# Chapter 3

# Myanmar Power Development Pathways for Low Costs and Low River Impacts

This chapter describes Myanmar's national energy expansion strategy. Next, in its analysis, this chapter combines an energy planning model with the strategic planning of hydropower dam portfolios that aim to simultaneously reduce the overall power cost as well as the sediment impact loss from the most damaging hydropower development projects. Sediment loss is an indicator of the level of environmental health and loss of land for agricultural production.

The modelling results demonstrate that renewables (excluding large-scale hydropower) and participation in the ASEAN power grid have a great potential to sustain the future of Myanmar's electricity supply.

## 3.1 Introduction

Myanmar's currently massive energy deficit hinders its economic development. Hence, expanding its energy production capacity is a national priority. Channelling investment funds towards low-cost and low-impact projects remains a key policy issue, given the ongoing tension over hydropower development and other electricity options.

Myanmar's power system is set to expand rapidly following an influx of foreign direct investment and multilateral development bank efforts to increase the country's access to electricity from around 33% to 100%. These imminent investments in renewable and non-renewable sources of electricity will determine the environmental and economic performance of Myanmar's electricity supply for the coming decades. Myanmar's territory includes the Salween and Irrawaddy Rivers, both harbouring considerable hydroelectric potential that could lay the foundation for the country's future in renewable energy use. Fully developing Myanmar's hydropower potential would, however, also lead to major long-term environmental impacts, such as on the basins' sediment budgets.

Myanmar's current power development plan features substantial expansion of hydropower and coal-fired power plants and downplays the possible expansion of other renewable resources such as solar energy. Previous analyses have not properly considered the great potential of solar power, nor did they pay attention to the environmental impact of large-scale hydropower. Additionally, research works linking the capacity expansion of the energy sector with its ecological impacts cannot be discounted. In Malaysian Borneo, for instance, the proposed Sarawak Corridor of Renewable Energy (SCORE) framework for hydropower development both entailed more upfront cost in the provision of electricity and harmed biodiversity for critical species native to the river basin in Sabah and Sarawak (Shirley et al., 2015). Moreover, over the past few decades, electricity resources in Myanmar and ASEAN have become less diverse and more reliant on hydropower, which is susceptible to security risks, as well as human and ecological damage to critical fisheries (Tongsopit et al., 2015). Plans developed by international development partners have not fully explored the opportunity of developing solar, wind, and biomass electricity projects that have gained technological learning and experienced significant cost reductions during the past four years.

Planning a national energy system from the ground up offers the opportunity to make strategic decisions regarding the development of an energy generation portfolio. Strategic decision-making should aim to balance economic objectives (energy cost and availability) with environmental objectives on multiple levels, from local to global. This could improve rural livelihoods, enhance the reliability of the overall power system, and enable broader access to clean electricity.

Compared to the common *site-by-site*, *ad-hoc* planning and development process, the strategic planning and trade-off analyses of dams' impacts and benefits can bring about dam portfolios with significantly lesser conflict between hydroelectricity use and dam sediment trapping (and other potential impacts) (Opperman et al., 2015; Schmitt et al., 2018). When expanding hydropower, a strategic trade-off analysis can clarify the sequence in which dams should be built to result in no-regret dam portfolios. It can also identify dam sites with the worst impact, and thus have to be removed from consideration, and a limit for 'sustainable' dam development in a basin (Schmitt et al., 2018). This type of analysis can be incorporated with power system optimisation planning to evaluate the cost of an alternative future in energy.

Energy system planning frameworks can point out cost-effective and low-carbon pathways in the expansion of a country's electricity production using different sources of electricity (Kittner et al., 2016). Such frameworks can inform decision makers about site selection and timing of future hydropower development from an economic and carbon emission perspective, but not from the perspective of the impact on river systems.

The Asian Development Bank (ADB) and other multilateral development banks have found a significant potential for renewable energy development in Myanmar, yet have many of their efforts centred on securing adequate hydropower capacity (ADB, 2015).

As an alternative, a few studies have aimed to understand the hydropower development plans from a regional perspective, incorporating surplus electricity trade into a least cost model. Such studies sought to understand what the true alternative energy costs are that will meet the projected power demand growth and provide electricity access nationwide. In Lao PDR and other countries along the Mekong, for instance, recent studies have found that exporting utility-scale renewable energy such as solar and wind power could provide more reliable and secure export revenues than would hydropower, which is susceptible to changing flows and river conditions due to climate change (Avila et al., forthcoming).

This research builds on a framework designed to optimise dam portfolios for minimal sediment trapping. Sediment trapping is the major cause of fish, land, and livelihood losses as a result of hydropower development. For example, the Mekong River has experienced the effect of sediment trapping due to decades of hydropower development.

Our research framework consists of estimates of sediment yield from various parts of the basin, a simplified sediment routing model with a component for reservoir sediment trapping, and a multi-objective evolutionary algorithm.[1] Dam portfolios consist of dam sites that are identified as candidates for development in the basin area (Open Development Mekong, 2014). That framework is then coupled with another framework for evaluating strategies that aim to meet Myanmar's electricity demand through different mixes of energy sources (Kittner, Dimco, et al., 2016).

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[1] See Garzanti et al. (2016), Kondolf et al. (2014), Schmitt et al. (2018), Hadka and Reed (2012).

The framework could be used to find optimal trade-offs amongst different objectives:

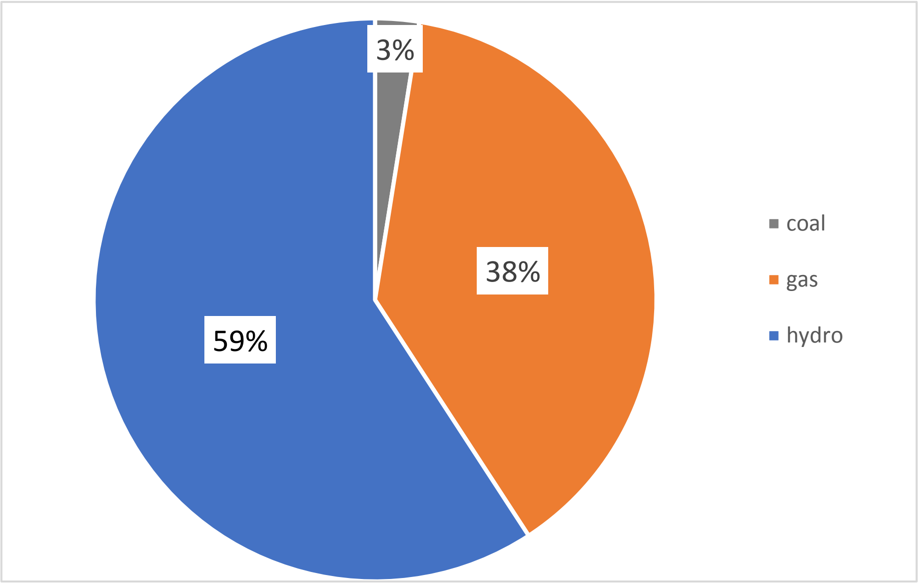
1) Total energy production coming from hydropower
2) Levelised cost of total electricity production from future portfolios [$/kWh]
3) Reduction in sediment load in the Irrawaddy [t/yr]
4) Reduction in sediment load in the Salween [t/yr]

Reducing the sediment load from the Irrawaddy and Salween river basins is challenging because the total amount of sediments in each of these rivers depends not only on Myanmar's dam development decisions, but also on the amount of dam construction in the upstream parts of these rivers in China.

### 3.2 Energy Modelling Scenarios

Figure 3-1 shows Myanmar's installed electricity generation mix by generation type. Hydropower currently provides the largest source of electricity generation, with natural gas and coal-fired power stations comprising the remainder. There are still ample opportunities to diversify the electricity sector.

**Figure 3-1. Current Installed Power Generation Mix in Myanmar by Generation Type**



Source: ADB (2016).

A holistic approach to analysing the least cost development in the power sector helps target those countries that could also pursue alternative investment plans in the energy sector to promote financial and environmental sustainability.

The energy modelling tool employed here not only allows energy system experts to evaluate the costs, benefits, and impacts of different projects; it also facilitates a dialogue with policymakers in other areas as well as with the public over the need for, and costs and impacts of, different energy pathways and strategies. No model is perfect, and all are limited by available data, but the use of a clear, open-access model is vital in making all interested parties understand the impact of individual projects and larger development objectives.

The Excel-based model determines the optimal generation portfolio based on the inputs on the energy resource potential of the region, existing installed capacity, average capacity factors, and peak contributions. It identifies discrete annual investment decisions by finding the least-cost generation capacity additions needed to meet annual load and peak demand. The least-cost generation mix is determined using a linear optimisation:

$$\min_{C} NPV(C_i)$$

Where the Total Generation Cost $\mathrm{C}_i = \text{Capital Cost} * \text{Capacity} + \text{Variable Cost} * \text{Generation}$ while Capital Cost is expressed in \$/MW, Capacity in MW, Variable Cost in \$/MWh, and Generation is expressed in MWh. Capacity (MW) is the decision variable of the linear programme.

Table 3-2 summarises the system parameters and scenarios developed in comparison with the JICA model (JICA, 2014).

**Table 3-1. System Parameters and Scenario Summary Compared to the JICA Model**

| Scenario | Notes | Estimated Capital Cost Expenditure | Reference Figure |
|---|---|---|---|
| JICA Masterplan | Follows guidelines and assumptions developed in the 2014 JICA Power Development Plan. In the original study, renewables are treated exogenously; we add renewables into the assumption mix and optimise endogenously. | US$11.7 billion | Figure 3-2 |
| Low-cost distributed energy resources | Follows current technology innovation and learning for renewable energy resources including solar PV, small-scale hydropower, wind, and energy storage facilities | US$8.1 billion | Figure 3-3 |
| ASEAN Power Grid (APG) Participation | Follows current technology innovation and learning while participating in an expanded power trade market for electricity imports and exports; APG includes 15 priority interconnection projects identified at the ASEAN level | US$8.4 billion | Figure 3-4 |

JICA = Japan International Cooperation Agency; PV = photovoltaic.

Source: Authors.

**Table 3-2. Technology and Capital Cost Assumptions Compared with Business-As-Usual Scenario**

| Technology | Lifetime (Years) | Initial Capital Cost ($2012/kW) | Capital Cost AGR (%) | Initial Fixed O&M Cost ($2012/kW/yr) | Fixed O&M AGR (%) | Initial Variable O&M Cost ($2012/MWh) | Variable O&M AGR (%) |
|---|---|---|---|---|---|---|---|
| Photovoltaic | 20 | 1,100 | -1.93% | 25 | -0.52% | 0 | 0.00% |
| Wind | 25 | 1,500 | -0.35% | 39 | -0.37% | 0 | 0.00% |
| Biomass | 30 | 2,200 | -0.27% | 74 | -0.27% | 0 | 0.00% |
| Small-hydro | 40 | 2,400 | 0.09% | 59 | 0.09% | 0 | 0.00% |
| Large-hydro | 50 | 1,940 | 0.47% | 47 | 0.44% | 0 | 0.00% |
| Coal | 40 | 1,200 | 0.00% | 40 | 0.00% | 4.47 | 0.00% |
| Natural Gas | 30 | 900 | 0.00% | 20 | 0.00% | 3.6 | 0.00% |
| Diesel | 20 | 371 | 0.00% | 3 | 0.00% | 13.88 | 0.00% |

O&M = Operation and Maintenance; AGR = Annual Growth Rate.

Source: Authors.

**Table 3-3. Variation of Capacity Factors, Both Real and Observed for Myanmar Based on Existing Literature**

| Resource | Capacity Factor | Reference |
|---|---|---|
| Gas | 70% | (Nam, Cham, and Halili, 2015) |
| Coal | 45% | (Nam et al., 2015) (World Wildlife Fund, 2016) |
| Hydro | 40% | (Fairhurst, 2016) |
| photovoltaic | 15.4% | (Siala and Stich, 2016) |

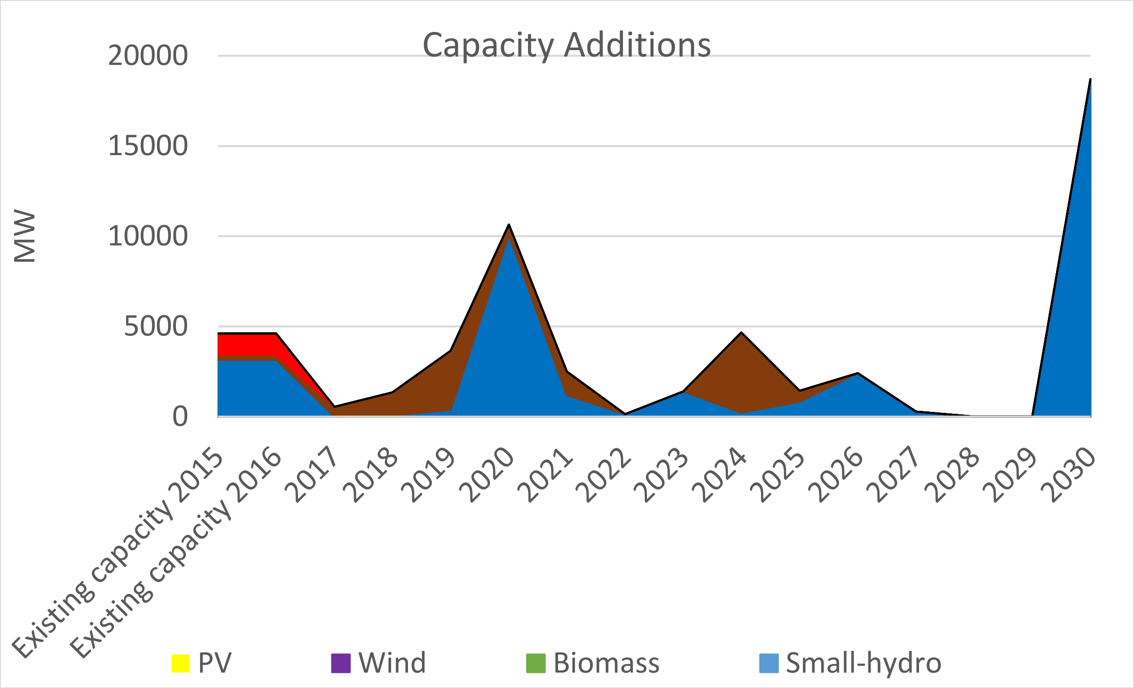
Source: Authors.

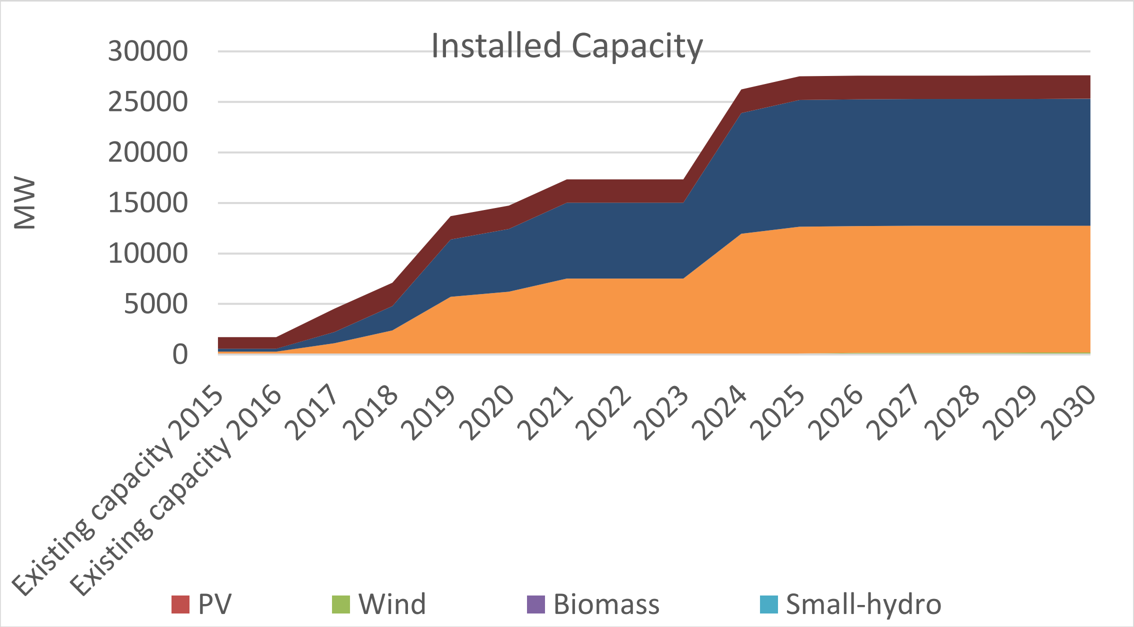
The study's scenarios based on the parameters and inputs in Table 3-2 and Table 3-3 are then compared with the proposed JICA power development plan to consider alternatives that can meet the power demand and export projections. Findings show that the low-cost solar and ASEAN power grid participation scenarios can generate reliable electricity at lower cost than some of the proposed large-scale hydropower projects that are under discussion (see Table 3-2). The model description can be found in Appendix 2 with full details on the inputs, outputs, and assumptions.

The hydropower dam portfolios are then compared within the different least-cost generation mixes presented in Figures 3-2 to 3-4 in a spatially and temporally explicit model. The model determines the optimal construction sequence of proposed hydropower portfolios to minimise environmental risk and reduce sediment trapping in rivers.

The model accounts for the non-dispatchability of some renewable energy sources using a peak load contribution factor, where wind and solar have less than a 10% contribution to peak demand. The model does not have high spatial and temporal resolution – a trade-off for the robust analysis without large data requirements that would be prohibitive in some regions. It also allows for quick sensitivity analysis by duplicating the model for varying scenarios, such as cost overruns and carbon prices. The model here underestimates the full dispatchability of solar and wind resources. But this could change due to the rapidly falling cost of storage resources that would facilitate integrated solar and wind systems to respond to grid operator controls within seconds to minutes (Kittner et al., 2017). It also follows on previous least-cost geospatial analyses of Myanmar's grid electrification effort (Modi et al., 2014), with a focus on larger-scale infrastructure investments.

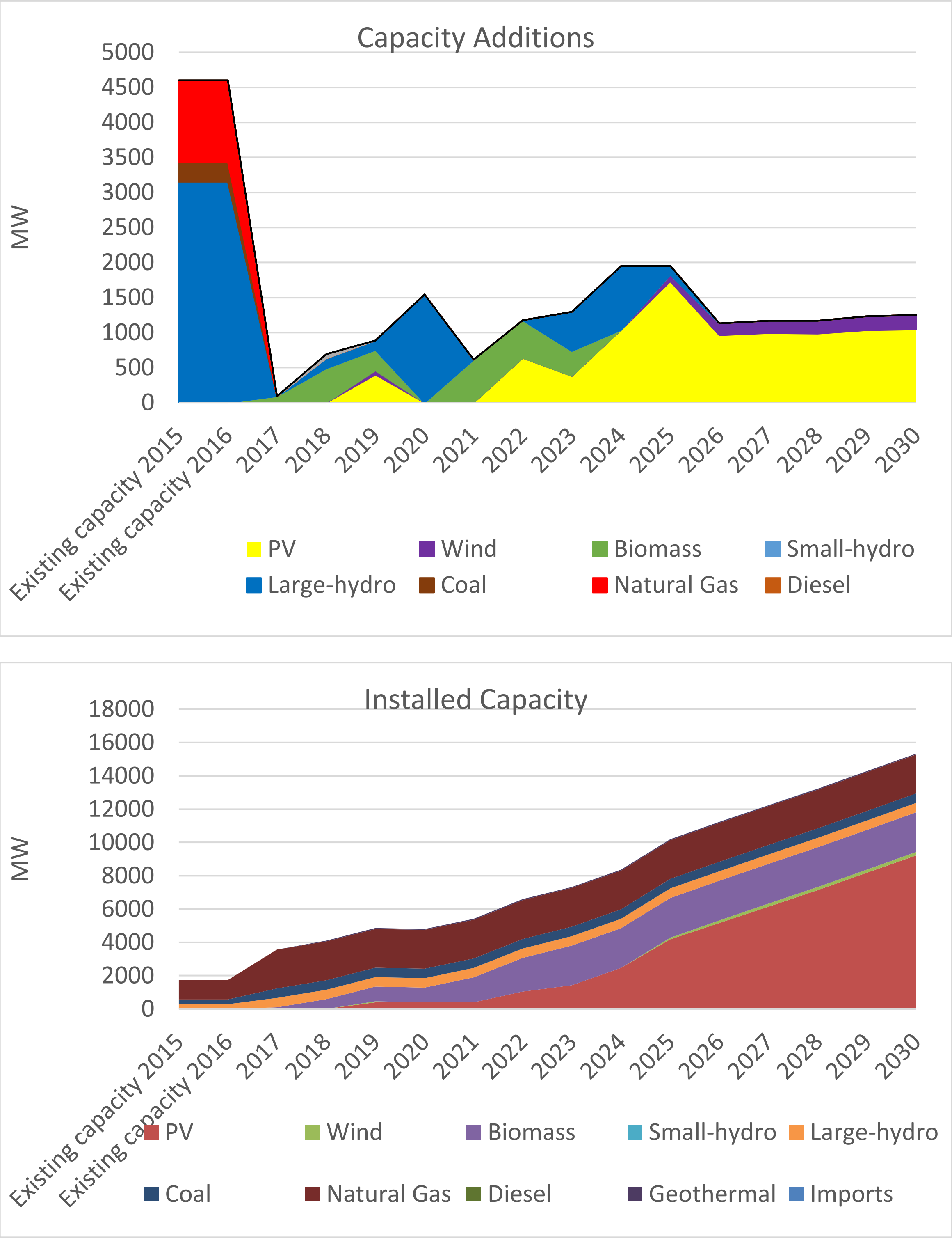
**Figure 3-2. Planned Business as Usual Capacity Expansion Based on JICA Scenarios**





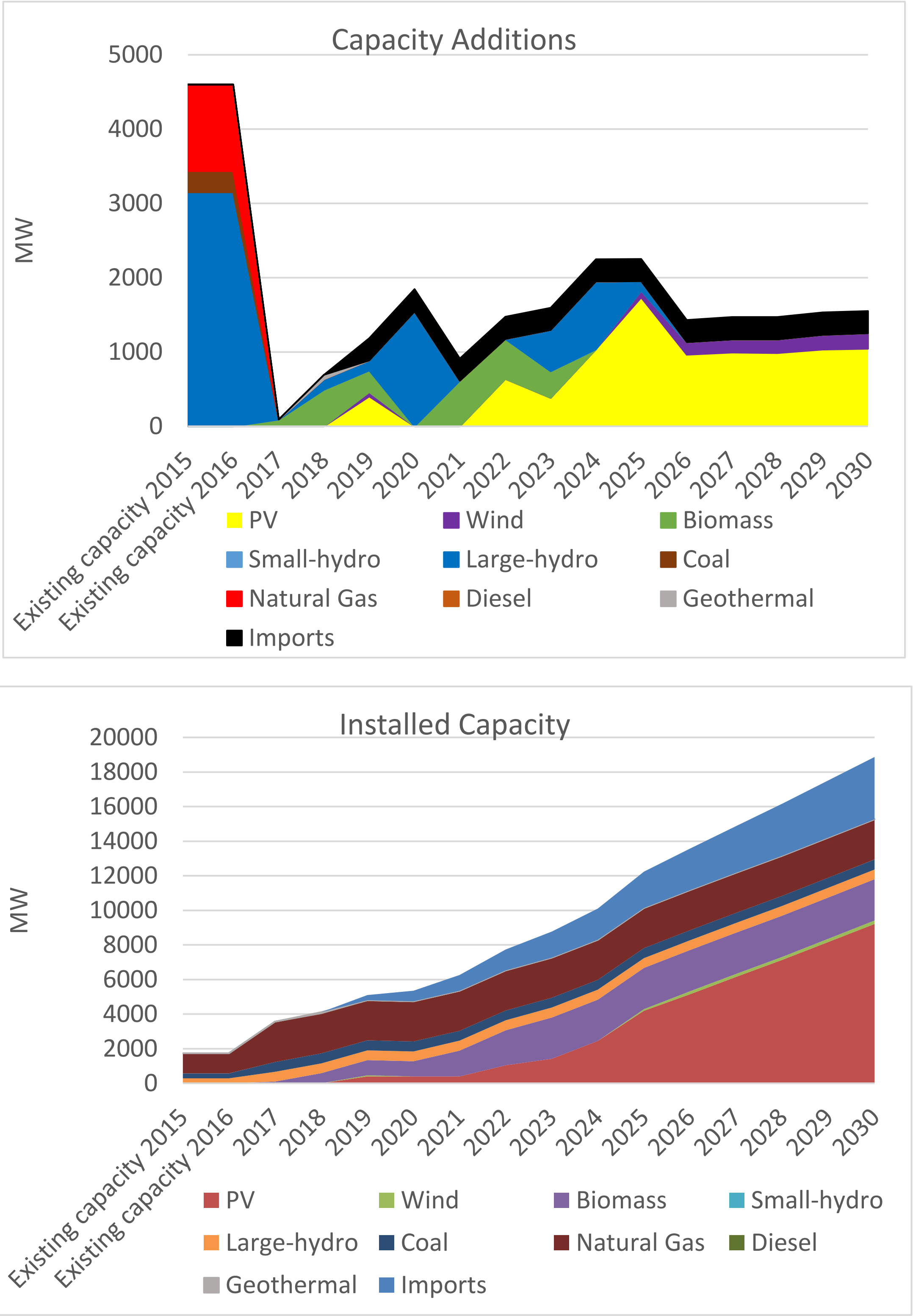
Source: Authors.

**Figure 3-3. Low-cost Solar Capacity Expansion Case**



Source: Authors.

**Figure 3-4. ASEAN Power Grid Participation Capacity Expansion Pathway**



MW = megawatt.

Source: Authors.

The optimisation process considers all candidate dam sites in Myanmar to find optimal dam portfolios. Dams that are already commissioned are included in all portfolios. Those in China are outside the spatial scope of this analysis, but could be easily included in a next step.

‘Sustainable’ hydropower in the country is then defined here as hydropower that does not trap more than 50% of the total incoming sediment in both rivers, and not more than 50% of the sediment in either river.[2] Both the Salween and Irrawaddy rivers have a hydroelectric potential of around 70 GW. Fully developing that potential would result in trapping around 60% and 70% of the total incoming sediment, respectively. Such would impact the sediment budget of the Salween river much more (< 90%) than that of the Irrawaddy river (<60%).

For portfolios that do not trap more than 50% of sediments in either river, there is a clear break point; that is, a limit for sustainable hydropower. Developing portfolios with more than 150,000 GWh/yr of hydropower production would lead to disproportional sediment trapping. Hence, it is proposed in this study that such production value be the limit for sustainable hydropower production.

It should be noted that this break point is not evident when considering all pareto-optimal portfolios, which follow a nearly linear trade-off between hydropower production and sediment production. However, pareto-optimal portfolios with high production would require trapping most of the sediment in the Salween river and are therefore not considered sustainable.

### 3.3 Discussion and Policy Recommendations

The proposed JICA pathway would incur higher direct costs to investors even before one starts considering the ecological impact of river ecosystems in the Irrawaddy and Salween basins. Furthermore, by identifying opportunities where solar, wind, and biomass generation are less expensive than large-scale hydro-power, the analysis highlights the fact that there are lower-cost options that can meet the same amount of electricity demand for in-country use and export without trapping large quantities of sediments. Therefore, this study (i) proposes an alternative sequencing to hydropower development that sustains the country’s electricity supply and

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[2] It can be debated if this is a good strategy or if one should allow for ‘sacrificing’ one river. However, that will also depend on the results of the energy model.

economic development; and (ii) identifies the most problematic hydropower dam sites that could instead benefit from solar, natural gas, biomass, and small-hydro substitution as electricity generation technologies.

Contrary to the JICA report, this study finds that when including realistic assumptions for alternative energy resources, results will show that future capacity expansion *can* utilise more solar photovoltaic than hydropower on a least-cost development basis. The use of solar photovoltaics becomes possible due to (i) its falling costs; and (ii) the potential for distributed energy resources to leapfrog centralised utility-scale fossil plants.

The authors of this study now plans to identify those dams that are not cost-optimal as well as contribute to the greatest amount of sediment trapping. Moreover, they are already identifying the most damaging hydropower plants that are in the pipeline and finding alternative sources that can meet the future electricity demand of the country.

Based on the modelling results, the next step for this study team is to consult with relevant government agencies so as to understand the viability of different scenarios, including the design of alternatives, and draw up the resulting recommendations. Beyond simply evaluating the investment characteristics, each scenario should include future stakeholder consultations on the feasibility of a smooth transition. Future positions on hydropower plans and large-scale energy investment are critical in understanding the energy transition in Myanmar.

Further study is necessary to implement the cost sensitivities into the optimisation framework. Additionally, there is a need to decide how to incorporate some of the distributed energy resources, including solar-based mini-grids and existing mini-hydropower plants that are in operation, but lack grid connections.

Small-scale hydropower complements solar power well, and local businesses in rural areas could do well to scale by attracting capital investment in areas where local small-scale hydropower installations have been operating for decades.

Finally, the research team acknowledges that the investment community needs to be considered, whether that be to pay closer attention to increased investment from Singapore relative to China or to understand the controversy and ongoing discussions on the Myitsone power plant within the National League for Democracy (Kittner and Yamaguchi, 2017).

The modelling results highlight that under a least-cost framework, distributed energy resources contribute as electricity generation options and are built before investing in large-scale hydropower and thermal projects. This has significant implications on power sector planning and implies that the high penalty cost of transmission for large-scale projects may face future cost overruns. Investors that are interested in promoting sustainable energy options in Myanmar have significant options available and solar resources to use at low cost.

Furthermore, if concomitant investment in regional transmission interconnections are made (thus expanding the viability for affordable imports and power trade), Myanmar can take advantage of electricity surplus from Thailand, Lao PDR, and China, and trade electricity in an integrated ASEAN market. This could lower the levelised cost of electricity compared to the business-as-usual case by 31%. Such significant cost savings justify the promotion of regional coordination and cross-border independent power producer agreements. Even if transmission interconnection projects falter and face higher costs, the second scenario in this study – which investigates the role of distributed solar power – shows cost savings of 20% relative to the base case scenario. The second scenario also eliminates future investment in thermal generation, given that there is now an oversupply of existing generation and low-cost availability of small-, medium-, and large-scale PV resources.

To summarise, there are three key takeaways from the energy pathways modelled here:

- The amount of hydropower needed is a function of different expansion strategies for renewables in the basin and can be significantly reduced when alternative options are considered.
- The base case would require nearly four times more hydropower capacity than a solar-based alternative that meets similar energy demands. This allows for minimal river and human impacts on resettlement.
- Either utilising low-cost solar power or participating in the ASEAN power grid would yield better economic and environmental performance compared to the business-as-usual pathway based on initial capital cost, levelised cost of electricity, and combined sediment trapping/river fragmentation between the Salween and Irrawaddy river basins.

As foreign direct investment targets Myanmar in its next wave of Green Climate Funding and other development-based finance, investors should take note that projected returns on hydropower and thermal investments may lead to future stranded assets. The emergent role of decentralised energy options would allow investors to improve the climate and public health by replacing expensive diesel generators, and simultaneously offering a viable alternative (Alstone et al., 2015). The abundant, low-cost availability of solar and wind power, and options to balance loads with transmission interconnections in a regional power grid undercut the cost of planned large-scale plants, making a significant economic argument for distributed energy.

Previous national electrification plans that treat solar and mini-hydropower as purely off-grid options should be revisited and updated. This time, the plans should reconsider their ability to provide flexible grid-scale resources both as rural electrification options and as alternatives to the large-scale hydropower dams that have been ecologically damaging.