	0%	0%	0%
Biomass	0%	0%	5%	11%	18%	17%
Biogas	0%	0%	0%	0%	0%	0%
Solar	0%	0%	13%	23%	30%	33%
CSP	0%	0%	0%	4%	8%	13%
Battery	0%	0%	0%	0%	0%	0%
Hydro ROR	0%	0%	0%	6%	5%	4%
Geothermal	0%	0%	0%	0%	1%	1%
Pump Storage	0%	0%	0%	0%	0%	0%
Ocean	0%	0%	0%	0%	0%	0%
Off-grid	0%	0%	0%	2%	1%	0%

6.5 Grid to Grid Power Flows

Figure 50 plots the imports and exports in the SES with the dotted line representing the net interchange. Myanmar exports its power to Thailand from 2020 as transmission developments occur from a much earlier stage with generation planning at the regional level. By the 2040's over 40,000GWh is traded across the Myanmar and Thailand border each year driven by significant demand growth in Thailand and Viet Nam relative to the other GMS countries and limitations on their renewable resource potential. Myanmar's net exporter status is driven by the vast amount of renewable energy resources available to the country.

Figure 50 Myanmar Imports and Exports (SES)



6.6 Generation Fleet Structure

As for the BAU, to gain insight into the nature of the mix of generation technologies deployed in the SES, we present a number of additional charts. Figure 51 and Figure 52 show Myanmar's installed capacity and generation by type for the SES – this is biased towards renewable generation forms.

Figure 51 **Myanmar Installed Capacity by Generation Type (SES, MW)**

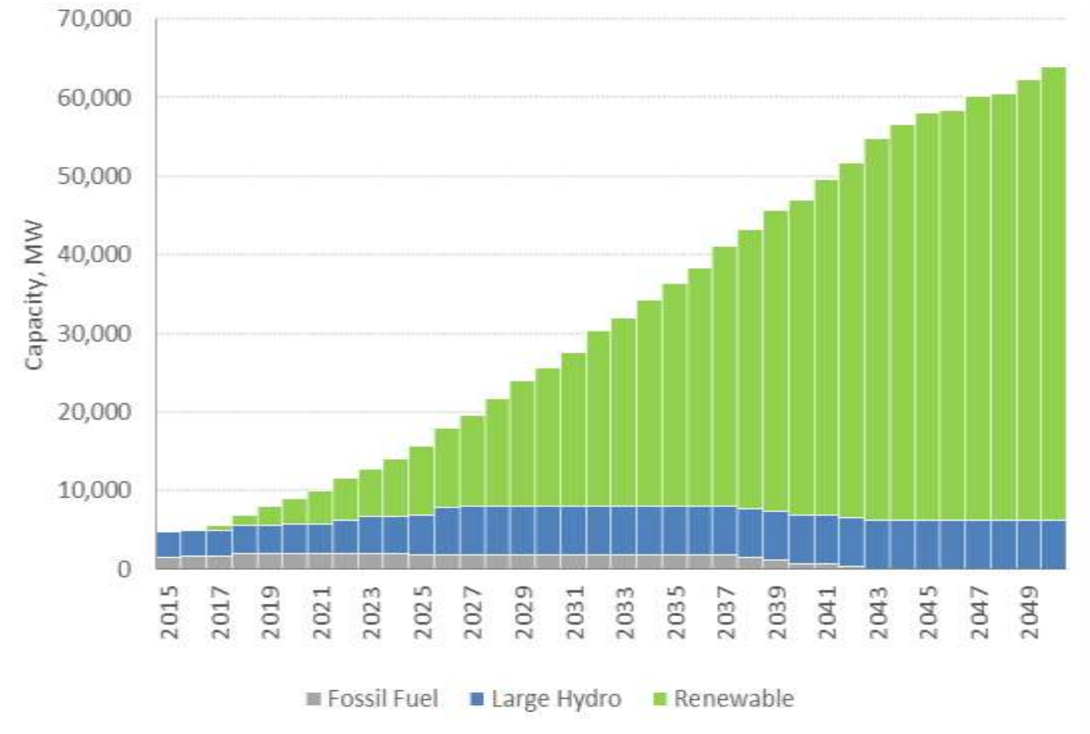


Figure 52 **Myanmar Generation Mix by Generation Type (SES, GWh)**

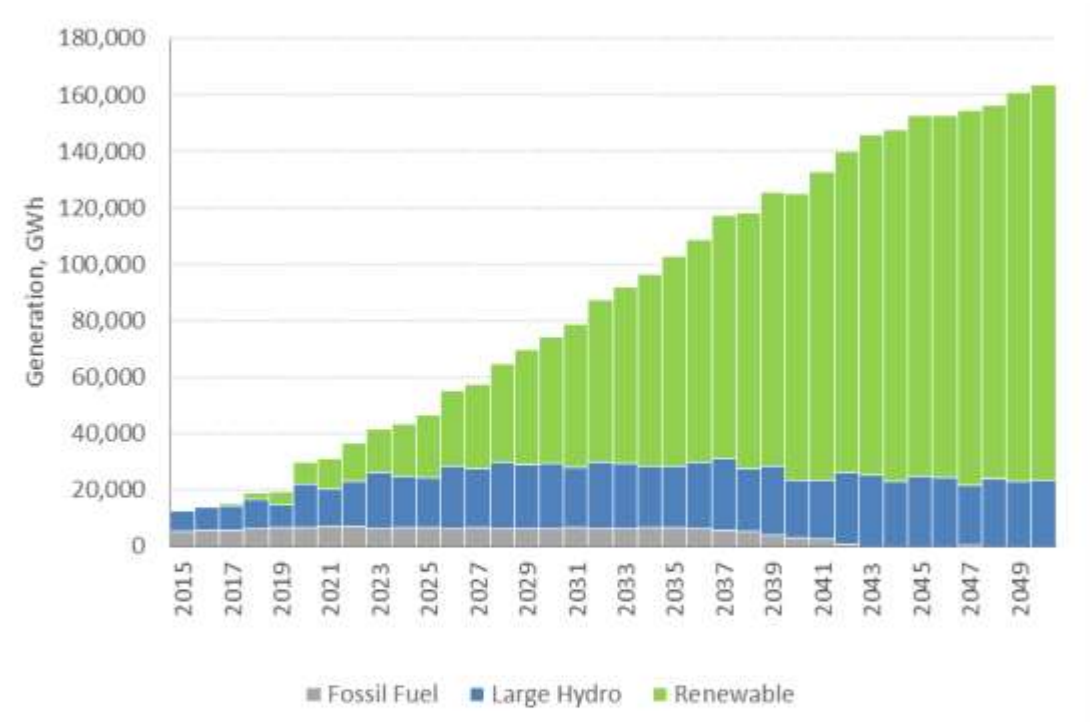
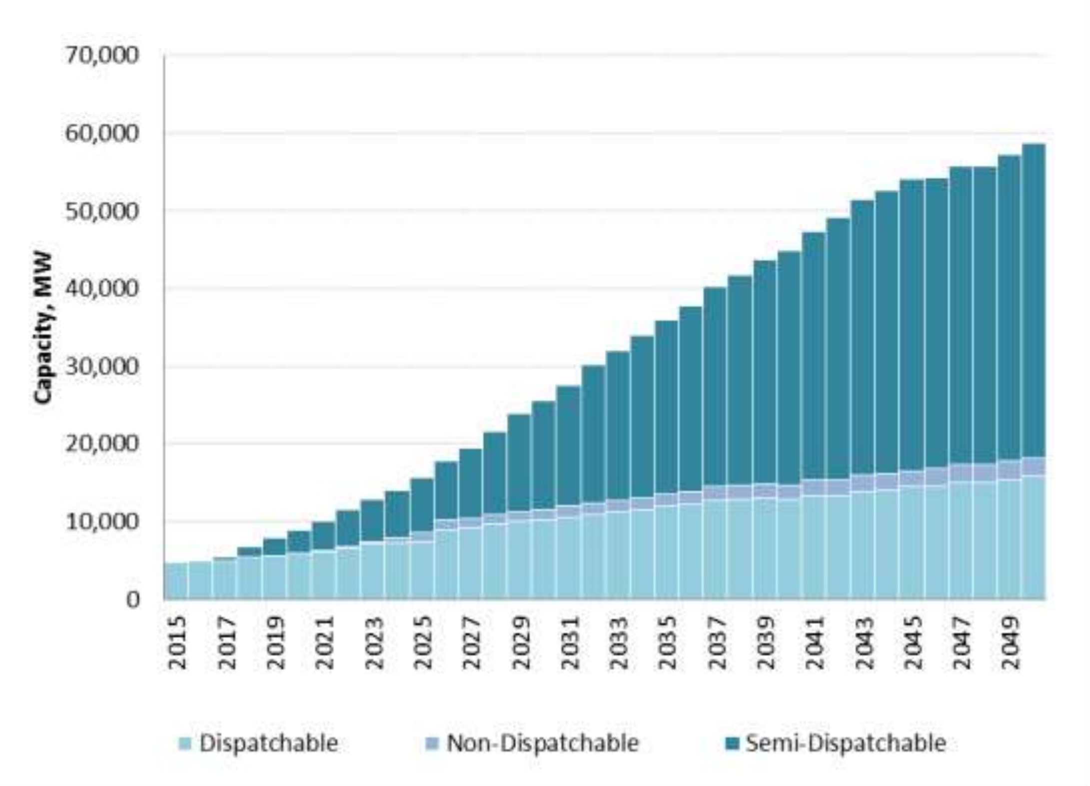


Figure 53, shows the dispatchable, semi-dispatchable and non-dispatchable components of installed capacity and it can be seen that semi-dispatchable increases to around 69% of the total system capacity compared to around 25% in the BAU by 2050. Based on operational simulations with this resource mix, it appears to be operationally feasible, although the reliance on generation forms that provide storage and having flexibility in the demand side play important roles. It is clear that short-term renewable energy solar and wind forecasting systems will be important, as will real-time updates on demand that can be controlled. Furthermore, control systems that can allow the dispatch of flexible resources on both supply and demand sides of the industry and across the region will be required.

Figure 53 Myanmar Installed Capacity by Dispatch Status (SES, MW)



6.7 Reserve Margin and Generation Trends

Figure 54 plots the reserve margin under the SES. Figure 55 and Figure 56, respectively, show the installed capacity mix and generation mix for different categories of generation in the power system. The reserve margin in the SES increases to almost 300% by 2030 as significant resources are invested into Myanmar generation projects (and transmission) to supply Thailand relieving potential energy constraints in Cambodia and Viet Nam. The reserve margin is naturally higher in the SES due to the lower capacity factor of renewable energy technologies like solar PV or wind compared to conventional technologies. Renewable technologies generally have much lower capacity factors and require more capacity to meet the same amount of energy produced from thermal-based technologies[28].

[28] Conventional reserve margin measures, based on peak demand and capacity alone are generally not a useful measures for systems with energy limited resources, high levels of renewable energy, battery storages and high levels of controllable demand side resources, as compared to power systems that are dominated by thermal generators and inelastic demand.

Figure 54 Myanmar Reserve Margin (SES)

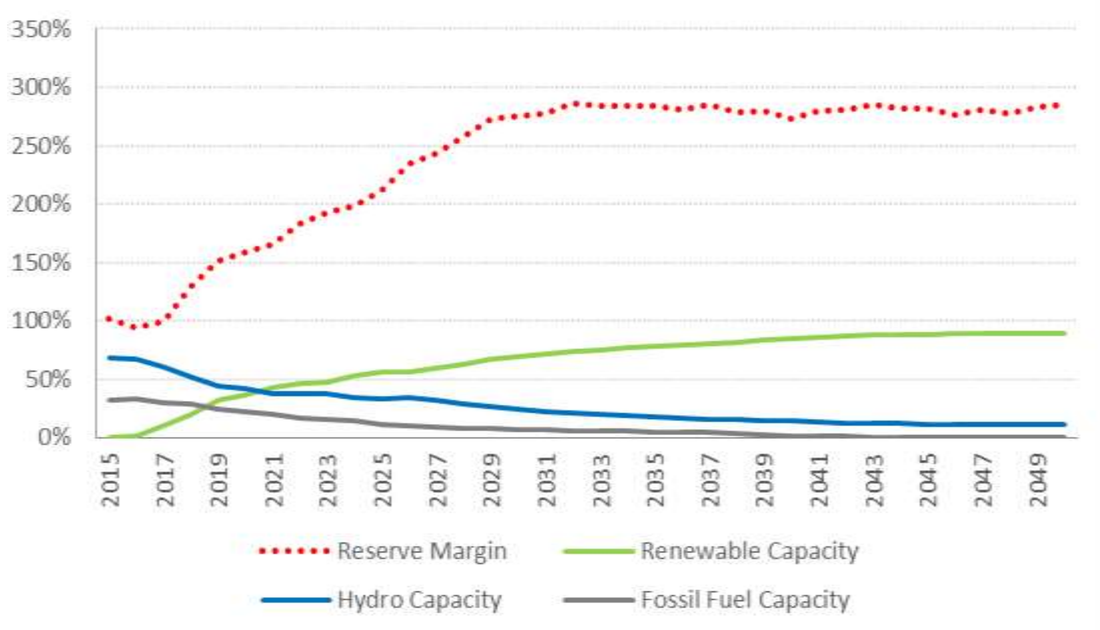


Figure 55 Myanmar Installed Capacity Shares for SES by Generation Type

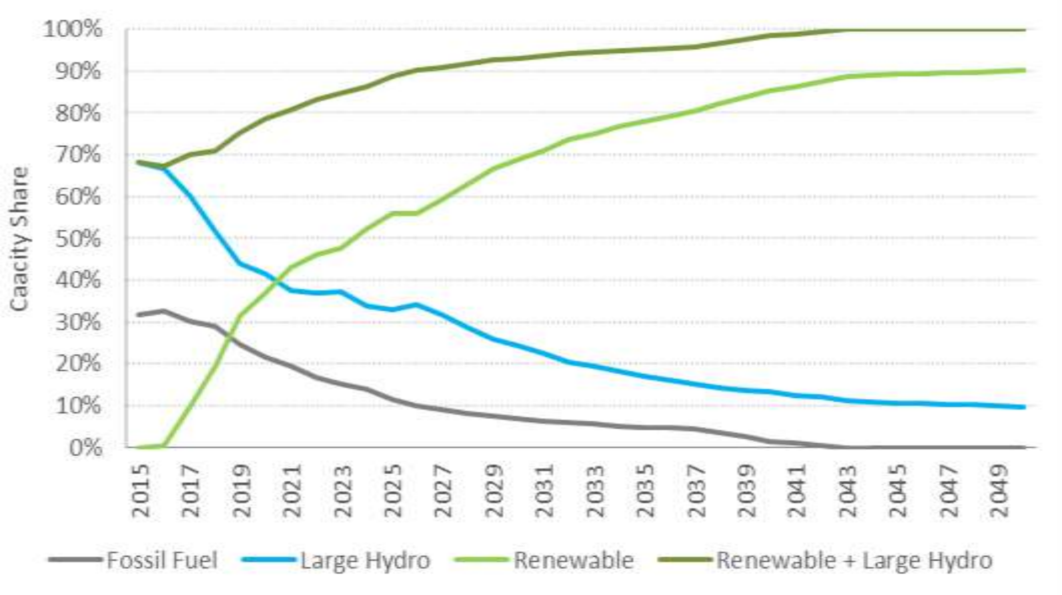
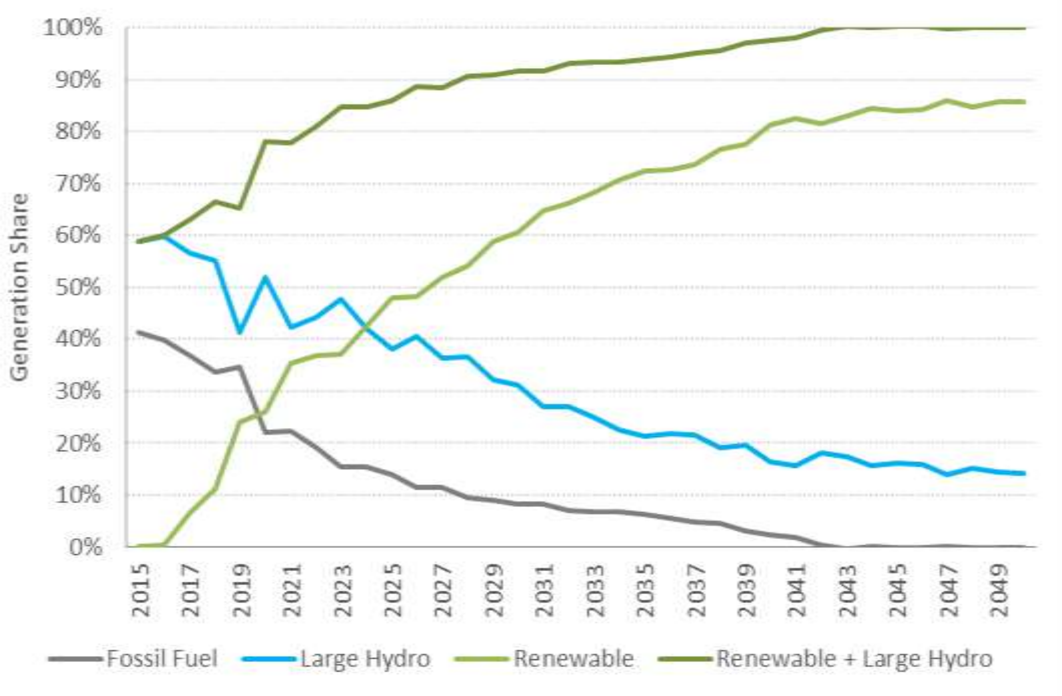


Figure 56 Myanmar Generation Shares for SES by Generation Type



6.8 Electrification and Off-Grid

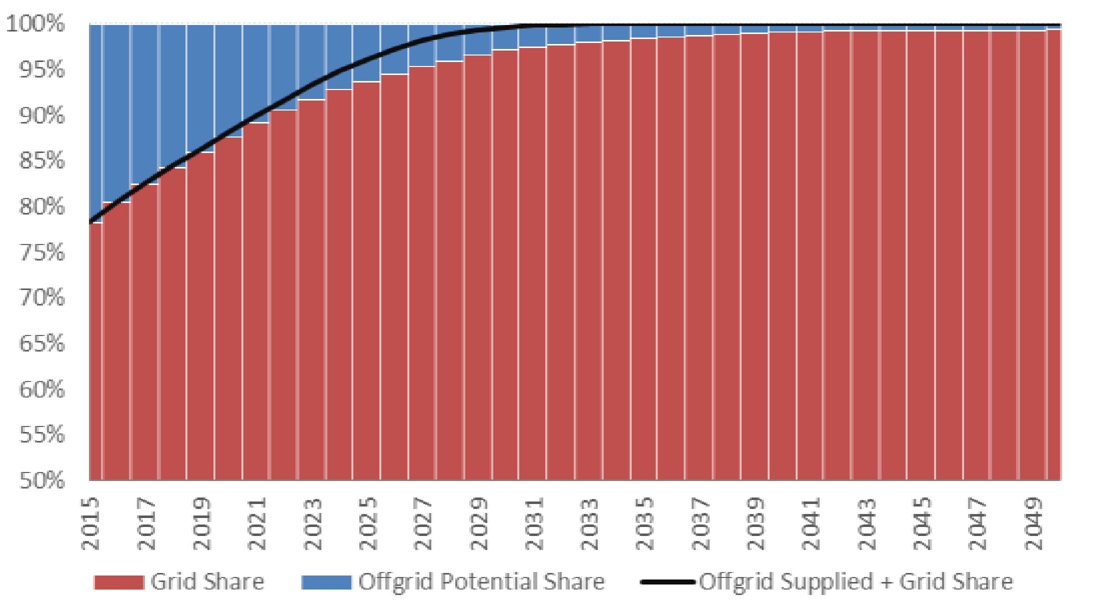
Myanmar in the SES is assumed to have slower grid electrification rates than the BAU with off-grid demand met by off-grid technologies (solar PV and battery storage in the interim before the transmission network is built out to all the provinces). As existing off-grid supplied regions are connected from 2030, existing mini grids are assumed to be integrated into the main grid. By 2030, the SES has similar electricity access rates as the BAU, but not all is connected to the main grid.

Figure 57 shows the percentage of total demand divided into grid and off-grid potential demand. Off-grid potential demand is demand that is not yet being satisfied either by grid connection or an off-grid power supply solution[29]. In 2015, 78% of total demand is grid-connected demand (red) and the rest is potential off-grid demand (blue). Over time, grid based demand increases due to progress with electrification while potential off-grid demand is supplied by solar PV and battery storage technologies. The black line represents the combined percentage of demand that has access to electricity either via grid connection or via an off-grid solution. The cost of off-grid supply based on solar PV and battery storage is assumed to cost US$171/MWh declining to US$101/MWh by 2030, reaching US$74/MWh by 2050[30].

[29] It is an estimate of the amount of demand that would be present if the household was either connected to the grid or supplied by an off-grid solution.

[30] Based on technology cost assumptions, 25% of solar PV generation stored for off-peak use and an 85% battery efficiency.

Figure 57 Off-grid Potential Demand Share (SES)



7 Advanced Sustainable Energy Sector Scenario

7.1 Advanced Sustainable Energy Sector Scenario

The ASES assumes that the power sector is able to more rapidly transition towards a 100% renewable energy technology mix under an assumption that renewable energy is deployed more than in the SES scenario with renewable energy technology costs declining more rapidly compared to BAU and SES scenarios.

7.2 Demand Growth

Figure 58 plots Myanmar's forecast energy consumption from 2015 to 2050 with the BAU and SES energy trajectory charted with a dashed line for comparison. The SES energy savings against the BAU are due to allowing Myanmar's energy demand to transition towards energy intensity benchmarks of comparable developed countries in Asia. The ASES applies an additional 10% energy efficiency against the SES demands excluding transport.

The ASES demand grows at a slower rate of 6.1% pa over the period from 2015 to 2050 with the commercial sector at 6.0% pa, industry growing at 5.9% pa and residential sector growing at 4.9% pa. Demand from the transport sector in the ASES is doubled and grows to 18 TWh or 18% of total demand by 2050, or 30% of all vehicles. Residential sector growth slows due to lower electrification rates as off-grid potential demand is supplied via solar PV and battery in mini and micro grids from 2025. Off-grid demand grows to almost 5 GWh by 2050.

Figure 59 plots the peak demand of Myanmar. The firm blue line represents peak demand in Myanmar without any demand side management impacts. Demand side management reflects demand responses to tight supply and network conditions. This is assumed to grow to as much as 17.5% of demand across all sectors by 2050, representing the portion of flexible demand that is not enabled via technology (i.e. battery storage). The load factor associated with the ASES is also assumed to reach 80% (compared to 75% under the BAU case) by 2030 as a further consequence of enhanced demand side management measures relative to the BAU.

Key drivers for demand growth and the demand projections are summarised in Table 17.

Figure 58 Myanmar Projected Electricity Demand (2015-2050, ASES)

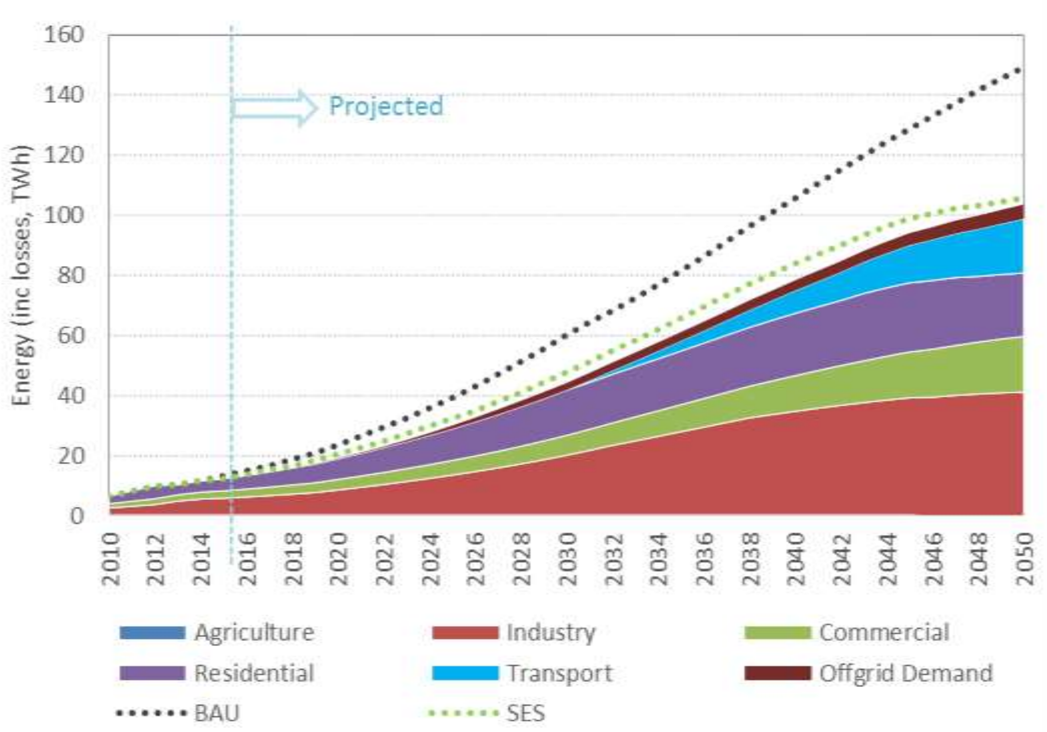


Figure 59 Myanmar Projected Electricity Demand (ASES, MW)

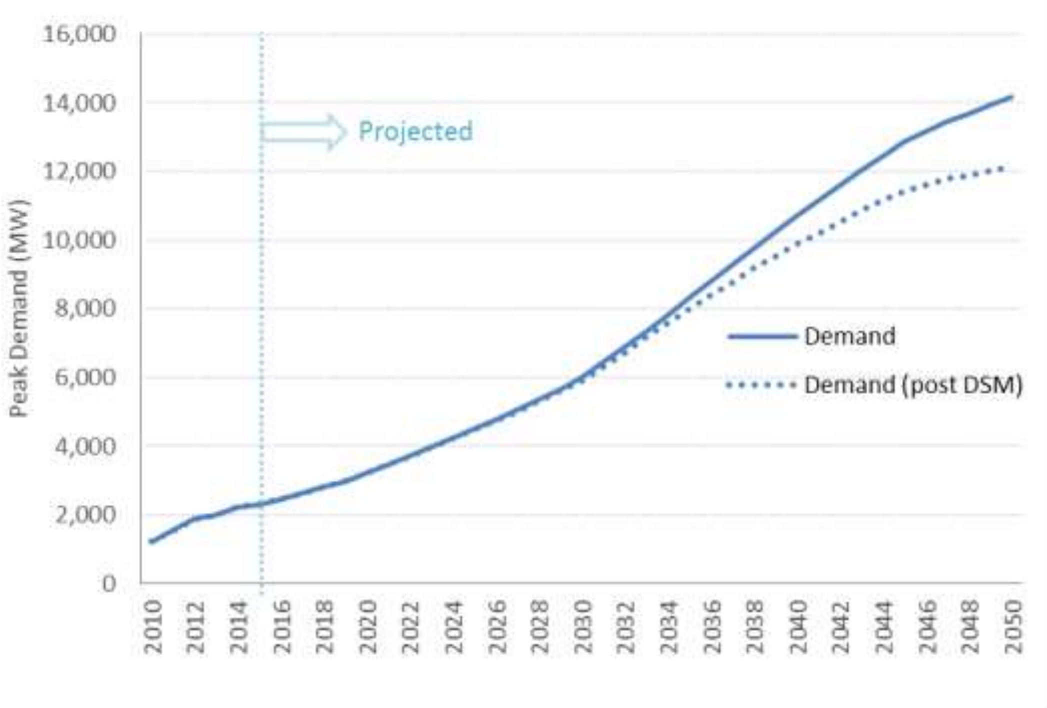


Table 18 Myanmar Demand and Demand Drivers (ASES)

No.	Aspect	2015-30	2030-40	2040-50
1	Demand Growth (pa)	8.4%	6.0%	2.9%
2	GDP Growth (Real, pa)	7.0%	5.6%	3.1%
3	Central grid connected electrification Rate (Population)	41.4%	58.7%	60.0%
4	Population Growth	0.56%	0.12%	-0.13%
5	Per Capita Consumption (kWh)	339	736	1,334
6	Electricity Elasticity*	3.23	2.17	1.81
7	Electricity Intensity (kWh/US$)	0.099	0.126	0.166

** Electricity elasticity is calculated as electricity demand growth divided by the population growth over the same period*

7.3 Installed Capacity Development

Figure 60 plots the installed capacity developments under the SES and Figure 61 plots the corresponding percentage shares. Table 19 and Table 20 provide the statistical details of the installed capacity and capacity shares by type including the 2010 levels. Existing thermal plant are retired earlier than in the SES to meet the imposed renewable generation targets across the region. By 2050, there is 31 GW of installed solar PV supported by 9 GW of battery storage capability mainly to defer generation for off-peak periods. Significant investment in onshore wind, bioenergy and CSP technologies occur to meet the rising demands, accounting for 20%, 6%, and 5% of total installed capacity by 2050. Myanmar is forecast to have sufficient agricultural residues to meet its biomass requirements in the SES. Up to 3.7 GW of off-grid technology is installed to provide Myanmar with close to 100% electricity access by 2030.

Figure 60 Myanmar Installed Capacity by Type (ASES, MW)

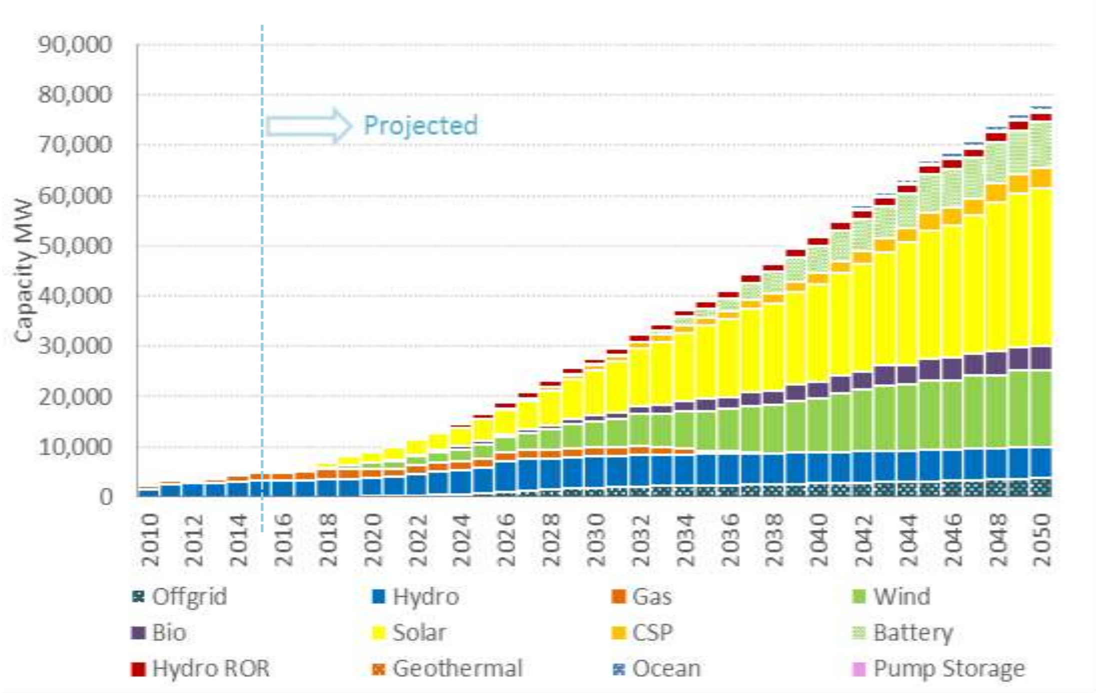


Figure 61 Myanmar Capacity Shares (ASES, %)

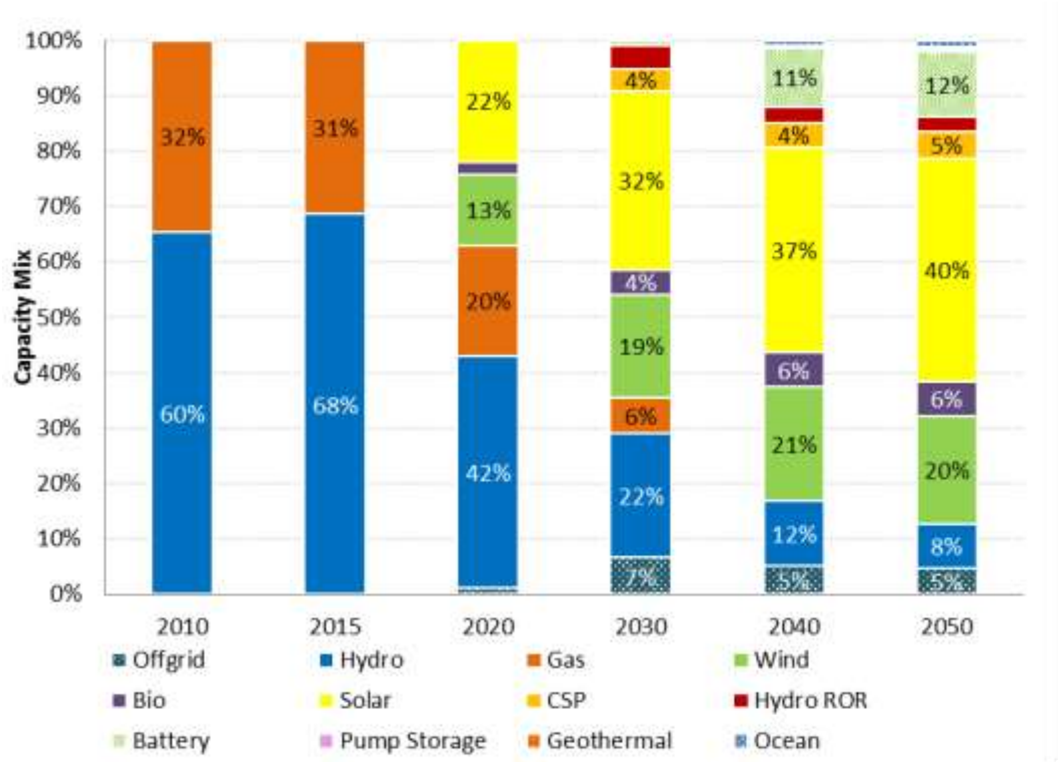


Table 19 Myanmar Capacity by Type (ASES, MW)

Resource	2010	2015	2020	2030	2040	2050
Coal	130	30	0	0	0	0
CCS	0	0	0	0	0	0
Diesel	70	0	0	0	0	0
Fuel Oil	0	0	0	0	0	0
Gas	770	1,490	1,774	1,774	0	0
Nuclear	0	0	0	0	0	0
Hydro	1,450	3,252	3,748	6,213	6,213	6,213
Onshore Wind	0	0	1,149	5,149	10,749	15,299
Offshore Wind	0	0	0	0	0	0
Biomass	0	0	205	1,205	3,205	4,805
Biogas	0	0	0	0	0	0
Solar	0	0	1,959	8,959	19,459	31,459
CSP	0	0	0	1,050	2,250	3,900
Battery	0	0	0	210	5,511	9,199
Hydro ROR	0	0	0	1,200	1,600	2,000
Geothermal	0	0	0	50	250	350
Pump Storage	0	0	0	0	0	300
Ocean	0	0	0	0	500	1,000
Off-grid	0	2	94	1,814	2,655	3,696

Table 20 Myanmar Capacity Share by Fuel (ASES, %)

Resource	2010	2015	2020	2030	2040	2050
Coal	5%	1%	0%	0%	0%	0%
CCS	0%	0%	0%	0%	0%	0%
Diesel	3%	0%	0%	0%	0%	0%
Fuel Oil	0%	0%	0%	0%	0%	0%
Gas	32%	31%	20%	6%	0%	0%
Nuclear	0%	0%	0%	0%	0%	0%
Hydro	60%	68%	42%	22%	12%	8%
Onshore Wind	0%	0%	13%	19%	21%	20%
Offshore Wind	0%	0%	0%	0%	0%	0%
Biomass	0%	0%	2%	4%	6%	6%
Biogas	0%	0%	0%	0%	0%	0%
Solar	0%	0%	22%	32%	37%	40%
CSP	0%	0%	0%	4%	4%	5%
Battery	0%	0%	0%	1%	11%	12%
Hydro ROR	0%	0%	0%	4%	3%	3%
Geothermal	0%	0%	0%	0%	0%	0%
Pump Storage	0%	0%	0%	0%	0%	0%
Ocean	0%	0%	0%	0%	1%	1%
Off-grid	0%	0%	1%	7%	5%	5%

7.4 Projected Generation Mix

ASES grid generation is plotted in Figure 62 and generation shares in Figure 63. The corresponding statistics for snapshot years are provided in Table 22 and Table 23. Myanmar's generation mix in the earlier years to 2020 is similar to the BAU case as committed new generation projects are commissioned and this has largely been kept the same. A notable difference is that there is an increase in wind and solar projects from 2016. Further non-renewable developments beyond 2019 cease; gas generation levels decline entirely by 2037 as units are retired while large-scale hydro generation continues at current levels.

Of the renewable technologies, by 2050, solar contributes the highest generation share (61 TWh), wind generation makes the next largest contribution to the generation mix (33 TWh), large hydro at 23TWh then CSP and bioenergy (17 TWh and 16 TWh respectively). By 2050, new renewable energy sources (excluding large-scale hydro) make up some 86% of the total generation requirement or 100% including large-scale hydro generation. Off-grid generation accounts for 3% of total generation by 2050.

Figure 62 Myanmar Generation Mix (ASES, GWh)

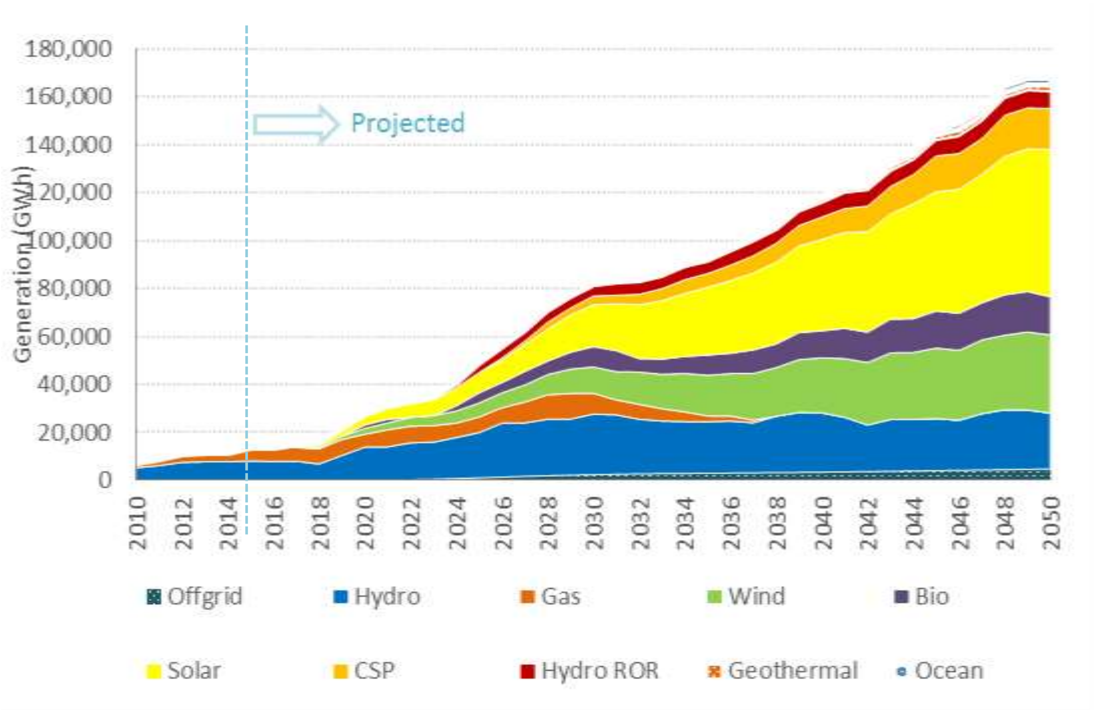


Figure 63 Myanmar Generation Mix (ASES, %)

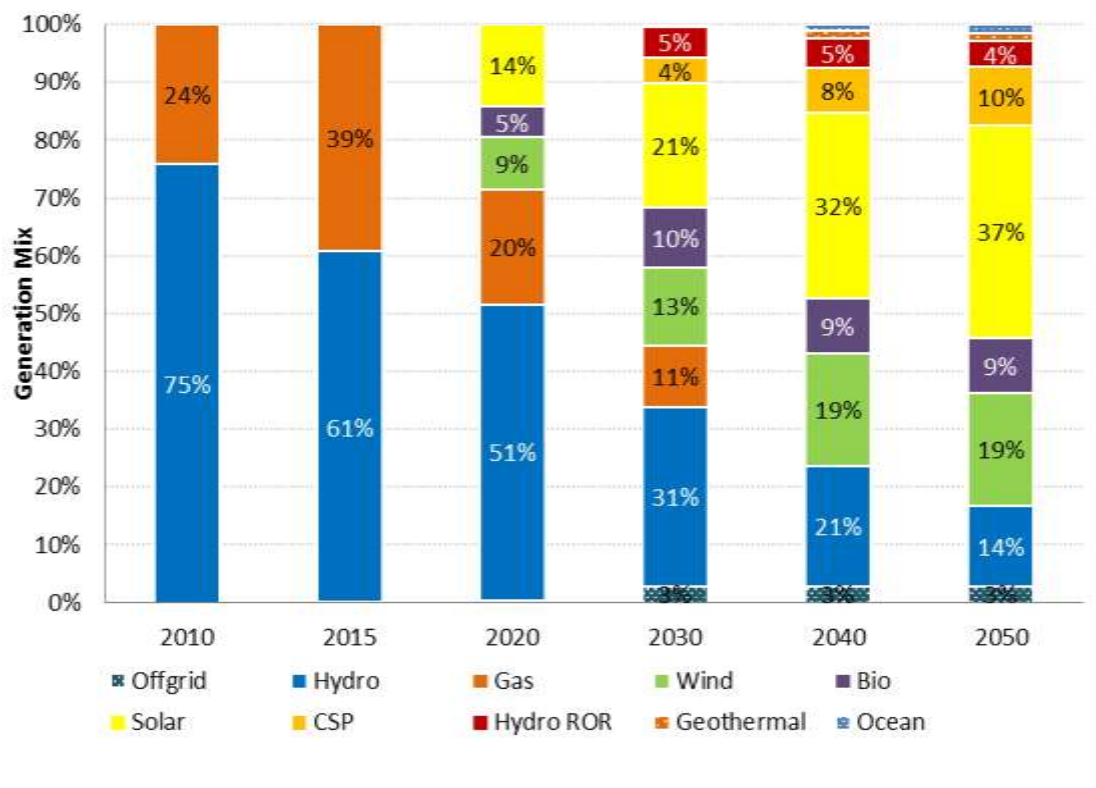


Table 21 Myanmar Generation by Type (ASES, GWh)

Generation	2010	2015	2020	2030	2040	2050
Coal	0	0	0	0	0	0
CCS	0	0	0	0	0	0
Diesel	30	0	0	0	0	0
Fuel Oil	0	0	0	0	0	0
Gas	1,678	5,233	5,345	8,728	0	0
Nuclear	0	0	0	0	0	0
Hydro	5,263	8,099	13,788	25,280	24,715	23,287
Onshore Wind	0	0	2,435	10,980	22,981	32,593
Offshore Wind	0	0	0	0	0	0
Biomass	0	0	1,441	8,445	11,261	15,923
Biogas	0	0	0	0	0	0
Solar	0	0	3,836	17,501	38,141	61,453
CSP	0	0	0	3,606	9,297	17,062
Battery	0	0	0	0	0	0
Hydro ROR	0	0	0	4,415	5,887	7,358
Geothermal	0	0	0	333	1,651	2,304
Pump Storage	0	0	0	0	0	357
Ocean	0	0	0	0	1,318	2,628
Off-grid	0	2	122	2,341	3,426	4,771

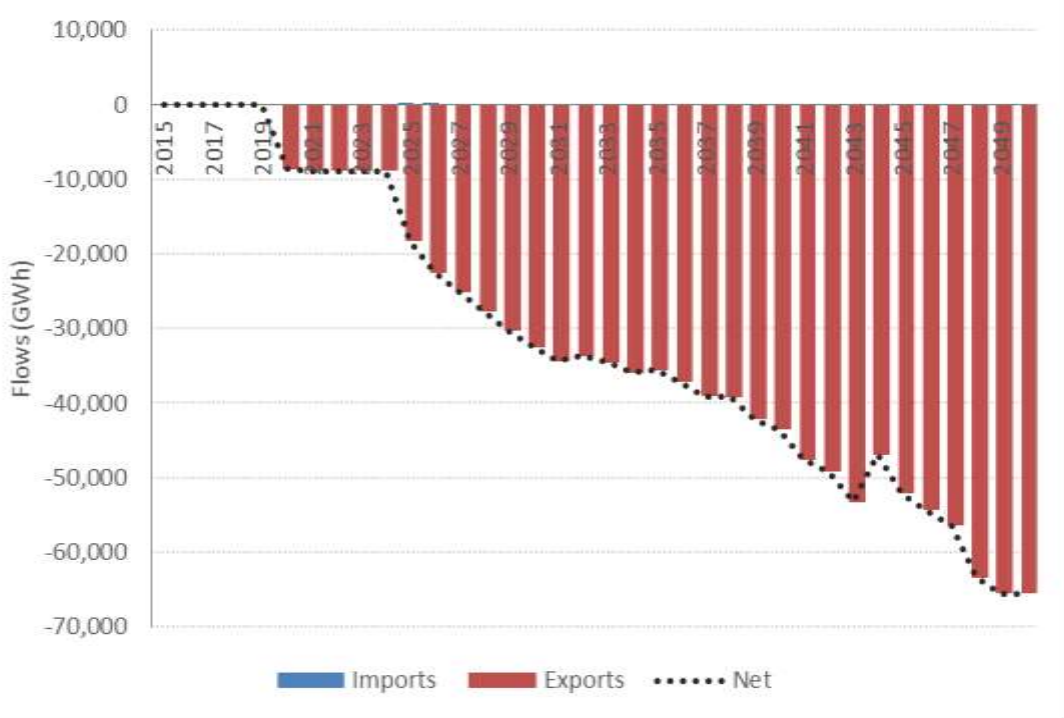
Table 22 Myanmar Generation Share by Type (ASES, %)

Generation	2010	2015	2020	2030	2040	2050
Coal	0%	0%	0%	0%	0%	0%
CCS	0%	0%	0%	0%	0%	0%
Diesel	0%	0%	0%	0%	0%	0%
Fuel Oil	0%	0%	0%	0%	0%	0%
Gas	24%	39%	20%	11%	0%	0%
Nuclear	0%	0%	0%	0%	0%	0%
Hydro	75%	61%	51%	31%	21%	14%
Onshore Wind	0%	0%	9%	13%	19%	19%
Offshore Wind	0%	0%	0%	0%	0%	0%
Biomass	0%	0%	5%	10%	9%	9%
Biogas	0%	0%	0%	0%	0%	0%
Solar	0%	0%	14%	21%	32%	37%
CSP	0%	0%	0%	4%	8%	10%
Battery	0%	0%	0%	0%	0%	0%
Hydro ROR	0%	0%	0%	5%	5%	4%
Geothermal	0%	0%	0%	0%	1%	1%
Pump Storage	0%	0%	0%	0%	0%	0%
Ocean	0%	0%	0%	0%	1%	2%
Off-grid	0%	0%	0%	3%	3%	3%

7.5 Grid to Grid Power Flows

Figure 64 plots the imports and exports in the ASES with the dotted line representing the net interchange. The power flows in the ASES are greater in magnitude compared to the SES after 2040, with a greater amount of exports from Myanmar as Thailand retires all of its gas plant. Up to 65 TWh is exported into Thailand by 2050, equivalent to 65% of Myanmar's electricity demand. The significant export out of Myanmar is driven by the need to optimise renewable energy resources across the region, and Myanmar's vast resources to achieve a 100% renewable energy target by 2050.

Figure 64 Myanmar Imports and Exports (ASES)



7.6 Generation Fleet Structure

To gain insight into the nature of the mix of generation technologies deployed in the ASES, we present a number of additional charts. Figure 65 and Figure 66 show Myanmar's installed capacity by generation type for the ASES – this is clearly biased towards renewable generation forms as there are no additional thermal projects or large-scale hydro built after 2015.

Figure 65 Myanmar Installed Capacity by Type (ASES, MW)

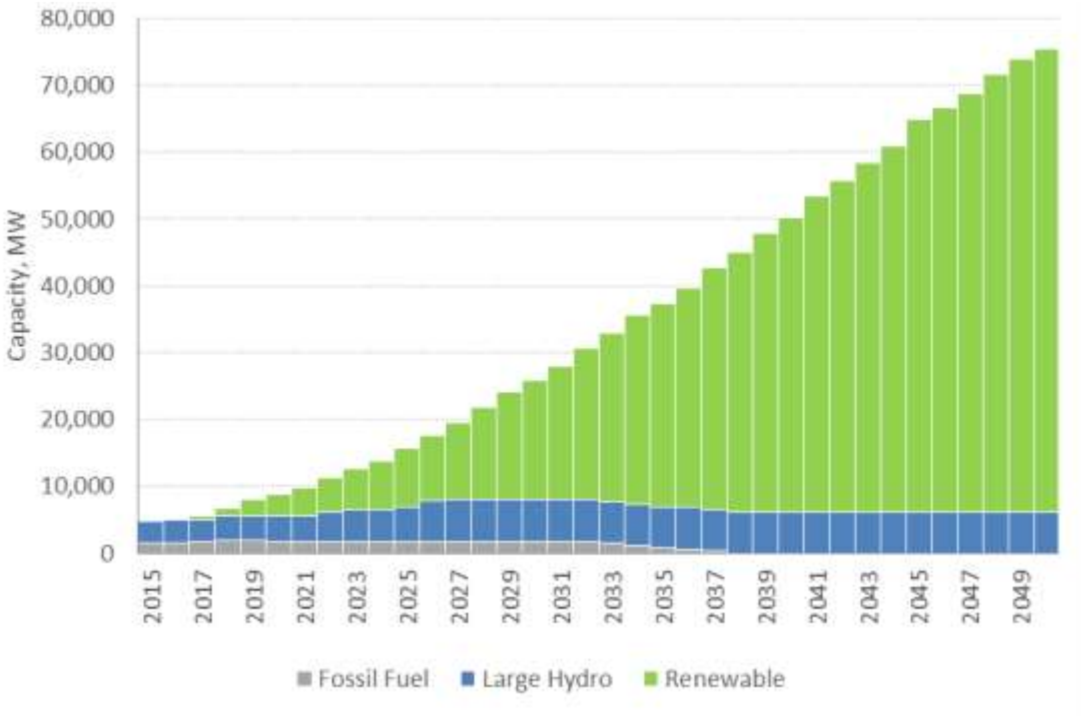


Figure 66 Myanmar Generation Mix by Type (ASES, GWh)

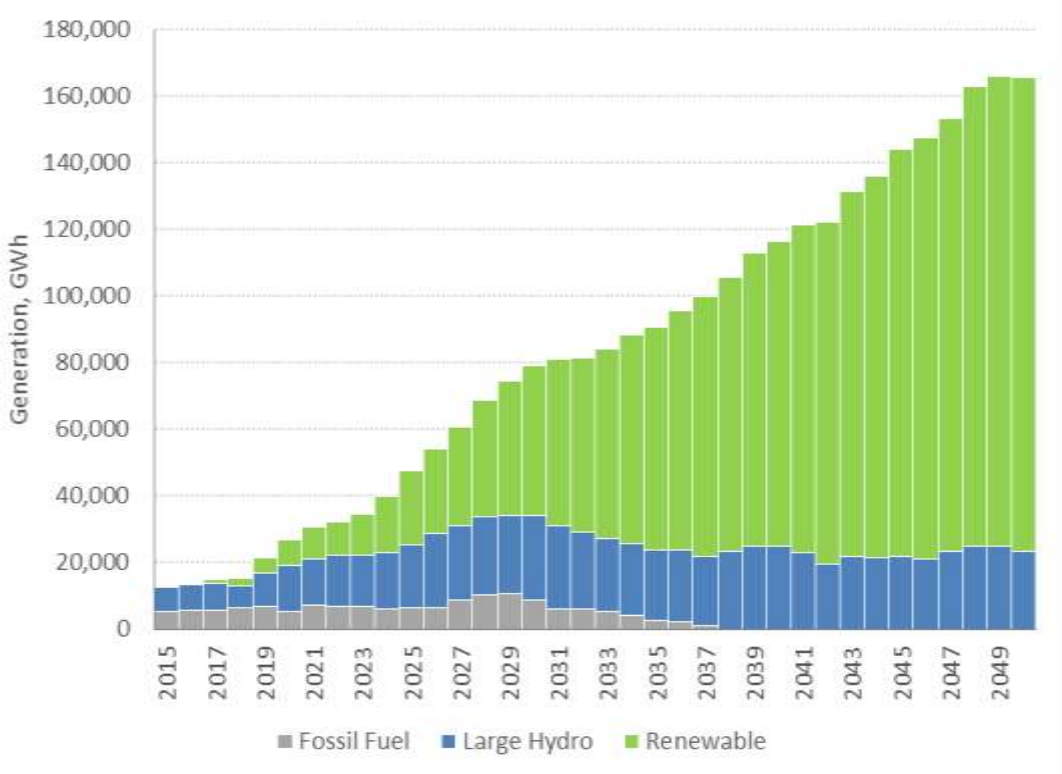
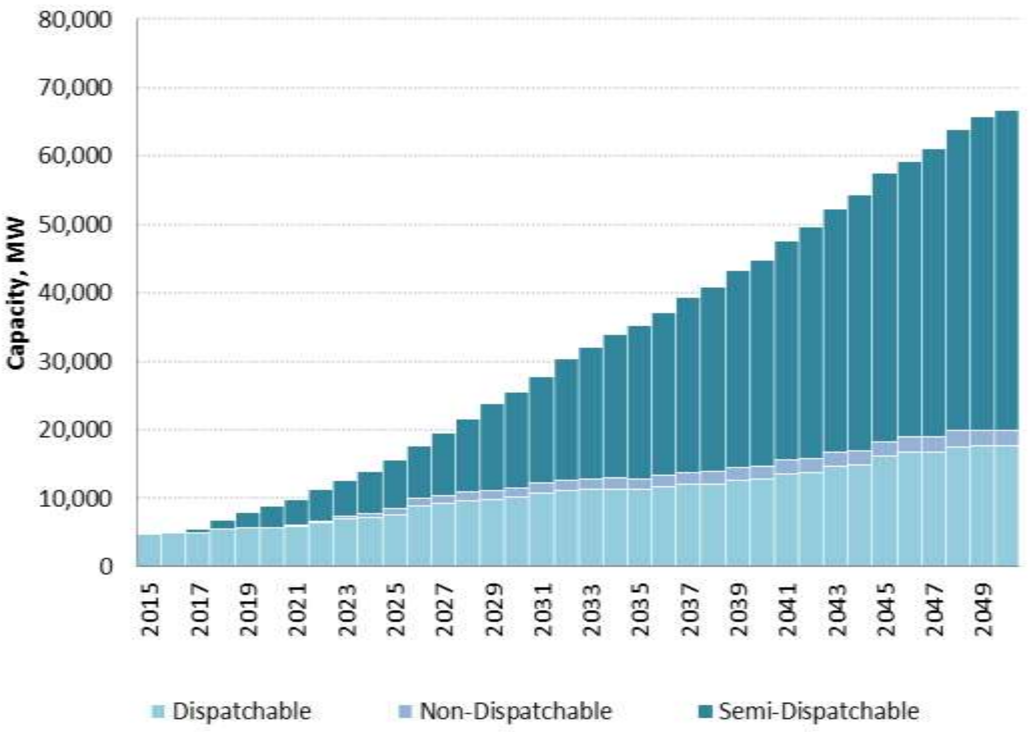


Figure 67, shows the dispatchable, semi-dispatchable and non-dispatchable components of installed capacity and it can be seen that semi-dispatchable increases to around 70% of the total system capacity compared to around 25% in the BAU by 2050. Based on operational simulations with this resource mix, it appears to be operationally feasible, although the reliance on generation forms that provide storage and having flexibility in the demand side play important roles. It is clear that short-term renewable energy solar and wind forecasting systems will be important, as will real-time updates on demand that can be controlled. Furthermore, control systems that can allow the dispatch of flexible resources on both supply and demand sides of the industry will be required.

Figure 67 Myanmar Installed Capacity by Dispatch Status (ASES, MW)



7.7 Reserve Margin and Generation Trends

Figure 68 plots the reserve margin under the ASES. Figure 69 and Figure 70, respectively, show the installed capacity mix and generation mix for different categories of generation in the power system. The ASES reserve margin trends increases over 350% as conventional base-load technologies are retired early around the region and Myanmar's renewable energy resources are developed to meet growing demands and to achieve a 100% renewable generation target by 2050, in Myanmar and abroad.

It is worth noting conventional reserve margin measures are generally not suited to measuring high renewable energy systems in the same context used for thermal-based systems. Renewable technologies generally have much lower capacity factors and require more capacity to meet the same amount of energy produced from thermal-based technologies.

Figure 68 Myanmar Reserve Margin (ASES)

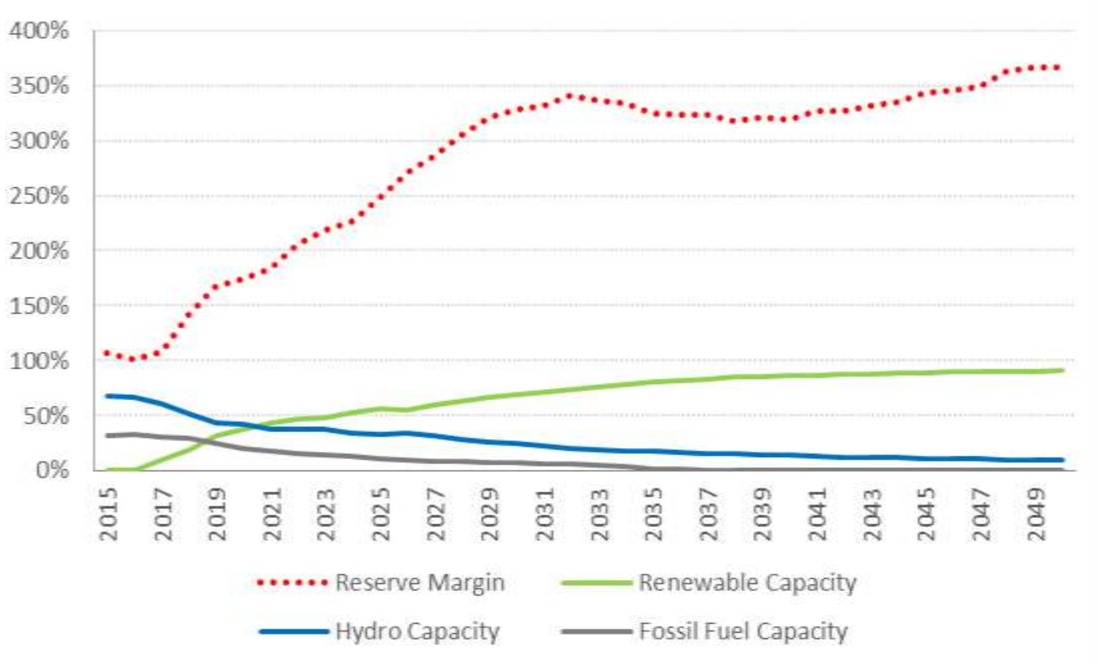


Figure 69 Myanmar Installed Capacity Shares for ASES by Generation Type

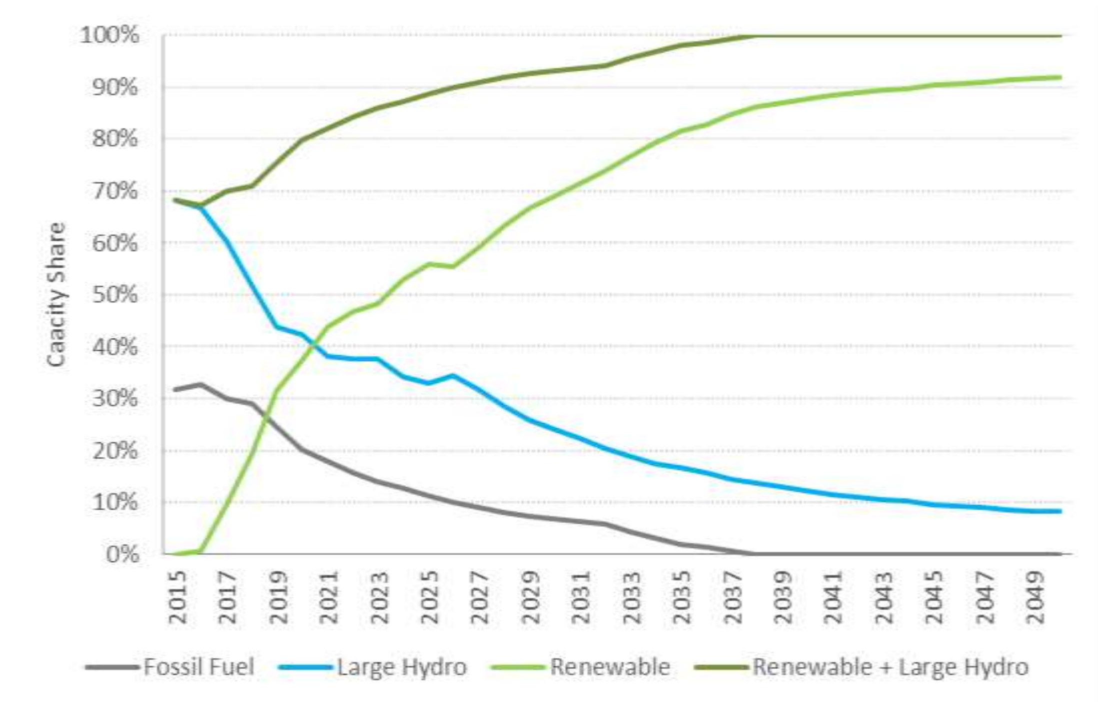
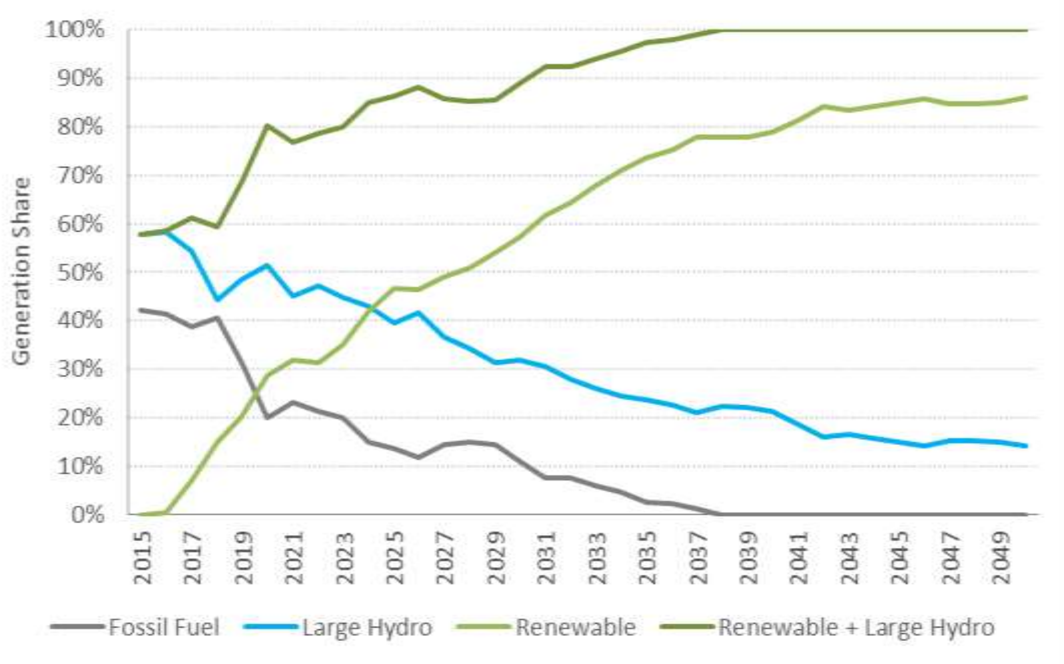


Figure 70 Myanmar Generation Shares for ASES by Generation Type



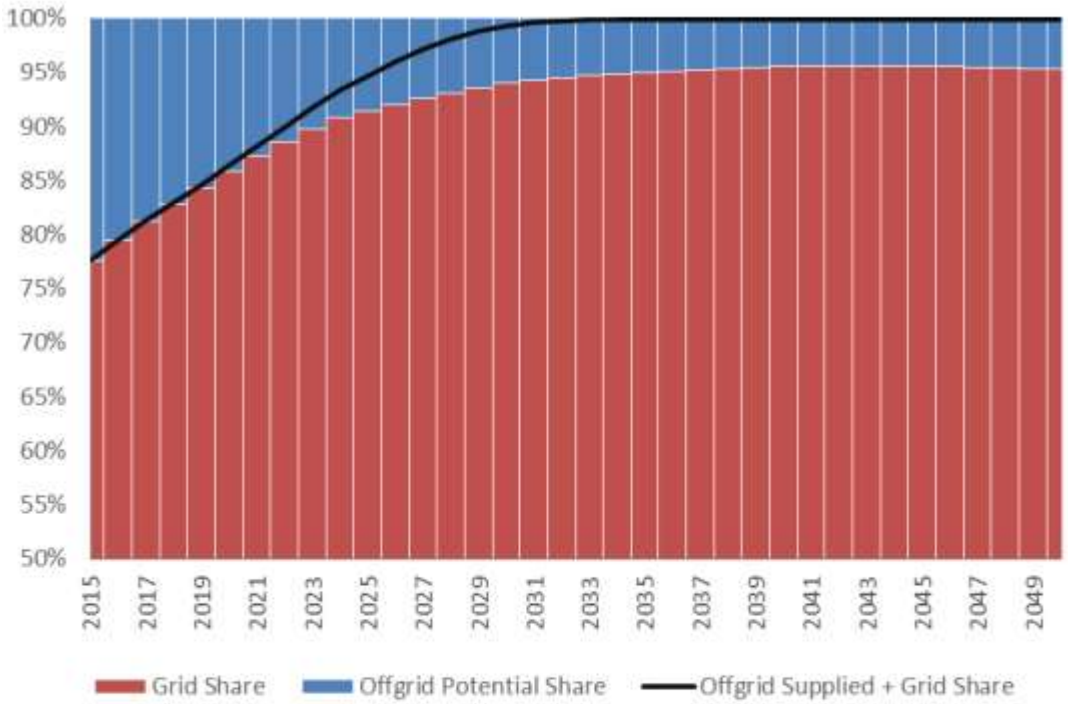
7.8 Electrification and Off-Grid

Myanmar in the ASES assumes slower electrification rates than the SES with central grid electrification ceasing as battery storage and solar PV based grids become cheaper than the grid cost of power which occurs from 2030. Demands continue to increase as off-grid per capita demand increases with the state of the economy. By 2030, the ASES has similar household electricity access rates as the BAU.

Figure 71 shows the percentage of demand split into grid and total off-grid potential demand in GWh terms. In 2015, 78% of total grid and potential off-grid demand is grid-based (red). Over time, grid based demand increases due to grid electrification efforts, and off-grid demand is supplied by solar PV and battery storage technologies. Grid electrification stops when off-grid technology reaches parity with grid-based cost of generation around 2030 and off-grid potential demand is supplied entirely by off-grid technologies. By 2050, grid based demand increases to 95% and off-grid demand converges to 5%. The cost of off-grid supply based on solar PV and battery storage is assumed to cost US$171/MWh declining to US$87/MWh by 2030, reaching US$63/MWh by 2050[31].

[31] Based on technology cost assumptions, 25% of solar PV generation stored for off-peak use and an 85% battery efficiency.

Figure 71 Off-grid Potential Demand Share (ASES)



8 Analysis of Scenarios

Section 5, section 6 and section 7 presented projections of capacity and generation mix for the BAU, SES and ASES scenarios respectively. In order to understand the implications of the SES and ASES over the BAU, we have formulated a set of metrics to assist in their comparison.

These are as follows:

- Overall energy consumption per year;
- Peak electricity demand per year;
- Renewable energy percentage comparisons;
- Carbon emissions measures;
- Hydro power developments;
- Analysis of bioenergy situation;
- A number of simple security of supply measures; and
- Interregional power flows.

8.1 Energy and Peak Demand

Figure 72 compares the total electricity consumption of the BAU, SES and ASES with Figure 73 plotting the percentage reduction in electricity consumption of the SES relative to the BAU and ASES relative to the BAU. As can be seen the energy consumption, the SES is lower than the BAU with the main driver being enhancements in energy efficiency in the SES. The reduction in energy in the ASES is partially offset by the doubling of transport demand.

Figure 72 Myanmar Energy Demand Comparison

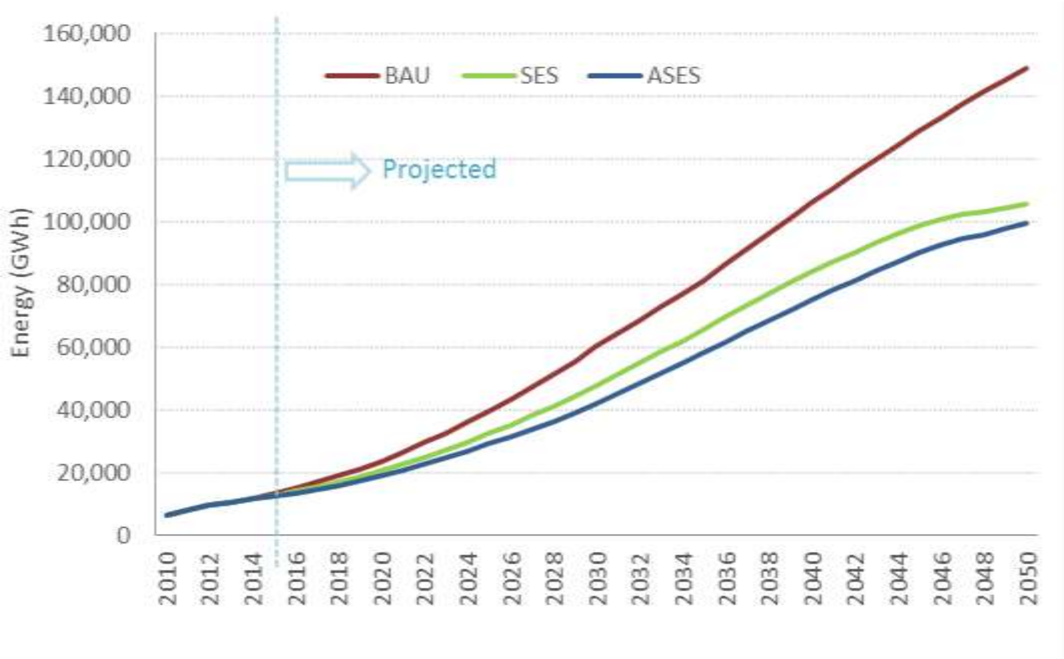


Figure 73 Myanmar Percentage Reduction in Electricity Demand

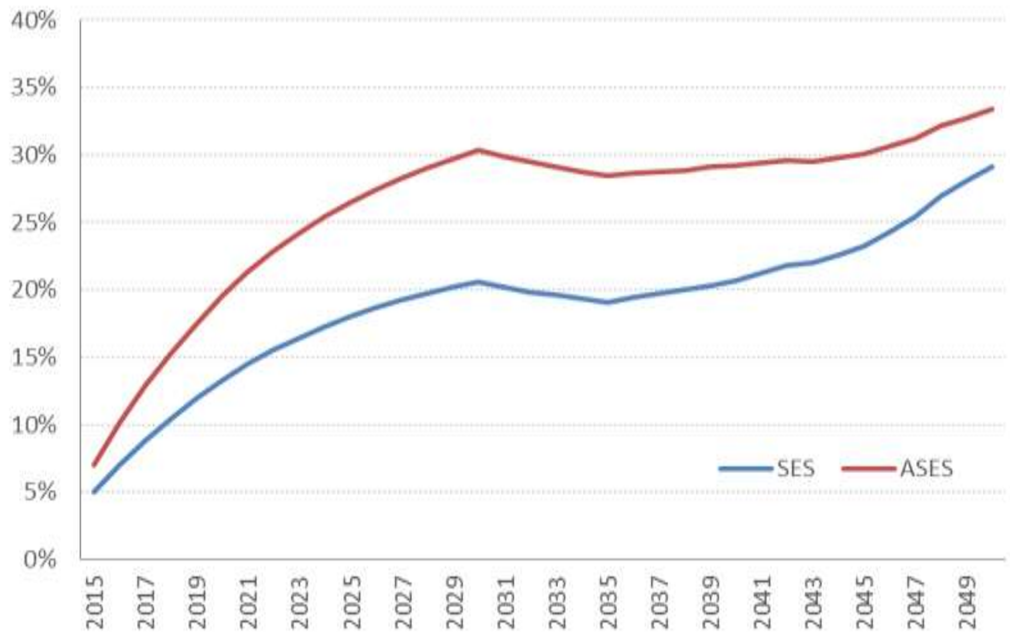


Figure 74 compares peak load and shows the same relativities. This is attributable to improvements in load factor (80% in SES and ASES). On top of this the SES and ASES has contributions from flexible and controllable demand that allows reductions in peak demand consumption (not shown here).

Figure 74 Myanmar Peak Demand Comparison

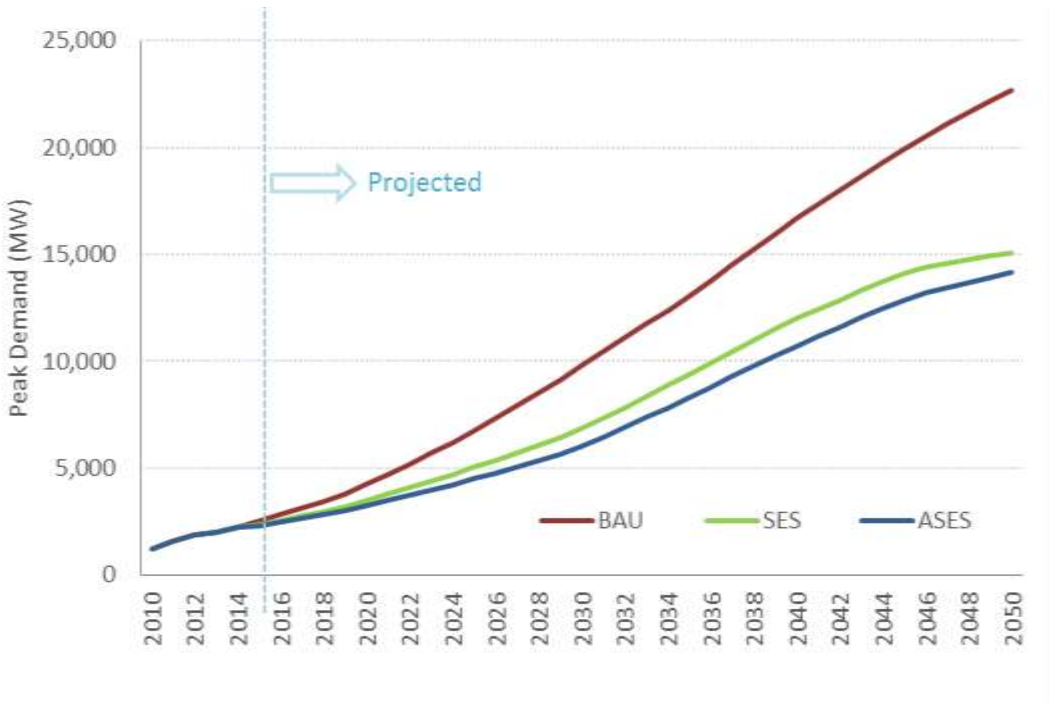


Figure 75 Myanmar Electricity Access Rate Comparison

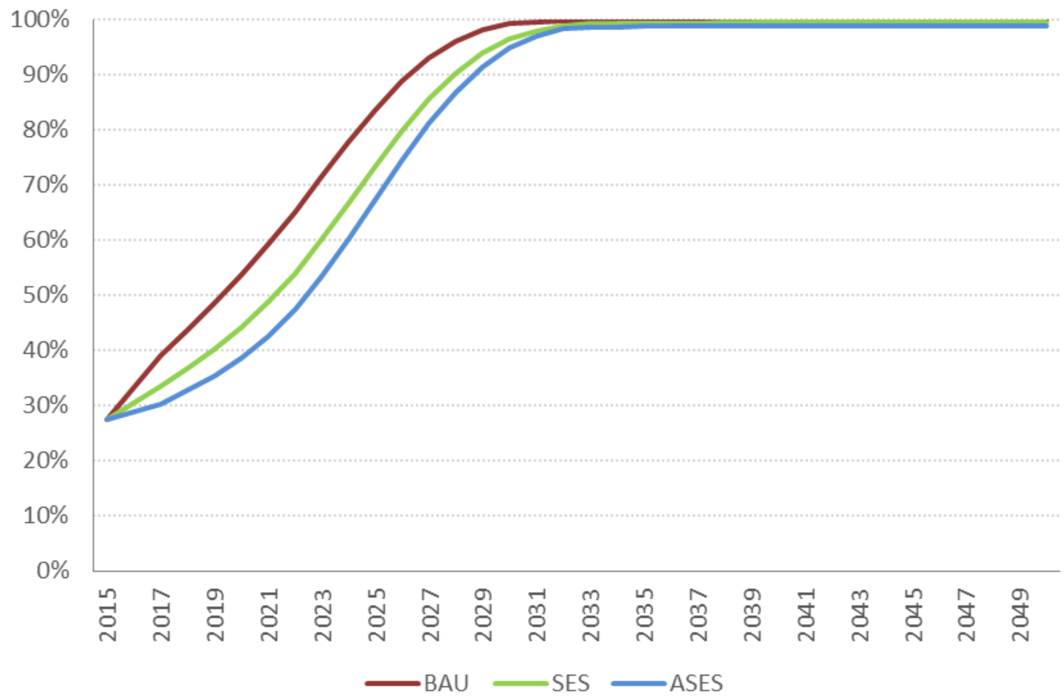
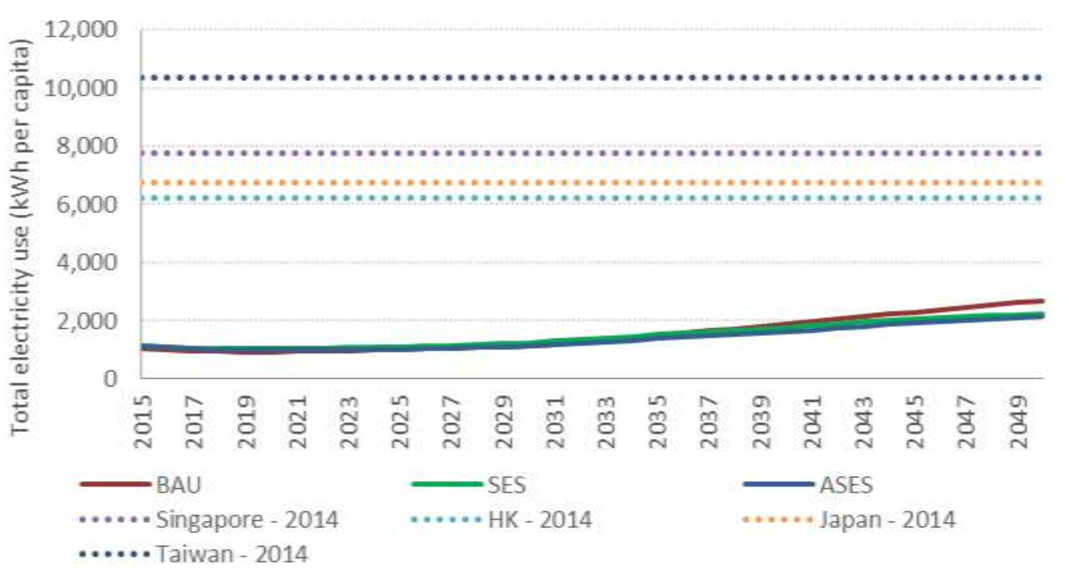


Figure 75 plots the access rates in the three scenarios and shows that although the BAU has overall higher access rates by means of electrification leading up to 2030, the SES and ASES achieve similar access to electricity rates via off-grid technologies within a few years beyond 2030. By 2030 the BAU has achieved some 99% via central grid connection whereas the SES achieves 97% access and the ASES achieves 95% with the deployment of off-grid solutions. The SES reaches full electricity access by 2032 and ASES by 2033.

8.2 Energy intensity

Figure 76 plots the per electrified capita electricity consumption per annum across the scenarios. Electricity consumption includes all electricity consumption across the country. In the BAU, per capita consumption levels increase at a rate of 2.7% to reach 2,684 kWh pa. In the SES, it increases more slowly at 2.0% pa to reach 2,239 kWh pa and the ASES at 2,148 kWh by 2050. The SES and ASES assumes higher energy efficiency savings. The per capita electricity use stays flat and dips a little in the earlier years as electricity demand growth does not keep pace with the electrification efforts.

Figure 76 Myanmar Per Capita Consumption Comparison (kWh pa)



8.3 Generation Mix Comparison

Figure 77 and Figure 78 below show the renewable capacity and generation mix between the two scenarios. Renewables (including large-scale hydro) reach 61% in the BAU which is equivalent to a 41% generation mix compared to the SES and ASES which have renewables (including large-scale hydro) accounting for 100% of total capacity and generation by 2050.

Figure 77 Myanmar Renewable Installed Capacity Mix

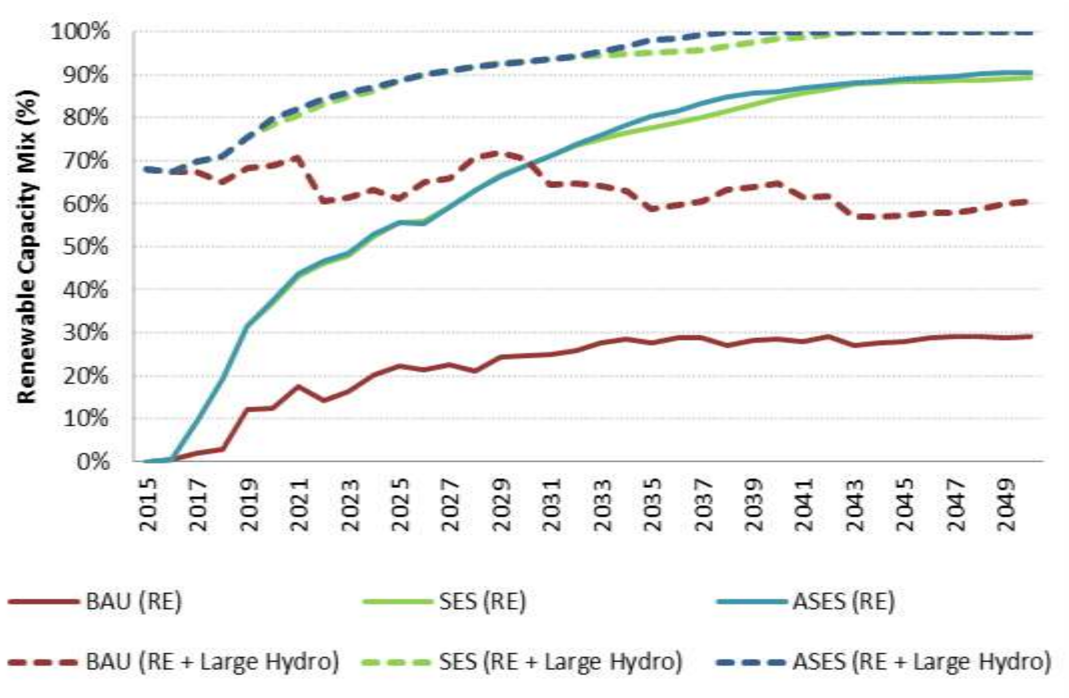
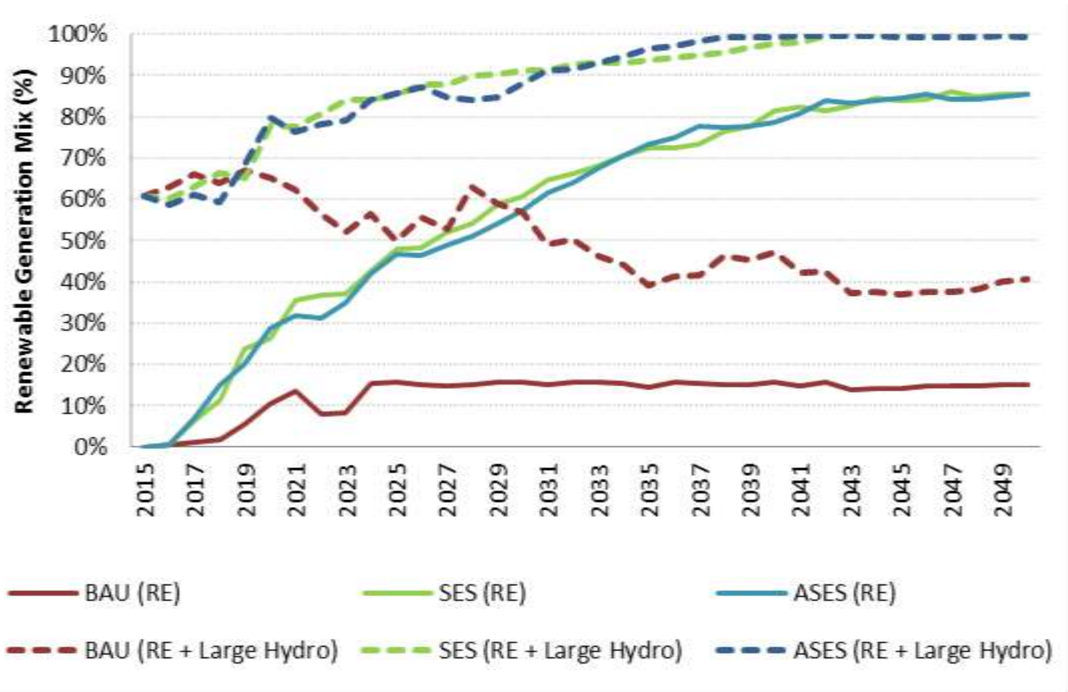


Figure 78 Myanmar Renewable Generation Mix Comparison



8.4 Carbon Emissions

Figure 79 and Figure 80 show the carbon intensity of Myanmar's power system and the total per annum carbon emissions respectively. The carbon intensity increases in the BAU as more coal-fired generators enter the system. The BAU trajectory then trends towards 0.48t-CO2e/MWh. The SES and ASES scenarios trend towards 0 as Myanmar reaches 100% renewable generation by 2043 and 2038 respectively[32].

In terms of total carbon emissions, the shift towards the SES and ASES saves up to 75 mt-CO2e, per year by 2050, 100% saving from the BAU. The BAU emissions level continues to peak as a result of increasing demands and the reliance on coal.

[32] We assume zero emissions from hydro and biogeneration.

Figure 79 Myanmar Carbon Intensity Comparison

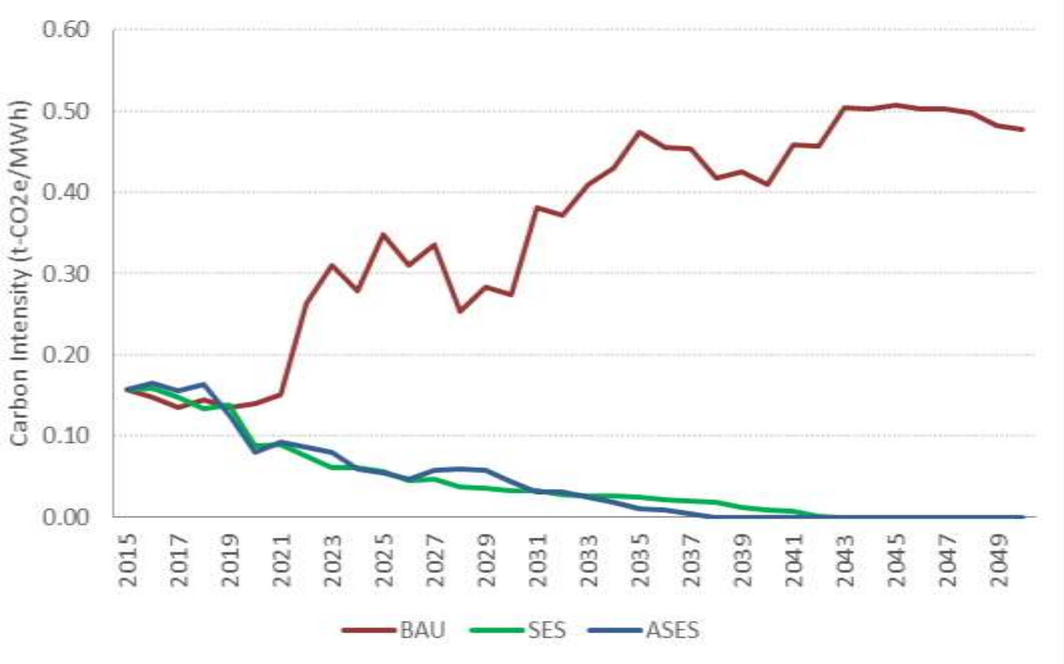
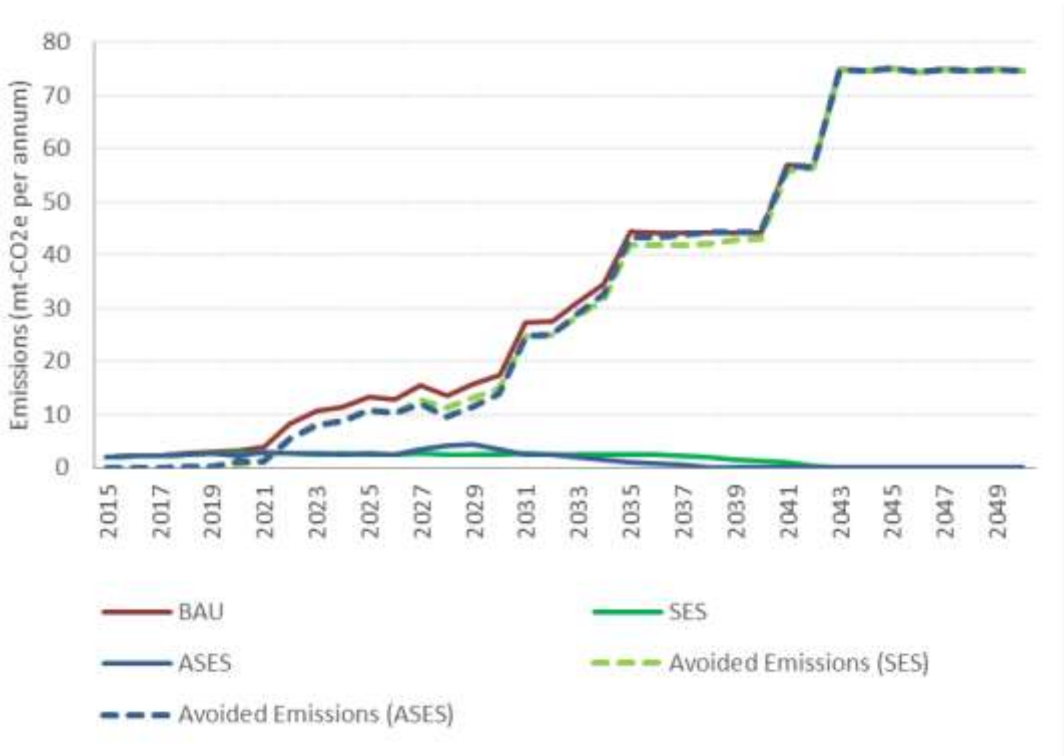


Figure 80 Myanmar Carbon Emissions Comparison



8.5 Hydro Power Developments

Table 23 lists the hydro generation projects and commissioning year under the three scenarios. Hydro projects are assumed to be refurbished as required to maintain operations throughout the modelling horizon. Up to 2,500 MW of non-committed large-scale hydro is developed to support renewable energy technologies in the SES and ASES[33].

Table 23 Myanmar Generation by Type (ASES, GWh)

Hydro Projects	Installed Capacity (MW)	Year Commissioned by Scenario		
		BAU	SES	ASES
Upper Nam Htwan	3.2	2016	2016	2016
Mong Wa	60	2016	2016	2016
Thahtay	111	2018	2018	2018
Upper Keng Tong	51	2018	2018	2018
Upper Baluchaung	30.4	2018	2018	2018
Upper Yeywa	280	2022	2022	2022
Shweli(3)	1050	2026	2023	2023
Middle Paunglaung	100	2027	2026	2026
Deedoke	66	2028	2025	2025
Dapein-2	140	2028	2026	2026
Upper Thanlwin(kunlong)	1400	2028	Not Commissioned in the SES or ASES scenarios	
Shweli-2	520	2037		
Middle Yeywa	320	2038	2025	2025
Bawgata	160	2038	2026	2026
Naopha	1200	2038	Not Commissioned in the SES or ASES scenarios	
Mangtong	225	2040		
Wan Ta Pin	33	2040	2026	2026
Solue	160	2040	Not Commissioned in the SES or ASES scenarios	
Keng Wang	40	2041	2026	2026
Manipur	380	2048	Not Commissioned in the SES or ASES scenarios	
Gawlan	120	2048		
Hkan Kawn	140	2048	2026	2026
Lawngdin	600	2049	Not Commissioned in the SES or ASES scenarios	
Tongxinqiao	340	2050		
Nan Tu (Hsipaw)	100	2050		

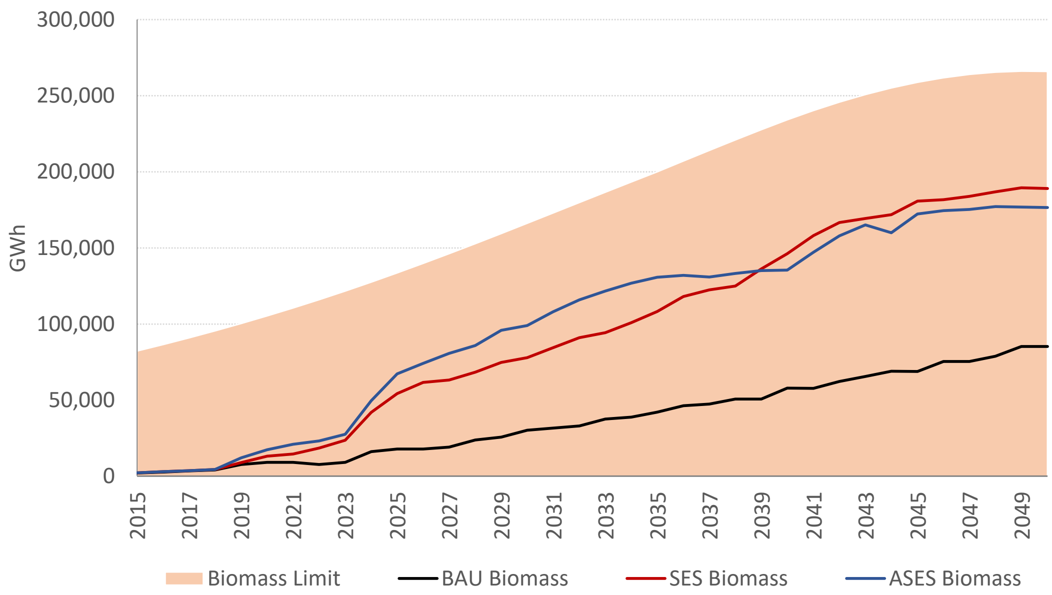
[33] The selected large hydro projects for future construction are example hydro projects and do not mean that we have a particular preference for the hydro projects that we bring online as compared to the others.

8.6 Analysis of Bioenergy

Figure 81 shows a projection of the biomass available for the GMS (converted to GWh) and the total biomass generation for each scenario for the GMS. The shaded area represents the projected total technical biomass resource availability[34] while the solid lines show the biomass consumption used by each scenario for the region. The projected available biomass was based on forecast growth rates in the agricultural sectors of each country. It was assumed that no more than 75% of the total projected available biomass resource was used. The remainder of the bioenergy requirements for each scenario was then assumed to be satisfied by biogas technologies.

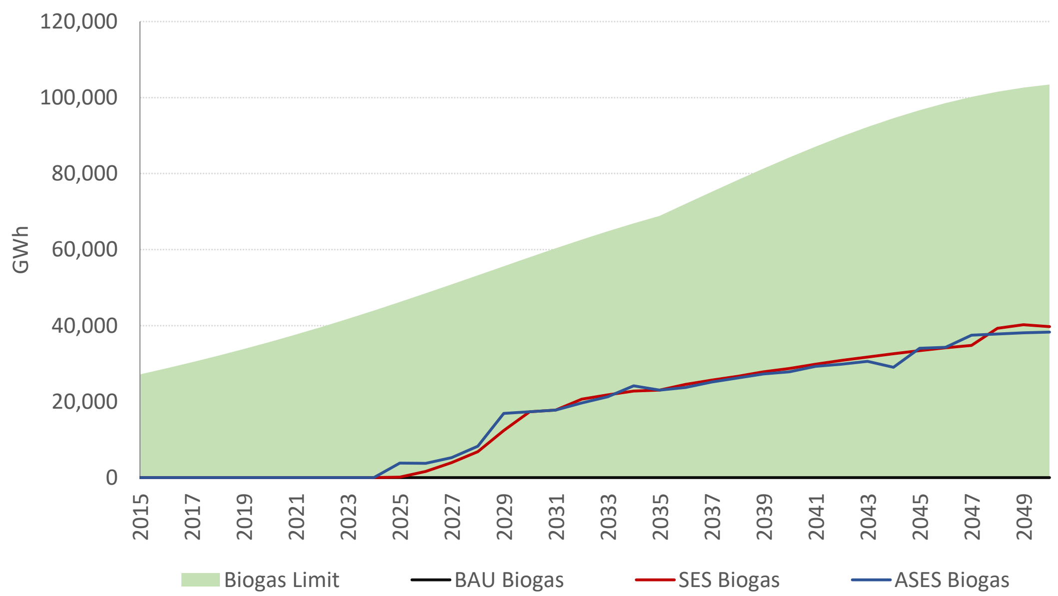
Figure 82 shows a similar chart to Figure 81 for the GMS except for biogas. The shaded area in this chart represents the amount of biogas available (again in units of GWh) and the corresponding generation from biogas in each scenario. This shows that the SES and ASES are dependent on biogas while the BAU is assumed to not deploy this technology. Based on the projections the biomass and biogas resources available to the region can be seen to be sufficient to support the amount of biomass and biogas generation to 2050.

Figure 81 Projected Biomass Availability and Consumption in the BAU, SES and ASES scenarios for the GMS as a whole



[34] Projections of biomass availability developed by IES based on baselines established from information on biomass and biogas potential reported in 'Renewable Energy Developments and Potential in the Greater Mekong Subregion', ADB (2015) report.

Figure 82 Projected GMS Biogas Requirements



8.7 Security of Supply Indicators

Figure 83 plots the energy reserve margin calculated as the difference between the maximum annual production from all plants accounting for energy limits and the annual electricity demands in percentage terms. For exporting and resource abundant countries like Myanmar the energy reserve margins are generally high as seen in the SES and ASES cases where generation is optimised across the region. As noted previously, an energy reserve margin is more suited to measuring systems that are renewables-based.

Figure 84 charts the percentage of electricity generated using domestic resources. The percentage generated using domestic fuel sources is 100% in the SES and ASES but drops to 47% in the BAU due to imported coal requirements. Myanmar has sufficient gas reserves to support its gas generation fleet. Figure 85 below plots the highest share of generation from a particular fuel source. In the BAU, the dominance is held by large-scale hydro initially then becomes coal-fired focused through the rest of the horizon. In the SES and ASES, it is dominated by hydro then solar by around 2033. Figure 86 plots the dependence on coal in all scenarios. The coal share increases past 50% under the BAU case indicating higher reliance on coal whereas the SES and ASES remain at 0%.

Figure 83 Myanmar Security of Supply Measure: Energy Reserve

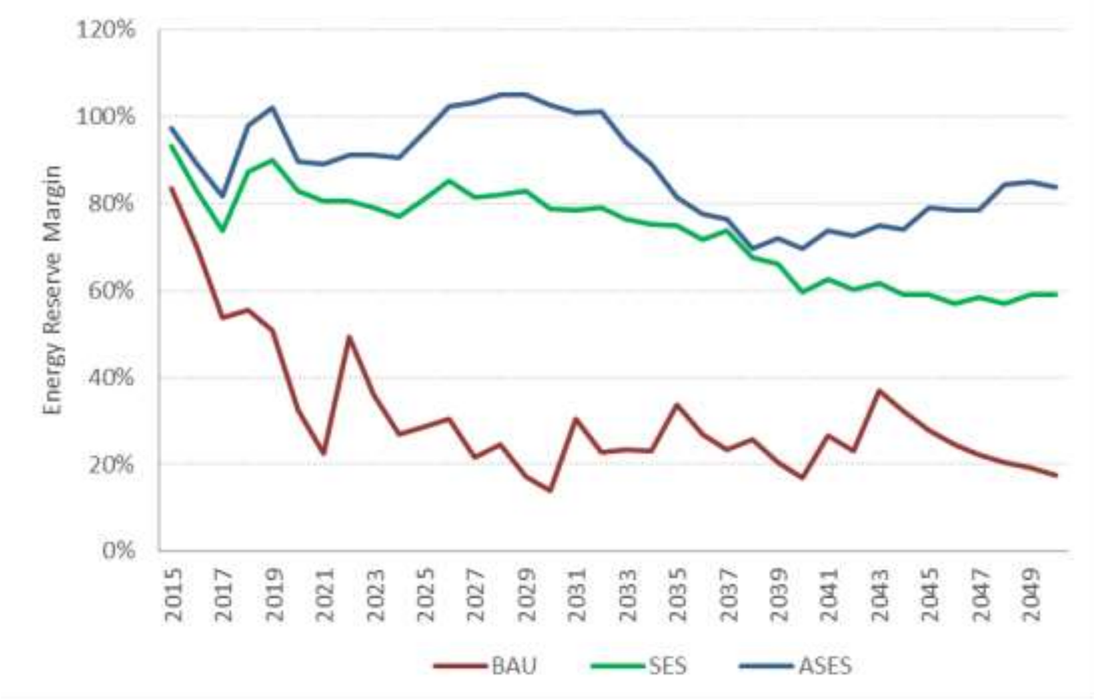


Figure 84 Myanmar Security of Supply Measure: Percentage of Electricity Generated by Domestic Resources

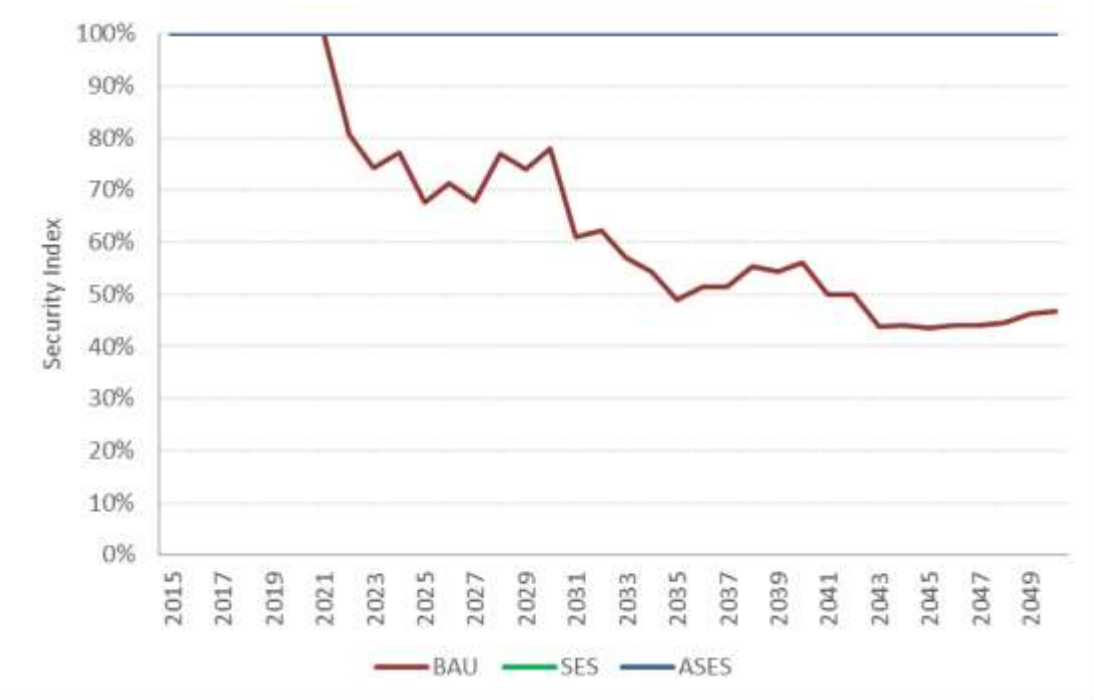


Figure 85 Myanmar Security of Supply Measure: Maximum Dominance of a Technology in Generation Mix

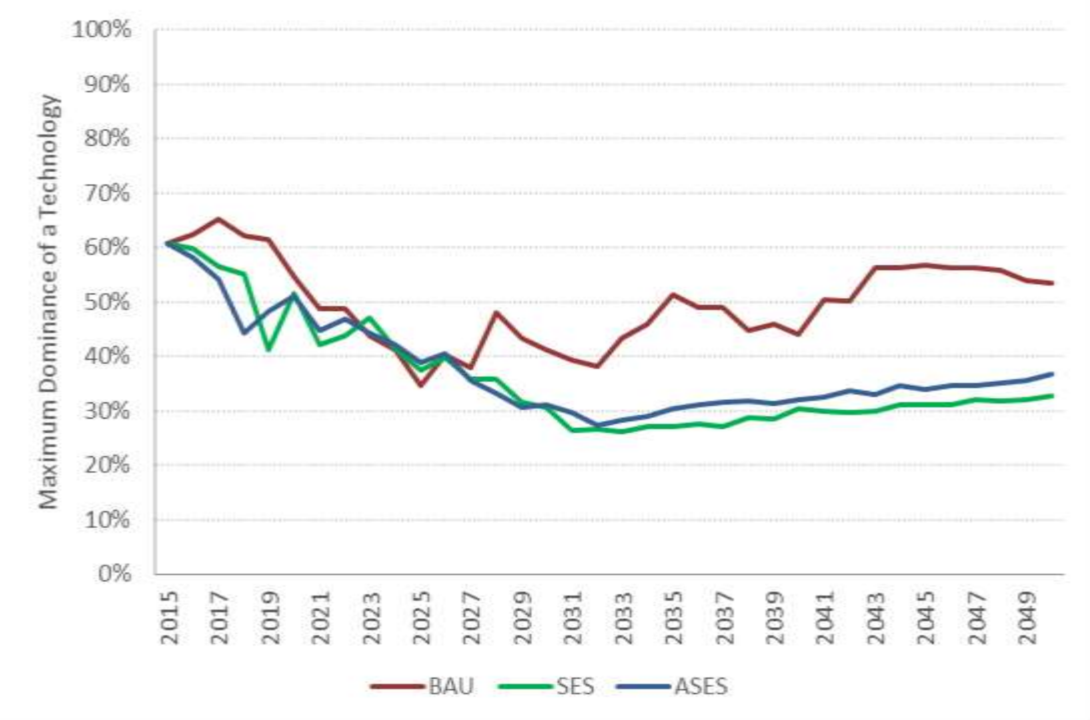
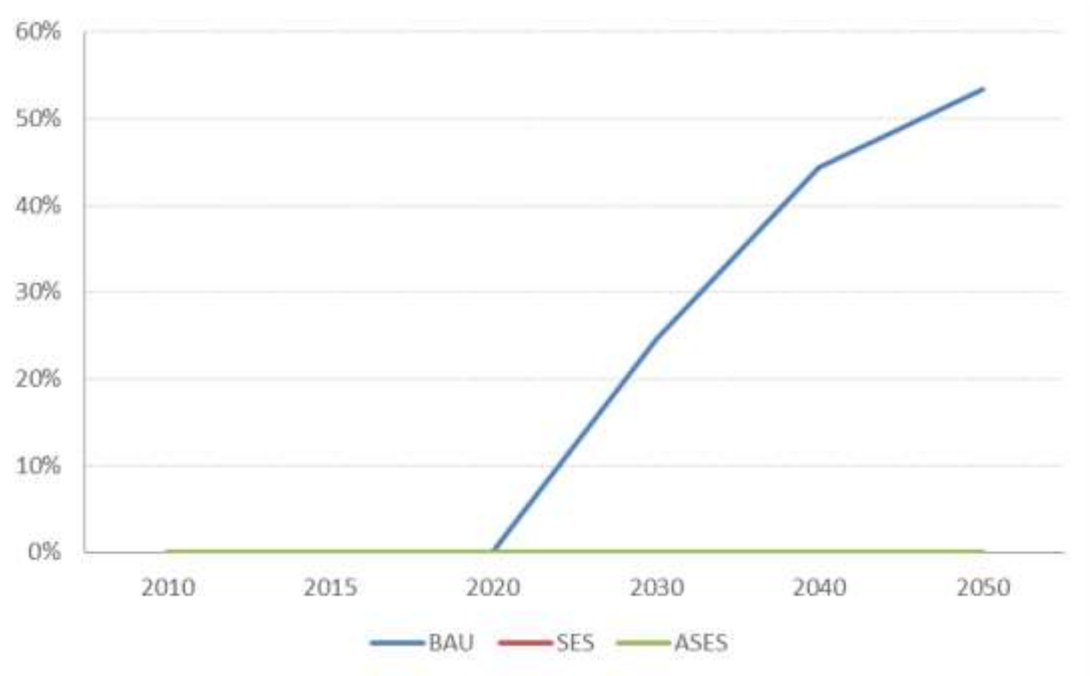


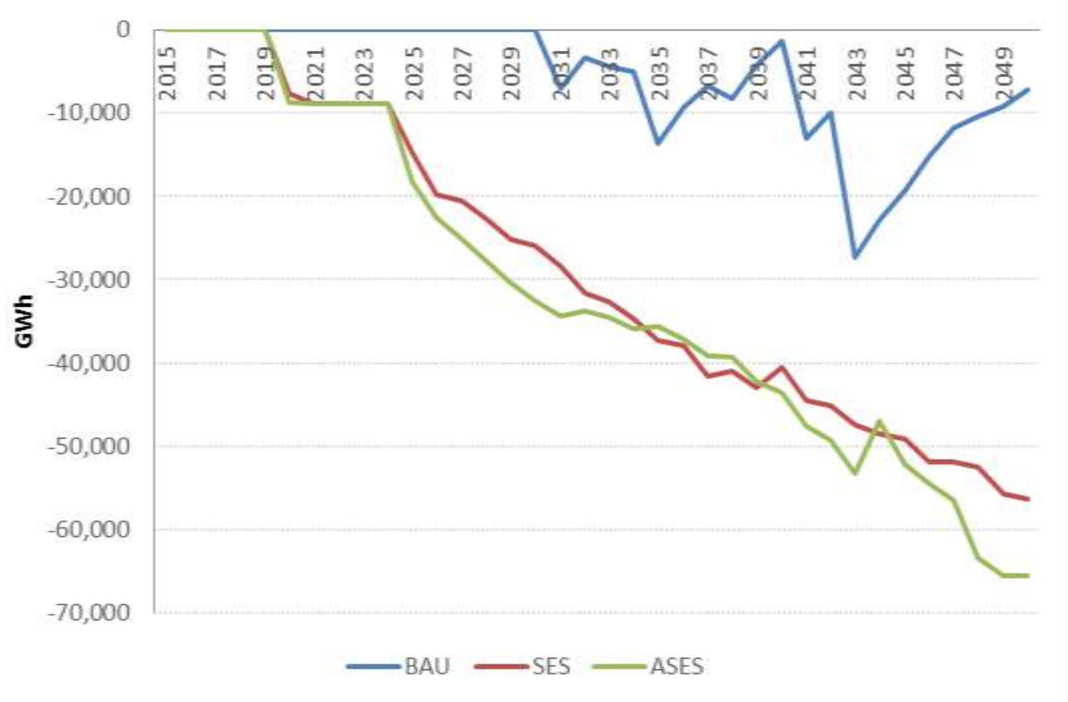
Figure 86 Myanmar Security of Supply Measure: Coal Share



8.8 Interregional Power Flows

Figure 87 compares the net flows in and out of Myanmar. Myanmar is a net exporter given its significant renewable resource and development potential. The SES and ASES both have a lot more exports than the BAU with the ASES scenario increasing the most especially in the last 7 or so years driven by the retirement of conventional thermal technologies in the GMS to meet renewable generation targets.

Figure 87 Myanmar Imports and Exports (GWh)



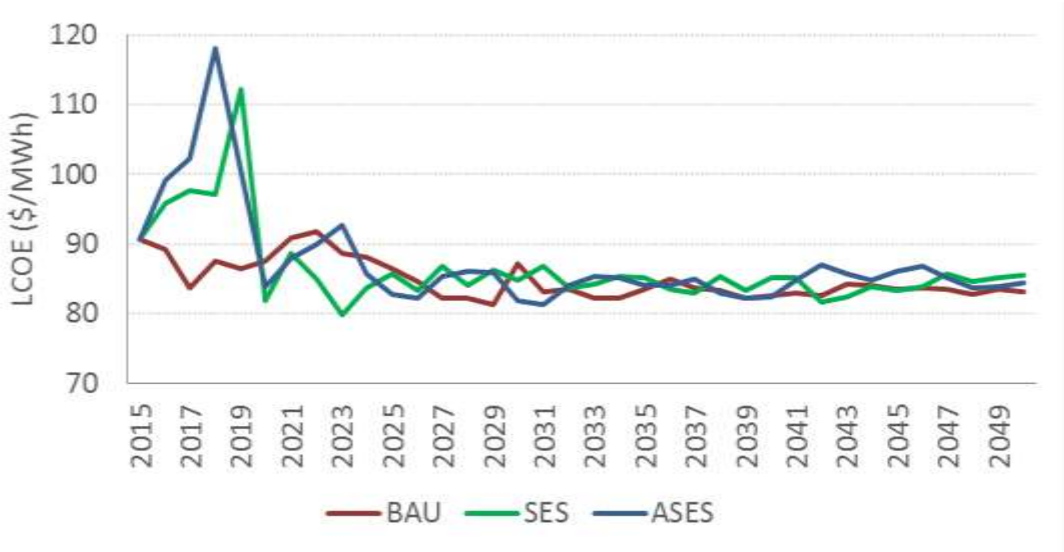
9 Economic Implications

In this section we consider the economic implications of the three scenarios and examine in particular: (1) the levelised cost of electricity (LCOE) generation for the entire system, (2) investment costs, (3) total operating and capital expenditure including the cost of energy efficiency, (4) additional transmission costs from the BAU (since SES and ASES include more off-grid developments), (5) off-grid costs and (6) implications for job creation. The analysis presented is supported by sensitivity analysis to examine how changes in fuel prices impact the LCOE and to examine how a carbon price would affect electricity costs. It should be noted that the analysis presented in this section is done for the purpose of comparison, and that the prices and costs provided are dependent on the fuel price projections and technology cost assumptions that were used in both scenarios and which have been listed in Appendix A and Appendix B.

9.1 Overall Levelised Cost of Electricity (LCOE)

The comparison of the LCOE (only includes generation costs) is shown in Figure 88. The LCOE for the BAU remains relatively flat as higher coal fuel costs are offset by lower LCOE hydro generation. The ASES and SES LCOE initially spikes up with the ramp up of solar and wind developments then closely follows the BAU LCOE as lower fuel costs are offset by more expensive renewable technology developments (CSP, battery and biogas generation). The LCOE in all three scenarios averages US$82/MWh from 2020. This LCOE analysis only compares central grid connected electricity production. It does not include the cost of externalities[35].

Figure 88 Myanmar LCOE for Generation



9.2 LCOE Composition

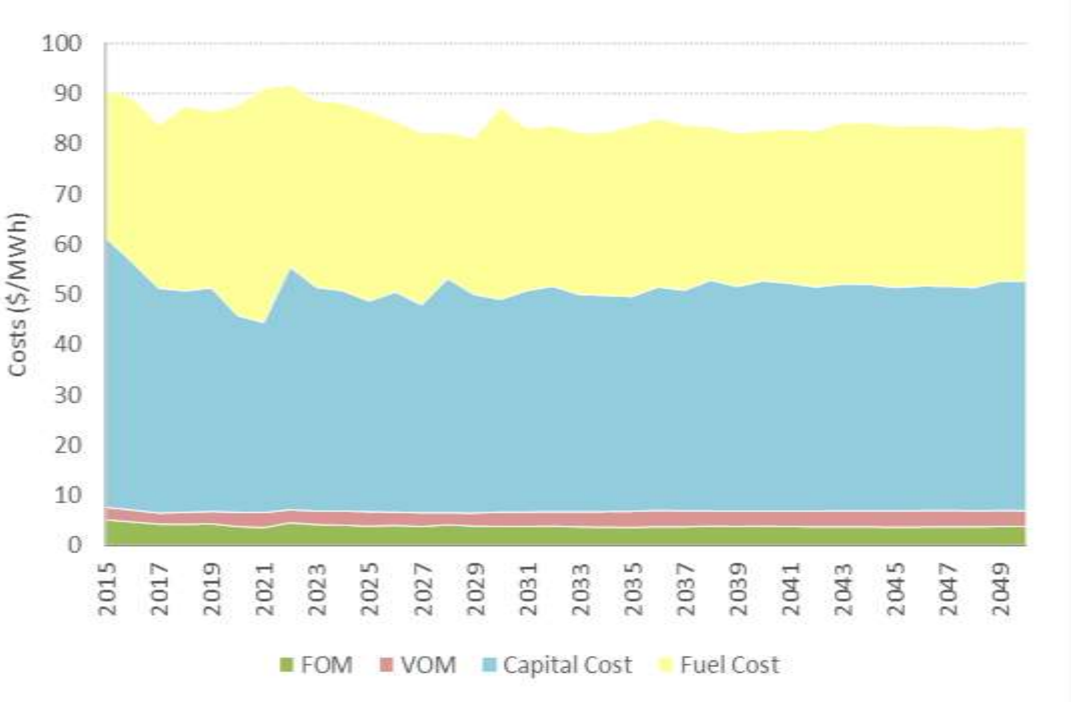
High integration levels of renewable energy allow for the avoidance of fuel costs. In order to understand the structure of the LCOE from the previous section we provide decomposed versions of the LCOE in Figure 88 for the BAU, Figure 89 for the SES and Figure 90 for the ASES. This reveals an important trend in the structure of

[35] A detailed study on the cost of externalities is presented in the following reference: Buonocore, J., Luckow, P., Norris, G., Spengler, J., Biewald, B., Fisher, J., and Levy, J. (2016) 'Health and climate benefits of different energy-efficiency and renewable energy choices', *Nature Climate Change*, 6, pp. 100–105.

the cost of electricity: a thermal-dominated system has a high portion of its costs as fuel costs while a renewable energy dominated power system is more heavily biased towards capital costs. As is shown in the SES and ASES case, the fuel cost component steadily decreases from early in the modelling[36].

The SES and ASES capital costs on a US$/MWh basis increases post 2025 due to greater investments in battery storage, CSP and some ocean energy in the SES and ASES.

Figure 89 Myanmar LCOE Composition in BAU



[36] It does not go to zero due to bio generation.

Figure 90 Myanmar LCOE Composition in SES

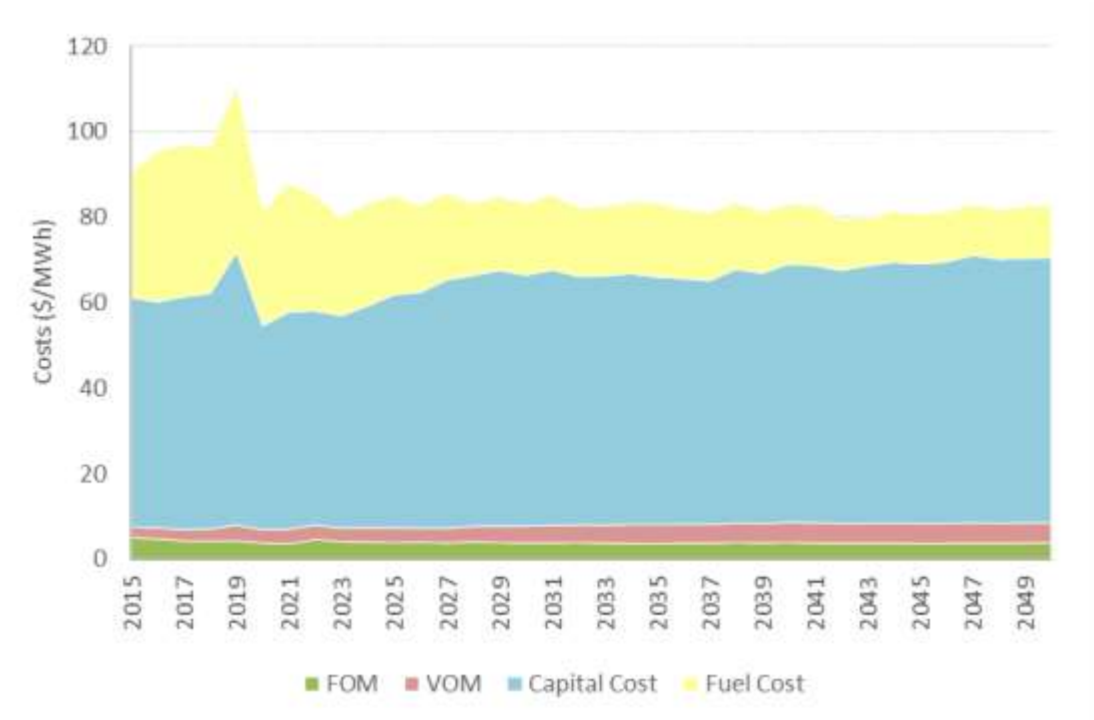
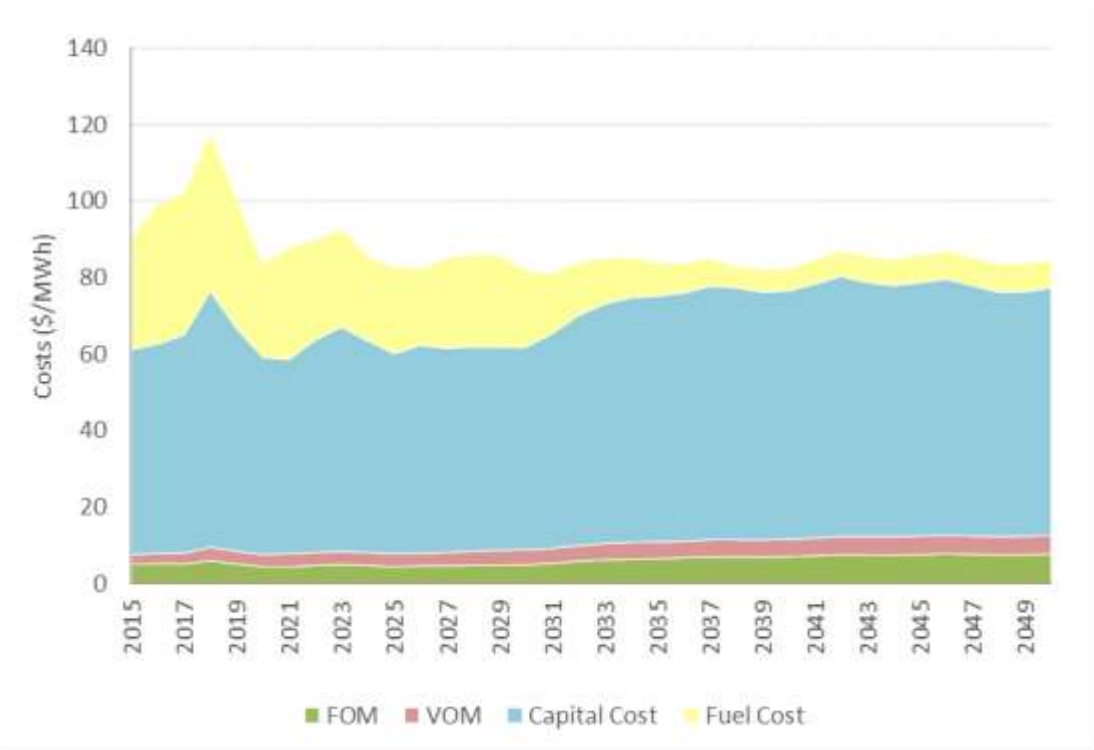


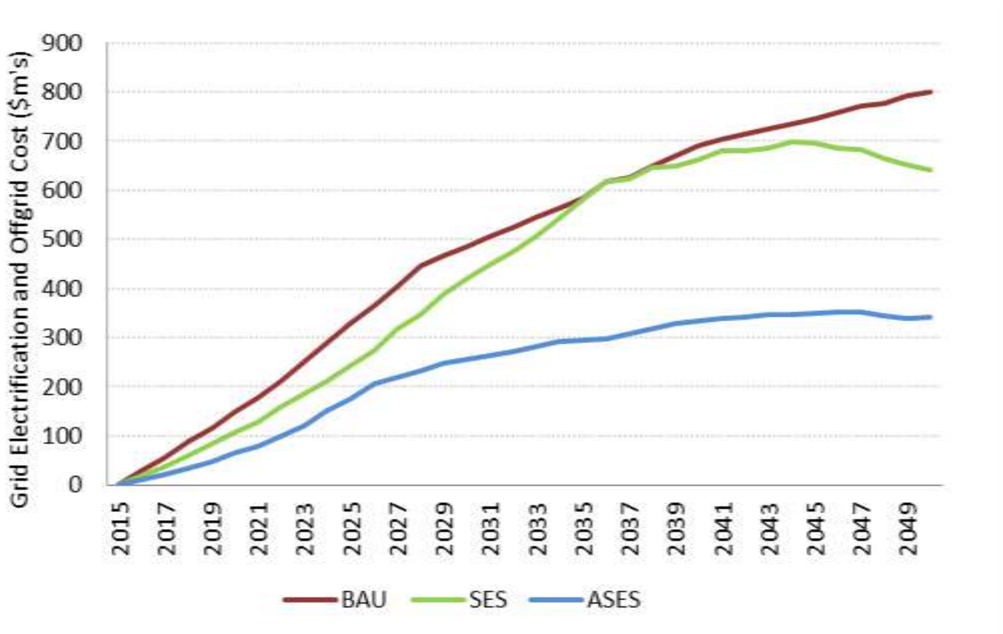
Figure 91 Myanmar LCOE Composition in ASES



9.3 Off-grid Cost Comparison

Figure 92 below compares the cost of providing 100% electricity access by 2050 across the three scenarios. The BAU is assumed to achieve close to 100% central grid based electrification by 2030 and the costs relate to grid electrification and grid generation costs to support the electrified loads[37]. The ASES assumes a much slower central grid based electrification which ceases around 2030 when off-grid solar and battery storage becomes economic. The ASES line comprises mainly investment costs relating to residential solar PV and battery storage and a small grid electrification cost component. The SES assumes a 100% central grid based electrification target albeit at a slower pace than in the BAU with off-grid demand supplied with solar PV and battery technology in the interim. The differences are mainly driven by the difference in electricity demands per capita between the scenarios.

Figure 92 Grid Electrification and off-grid Costs



9.4 Cumulative Capital Investment

The following section details the investment costs of meeting demand in Myanmar taking into account exports and imports i.e. costs relating to exported energy is reallocated to the importing countries. Figure 93 shows the cumulative investment in generation CAPEX, grid electrification, off-grid investment and energy efficiency in millions of Real 2014 US$. The earlier observation of the SES and ASES having lower demand owing to energy efficiency gains should be recognised. Figure 93 shows the BAU requiring higher capital investment by the end of the modelling horizon primarily. The SES and ASES includes investment in energy efficiency measures and greater investments in more expensive capital costs of renewable generation. The breakdown of costs by generation type are presented in Figure 94, Figure 95 and Figure 96.

37 Myanmar National Electrification Program Roadmap and Investment Prospectus, Castalia Strategic Advisors (2014). Electrification costs were based on Myanmar's cost estimates of 100% electrification (7.2 million households by 2030) costing US$5.8 billion and pro-rated based on Myanmar population figures.

Figure 93 **Myanmar Cumulative Investment (Real 2014 US$)**

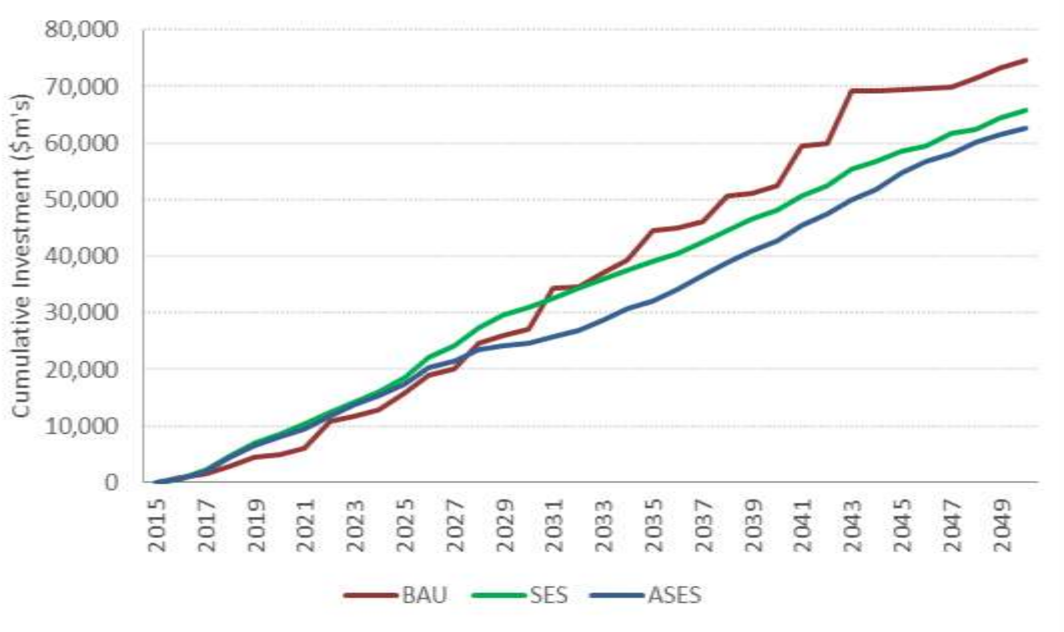


Figure 94 **Myanmar Cumulative Investment by Type (BAU, Real 2014 US$)**

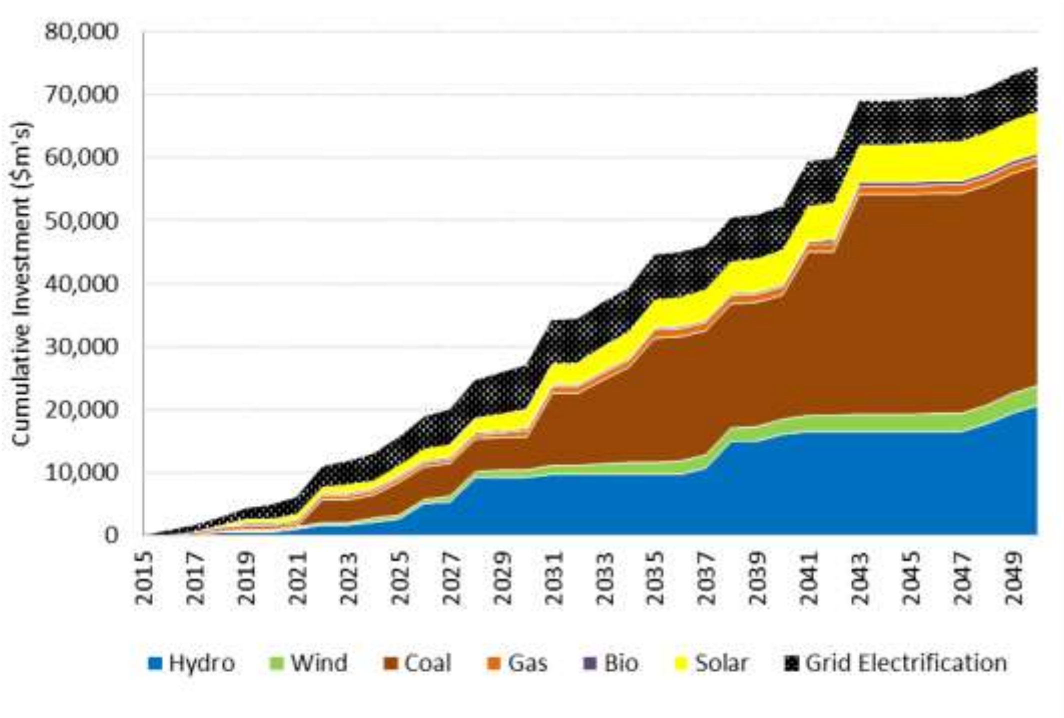


Figure 95 Myanmar Cumulative Investment by Type (SES, Real 2014 US$)

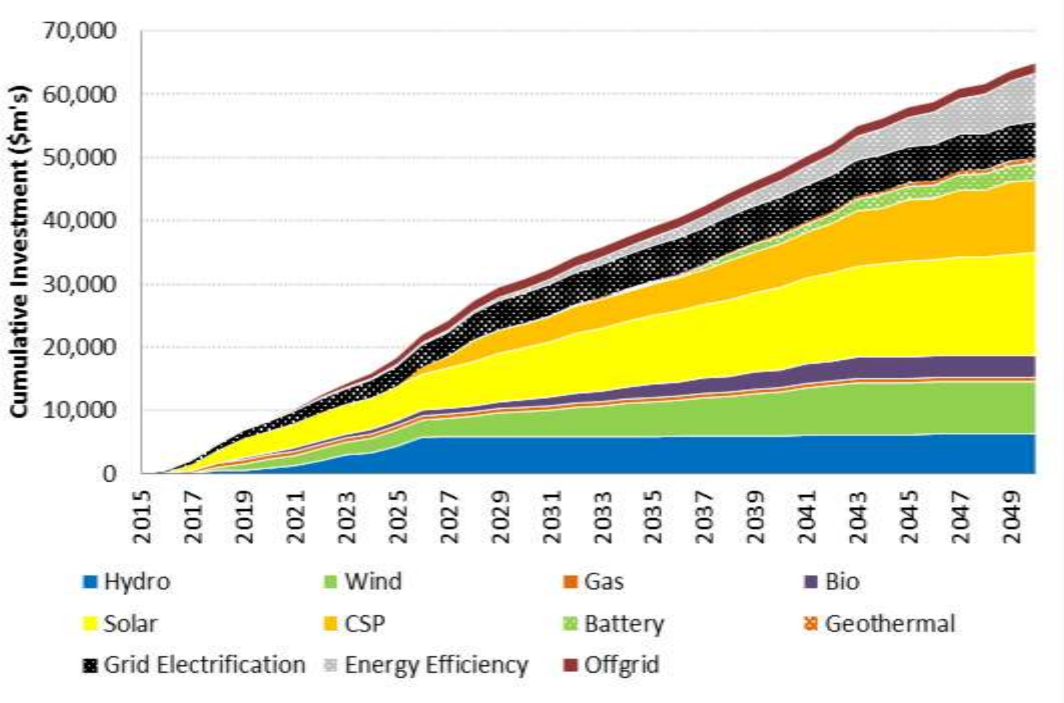


Figure 96 Myanmar Cumulative Investment by Type (ASES, Real 2014 US$)

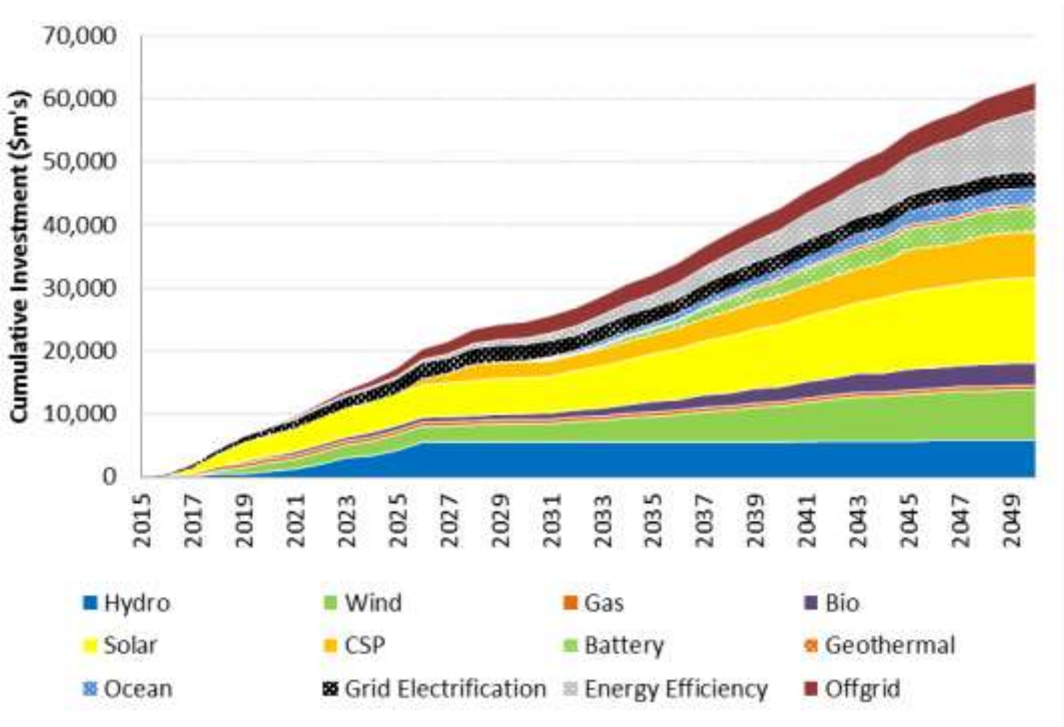


Figure 97, Figure 98 and Figure 99 plot the cumulative investment split for imports and exports. The BAU investment cost is primarily for the country's own electricity demand with only small amounts of power exported (and paid for by the neighbouring countries). By 2050, US$74 billion is required to develop the BAU generation requirements. In the SES, US$65 billion is required to develop generation projects (and energy efficiency) in Myanmar, with a further US$51 billion invested in projects within Myanmar for exporting into Thailand. The ASES requires US$63 billion with an additional US$59 billion invested in Myanmar from neighbouring countries for exports similar to the SES.

Figure 97 Myanmar Cumulative Investment of BAU (Real 2014 US$)

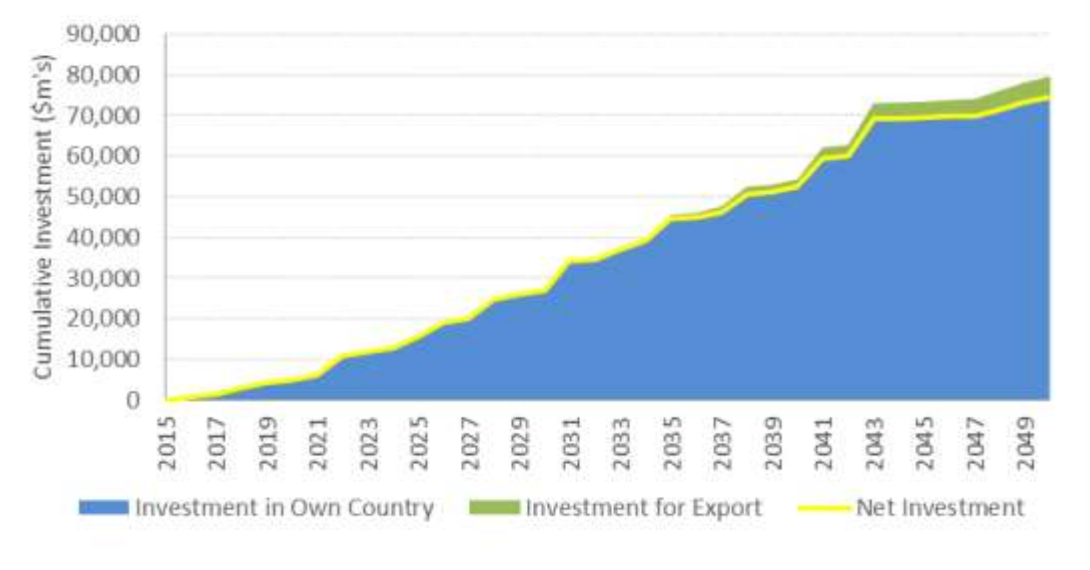


Figure 98 Myanmar Cumulative Investment of SES (Real 2014 US$)

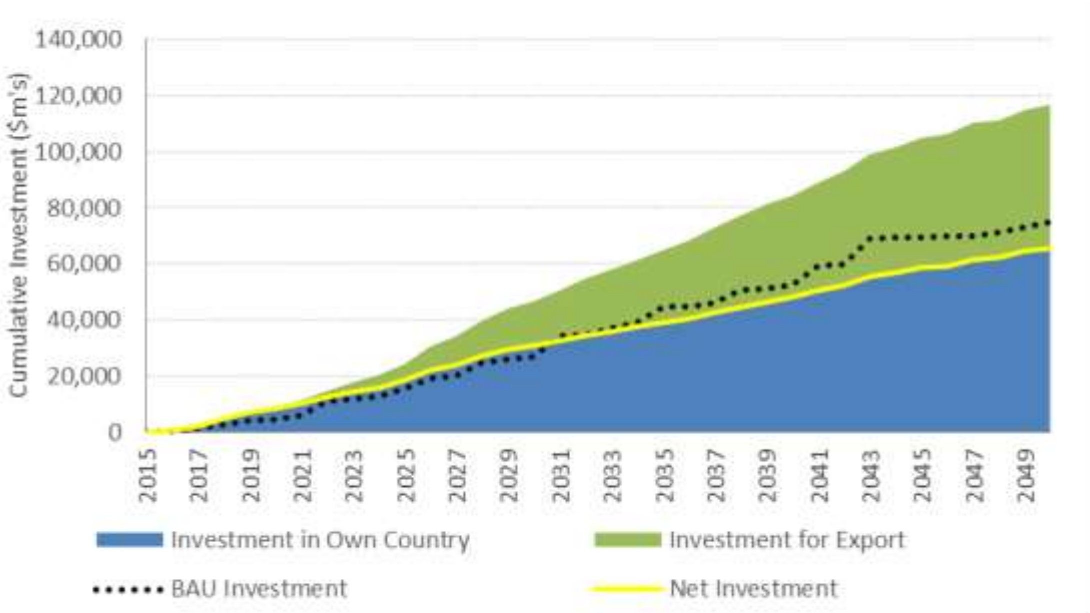
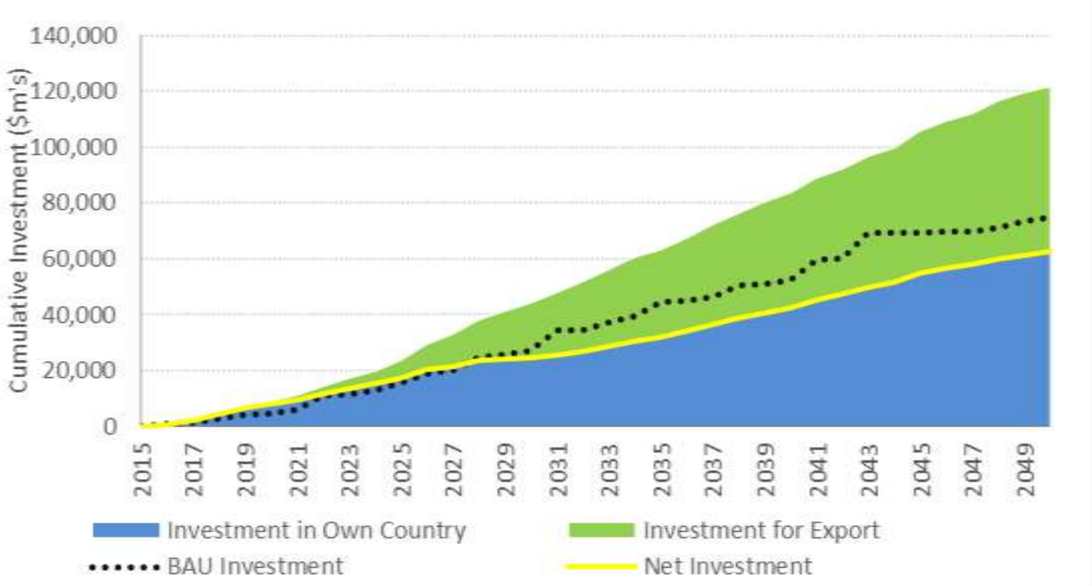


Figure 99 Myanmar Cumulative Investment of ASES (Real 2014 US$)



9.5 Operating, Amortised Capital and Energy Efficiency Costs

Figure 100 plots the total CAPEX, OPEX, grid electrification, off-grid and energy efficiency costs as a proportion of total forecast GDP. Capital expenditure has been amortised over the life of the project to derive annual capex figures. The costs have also been adjusted for exports and imports. The BAU rises to 2.6% of GDP mainly driven by the ramp up in demands in Myanmar. The BAU requires a higher cost outlay than the SES and ASES by about 0.2% of GDP through to 2050. Figure 101, Figure 102, and Figure 103 plots the total system cost for each of the scenarios.

Figure 100 Total System Cost over GDP

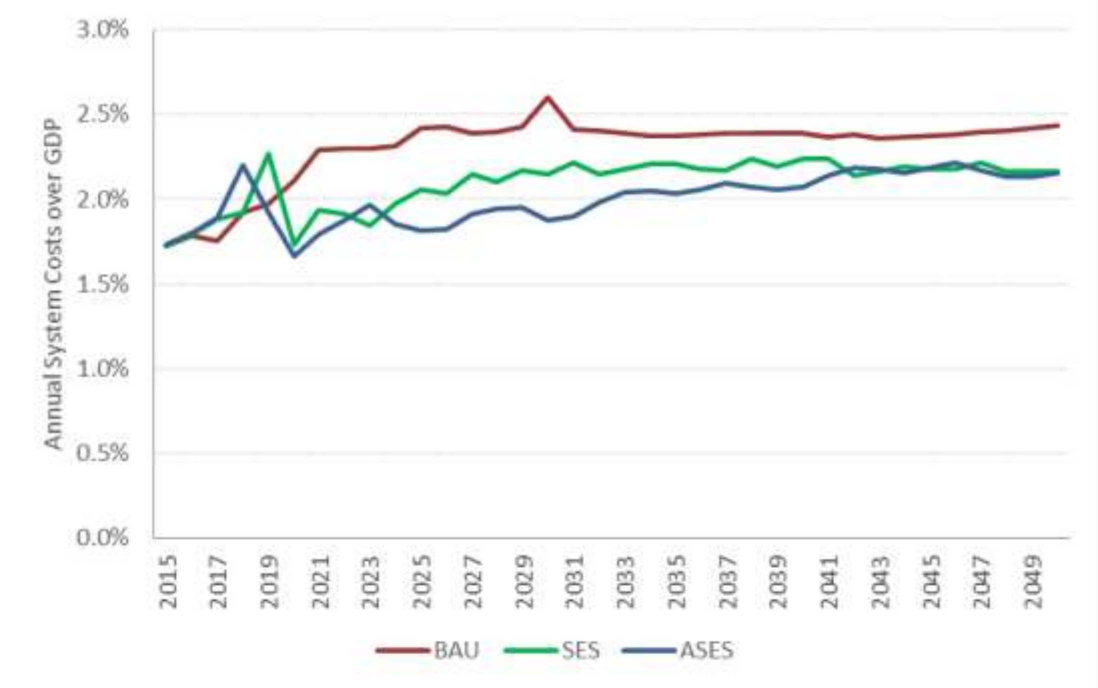


Figure 101 Total System Cost by Type (BAU)

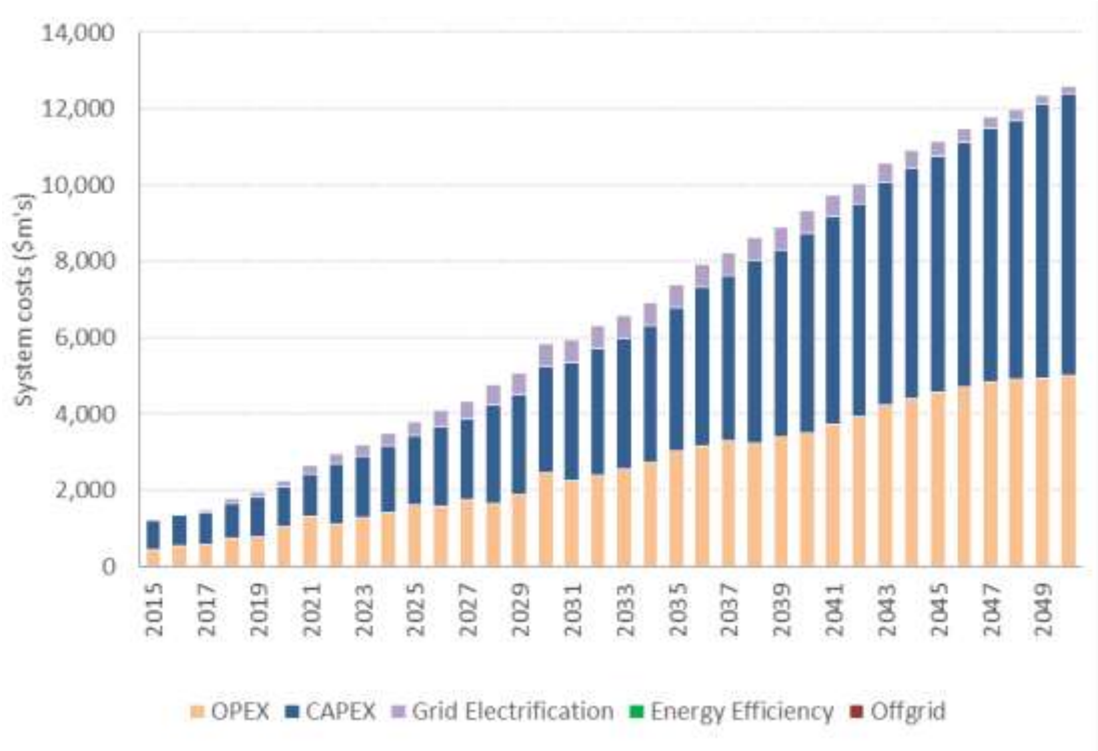


Figure 102 Total System Cost by Type (SES)

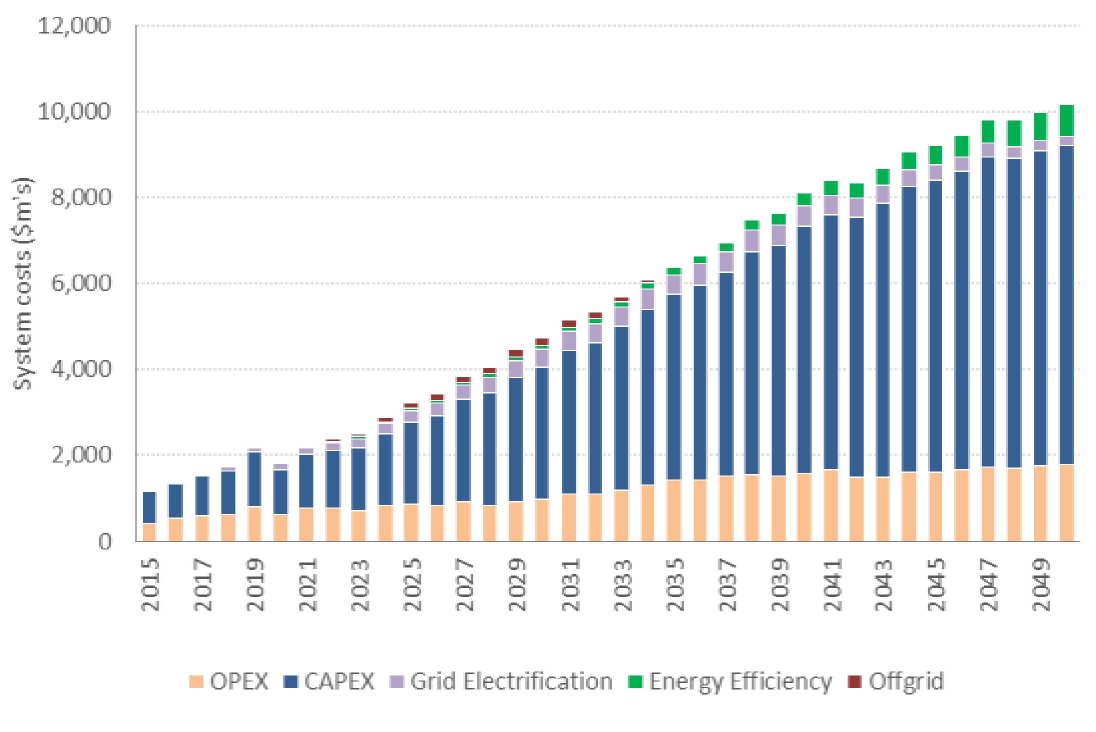


Figure 103 Total System Cost by Type (ASES)

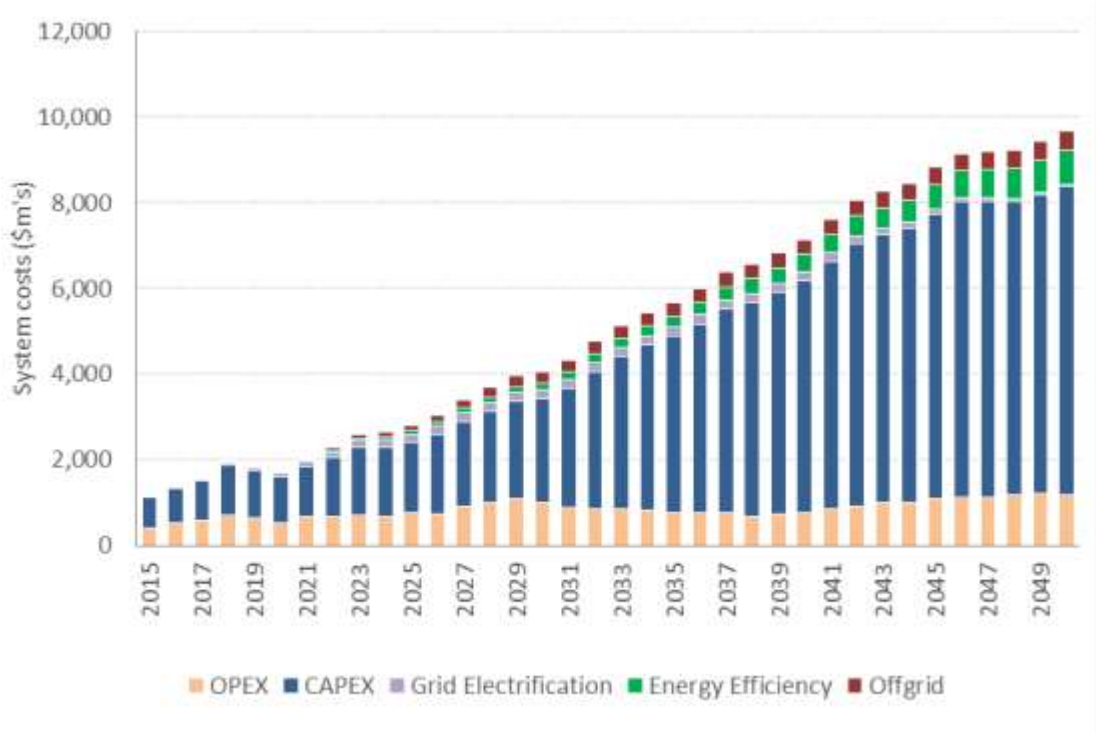
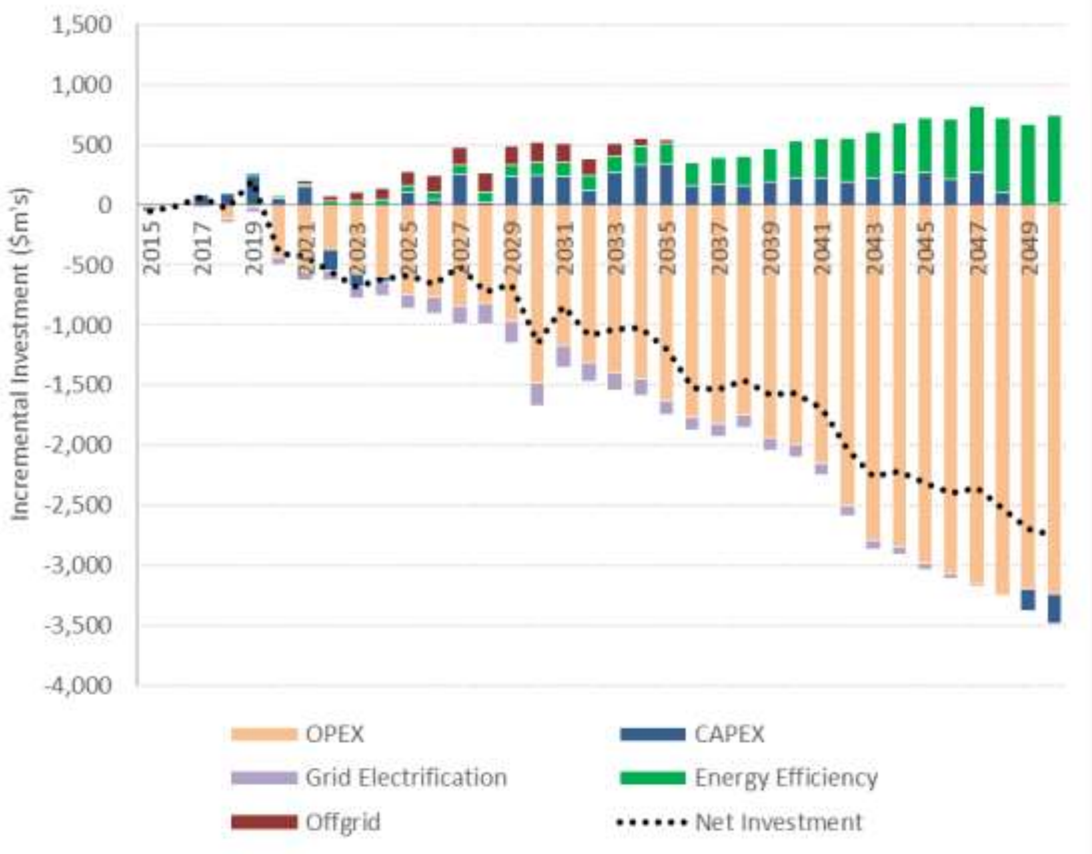


Figure 104 and Figure 105 plots the difference in amortised CAPEX, OPEX, grid electrification and energy efficiency costs between the SES and BAU, and ASES and BAU respectively[38]. The costs have also been adjusted for exports and imports. Positive amounts represent an additional investment required in either the SES or ASES and negative amounts correspond to cost savings.

For the SES against BAU case, there are fuel savings of up to US$3.2 billion as more coal capacity comes online whereas additional CAPEX in the SES is needed over and above the BAU peaking at US$340 million towards 2035. This is due to higher renewable energy technology costs against low cost conventional technologies in the earlier years. After taking into account the US$730 million pa energy efficiency cost, the SES results in significant cost savings of US$2.7 billion pa by 2050.

The ASES experiences additional cost savings in OPEX due to less coal generation offset with slightly higher energy efficiency costs. The CAPEX difference is roughly even driven by accelerated declines in renewable technology costs. Off-grid costs increase driven by greater investment in off-grid supply and is offset by savings in grid electrification costs of up to US$190 million. The ASES net cost saving reaches US$3.1 billion pa by 2050.

Figure 104 Difference in CAPEX, OPEX and Energy Efficiency Costs (SES and BAU)



[38] Off-grid costs here represent the capital costs of off-grid supply whereas grid electrification does not include generation costs.

Figure 105 Difference in CAPEX, OPEX and Energy Efficiency Costs (ASES and BAU)

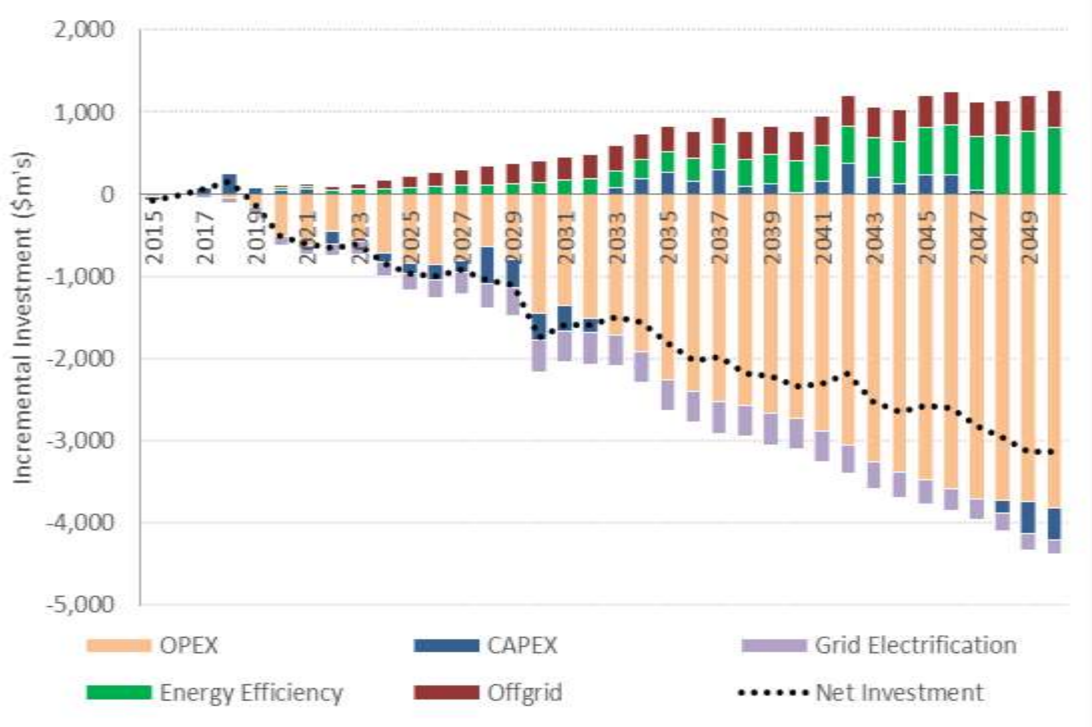


Figure 106 NPV of System Costs (Real 2014 US$)

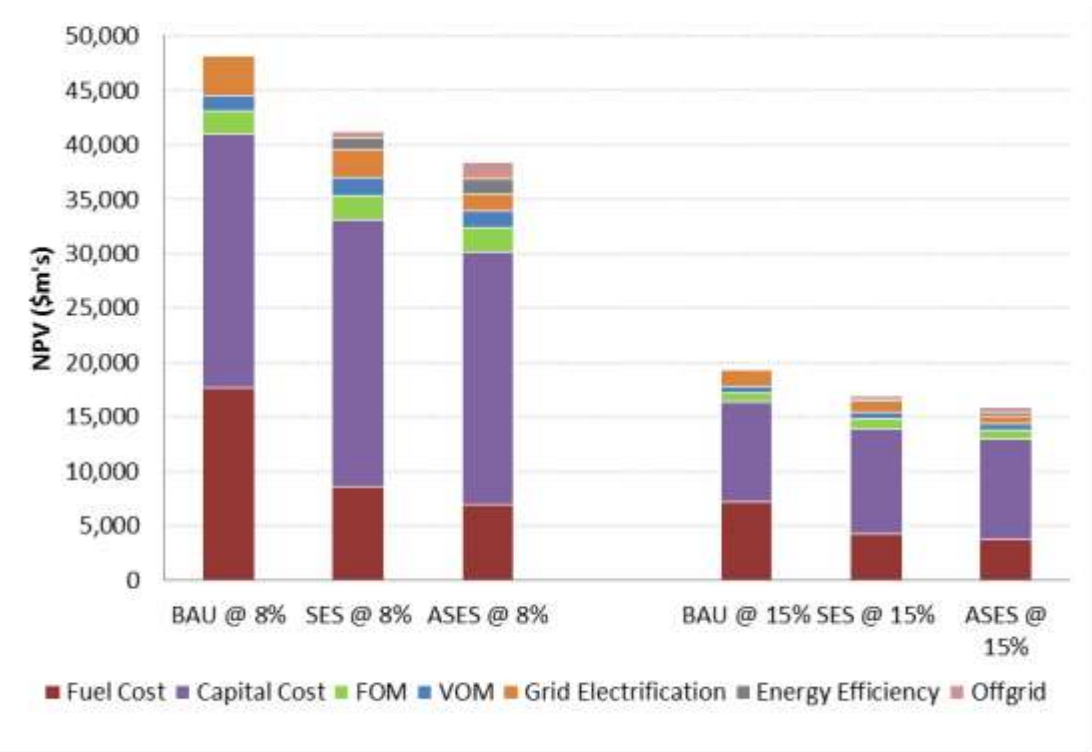


Figure 106 and Table 24 present the net present value of the power system costs by component using an 8% and 15% discount rate. Similar to the conclusions from previous charts, the BAU has the highest cost followed by SES then the ASES. The BAU is comprised of a higher percentage of fuel costs, whereas the ASES has the highest percentage relating to capital costs. The total NPV difference between the BAU and ASES is approximately US$10 billion.

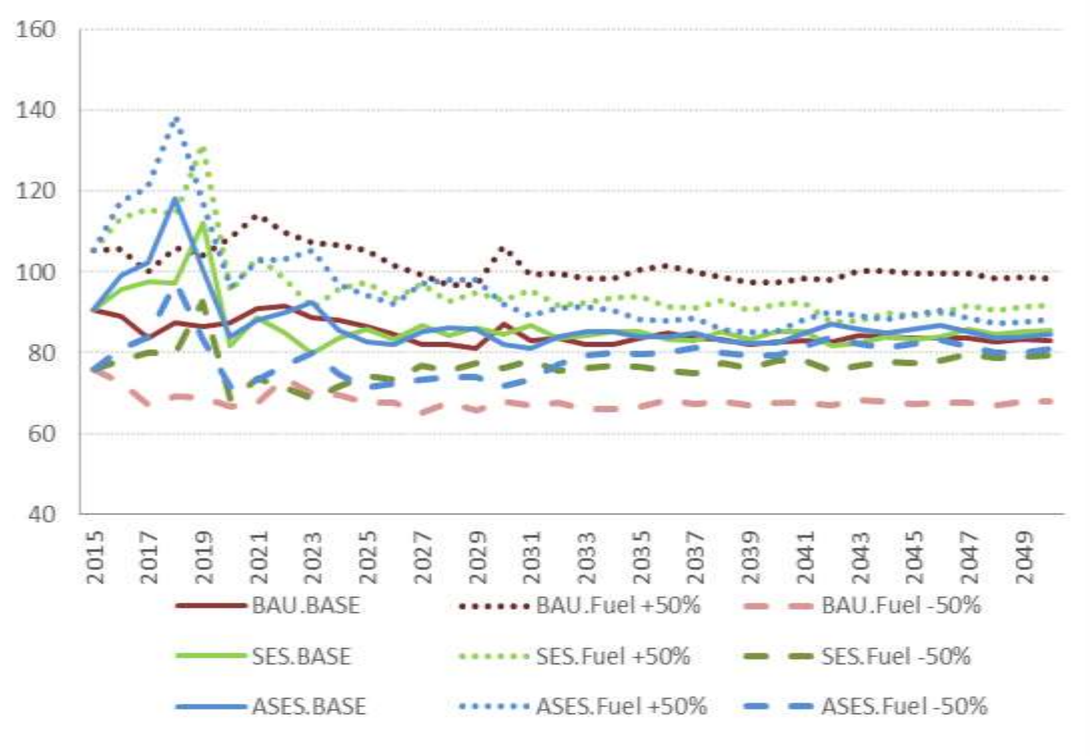
Table 24 NPV of System Costs (Real 2014 US$)

NPV	BAU @ 8%	SES @ 8%	ASES @ 8%	BAU @ 15%	SES @ 15%	ASES @ 15%
Fuel Cost	17,668	8,591	6,951	7,158	4,218	3,770
Capital Cost	23,339	24,462	23,157	9,237	9,696	9,191
FOM	2,046	2,264	2,291	835	875	862
VOM	1,516	1,671	1,514	568	613	563
Grid Electrification	3,588	2,629	1,488	1,481	1,050	658
Energy Efficiency	0	1,071	1,429	0	301	420
Off-grid	0	578	1,563	0	259	495
Total	48,157	41,265	38,392	19,279	17,012	15,959

9.6 Fuel Price Sensitivity

Figure 107 plots the LCOE of the BAU, SES and ASES as discussed in section 9.2. In addition, it plots the LCOE for a 50% increase to the fuel prices, which reflects the difference between IEA's crude oil pricing under the 450 Scenario and the Current Policies Scenario (US$95/bbl and US$150/bbl respectively). It can be seen that the LCOE of the BAU rises more (up to US$5/MWh) against a fuel price increase compared with smaller increases in the SES and ASES as would be anticipated as a direct consequence of having a higher thermal generation share in the BAU compared to renewable energy in the SES and ASES. The SES increases, and the ASES to a smaller extent, as a consequence of bioenergy generation, but still less sensitive to fuel price shocks than the BAU.

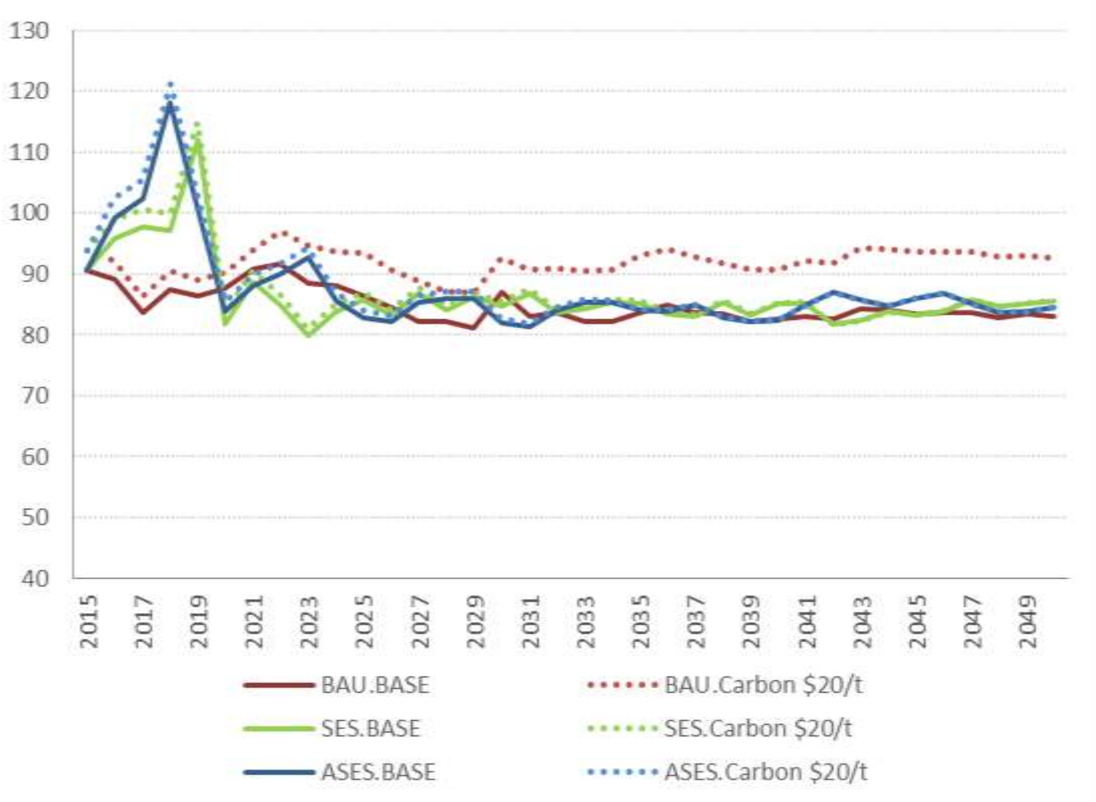
Figure 107 Myanmar Fuel Price Sensitivity (US$/MWh)



9.7 Impact of a Carbon Price

In a similar way to the previous section, Figure 108 plots the LCOE under the BAU, SES and ASES and the LCOE under a carbon price scenario. The carbon scenario puts a US$20/t-CO2 impost throughout the entire modelled period. This is intended to show the sensitivity of the BAU, SES and ASES to the carbon prices. In a similar way to the previous section, this shows that LCOE in the SES and ASES is insensitive to carbon prices by 2050 while for the BAU, it adds an additional US$8 Real 2014 US$/MWh to the LCOE because of its coal generation.

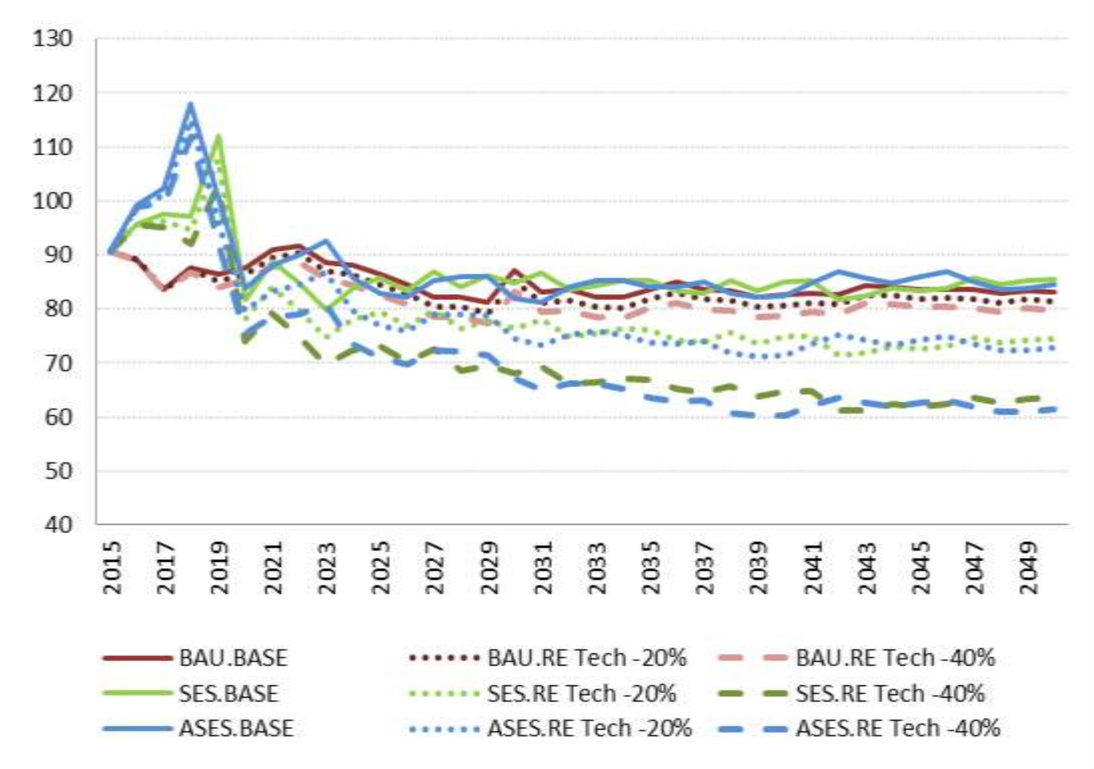
Figure 108 Myanmar Carbon Sensitivities (US$/MWh)



9.8 Renewable Technology Cost Sensitivity

Figure 109 shows the LCOE sensitivity to 20% and 40% decreases in renewable technology costs. As expected the ASES followed by the SES is the most sensitive with potential declines of up to US$23/MWh. The results also show that a 20% drop in the assumed renewable technology CAPEX will bring the SES and ASES LCOE well below the BAU.

Figure 109 Myanmar Renewable Technology Cost Sensitivities (US$/MWh)



9.9 Jobs Creation

To assess the implications for Job Creation for each scenario we applied the methodology used by the Climate Institute of Australia. The methodology is summarised in Appendix C. The numbers of jobs created for each of the scenarios are shown in Figure 110, Figure 111 and Figure 112. The job categories shown include: manufacturing, construction, operations and maintenance and fuel supply management. Figure 113 provides a comparison of total jobs created for BAU, SES and ASES. The key observations are:

- Across all scenarios, manufacturing and construction account for most of the jobs with a much smaller share attributable to O&M and fuel supply.
- The BAU job creation profile peaks at around 55,000 jobs compared to SES job creation peaking towards 140,000 or more than two times that in the BAU. This is entirely driven by renewable energy developments that require more jobs in the manufacturing and construction phases. See Appendix C for assumptions.
- The ASES job creation peaks at 155,000 jobs, almost more than three times that of the BAU driven by even more renewable energy projects required as the region moves towards a 100% renewable generation target by 2050. The significant difference against the BAU is also driven by the need to develop projects in Myanmar for exporting to its neighbouring countries.
- Different skills are required between the scenarios, BAU has people working on conventional coal and hydro, whereas the SES and ASES has people mainly working on solar & battery storage systems.
- Note that the manufacturing and fuel supply jobs shown to be created may not be created within Myanmar with manufacturing of equipment and fuel management (for imported fuels) occurring in other countries.

Figure 110 Job Creation by Category (BAU)

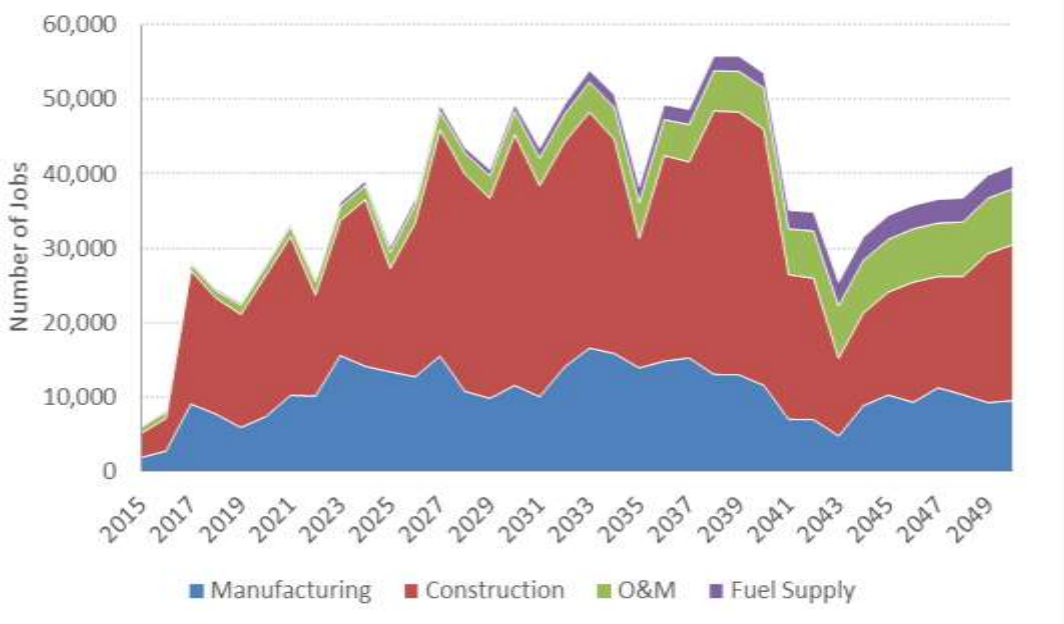


Figure 111 Job Creation by Category (SES)

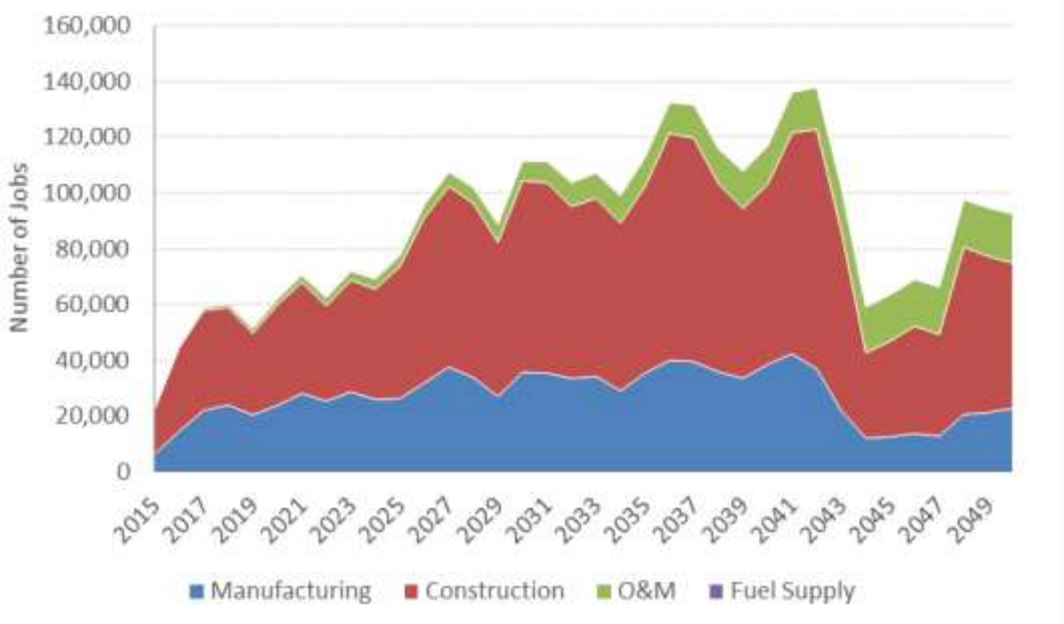


Figure 112 Job Creation by Category (ASES)

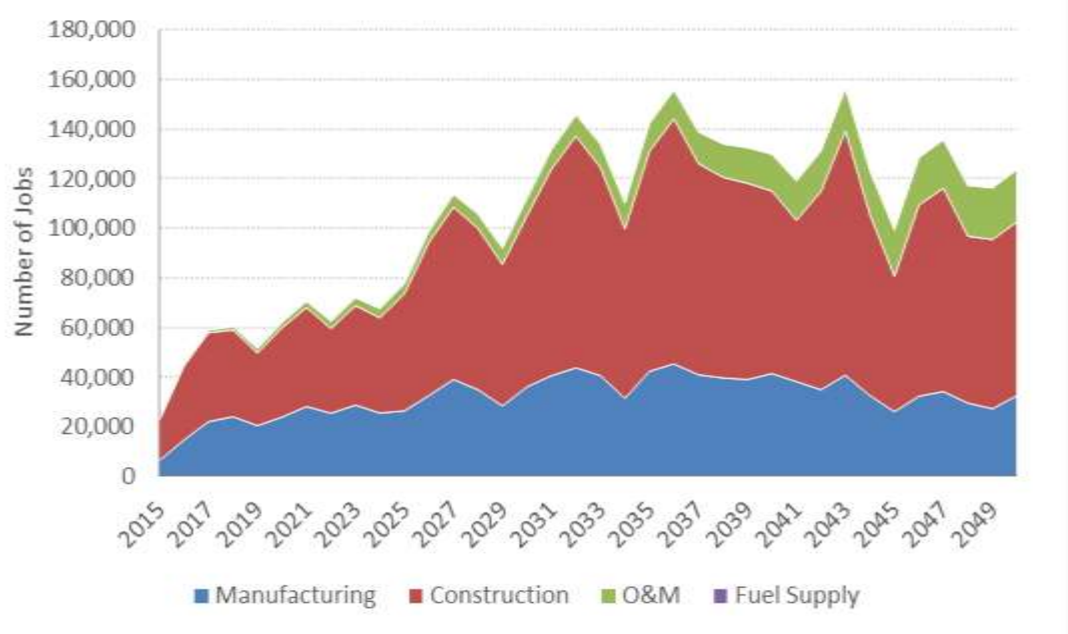


Figure 113 Total Job Creation Comparison BAU, SES and ASES

10 Conclusions

Myanmar's electricity sector has experienced significant growth in demand in the recent past putting pressure on aging and inadequate infrastructure. This has resulted in the deployment of stop gap measures in the form of investment in small gas engine technologies and distribution system rehabilitation programs. As the country's economy has been undergoing a process of economic reform, the outlook and prospects for economic growth in the near term future are optimistic. Key to economic growth in the country will be a continuous supply of energy to enable the country to prosper. The ongoing enhancement and expansion of Myanmar's electricity industry is thus an important part of enabling economic growth to occur. Myanmar also has one of the lowest electrification rates in the region. Enhancing energy access is therefore a major concern. Strategies for enhancing access to electricity include the approach of investing heavily in transmission and distribution equipment to expand the national grid as is the traditional approach, or, given advances in distributed technologies; deployment of distributed generation solutions.

In this report we have presented the findings of power system modelling of Myanmar's power system for a Business as Usual (BAU), Sustainable Energy Sector (SES) and Advanced SES (ASES) scenarios. The BAU outlook assumed that future power sector developments would be based on continued large scale hydro development, imported coal projects and at a later stage, natural gas. The SES and ASES have both taken measures to instead deploy a maximal amount of renewable energy and apply energy efficiency measures. This provides some alternative scenarios for the country's electricity sector. The SES and ASES both also assume a more rapid program of cross-border interconnection in the GMS, which allows the region to more fully exploit diversity in demand as well as geographically dispersed areas with high renewable energy potential. This allows the region to benefit from the development of Myanmar's significant solar, wind and biomass potential.

10.1 Comparison of Scenarios

The following are the key conclusions that have been drawn from the analysis:

- The SES delivers an energy efficiency gain beyond the BAU case of about 29% compared to the BAU. The ASES delivers efficiency gains of 33% after doubling transport electricity demand;
- The SES and ASES are able to achieve a power system that delivers 100% of generation from renewable energy resources (including large-scale hydro) by 2050. In contrast, 41% of the generation in the BAU is provided by renewable energy resources[39];
- By 2050, the SES and ASES avoid around 75 million tons of greenhouse gas emissions per year compared to the BAU. The SES and ASES intensity goes to zero vs. 0.48 t-CO_2/MWh for the BAU case by 2050. The BAU case achieves a higher emissions intensity level because of increased coal generation reliance while the SES and ASES deliver a low emissions intensity due to widespread deployment of solar and wind technologies.
- Based on some simple measures for energy security:
  - Under the ASES and SES, Myanmar benefits from a more diverse mix of technologies and is not as dependent on a single source of primary energy as the BAU; for example, the BAU is highly dependent on large-scale hydro and coal, while the SES and ASES diversifies supply across a range of renewable energy technologies;
  - The BAU has 47% of its generation from domestically controlled and managed resources compared to the SES and ASES at 100%; and
  - The ASES and SES achieves a reliable power system through coordination on both the supply and demand side of the industry, with similar energy reserve margins as the BAU. Though as a measure of energy supply storage and flexibility the ASES and SES overall are lower than the BAU, which

[39] Large-scale hydro is included

means that the BAU would be more resilient against extreme events. This enhances the need to pursue an integrated regional power system through cross-border trading. While modelling has shown that the ASES and SES is operationally feasible (even with less directly dispatchable resources in the SES compared to the BAU), stress testing of both the BAU, SES and ASES scenarios against more significant threats to the operation of the power system would likely not be handled as well compared to the BAU. More work to understand and develop appropriate mitigation measures is required.

10.2 Economic Implications

10.2.1 Electricity Costs

Based on the outcomes of modelling the BAU, SES and ASES scenarios, we also examined the following issues in relation to electricity costs: (1) levelised cost of electricity, (2) investment requirements, (3) sensitivity of electricity prices to fuel price shocks, and (4) the implications of a price on carbon equivalent emissions for electricity prices. Based on this analysis we draw the following conclusions:

- The BAU requires higher levels of capital investment than the SES and ASES, and in relation to generation costs, the SES and ASES across the modelling period deliver a lower overall generation cost;
- Under the SES and ASES significant benefits are gained in the form of avoided fuel costs and this contributes to achieving a lower overall dollar cost for Myanmar. The observation is made that the composition of LCOE under the SES and ASES is largely driven by investment costs, hence exposure to fuel shocks is significantly reduced; and
- The LCOE under the SES and ASES is also largely insensitive to a carbon price, as could be reasonably anticipated for a power system that is entirely dominated by renewable energy.

10.2.2 Investment Implications

From 2015 to 2050, the overall investment for each scenario is similar: US$75 billion in the BAU compared to US$66 billion in the SES and US$63 billion in the ASES (Real 2014 US$). However, the composition of the investments is quite different. The BAU directs most investment (75%) to coal and hydro projects, while in the SES (and ASES) investments are spread over a wider range of technologies: 42% (33%) is directed to solar[40] and battery system technologies, with other significant investments in energy efficiency measures (12% SES and 15% ASES), wind (13% in SES and ASES) and off-grid. Clearly, compared to the BAU, the SES and ASES will require investments across a more diverse range of technologies and also technologies that are of a smaller scale and more distributed rather than a smaller number of large scale developments as per the BAU. This highlights the importance to the SES and ASES of having investment frameworks for energy infrastructure that can accommodate a larger number of smaller investments.

10.2.3 Jobs Creation

The SES and ASES scenarios both result in quite different technology mixes for Myanmar compared to the BAU. Each has quite different implications for the workforce that would be required to support each scenario. Based on analysis of the required jobs we estimate that[41]:

- The BAU from 2015 to 2050 would be accompanied by the creation of some 1.4 million job years[42] (28% manufacturing, 57% construction, 11% operations and maintenance, and 4% fuel supply);

---

[40] PV and CSP technologies.

[41] Based on the employment factors presented in Appendix C.

[42] A job year is one job for one person for one year. We use this measure to make comparisons easier across each scenario as the number of jobs created fluctuates from year to year.

- The SES would involve the creation of some 3.2 million job years (31% in manufacturing, 59% in construction, 10% in operations and maintenance and 0.1% in fuel supply); and
- The ASES would involve the creation of 3.8 million job years (30% in manufacturing, 60% in construction, 9% in operations and maintenance and 0.1% in fuel supply).

10.3 Identified Barriers for the SES and ASES

While Myanmar has abundant renewable energy resources, the renewables industry is underdeveloped, and faces a number of issues in developing viable projects, including:

- Lack of a fully transparent institutional and legal framework to support exploration, development, and deployment;
- There are no specific renewable energy incentives at present;
- Limited financial capital to support research and development, market-based investment programs, and development of physical infrastructures
- Subsidised cost of electricity and petroleum products that discourages investments into renewable energy;
- Lack of human resource capacity;
- Lack of adequate transmission and distribution infrastructure;
- Competition from cheaper gas alternatives (Myanmar has the 10th largest gas reserves of any country);
- No information and educational programs; and
- Inadequate inter-governmental cooperation in the electricity market generally.

The ASES and SES also require a high level of energy efficiency measures to be implemented. Some of the current barriers to achieving significant energy efficiency reform include:

- Lack of well-defined policies, strategies and plans for promoting energy efficiency and conservation;
- There are no specific incentives at present to encourage energy savings;
- Limited financial capital to support research and development, market-based investment programs, and development of consumer support schemes;
- Subsidised cost of electricity and petroleum products that discourages energy efficiency and conservation;
- Lack of human resource capacity; and
- Lack of information and educational plans.

10.4 Recommendations

The following are key recommendations to reduce the barriers and “enable” the SES and ASES:

- Formation of more comprehensive energy policies to create an environment that is appropriate for investment in renewable energy technologies and energy efficiency measures. Investor confidence in renewable energy investment will be enhanced by having a transparent regulatory framework that provides certainty to investors and appropriately considers the ramifications of high levels of renewable energy in the generation mix.
- Conduct more detailed assessments of renewable energy potential and make the results publicly available to enable prospective investors to understand the potential, identify the best opportunities and subsequently take steps to explore investment and deployment.
- Knowledge transfer and capability building in the renewable energy technologies and energy efficiency for policy makers, staff working in the energy industry, as well as within education institutions to ensure the human capacity is being developed to support a national power system that has a high share of generation from renewable energy. As we have shown the SES and ASES will require a large number of skilled workers to support a technology mix that is centred on renewable energy.
- Investments in ICT systems to allow for greater real-time monitoring, control and forecasting of Myanmar’s national power system, including SCADA/EMS, and smart-grid technology and renewable

energy forecasting systems and tools. This will enable efficient real-time dispatch and control of all resources in Myanmar's national power system and will create an environment more conducive for the management of high levels of renewable energy in the generation mix.

- Take measures to encourage cross-border power trade in the region, as this works to the advantage of exploiting scattered renewable energy resource potentials and diversity in electricity demand. In particular:
  - Develop an overarching transmission plan that has been informed by detailed assessments and plans to leverage renewable energy potential in the region and diversity in demand and hydrological conditions. We see that in all scenarios Myanmar becomes a net exporter of electricity, however, in the SES and ASES the volume of exports is greater than in the BAU as Myanmar's high level of renewable energy are developed to benefit of the region as a whole.
  - Enhance technical standards and transmission codes in each country to allow for better interoperation of national power systems.
  - Establish dispatch protocols to better coordinate real-time dispatch of power systems in the region to make the best use of real-time information and continuously updated demand and renewable generation forecasts.
  - Develop a framework to encourage energy trade in the region, and in particular towards a model that can support multilateral power trading via a regional power market or exchange (for example).
- Take measures to improve power planning in the region to:
  - Explicitly account for project externalities and risks,
  - Evaluate a more diverse range of scenarios including those with high levels of renewable energy,
  - Take into consideration energy efficiency plans,
  - Take into consideration overarching plans to have tighter power system integration within the region, and
  - Carefully evaluate the economics of off-grid against grid connection where this is relevant.

Appendix A Technology Costs

Table 25 sets out the technology cost assumptions that were used in the modelling presented in this report for the BAU and SES scenarios. Table 26 sets out the technology costs used in the ASES. The technology costs of coal and gas do not include overheads associated with infrastructure to develop facilities for storing / managing fuel supplies. These costs were however accounted for in the modelling.

Figure 114 and Figure 115 presents the levelised cost of new entry generation based on assumed capacity factors. LCOE levels presented in Section 9 are based on weighted average LCOE's and modelled output and will differ from the LCOE's presented here. The LCOE for battery storage is combined with solar PV technology assuming 75% of generation is stored for off-peak generation.

Table 25 Technology Costs Assumptions for BAU and SES Scenarios

	Technology Capital Cost (Unit: Real 2014 US$/kW)			
Technology	**2015**	**2030**	**2040**	**2050**
Generic Coal	2,492	2,474	2,462	2,450
Coal with CCS	5,756	5,180	4,893	4,605
CCGT	942	935	930	926
GT	778	772	768	764
Wind Onshore	1,450	1,305	1,240	1,175
Wind Offshore	2,900	2,610	2,480	2,349
Hydro Large	2,100	2,200	2,275	2,350
Hydro Small	2,300	2,350	2,400	2,450
Pumped Storage	3,340	3,499	3,618	3,738
PV No Tracking	2,243	1,250	1,050	850
PV with Tracking	2,630	1,466	1,231	997
PV Thin Film	1,523	1,175	1,131	1,086
Battery Storage - Small	600	375	338	300
Battery - Utility Scale	500	225	213	200
Solar Thermal with Storage	8,513	5,500	4,750	4,000
Solar Thermal No Storage	5,226	4,170	3,937	3,703
Biomass	1,800	1,765	1,745	1,725
Geothermal	4,216	4,216	4,216	4,216
Ocean	9,887	8,500	7,188	5,875
Biogas (AD)	4,548	4,460	4,409	4,359

**Battery technology quoted on a US$/kWh basis*

Figure 114 Levelised Cost of New Entry (BAU & SES, US$/MWh)

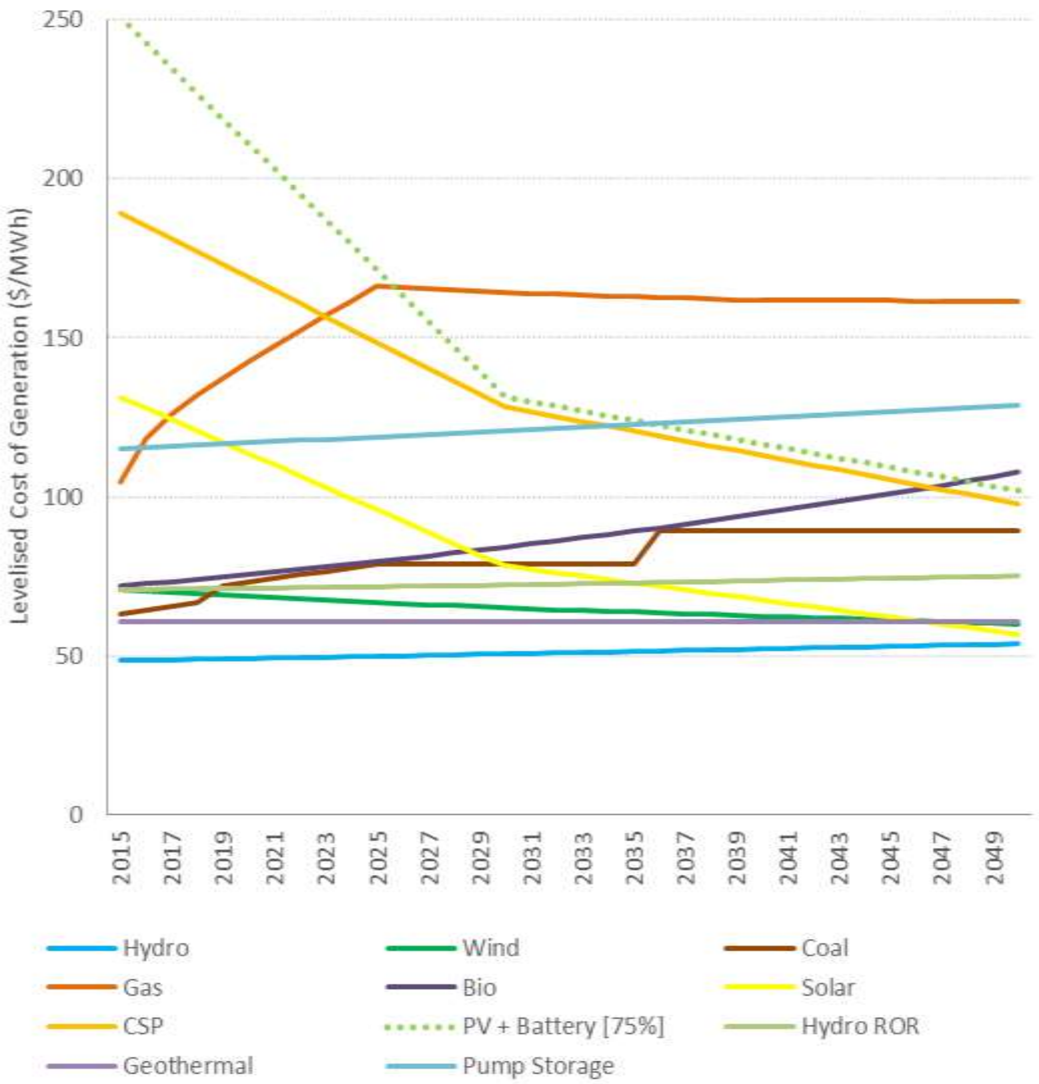
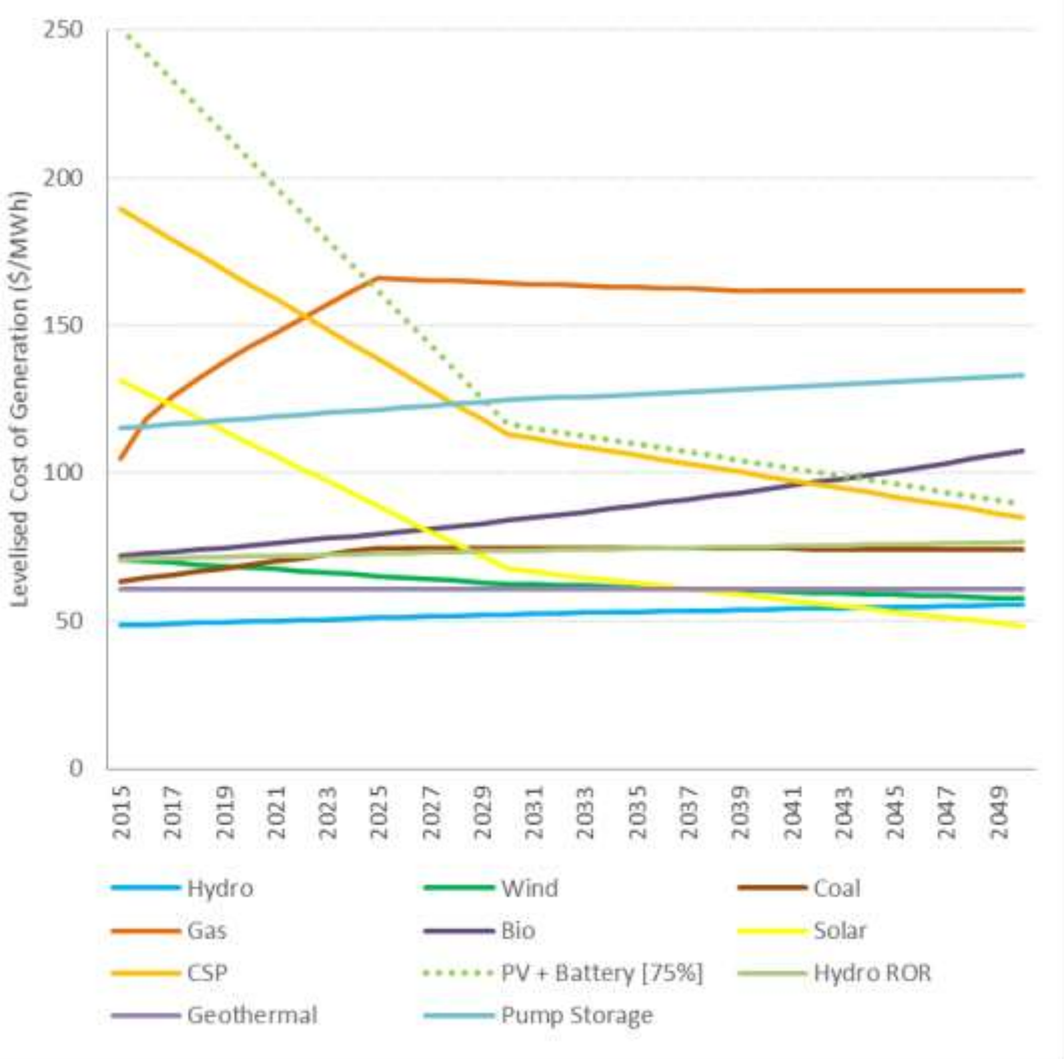


Table 26 Technology Costs Assumptions for ASES Scenario

	Technology Capital Cost (Unit: Real 2014 US$/kW)			
Technology	**2015**	**2030**	**2040**	**2050**
Generic Coal	2,492	2,462	2,450	2,437
Coal with CCS	5,756	4,893	4,605	4,334
CCGT	942	930	926	921
GT	778	768	764	761
Wind Onshore	1,450	1,240	1,175	1,113
Wind Offshore	2,900	2,480	2,349	2,225
Hydro Large	2,100	2,275	2,350	2,427
Hydro Small	2,300	2,400	2,450	2,501
Pumped Storage	3,340	3,618	3,738	3,861
PV No Tracking	2,243	1,050	850	688
PV with Tracking	2,630	1,231	997	807
PV Thin Film	1,523	1,131	1,086	1,043
Battery Storage - Small	600	338	300	267
Battery - Utility Scale	500	213	200	188
Solar Thermal with Storage	8,513	4,750	4,000	3,368
Solar Thermal No Storage	5,226	3,937	3,703	3,483
Biomass	1,800	1,745	1,725	1,705
Geothermal	4,216	4,216	4,216	4,216
Wave	9,887	7,188	5,875	4,802
Biogas (AD)	4,548	4,359	4,309	4,259

**Battery technology quoted on a US$/kWh basis*

Figure 115 Levelised Cost of New Entry (ASES, US$/MWh)



Appendix B Fuel Prices

Table 27 sets out the Free on board (FOB) fuel price assumptions that were used in the modelling presented in this report. This fuel price set was common to all three scenarios.

Table 27 Fuel Price Assumptions (Real 2014 US$/GJ)

Year	Coal	Gas	Diesel	Uranium	Fuel Oil	Biomass	Biogas
2015	2.39	10.08	13.34	0.72	9.13	2.57	1.00
2016	2.51	11.88	15.24	0.76	10.49	2.62	1.00
2017	2.63	12.91	15.28	0.80	11.68	2.67	1.00
2018	2.74	13.72	16.41	0.80	12.43	2.72	1.00
2019	2.86	14.47	17.53	0.80	13.18	2.78	1.00
2020	2.98	15.16	18.64	0.80	13.93	2.83	1.00
2021	3.10	15.81	19.73	0.80	14.65	2.89	1.00
2022	3.21	16.46	20.80	0.80	15.36	2.95	1.00
2023	3.33	17.10	21.86	0.80	16.06	3.01	1.00
2024	3.45	17.72	22.90	0.80	16.76	3.07	1.00
2025	3.56	18.34	23.93	0.80	17.44	3.13	1.00
2026	3.56	18.29	23.86	0.80	17.39	3.19	1.00
2027	3.56	18.24	23.79	0.80	17.34	3.25	1.00
2028	3.56	18.19	23.72	0.80	17.29	3.32	1.00
2029	3.56	18.14	23.65	0.80	17.24	3.39	1.00
2030	3.56	18.09	23.58	0.80	17.19	3.45	1.00
2031	3.56	18.06	23.53	0.80	17.15	3.52	1.00
2032	3.56	18.02	23.49	0.80	17.12	3.59	1.00
2033	3.56	17.99	23.44	0.80	17.08	3.67	1.00
2034	3.56	17.96	23.40	0.80	17.05	3.74	1.00
2035	3.56	17.92	23.35	0.80	17.02	3.81	1.00
2036	3.56	17.89	23.30	0.80	16.98	3.89	1.00
2037	3.56	17.86	23.26	0.80	16.95	3.97	1.00
2038	3.56	17.83	23.21	0.80	16.92	4.05	1.00
2039	3.56	17.79	23.16	0.80	16.88	4.13	1.00
2040	3.56	17.76	23.12	0.80	16.85	4.21	1.00
2041	3.56	17.76	23.12	0.80	16.85	4.29	1.00
2042	3.56	17.76	23.12	0.80	16.85	4.38	1.00
2043	3.56	17.76	23.12	0.80	16.85	4.47	1.00
2044	3.56	17.76	23.12	0.80	16.85	4.56	1.00
2045	3.56	17.76	23.12	0.80	16.85	4.65	1.00
2046	3.56	17.76	23.12	0.80	16.85	4.74	1.00
2047	3.56	17.76	23.12	0.80	16.85	4.84	1.00
2048	3.56	17.76	23.12	0.80	16.85	4.93	1.00
2049	3.56	17.76	23.12	0.80	16.85	5.03	1.00
2050	3.56	17.76	23.12	0.80	16.85	5.13	1.00

Appendix C Methodology for Jobs Creation

This section briefly summarises the methodology that we adopted for jobs creation. The methodology that we have adopted has been based on an approach developed by the Institute for Sustainable Futures at the University of Technology, Sydney and used by the Climate Institute of Australia[43]. In essence the jobs created in different economic sectors (manufacturing, construction, operations & maintenance and fuel sourcing and management) can be determined by the following with the information based on the numbers provided in Table 28.

Figure 116 Job Creation Calculations

Jobs = manufacturing + construction + operations and maintenance (O&M) + fuel, where:

Manufacturing	=	MW installed per year	x	Manufacturing employment multiplier	x	Annual decline factor (years)	x	% local manufacturing
Construction	=	MW installed per year	x	Construction employment multiplier	x	Annual decline factor years		
O&M	=	Cumulative capacity	x	O&M employment multiplier	x	Annual decline factor years		
Fuel supply (coal)	=	Electricity generation	x	Fuel employment multiplier	x	Annual decline factor years		
Fuel supply (gas)	=	Electricity generation	x	Fuel employment multiplier	x	Annual decline factor years	x	% local fuel supply

We have applied this methodology to the results in each scenario discussed in this report in order to make estimates of the jobs creation impacts and allow comparisons to be made[44].

[43] A description of the methodology can be found in the following reference: The Climate Institute, "Clean Energy Jobs in Regional Australia Methodology", 2011, available: http://www.climateinstitute.org.au/verve/_resources/cleanenergyjobs_methodology.pdf.

[44] The percentage of local manufacturing and local fuel supply is assumed to be 1 to reflect the total job creation potential.

Table 28 Employment Factors for Different Technologies

Technology	Annual decline applied to employment multiplier 2010-20	Annual decline applied to employment multiplier 2020-30	Construction time years	Construction per MW	Manufacturing per MW	Operations & maintenance per MW	Fuel per GWh
Black coal	0.5%	0.5%	5	6.2	1.5	0.2	0.04 (include in O&M)
Brown coal	0.5%	0.5%	5	6.2	1.5	0.4	
Gas	0.5%	0.5%	2	1.4	0.1	0.1	0.04
Hydro	0.2%	0.2%	5	3.0	3.5	0.2	
Wind	0.5%	0.5%	2	2.5	12.5	0.2	
Bioenergy	0.5%	0.5%	2	2.0	0.1	1.0	
Geothermal	1.5%	0.5%	5	3.1	3.3	0.7	
Solar thermal generation	1.5%	1.0%	5	6.0	4.0	0.3	
SWH	1.0%	1.0%	1	10.9	3.0	0.0	
PV	1.0%	1.0%	1	29.0	9.0	0.4	

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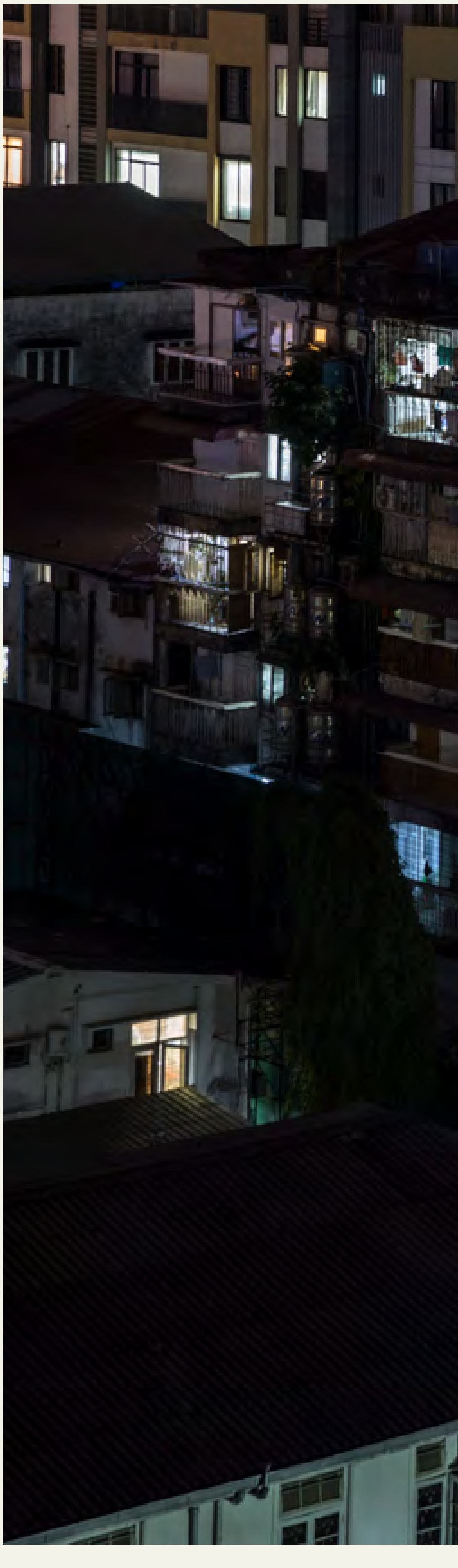


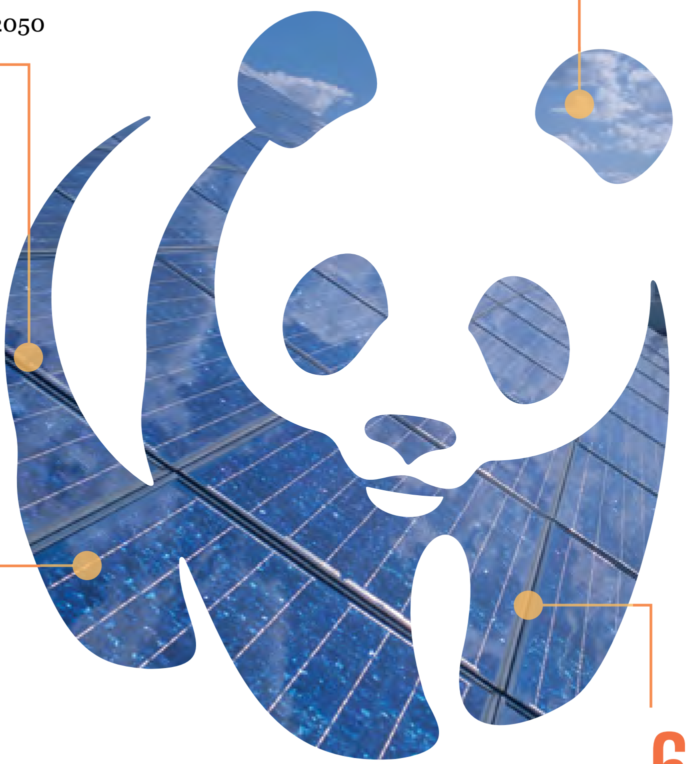
Myanmar's Electricity Vision in numbers

0%

fossil fuel based generation starting 2043

46%

of solar energy by 2050



17%

of wind energy by 2050

64,904MW

installed capacity using diverse renewable energy resources by 2050