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ALTERNATIVE DEVELOPMENT PATHWAYS

for Thailand's Sustainable Electricity Trade with Laos

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ABSTRACT

In order to guarantee national energy security, Thailand has for decades promoted a diverse energy mix which includes imports from neighboring countries. In 2016, Thailand established a Memorandum of Understanding (MOU) with Laos to purchase electricity from 9,000 MW of generation capacity. Laos is moving forward with a set of proposed dams on the mainstream of the Mekong River which could meet this MOU, but dams disrupt the natural flow of fish, sediment, and nutrients, threatening communities that depend on the Mekong's food, income, and overall security. Reducing future electricity imports from Laos would be complicated given the MOU, but existing excess capacity, the renewable energy transition, and market shifts in Thailand provide an opportunity to reconsider the timing and type of electricity that Thailand chooses to import. This study explores four potential energy scenarios and investment portfolios across a range of key policy, economic, environmental, and social considerations to provide strategic insights about the energy development pathways Thai policymakers could choose to pursue.

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KEY ACRONYMS

ACMECS	Ayeyawady – Chao Phraya – Mekong Economic Cooperation Strategy
AEDP	Alternative Energy Development Plan
ASEAN	Association of Southeast Asian Nations
CBAM	Carbon Border Adjustment Mechanism
CO2	carbon dioxide emissions
EEP	Energy Efficiency Plan
EGAT	Electricity Generating Authority of Thailand
ESG	Environmental, Social, and Governance
EU	European Union
EV	electric vehicles
FiT	Feed-in Tariff
GDP	Gross Domestic Product
GO	Guarantees of Origin
GW	Gigawatt
GWh	Gigawatt-hour
IFC	International Finance Corporation
i-REC	International renewable energy certificate
kWh	Kilowatt-hour
LCOE	Levelized cost of electricity
LNG	Liquified natural gas
MOE	Ministry of Energy

MOU	Memorandum of Understanding
Mt	Megaton
MW	Megawatt
MWh	Megawatt-hour
PDP	Power Development Plan
PNPCA	Procedures for Notification, Prior Consultation, and Agreement under the Mekong River Commission
PPA	Power Purchase Agreement
PV	Solar photovoltaic
REC	Renewable Energy Certificate
THB	Thai baht

Photo of electricity lines in Phuket, Thailand is under public domain and supplied courtesy of Mussi Katz's Flickr account.

INTRODUCTION

In order to guarantee national energy security, Thailand's decision makers have for decades promoted a diverse energy mix which includes imports from neighboring countries. As part of this plan, Thailand has turned to neighboring Laos for power imports via Laos's Battery of Asia scheme. In 2016, Thailand established an MOU with Laos to purchase electricity from 9,000 MW of generation capacity over the following two decades to help meet Thailand's energy demand. As of early 2021 Thailand was importing approximately 5,500 MW of electricity from coal and hydropower projects in Laos out of the planned 9,000 MW. Thailand's Power Development Plan 2018 rev.1 lays out plans to purchase an additional 3,500 MW from unspecified projects through 2037. This rose to 5,720 MW of imports by July 2021 and Thailand has agreed to purchase an additional 1,200 MW of electricity on top of the 9,000 MW.[1] Laos is continuing to move forward with a set of proposed dams on the mainstream of the Mekong River which could meet this additional capacity.

The remaining 3,500 MW of power generation committed under Thailand's MOU with Laos is small compared against regional plans to build 170,000 MW of generation in coming decades. However, Thailand's decision about which projects to purchase electricity from will have broad implications for the Mekong's ecology and the tens of millions whose livelihoods depend on it. The Mekong River plays a defining role for mainland Southeast Asia, supplying the world's richest and most productive freshwater fishery; replenishing nutrients to agricultural land along riverbanks and on floodplains; and delivering sediment to coastlines along the Mekong Delta. It also provides a key source of electricity to nearly 70 million people living in the river basin and beyond. Hydropower dams make up the majority of projects in Laos which Thailand is considering, but dams disrupt the natural flow of fish, sediment, and nutrients, thereby threatening communities that depend on the Mekong's food, income, and overall security.

While hydropower was historically the only economically competitive alternative to fossil fuels, the global power market has significantly changed over the last five years. Other renewable energy technologies such as wind and solar PV are now on competitive footing with new fossil fuels and hydropower projects. For example, in Cambodia the purchase price of solar at auction dropped nearly 60% from $0.091/kWh for a pilot project in 2016 to $0.0388/kWh in 2019 at a larger solar park. While solar projects without battery storage do not provide firm generation, grid management and integration approaches adopted in the United States, Europe, and the Global South are supporting higher levels of renewable energy than previously anticipated. The cost of lithium-ion battery storage technologies dropped 87% from 2010 to 2019 and are now commercially viable when paired with new solar or wind generation in some markets.[1]

The current status of the energy system and trends that impact Thailand's power sector—such as existing excess capacity, increasing domestic deployment of distributed solar, and increasing adoption of electric vehicles and battery storage technologies—suggest that Thailand may not actually need to pursue additional investments and power imports from dams in Laos.

Thailand is currently a major investor in power generation throughout the Mekong region: Thai companies are involved in 60% (6,267 MW) of the existing power generation in Laos and in many planned projects.[2] Laos has limited access to financing on its own, meaning that Thailand influences which power generation projects move forward in Laos by providing direct investment and revenue guarantees in the form of power purchase agreements. Reducing future electricity imports from Laos would be complicated given Thailand's existing MOU, but the existing excess capacity and market shifts in Thailand provide an opportunity to reconsider the timing and type of electricity that Thailand chooses to import. The excess electricity provides Thai policymakers with time to carefully consider the timing of power imports, how imports from Laos could support rapidly rising domestic renewable energy production, and how power purchases impact goals to work towards carbon neutrality.

This study explores four potential energy scenarios and investment portfolios that Thailand could pursue through power purchases with Laos. Each scenario is informed by the plausible system shocks and energy trends discussed above and potential policy decisions that Thailand might pursue in the near future and is in line with best planning practices in the international energy sector. The scenarios include:

Scenario 1: Business-as-Usual Scenario, which includes dams on the mainstream of the Mekong currently under consideration by the Ministry of Energy. This scenario is derived from an historical baseline but is becoming increasingly unlikely given rising public pushback and indication from Thai authorities that the potential impacts on communities in Thailand, Laos, and Cambodia make them an unattractive option. However, these projects have not officially been ruled out.

Scenario 2: Tributary Dam Scenario, wherein Thai decision makers choose to avoid dams on the mainstream of the Mekong due to concerns about social and environmental impacts on Thai communities and instead prioritize purchases from projects on tributaries to the Mekong inside Laos. This scenario prioritizes hydropower under the assumption that Thailand prefers dispatchable electricity but also includes a limited amount of solar imports from Laos.

Scenario 3: Floating Solar Scenario, wherein Thailand purchases power from floating solar projects built on the reservoirs of dams currently exporting electricity to Thailand via existing transmission lines. This scenario anticipates that Thailand has a successful experience deploying floating solar domestically and chooses to support similar projects in Laos rather than build new dams.

Scenario 4: Domestic Renewable Energy Scenario, wherein Thailand retains its commitment to purchase 9,000 MW of electricity from Laos but holds off on new power purchases until after the current planning framework ends in 2037. In this scenario the 3,500 MW originally sourced from imports in the Power Development Plan 2018 rev.1 would be replaced with domestic solar PV.

Scenario 1 is most similar to Thailand's past power purchasing approaches and includes hydropower projects directly suggested by the government of Laos to Thailand in discussions about electricity trade. Recent comments about mainstream Mekong dams from Thailand's Office of National Water Resources indicate that decisionmakers inside Thailand may be rethinking purchases from these projects.[3]

The impacts of these four illustrative scenarios are analyzed across a range of key policy, economic, environmental, and social considerations to provide information and strategic insights about the energy development pathways Thai policymakers could choose to pursue. If Thai policymakers incorporate factors such as cost, environmental sustainability, and multi-sector impacts into their decisions to invest in and trade electricity with neighboring countries, Thailand could play a leading role in helping shift Laos towards a more diverse and sustainable development trajectory while also working towards carbon neutrality, meeting Thailand's commitments under the Paris Agreement, and supporting regional progress towards the sustainable development goals.

INFLUENCES IN THAILAND'S ENERGY SECTOR

Thailand's Ministry of Energy has institutionalized regular updates and revisions to the national power planning process and is currently developing a new National Energy Plan in 2022. This process includes reassessment of current electricity demands and projections as well as adjustments to target generation technologies in line with Thailand's Nationally Determined Contributions under the Paris Agreement and other policy decisions such as slowly moving towards decarbonization of the power sector.

While power market disruptions from the clean energy transition and COVID-19 pandemic are felt globally, the impacts in Thailand intersect with a number of existing national challenges and policy changes ranging from excess electricity capacity to increasing interest in carbon neutrality. In examining potential pathways for Thailand's electricity trade with Laos, the following policy drivers, market shifts, and technology trends were given consideration. All of these trends are in line with Thailand's current operational, environmental, and planning priorities and consider best practices and global trends.

Policy Trends

Anticipated updates to Thailand's Power Development Plan (PDP). Thailand regularly updates its national power development plans approximately every three to four years. The speed of market changes in recent years have led to notable differences between the planned energy generation mix between PDP2015 and PDP2018 rev.1. PDP2018 rev.1 increased the planned share of renewable energy in 2037 by 1% and reduced the role of imported hydroelectricity from 18% to 10%.[4] PDP2018 rev.1 also relatively increased the share of fossil fuels, albeit in a way that supports long-term emission reductions: the share of coal decreased from 23% to 13%, the share of natural gas rose from 37% to 53%. This is in part because the PDP set balancing between economic, environment dimensions, and energy security as a guiding pillar. Natural gas has low generation cost and comparatively low CO2 emissions compared to coal. While natural gas imports and hydroelectricity from Laos are subject to similar concerns over supply dependency, Thailand can store natural gas reserves and has many supply sources from the global market.

The Ministry of Energy produced a revision to PDP2018 in mid-2020 in response to divergences between short-term plans and real-world conditions. PDP2018 rev.1 included reductions in residential solar program targets due to low buy-in; increasing the role of community based power plants; increasing planned biogas generation capacity; and extensions to the lifetime of existing coal plants which produce electricity at relatively low cost.[5] The 2020 revisions to PDP2018 provide some indication of how the system may change in response to further market shifts in the next power development plan which is expected to be released in 2022.

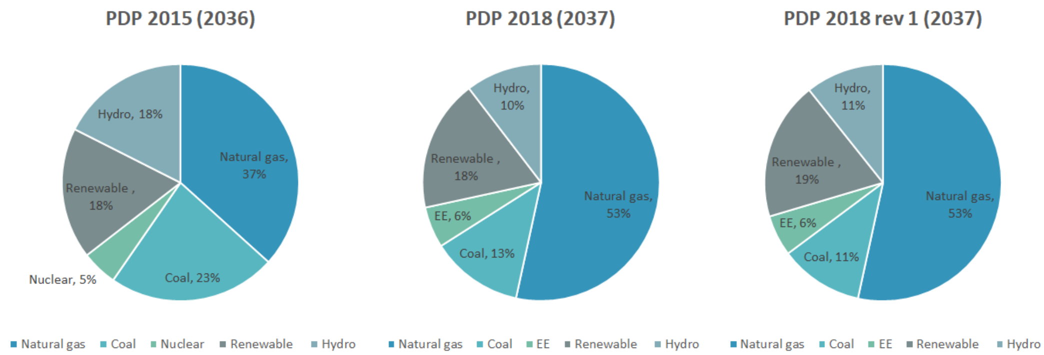


Figure 1: Energy generation mix under different Power Development Plans (in billion Wh). Graphic courtesy of author Dr. Siripha Junlakarn, utilizing data from each of the Power Development Plan documents.

Evolving official renewable energy targets. Thailand's official Alternative Energy Development Plan (AEDP) 2018 sets a new target to increase alternative renewable energy technology to 29,411 MW by 2037, or approximately 34.23% of the total installed capacity.[6] This is higher than the AEDP2015 target of 20.11% in 2036.[7] Thailand currently has approximately 11,000 MW of renewable energy capacity and AEDP2018 expects to add 18,696 MW of new capacity by 2037. This is a breakdown of the AEDP 2018 targets:

	AEDP 2015 Targets (MW)	AEDP 2018 Targets (MW)	Estimated Potential (MW)
Solar	6,000	12,015	50,000
Biomass/biogas/waste	7,726	5,127	7,000+
Wind	3,000	1,485	13000
Small Hydropower	376	69	700
Community power plants for the local economy project	N/A	1,933	N/A

Data in the chart is taken from AEDP2015, AEDP2018, Thailand Power Sector Vision 2050,[8] Renewable Energy Outlook: Thailand.[9] Small-scale hydropower data and biomass data are taken from a range of sources.[10] The community power plants may include small-scale biomass/biogas projects but are calculated separately.

While solar will compose a major portion of renewable installed capacity, there have been challenges in rolling out residential rooftop solar along the anticipated timeline as well as regulatory issues related to the deployment of wind power. As a result, the residential solar target has been reduced from 100 MW per year to 50 MW per year for 10 years and the target for wind capacity has been reduced. Much of the new solar capacity added under PDP2018 and PDP2018 rev. 1 are floating solar plants.

Changes to the national power reserve margin. Thailand has maintained a relatively high reserve capacity in recent decades, which is beneficial for supply security but comes at the cost of maintaining idle generation capacity. Power planners anticipate the need for excess or reserve capacity to help manage sudden spikes in demand or respond immediately to temporary supply disruptions, and general global practices usually lead to a preference for reserve capacity of approximately 15% beyond projected peak demand. Thailand's excess electricity capacity has historically been in the range of 40%.[11] This is in part a result of preferences for a higher than average reserve capacity, but one major factor is historical overestimates of GDP and electricity demand growth. A 2004 review indicated that ten out of eleven of Thailand's most recent energy forecasts had overestimated electricity demand growth.[12] This has led to a slowly rising excess electricity above what is needed to meet peak demand and ensure reserve capacity, and means that over time EGAT has been signing PPAs with a minimum offtake requirement for electricity that Thailand does not need.

The COVID19 economic downturn has negatively impacted electricity demand globally, putting financial pressure on utilities. This impacted the Electricity Generating Authority of Thailand (EGAT) as well by providing additional pressure to reduce payments for excess electricity. Recent statements from EGAT commit to reducing the expensive-to-maintain electricity reserve margin from 40% to 15%.[13] While this could change as the economy rebounds or in response to rising penetration of variable renewable energy, the existing excess in the system provides some opportunity for Thailand to strategize about how to best build out its future power system by reducing immediate pressure to sign new power purchase agreements.

Thailand's stated goal of becoming an electricity trading hub for ASEAN. Thailand aims to become an electricity trading hub in the Association of Southeast Asian Nations (ASEAN) through expanding its high-voltage transmission lines and transmitting hydroelectricity from Laos and selling it to markets in Malaysia, Singapore, Cambodia, and Myanmar.[14] Thailand, Laos, and Malaysia have already committed to making about 300 MW of electricity capacity available for trade starting in 2021 as part of a power integration project.[15] After years of consideration, Singapore agreed to join this project and start importing 100 MW of electricity in 2020, sold from Laos through Thailand and Malaysia.[16] EGAT has also started talks with Cambodia and Myanmar to sell some of Thailand's excess electricity starting in 2023. As Cambodia and Myanmar have faced electricity shortages in recent years. The sale to Cambodia will be faster than to Myanmar as some transmission lines have already been developed in Cambodia.[17]

In September 2020, EGAT began a six-month study on wholesale electricity markets as an initial step towards becoming an electricity trading hub.[18] Following the initial phase of the study, EGAT signed a cooperation agreement with the Stock Exchange of Thailand to conduct a more in-depth study of a trade-oriented market model. The partnership also aims to explore trends in the electricity industry and adopt electricity trading regulations that suit Thailand's goal of becoming an electricity trading hub. This is a long-term policy goal for Thailand and will require both physical infrastructure upgrades as well as expansion of MOUs and power purchase agreements with neighbors, improved coordination with neighboring grids, and regulatory changes. The scenarios considered the role that electricity imports and resale might play in regional trade.

Pressures to reduce carbon emissions from the power sector. Thailand has committed under the Paris Agreement to reduce its greenhouse gas emissions by 20-25% from the business-as-usual projections by 2030, which is equivalent to 110-140 Million tons of carbon dioxide equivalent.[19] In early 2021 in response to global pressures to move towards carbon neutrality, Thailand started to draft a long-term plan to reach net zero carbon emissions.[20] The plans, targets, and timelines for the energy, transport and industry sectors to achieve carbon neutrality are currently under discussion. The energy sector is one of the main CO_2 contributors, and the reduction of CO_2 emissions can be implemented through changing the power mix to favor renewable energy, developing the electric vehicle (EV) industry, and deployment of bio- circular and green economy approaches to improve waste and energy efficiency.

Thailand considers carbon pricing as one of the core action plans to reduce emissions and has experimented with a multi-phase voluntary pilot carbon trading market.[21] Growing pressures from international trade partners to implement a carbon border adjustment mechanism have prompted attention to relevant policy and supporting mechanisms. The Ministry of Energy has investigated emission trading system regulations that could help support the growth of renewable energy under Thailand's domestic power market structure. One of the emission trading systems that has caught Thai government interest is the renewable energy certificate (REC) system. REC is a market-based instrument that allows producers to trade the property and use rights of electricity produced by renewable energy resources. REC can be traded around the world through the international renewable energy certificate (i-REC). The Electricity Generating Authority of Thailand, the national utility responsible for bulk electric energy sales, entered this business by signing on as the official i-REC issuer for Thailand. The first REC was sold in October 2020 to Toyota, and other international firms operating in Thailand have expressed interest in REC to help meet company-level sustainable energy targets.[22] This is a burgeoning market and is likely to grow in the future as various stakeholders push for decarbonization of the energy sector. All scenarios consider the pressure to avoid further fossil fuel investments.

Changing Thai government stance on mainstream Mekong dams. Thailand has long been the primary market for hydroelectricity produced inside Laos, and this included signing a power purchase agreement for the Xayaburi Dam, which was the first mainstream dam on the Mekong. Other mainstream dams including Pak Beng, Pak Lay, and Sanakham Dam have gone through mandatory review processes with statements that the projects intended to sell power to Thailand. However, the politics surrounding mainstream Mekong dam power imports have shifted. Shortly after the Xayaburi Dam was completed in 2019, a severe drought and operational practices of upstream dams in China led to low river levels and lower than anticipated power generation at Xayaburi and other dams in the basin. There was also the almost unprecedented phenomena of a clear blue Mekong River, which indicates a severe lack of the river's normal sediment load which impacts fisheries and riverbank agriculture. This received significant media coverage, and the general public in Thailand now has better understanding and awareness of potential transboundary impacts of imported electricity from mainstream hydropower dams in Laos.

For many years, civil society movements in the Golden Triangle area and the eight riparian provinces of Thailand have actively pushed back against mainstream Mekong dams due to concerns over impacts on Thai communities. This civil society movement has birthed the Mekong Council, which has submitted legal complaints against EGAT for violation of constitutional requirements requiring consideration of impacts and an obligation to ensure the rights of affected Thai communities when signing a Power Purchase Agreement for the Xayaburi Dam. The same community also issued a public statement requesting that the government not purchase power from the Luang Prabang Dam.[23]

The combination of rising public awareness and continuous news media coverage of issues linked to hydropower appears to have prompted the Thai government to change its stance on purchasing electricity from dams on the mainstream of the Mekong River. Although the Pak Beng project went through the mandatory review processes under the Mekong River Commission with a stated plan to sell the produced electricity to Thailand, no power purchase agreement with Thailand has yet been signed. In mid-2020, the head of Thailand's National Mekong Committee called for international monitoring of the Luang Prabang Dam given potential impacts on the shared river.[24] EGAT indicated that it also had not yet decided to sign a PPA for the Luang Prabang dam.[25] And more recently, the Thai government outright rejected the transboundary EIA on the proposed Sanakham Dam and some officials indicated that they didn't need the electricity.[26] There has been significantly less public dialogue about the potential impacts of tributary dams.

Thai Villagers outside Ch. Karnchang HQ, photo used under Creative Commons license courtesy of International Rivers Flickr account.

Renewable Energy and Disruptive Technologies

Energy Efficiency Improvements. Thailand's most recent Energy Efficiency Plan 2018 (EEP2018) aims to decrease final energy consumption in 2037 by approximately 30% from the business-as-usual projection of 181,238 ktoe to the implemented energy efficiency plan case of 126,867 ktoe (Figure EE-1). According to the EEP2018, the cumulative energy saving during 2011 to 2017 is 5,307 ktoe. There are two methods identified for achieving the target: (1) decrease overall energy consumption by 49,064 ktoe, and (2) reduce the peak demand by 4,000 MW. Strategies which can be used to decrease energy consumption include mandatory efficiency requirements for equipment and construction, promotion and support of energy conservation, and behavioral changes.

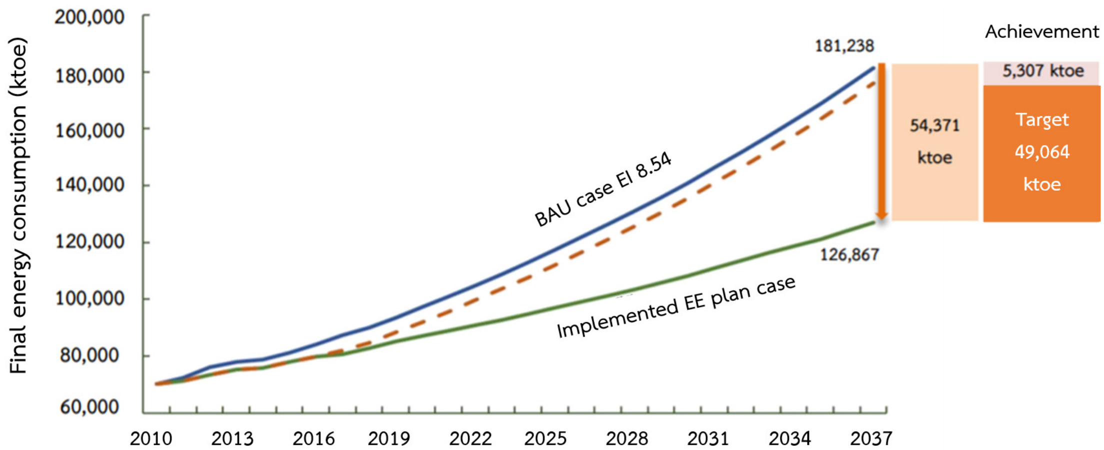


Figure 2: Target of energy efficiency plan in 20 years (2018-2037).[27] Graph courtesy of Dr. Siripha Junlakarn.

Electric Vehicle Deployment and Energy Demand. The deployment of EVs will significantly reduce CO2 emissions from the transportation sector, and EVs were mentioned for the first time in Thailand's Energy Efficiency Plan 2015 as a pathway toward energy savings. The plan included a target of deploying 1.2 million EVs cumulatively by 2036.[28] In 2021 a new target of 15.58 million vehicles cumulatively by 2035 was set as part of a push for zero emission vehicles, split across 6.4 million passenger cars and pickup trucks, 8.75 million motorcycles, and 0.43 million buses and trucks.[29] The impacts of the new EV target on electricity demand projections are likely to be incorporated into the new PDP in 2022 and have not yet been published. However, the previous target of 1.2 million of EVs was expected to increase electricity demand by about 3,000 GWh, or approximately 1% of the 2030 electricity demand estimates in PDP2015.[30] As Thailand moves forward with electrification of the transportation sector, this will decrease CO2 emissions even if electricity is still generated from fossil fuels due to the higher efficiency of EVs compared to internal combustion engines. If electricity for EVs is supplied from renewable energy, then the transport sector would vastly reduce carbon emissions.

Big C celebrates first solar rooftop system, photo by Richard Nyberg and used courtesy of USAID Asia's Flickr account under a Creative Commons license.

Deployment of rooftop or distributed solar. Thailand began rolling out a rooftop solar market in 2013 with the introduction of a two-year Rooftop Feed-in Tariff (FiT) program, which offers premiums for generating PV electricity and exporting it into the grid. The Rooftop FiT program provided a quota of 200 MW power purchase agreements to be signed with distributed solar generators, with 100 MW for commercial rooftops at a fixed price of 6.96 baht/kWh and another 100 MW for residential rooftop solar at a fixed price of 6.55 baht/kWh.[31] The quota of 100 MW for commercial and industrial systems was fully subscribed in 2013. Residential rooftop solar adoption was slower with only 31.28 MW subscriptions in the first year, motivating the government to raise the residential rooftop FiT 6.85 Baht/kWh in 2014. Later in 2015, the FiT program was replaced by the self-consumption policy to allow distributed solar to directly meet demand on site and therefore reduce the draw on the grid.

The government introduced a new net billing program in May 2019. The new net billing program was launched with targets of 100 MW of residential rooftop solar annually through 2027 and of 1,000 MW per year from 2028 to reach a total of 10,000 MW by 2037.[32] This program is in line with Thailand's PDP 2018, which aims to reach a total of 12,725 MW of installed solar capacity by 2037. Unlike the earlier FiT policy, the new rooftop solar policy limits the size of solar systems to no more than 10 kW per system and caps purchases at 1.68 per baht/kWh under a 10-year contract. Subscription in the first year was very slow, with less than 3 MW out of 100 MW. In response, in 2021 the government increased the purchase price from 1.68 THB/kWh to 2.20 THB/kWh to attract more participants. However, this is still significantly less than the 2.36 THB/kWh to 3.20 THB/kWh prices offered to wholesale producers.[33]

Changes to grid management due to rising numbers of prosumers. With the increasing integration of rooftop PV systems into the distribution grid, there is a growing role for prosumers, who unlike traditional consumers both produce and consume electricity and are able to sell excess generation back to the grid. The increasing number of prosumers has implications for the distribution grid due to their changing behavior in electricity consumption. In 2018 there were only 72 MW of installed capacity among commercial and industrial users; as of 2021, this had risen to 343.86 MW.[34] Typically, electricity generation from solar panels occurs when sunlight is available. During the day, prosumers mainly use electricity from their own generation on site or sell excess generation to the grid. These prosumers also consume electricity from the grid when there is a shortage of local solar production at night or other times when there is no sunlight. As a result, the amount of electricity that these prosumers draw from the grid is less than that of a traditional consumer, while the complexity of power system control and planning increases given the rising number of variable producers.

Operational experience managing floating solar projects and growing buy-in for the technology. While solar is undergoing a global boom in investment, floating solar occupies a relatively niche market. It accounted for only 2.6 GW of all solar installed globally as of August 2020, but is growing rapidly and investment is driven by developing Asia.[35] Floating solar has numerous efficiency benefits compared to traditional ground-mount solar: building floating power systems on lakes or dam reservoirs avoids high land rental or purchase fees; floating solar panels receive natural cooling from the water below, which improves efficiency; and it is possible for floating solar projects to plug into existing transmission lines that have been built out to the hydropower plants.[36] Developing hybrid floating solar and hydropower plants also helps avoid seasonal imbalances in production: solar is most productive during the dry season when hydropower's capacity drops due to low reservoir levels, and conversely during the wet season hydroelectric dams can operate at full or near full capacity while solar production drops due to cloud cover. Thailand's PDP2018 includes plans for 2,725 MW of domestic floating solar generation by 2037. A 2 MW pilot project came online to support local industrial production in February 2021, and a 45 MW floating solar plant on the Sirindhorn Dam in Ubon Ratchathani is anticipated to come online in September 2021.[37] Laos is proceeding with a 1,200 MW floating solar project on the Nam Ngum 1 Dam and a 240 MW floating solar project on the Nam Theun 2 dam, which of which currently sell electricity to Thailand.[38] If Thailand's initial floating solar projects are successful, Thai investors and EGAT could look to build on this successful experience through investing abroad as they have done with traditional hydropower projects.

Shocks to the Power Sector

Potential external carbon tax on exports. The implementation of climate incentives such as a carbon tax may pressure export-oriented industries in Thailand to move away from fossil fuel energy source in order to sell to major international markets. One example is the carbon border adjustment mechanism (CBAM), which is in the process of being established by the EU under the European Green Deal in 2023.[39] [40] [41] Under the CBAM, a carbon price would be placed on specific goods imported from outside the EU that produce high carbon dioxide emission, such as metals and batteries. While the United States and Japan do not yet have a clear path for a carbon price, the United States rejoined the Paris Agreement in 2021 and has a target to reduce 50-52% of carbon dioxide emission from 2005 by 2030 and Japan has set a goal of net-zero emissions by 2050.[42] [43] Both countries have expressed interest in a carbon border tax and this could impact Thailand seeks to export to their markets. A global carbon tax mechanism has drawn significant concern from emerging and developing countries since it is complex and could lead to an unfair burden. However, it remains a possible future shock to the power sector that should be considered in national energy planning processes.

COVID-19 impacts on the energy sector. COVID-19 caused many serious disruptions to the global economy, and although Southeast Asia effectively managed the spread for much of 2020, the economy suffered. Southeast Asia's GDP contracted 4% in 2020, and Thailand's GDP suffered a 7.8% contraction.[44] This was driven in part due to a drop in global demand for goods and in part by major supply chain disruptions due to quarantines and lockdowns. This had a major impact on electricity usage in many countries, with manufacturing and commercial demand dropping. Thailand's Energy Policy and Planning Office reported a 3% year-on-year decline in total electricity demand for 2020.[45] This has impacted infrastructure pipelines: quarantines and lockdowns have disrupted movement of the workforce and supply chains for key infrastructure projects, causing delays to many projects and increasing risk on future projects for investors.[46] While the region's long-term electricity demand will likely recover along with economic activity, given the spread of the highly infectious COVID Delta variant in mid-2021 and a relatively slow vaccination rate in Southeast Asia it is likely that quarantines and occasional lockdowns will cause continued disruptions on a situational basis. Combined with excess electricity, this potentially reduces pressure to sign new agreements in the immediate term and allows for strategic planning down the road as the economy and electricity demand both recover fully.

Changing role of natural gas in future power system. Natural gas is globally considered as a bridge fuel in the ongoing energy transition. As demand for energy is continuously increasing, environmental concerns will ultimately require fossil energy to be phased out. Given that renewable energy generation like solar and wind are intermittent, it will be technically challenging and expensive to fully shift to 100% variable renewable energy until energy storage becomes commercially available. Natural gas provides the fastest and most economic path to a less carbon intensive future and policymakers in Thailand consider it as a bridge fuel to replace coal while energy storage technology and other alternatives are developed and scaled up. In response to targets of reducing carbon emissions, Thailand's PDP 2018 turned back toward utilizing more natural gas when compared to the PDP 2015 which prioritized new coal projects. In addition, the Thai government plans to establish a free-trade hub for liquefied natural gas in this region which will allow both state agencies and private companies to import and export LNG. Within this context, EGAT aims to import natural gas for domestic power production. However, the inflexible power purchase agreement of natural gas is a barrier to integrating more renewable energy in the power system.[47] As Thailand currently has high reserve capacity and has signed inflexible and long-term power purchase agreements with existing plants, it is difficult to incorporate new renewable generation in the near future. If new generation is brought online without corresponding retirement of older plants or a rise in demand growth, it will lead to growing excess and an increase in electricity cost for the country.

As Thailand moves in future to fulfill its electricity trade MOU with Laos and purchases additional power, all of the above considerations are likely to factor into the individual projects and power sources that Thailand selects. All of these policy processes, market trends, and technological developments were considered in designing the scenarios below.

SCENARIO OVERVIEWS

This study identifies the following four illustrative scenarios based on a variety of current trends and pressures on the power sector inside Thailand which are likely to impact future power buildout. These trends cross a wide range of sectoral shocks, policy shifts, and technological innovations and were identified through a collaborative process among the technical team that utilized existing knowledge of Thailand's energy sector and reviews of public statements and presentations by government officials, Thailand's Power Development Plan 2018 and its first revision, media coverage of energy developments, and existing literature on Thailand's energy planning processes and trends.

Trends and potential system shocks which fed into scenario development include:

- Policy changes on national power reserve targets and excess capacity
- Targets and guidance from Power Development Plan 2018 and changes in Revision 1
- Thailand's stated goal of becoming an electricity trading hub for ASEAN
- Thailand's evolving official renewable energy targets
- Pressures to move towards carbon neutrality in Thailand
- Evolving Thai government stance on support for mainstream Mekong dams
- Targets for deployment of electric vehicles in Thailand and their potential impacts on Thai power demand
- Rooftop solar and distributed generation growth in Thailand
- Thailand's ongoing investments in floating solar projects and potential interest
- COVID-19 impacts on energy sector and project pipeline
- The changing role of natural gas in Thailand's power system

Each scenario has identified key baseline assumptions about the energy sector's future development based on these trends and includes portfolios of projects which make political and economic sense within the baseline assumptions. Each scenario would result in a very different portfolio of investments while still meeting Thailand's energy needs through 2037 and meeting commitments to purchase electricity under the existing MOU with Laos. Projects were selected based on whether they met baseline assumptions for an individual scenario and with consideration to existing transmission networks. An overview of projects included in each scenario can be seen on the following page and further details are in Appendix B. All of the projects included in each scenario are potential projects which have been proposed but have not yet begun construction.

One consideration which varies by scenario is timeline. Given Thailand's commitment to uphold its MOU with Laos, all of the proposed scenarios will ultimately include an expansion of power imports. However, the timelines vary by scenario in consideration of the significant excess capacity that currently exists within the system. The first three scenarios anticipate that power would come online before 2037 through the existing timeframe mentioned in the Power Development Scenario 2018 rev. 1, albeit perhaps on a slightly delayed schedule that brings new capacity online in the early-to-mid 2030s rather than the late 2020s.The fourth scenario anticipates that Thailand would withhold from signing new PPAs for imported power for the foreseeable future and would instead prioritize domestic renewable energy through 2037, but would sign additional PPAs for as-yet unspecified power plants to meet its commitments over a longer timeframe.

SCENARIO 1: Business-as-Usual Mainstream Dam Scenario

This map shows all of the proposed projects included in Scenario 1: Business-as-Usual Mainstream Dam Scenario, mapped by location. The size of the circle reflects the relative size of the project's installed capacity. The map was created by the Stimson Center through DataWrapper using information from the Mekong Infrastructure Tracker, which is supported by USAID and The Asia Foundation.

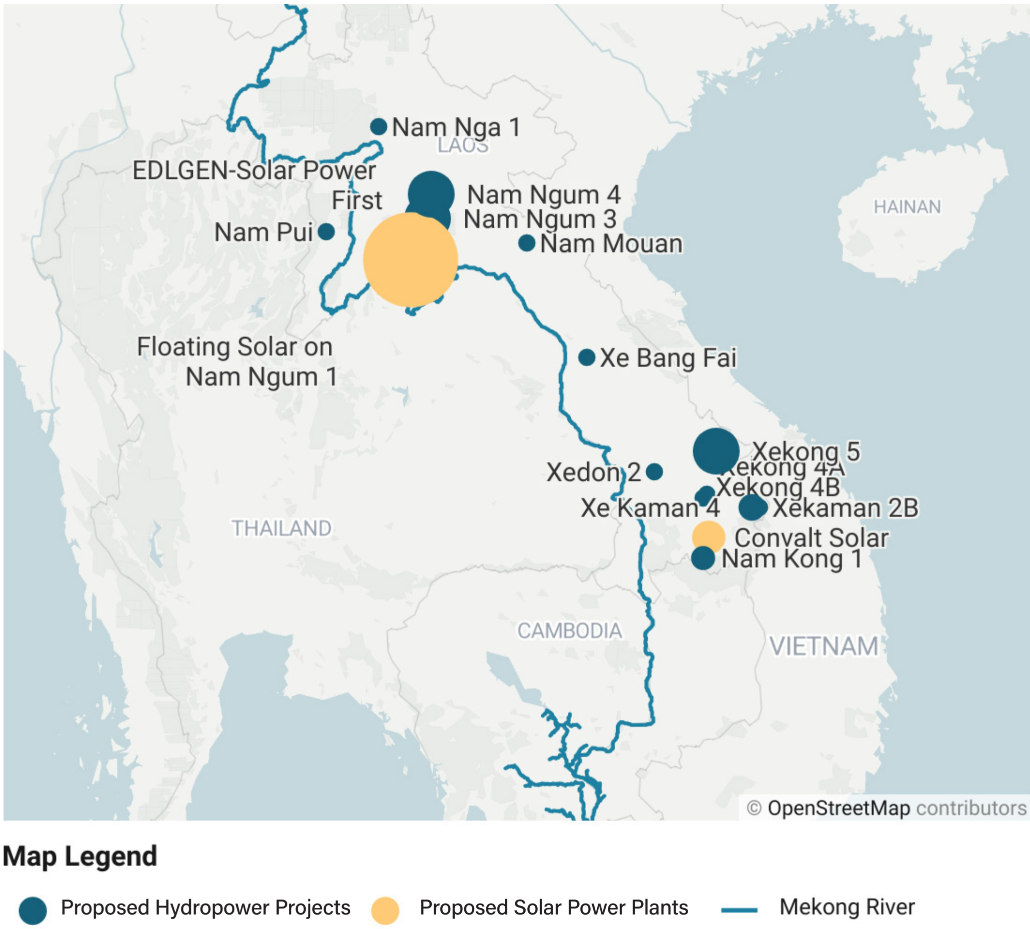
This scenario includes electricity imports through 2037 from dams on the mainstream of the Mekong River in Laos, including the Sanakham Dam (currently going through the Mekong River Commission's Procedures for Notification, Prior Consultation, and Agreement, or PNPCA) as well as the Pak Lay, Pak Beng, and Luang Prabang projects which have already completed the PNPCA review process. A full list of projects is included in Appendix B.

This is an increasingly unlikely scenario because of both the existing excess capacity in Thailand's power system as well as public pushback against dams on the mainstream of the Mekong River. Given the drop in cost of renewable energy and lack of immediate pressure to move forward on these projects, it is unlikely that Thailand will sign agreements for these projects. However, this scenario is still given consideration because the Thai authorities have not yet made definitive statements that Thailand will refuse to purchase power from any more of the proposed mainstream dam projects as a matter of policy.

There are many reasons to avoid purchases from mainstream hydropower dams, but there are some power sector trends and policy considerations which could result in one or more of these mainstream dams ultimately moving forward regardless of concern over negative social and environmental impacts. This is unlikely to occur in the near future, but in light of planned domestic expansion of variable solar and wind, Thai policymakers may prioritize an import portfolio in the early 2030s which would be dispatchable rather than considering additional variable renewable energy projects in Laos which would otherwise be economically competitive. There could be pressure to ensure dispatchability of electricity from Laos in order to manage potential changes in the timing of peak demand tied to the integration and charging of electric vehicles in Thailand in coming years. These considerations would likely lead to a preference for dispatchable coal or hydropower for imports. Since Thai policymakers may want to avoid investing in additional coal electricity in light of carbon neutrality targets, hydropower would be the most attractive dispatchable power source.

To date the government of Laos has continued to prioritize the construction of mainstream Mekong dams in negotiations with Thailand. While the construction of one or more additional mainstream dams is increasingly unlikely due to political considerations, mainstream dams could still result if environmental impacts are managed such that the dam passes environmental and social criteria during review by the Electricity Generating Authority of Thailand. Thai companies are involved in developing the Luang Prabang Dam, which provides a potential source of pressure to support a PPA. Mainstream dam projects are significantly larger in capacity than alternatives on tributaries in Laos. From a legal perspective this would require negotiation of fewer individual power purchase agreements than a series of many smaller hydropower projects. It also would likely require additional investments in transmission and grid management, which could increase final selling prices to Thailand.

SCENARIO 2: Tributary Dam Scenario



This map shows all of the proposed projects included in Scenario 2: Tributary Dam Scenario. All solar and hydropower projects are mapped by location. The size of the circle reflects the relative size of the project's installed capacity and the color reflects the type of power plant. The map was created by the Stimson Center through DataWrapper using information from the Mekong Infrastructure Tracker, which is supported by USAID and The Asia Foundation.

This scenario anticipates many of the same baseline power sector trends as Scenario 1 that lead to a preference among Thai policymakers for importing hydropower from Laos. This scenario also anticipates that the timeline for these projects would be pushed back a few years given the existing excess capacity in the system.

Scenario 2 differs from Scenario 1 in that it assumes a policy decision in Thailand to avoid power purchases from mainstream Mekong hydropower dams, apart from the already operational Xayaburi Dam. As of early 2021 the Thai government has indicated that it will set up a committee to re-examine the mainstream dam projects in response to protest by local communities and the People of 7 Mekong Provinces. The additional review of these projects, combined with rising concern from the Office of National Water Resources and other stakeholders in the Thai government over the potential impacts of these projects on Thai citizens, makes it politically likely that Thailand will abstain from future mainstream dam purchases. This is especially true for the Sanakham Dam which is only 2 km away from Thai border.[48] Imported hydropower in this scenario would therefore come entirely from dams on tributaries, many of which are storage dams with some capacity to manage water flow across seasons.

Apart from this site-specific constraint on imported hydropower, this scenario shares many baseline assumptions with Scenario 1. It anticipates that the pressures and goals of reducing carbon emissions while still ensuring sufficient dispatchable energy to help meet peak demand needs will lead to a continued preference for hydropower. This scenario does however consider the rising economic competitiveness of solar and recent interest from the government of Laos in developing both ground-mount and floating solar projects. It also recognizes the interest in Thailand in supporting a move towards carbon neutrality. As a result, while this scenario prioritizes hydropower, it does give some consideration to alternative renewable energy projects which could easily be connected to the Thai grid. Power purchases from projects in Laos under this scenario will consist of 2,240 MW of hydropower and 1,296 MW of solar power from projects already in the development pipeline in Laos.

Keeping these broad power sector trends in mind, this scenario includes a portfolio of projects selected based on the following criteria:

- Inclusion in current lists of projects under consideration by the Ministry of Energy;
- Projects which are invested in by Thai companies with a stated intent of power sales to Thailand;
- Projects which are relatively close to existing transmission lines connected to Thailand's national power grid or projects which are already under consideration by the Ministry, potentially limiting additional investment in transmission;
- Projects with sufficient data on dam height and reservoir projections, for modeling the geospatial impacts.

A full list of projects in this scenario is included in Appendix B.

SCENARIO 3: Floating Solar Scenario

This map shows all of the proposed projects included in Scenario 3: Floating Solar Scenario, mapped by location. The size of the circle reflects the relative size of the project's potential floating solar capacity. The map was created by the Stimson Center through DataWrapper using information from the Mekong Infrastructure Tracker, which is supported by USAID and The Asia Foundation.

Scenario 3 anticipates that Thai policymakers will remain committed to signing power purchase agreements with 9,000 MW of projects through 2037, but that a successful renewable energy transition inside Thailand leads to a preference for purchasing the remaining 3,500 MW from alternative renewable energy projects. This scenario would include no new PPAs for hydroelectricity or coal but would install floating solar on reservoirs of hydropower projects which are already selling power to Thailand. This scenario anticipates that additional renewable imports could support Thailand's push over time to decarbonize the power system and reduce the role of coal.

Lao policymakers have already announced their intent to move forward with a floating solar project on the reservoir of the Nam Ngum 1 project, which currently sells hydroelectricity to Thailand. Thailand is currently constructing a 45 MW floating solar project on the Sirindhorn Dam, the first of nine floating solar projects that it will build domestically through 2037. This scenario anticipates that these projects are successfully integrated to the Thai national grid and prove a commercial success. This would build confidence in the technology and would likely heighten commercial interest from Thai companies in investing in additional floating solar projects abroad, as has been the case for ground-mount solar and hydropower projects in the past. Given the availability of existing transmission lines and negligible cost of land for floating solar, this scenario anticipates that Thailand might prefer to purchase power from floating solar projects on reservoirs of dams which are already connected to the Thai grid rather than bear the additional cost of land and new transmission lines for ground-mount solar projects.

This scenario would support Thailand's long-term goal of decreasing carbon emissions and anticipates that Thailand would still purchase an additional 3,500 MW of installed capacity from Laos by 2037. However, as non-dispatchable solar power, this would purely be used to help replace aging fossil-fuels with renewable alternatives and provide flexibility. Thailand and Laos operate on separately managed grids, flexibility could be provided inside Laos to supply different generators for export. When there are local weather disruptions in Thailand, electricity trade provides geographic flexibility with the probability that some solar power plants in Laos would still operational. While all electricity from Laos could be resold through Thailand to Malaysia and Singapore, this scenario anticipates that power produced by floating solar projects would meet criteria for stringent renewable energy certification processes requested in those advanced economies in a way that hydroelectricity would not. Getting a stated interest from Singapore in purchasing solar could help secure future investments against the risk of not having a purchaser, in the event that excess electricity continues to be a market problem through the late 2020s.

The Nam Ngum 1 and Nam Theun 2 dams already have floating solar projects under development, but other reservoirs with surface area over 10 km2 and could host floating solar projects include:

- Nam Ngum 2
- Theun-Hinbeun Expansion
- Xayaburi
- Nam Ngiep 1
- Nam Khan 2
- Nam Lik 1
- Houay Ho
- Nam Ou 2
- Nam Ou 5
- Nam Ou 6
- Nam Leuk
- Nam Mang 1
- Nam Man

SCENARIO 4: Domestic Renewable Energy Scenario

Scenario 4 differs from the previous scenarios because it anticipates Thailand will not sign PPAs with new projects in Laos until after the current Power Development Plan expires in 2037. Thailand currently has PPAs for approximately 5,500 MW, with a commitment to ultimately expand PPAs to cover 9,000 MW. Under this scenario, Thailand will push the timeline for additional PPAs out due to the current excess of electricity in the power system and pressure for further domestic renewable energy development. All projects which have already signed PPAs and which are specified by name in PDP2018 rev. 1 will continue to supply electricity to Thailand, but all of the 3,500 MW of power which were specified as planned foreign electricity imports with no specific project listed will instead come from energy efficiency measures and domestically produced renewable energy sources.

This scenario anticipates that domestic pressures to increase renewable energy and make substantive moves towards carbon neutrality will result in a boom in domestic renewable energy projects. This has several additional baseline assumptions which will impact the domestic power market in Thailand and help rationalize the decision to avoid PPAs. The first of these is that rooftop solar will be broadly adopted around Thailand and result in significant expansion of distributed generation. There are indications that this is already beginning to occur.

As distributed generation becomes more prominent, a second baseline assumption is that widespread adoption of a prosumer model will lead to significant behind-the-meter demand savings and reduce overall pull from the grid. This parallels the rise of direct power sales between independent suppliers and users, which the Thai government is currently working to open up. Both of these trends would reduce reliance on the grid and would likely lead to an overall decrease in EGAT's role as an offtaker in the power system over the next fifteen years due to rising participation in the power market by IPPs.

It is likely that some commercial scale solar projects inside Thailand will also move forward given the PDP's existing solar targets. However, a substantial amount of utility-scale floating solar has already been written into the PDP and so for comparison purposes this scenario anticipates that the 3,500 MW of power which was originally planned to be imported from Laos could easily be supplied by rooftop solar projects around the country which help to reduce demand on the grid by supplying local electricity for prosumers. This is in part a response to the clear case study in the form of Vietnam, where 9,300 MW of rooftop solar were added to the grid in 2020 alone. Most of this was on commercial and industrial buildings by the companies involved in order to limit electricity expenditures, and this model has also become increasingly popular in Thailand. Given Thailand's land area and growing policy and commercial models for distributed generation and direct power sales, it is easily possible for Thailand to deploy well over 3,500 MW of rooftop solar by 2037.

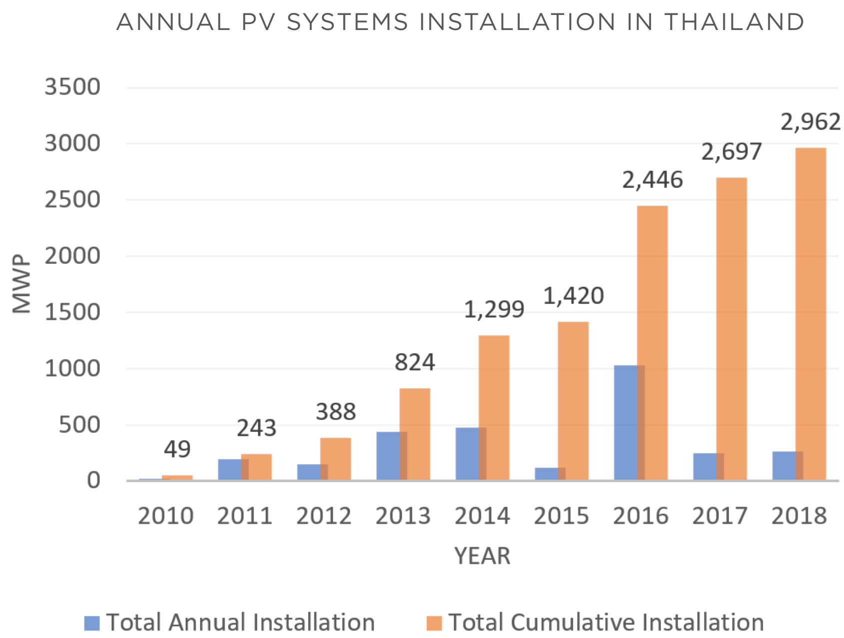


Figure 3: Annual PV systems installation in Thailand. Data Source: Thailand Ministry of Energy, Thailand PV Status Database 2018, accessible at https://pvgis.kmutt.ac.th/pvstatus2018/pv_systems_installation.html.

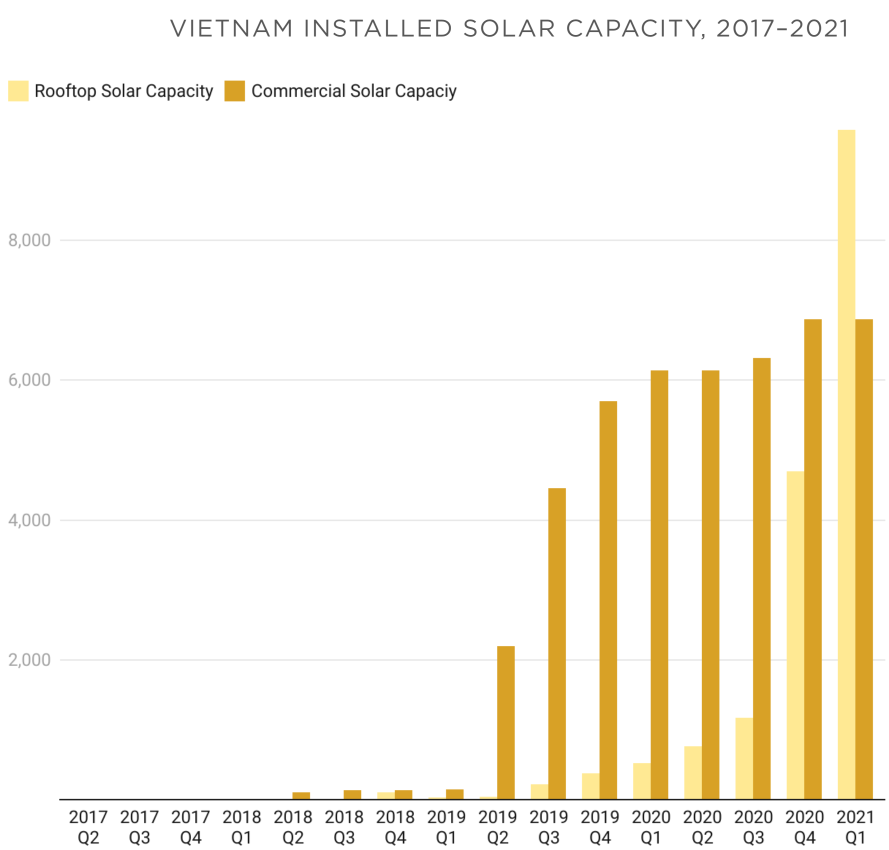


Figure 4: Vietnam Installed Solar Capacity, 2017–2021. This chart shows the rapid growth of installed solar capacity in Vietnam, including more than 9,000 MW of rooftop solar added in 2020. Created by Courtney Weatherby in DataWrapper utilizing data compiled from the Mekong Infrastructure Tracker, Electricity Vietnam, International Renewable Energy Agency, and Viet Nam Energy Partnership Group.

LAO ENERGY PROJECTS IN THAI SCENARIOS

Project Name	Capacity MW	Current Status	Project Type	River Basin/Tributary	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Nam Ngum 3	480	Under Construction	Hydro	Nam Ngum	1	1	0	0
Pak Beng	912	Planned	Hydro	Mekong	1	0	0	0
Pak Lay	770	Planned	Hydro	Mekong	1	0	0	0
Sanakham	700	Planned	Hydro	Mekong	1	0	0	0
Luang Prabang	1,410	Planned	Hydro	Mekong	1	0	0	0
Xekong 4A	165	Planned	Hydro	Nam Kading-Xe Bang Fai	1	1	0	0
Xekong 4B	175	Planned	Hydro	Sekong	1	1	0	0
Convalt Solar 250 MW	250	Planned	Solar	N/A	0	1	0	0
Convalt Solar 50 MW	50	Planned	Solar	N/A	0	1	0	0
EDLGEN – Solar Power First Project	68	Planned	Solar	N/A	0	1	0	0
Xekong 5	330	Planned	Hydro	Sekong	0	1	0	0
Floating Solar Nam Ngum 1 Reservoir	1,200	Planned	Solar	N/A	0	1	1	0
Xe Bang Fai	110	Planned	Hydro	Nam Kading-Xe Bang Fai	0	1	0	0
Nam Nga 1	100	Planned	Hydro	Nam Ou	0	1	0	0
Nam Kong 1	150	Under Construction	Hydro	Sekong	0	1	0	0
Xe Kaman 2B	180	Planned	Hydro	Sekong	0	1	0	0
Nam Puoy (Nam Pui)	60	Planned	Hydro	Nam Pouy	0	1	0	0
Nam Ngum 4	240	Planned	Hydro	Nam Ngum	0	1	0	0
Xedon 2	54	Planned	Hydro	Xe Don	0	1	0	0
Nam Khan 1	102	Planned	Hydro	Nam Khan	0	1	0	0
Nam Phak	75	Planned	Hydro	Nam Phak	0	1	0	0
Nam Seuang 2	108	Planned	Hydro	Nam Xeng	0	1	0	0
Xe Kaman 4	96	Planned	Hydro	Sekong	0	1	0	0
Nam Mouan	100	Planned	Hydro	Nam Kading-Xe Bang Fai	0	1	0	0
Floating Solar	14	Planned	Solar	N/A	0	0	1	0
Floating Solar Nam Ngum 1 Reservoir	1,200	Planned	Solar	N/A	0	1	1	0
Various Floating Solar	2,300	Planned	Solar	N/A	0	0	1	0

This table provides a comparative list of which projects are included in which scenario. The project-level data in this table is drawn from the Stimson Mekong Infrastructure Tracker, supported by USAID and The Asia Foundation. Full details are in Appendix B.

MODELING APPROACH AND METHODOLOGY

The energy analysis details the consequences of four different planning scenarios related to Thailand and Lao's memorandum of understanding (MOU) for Thailand to purchase 3,500 MW of capacity from Laos. The total capacity can come from a mix of generation sources. As the technology cost of solar electricity has declined, new combinations of solar electricity options have emerged as possible technologies to supply the 3,500 MW of capacity.

Project level data were compiled in line with the scenario descriptions. For proposed hydropower plants, data are gathered based on projected capital expenditures and capacities. For each project, the estimated annual generation and capital cost are used to estimate project-level LCOEs that can then be aggregated at a scenario level. The LCOE does not consider extra transmission construction costs and can be used as an estimate based on project details. For floating solar configurations, solar generation is estimated on an hourly basis based on weather data for Laos and default technology cost and performance information from NREL. The available surface area is estimated based on the reservoir at 1% and 0.1% total surface coverage, which represents a conservative estimate of the capacity installed at different existing hydropower reservoirs in Laos. Key project metrics are analyzed including estimated capital expenditure, estimated range of LCOE, and an estimation of expected additional annual electricity generation.

This analysis estimates the levelized cost of electricity to meet the power purchase agreement target of 3,500 MW and demonstrates how different choices will affect Thailand's overall electricity portfolio. There are a range of differences between meeting this need through traditional hydropower plants and implementing floating solar that could be developed in Laos. Additionally, the different hydropower dams being planned could have varying impacts on the environment as detailed in the next section.

COMPARATIVE ANALYSIS

Summary of Energy Analysis by Scenario					
Scenario	**New Projects**	**Installed Capacity (MW)**	**Estimated Additional Annual Generation (GWh)**	**Estimated Capital Expenditure**	**Estimated LCOE for New Power**
Business-as-Usual Mainstream Dam Scenario	•7 new dams, ranging in size from 165 MW to 1410 MW •4 dams on the mainstream of the Mekong	Total: 4,612 MW For Thailand: 3,500 MW	24,077 GWh	$11.7 billion (total installed capacity, although a portion is not sold to Thailand)	$45-$140/ MWh
Tributary Hydropower	•17 new projects •4 solar projects •13 hydropower projects on tributaries	Total: 3,808 MW For Thailand: 3,500 MW	9,523 GWh	At least $6.5 billion	$25 - $50/ MWh
Floating Solar	•15 potential floating solar sites on dams selling power to Thailand •Considered size is 1% of the surface area of each reservoir	Potential: At least 8,990 MW Actual buildout would be modular to meet demand.	2,650 GWh	For 3,500 MW of capacity: $4 billion Full build out: $42.8 billion	$30 - $40/ MWh
Domestic Renewable Energy	•Numerous rooftop solar projects installed on commercial and industrial zones around the country	3,500 MW through rooftop solar projects	4,750 GWh	At least $5.7 billion	$80-100/MWh

The table above presents an average levelized cost of electricity range for electricity purchased from the weighted average of projects considered in each scenario. Distributed rooftop solar applies generation data from 3-kW base systems with capacity factor of 15.5% including O&M, inverter, and connection costs. This also includes the total expected additional generation in GWh under each scenario. Further details on the project-specific cost breakdowns are included in Appendix B.

All four scenarios would provide 3,500 MW of installed capacity to Thailand, but the capital investment costs, estimated levelized cost of electricity, and annual generation of electricity differ significantly. Each would contribute differently to Thailand's power mix and could be utilized differently based on the baseline assumptions previously discussed in each scenario outline.

As of 2021, Thailand currently imports about 14% of its total generation mix. This could rise significantly depending on how Thai policymakers utilize future electricity imports. With a full build of mainstream hydropower plants under Scenario 1 to supply 3,500 MW of new imported capacity, the electricity produced could balloon to nearly 24% by 2037 assuming high utilization of the large-scale hydropower plants and low marginal operating costs. Scenario 2 with a large buildout of tributary dams could also reach high levels of utilization. This percentage would change depending on the level of hydropower investment and dispatchability of the hydropower based on climate change and seasonal availability. For hydropower plants facing variable weather extremes and loss of production due to drought, that number could decrease.

Scenario 3 consists entirely of floating solar and would reduce total imports compared to the first two scenarios due to dispatchability. The capacity factor—or the ratio of electricity output compared to the total potential installed capacity of a project—is noticeably lower for solar than for hydropower. A nameplate capacity of 3,500 MW of floating solar would not provide the same amount of electricity generation in kWh as an equivalent amount of hydropower. Floating solar therefore wouldn't provide the same type of bulk power imports that would be provided by hydropower. Although floating solar would not be useful to Thailand's grid at all hours of the day, marginal costs would be low and therefore importing floating solar as needed could help reduce peak demand in the afternoon.

Scenario 4 would consist entirely of solar, the primary difference being that Scenario 4 would utilize only domestically sourced rooftop solar power and the impacts would primarily come from a reduction of energy demand behind the meter rather than as a direct and dispatchable power source for the grid.

Capital Investment

While it is possible that Thailand could purchase electricity from existing dams in the near-term, longer-term power purchases starting in 2027 are likely to be from projects currently planned and which will require further investment. Most projects currently selling to Thailand have Thai investors involved in sponsoring or financing the project and some of this investment could come directly from Thai banks. In terms of investment needs for 3,500 MW of installed capacity, the Mainstream Dam Scenario is the most expensive with a price point of approximately $11.7 billion compared to at least $6.5 billion for a Tributary Dam scenario or approximately $4 billion for floating solar projects.

The significant expense of the Mainstream Dam Scenario is due to the relatively high costs of mainstream Mekong dams: the Luang Prabang dam ($3 billion), Pak Beng ($2.7 billion), Pak Lay ($2.2 billion),and Sanakham ($2 billion) are all exceptionally expensive projects. For comparison, similar-sized floating solar projects which could produce up to 1,000 MW of power are expected to have capital investment costs below $1 billion.

The tributary dams are all much smaller individual projects and cost significantly less upfront. These costs do not account for external costs such as transmission lines and are based on construction cost, potentially undercounting full compensation costs of relocation. These costs also do not account for delays and resulting cost overruns, which are a regular occurrence for large-scale hydropower projects.[49]

Least Cost of Electricity

In terms of total system costs, developing domestic solar generation as it may require less transmission investment and rooftop solar power can be directly used for demand reduction at the point of use. There is significantly lower risk of curtailment with distributed PV systems. However, this approach would be politically difficult given that it would require either delaying or cancelling part of Thailand's agreement to purchase power from Laos. On a LCOE basis, floating solar projects in Laos appear increasingly attractive given the financial benefits of using existing transmission system infrastructure and lack of necessity for purchasing or renting new land for solar farms. In some cases transmission lines would need to be upgraded to accommodate additional electricity from floating solar. The levelized cost of electricity from floating solar is much less than that for proposed large-scale mainstem hydropower dams. When the externalities associated with the damaging effects of hydropower on biodiversity, river fragmentation, and sediment loss are considered, floating solar is likely to be even more attractive.

Although this lower levelized cost of electricity could also help keep electricity prices in Thailand lower, there is significantly less electricity generation from a similar capacity rating of solar as larger hydropower. Due to variability in production at nighttime or when there are clouds, 3,500 MW of installed solar capacity is likely to produce only a fraction of electricity compared to hydropower projects. Using a majority of floating-solar based projects to fulfill remaining power purchase commitments would reduce the total amount of electricity imported from approximately 24,077 GWh/year to 2,650 GWh/year. This may not be an issue depending on how Thailand intends to utilize electricity imports. Much of the value of the Floating Solar Scenario comes from the timing of the available capacity as a peak demand reduction strategy. The Floating Solar Scenario may generate less total electricity compared to other scenarios but would provide extra economic value in meeting peak afternoon electricity demand.

On a capacity basis this amount of floating solar would still be sufficient to allow for peak demand reduction in Thailand during the middle of the afternoon. Mid-afternoon is when solar electricity production would be strongest, and it coincides with air conditioning demand in the middle of the day. While this extra capacity would be intermittent, it could help with load management. The different electricity configurations from hydropower dams could provide electricity, but generally at a higher LCOE of electricity than investments in floating solar. Most floating solar projects would cost less on a levelized cost of electricity basis than large-scale dams. The biggest potential obstacle lies not in the management of electricity imports but rather on EGAT's willingness as an offtaker to consider non-firm or non-dispatchable power imports. Thailand's PPAs are currently designed around firm generation purchases. Vietnam recently established a process for purchasing wind electricity from Laos, and the terms and negotiation process for that new PPA approach could be a useful reference case.

Annual Electricity Generation

In terms of total generation, a similar amount of installed capacity in each scenario would not necessarily affect Thailand's overall electricity mix in the same way. Floating solar utilized for the power purchase agreements would mostly provide demand management and comprise about 1% of Thailand's current electricity generation mix.

The Mainstream Dam scenario would constitute a significantly larger investment and construction than the Tributary Dam scenario. Estimated LCOE ranges for Mainstream Dams range from $45-140/MWh compared to $25-50/MWh electricity from Tributary Dams. Since most proposed mainstream dams are larger in capacity, fewer dams would be needed to fulfill the remaining 9,000 MW of power purchase agreements. The Tributary Dam scenario includes a broader range of medium-scale hydropower projects and supplements these with cost-effective and renewable solar PV.

A variety of floating solar installations identified in Scenario 3 would allow for Thailand to import electricity from Laos as part of its 3,500 MW power purchase agreements. This could be complicated to manage because solar electricity is intermittent. Since the power purchase agreements deal explicitly with capacity, there is some ambiguity regarding the role of alternative generation options to meet the MOU needs. Floating solar is less controllable and dispatchable. However, it could be coupled for smooth generation with existing hydropower facilities that already export power from Laos to Thailand. An aggregate sum of 3,500 MW of floating solar capacity participating will yield less annual electricity generation than a comparable combination of large-scale hydropower plants. However, the timing of this generation could be valuable by reducing peak demand in the afternoon and reducing temporary marginal power price surges. This could provide EGAT with some flexibility in dispatching other operational power plants.

Thailand could strategically import solar electricity from floating reservoirs during peak demand periods in the middle of the afternoon and use the floating solar as a means to benefit from peak shaving. There would be seasonal differences in generation from floating solar PV projects. Notably, the dry season has greater availability of solar electricity than the rainy season. This could complement hydropower generation well: during the dry season, excess solar may balance a drop in hydropower generation due to low reservoir levels; during the wet season, hydropower production rises and could balance reduced solar electricity generation.

HOURLY AC SYSTEM OUTPUT

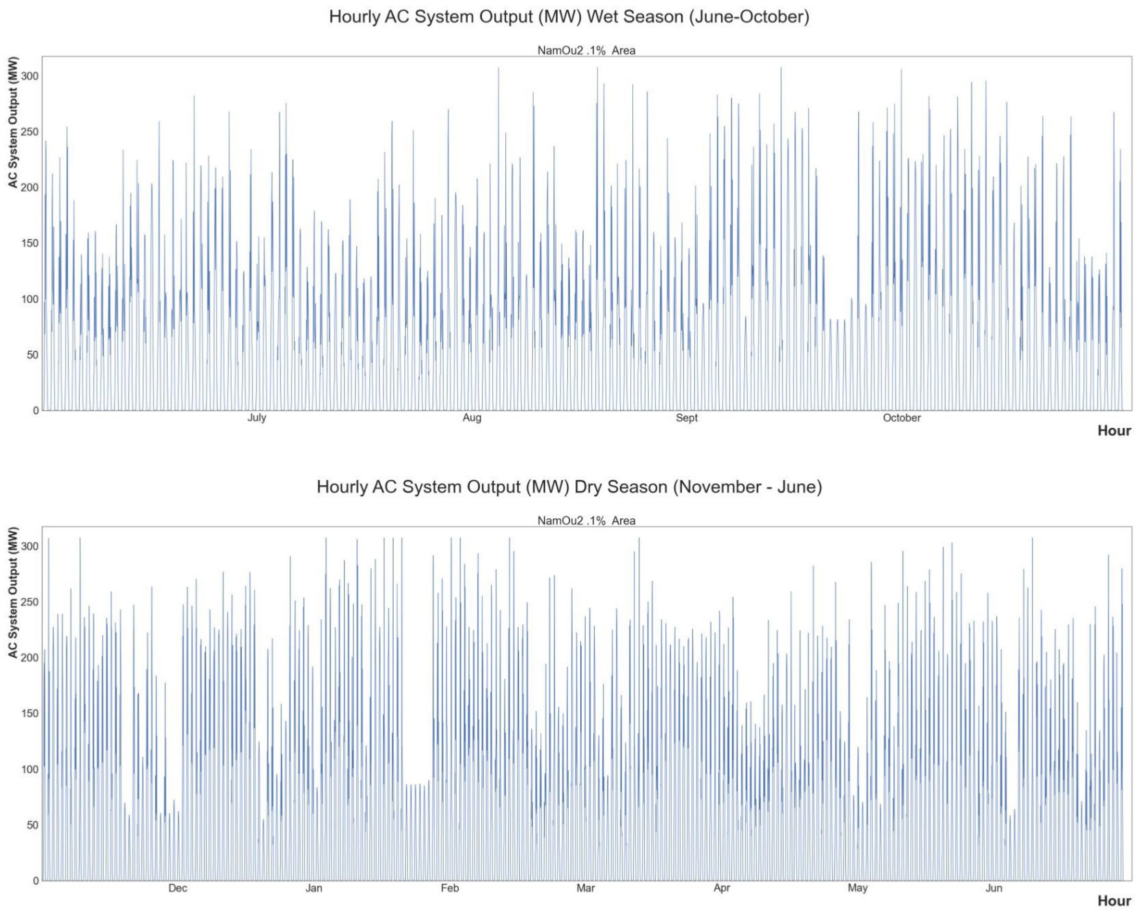


Figure 5: Sample hourly output for sample floating solar installation on Nam Ou 2 hydropower reservoir for dry (November - June) and wet (June - October) seasons, assuming 300 MW of installed capacity. The estimates are based on 0.1% total reservoir areal coverage and estimated efficiencies using NREL System Advisor Model. Model courtesy of Noah Kittner and Vidhi Patel. Further information available at https://tarheels.live/mekongsolar/.

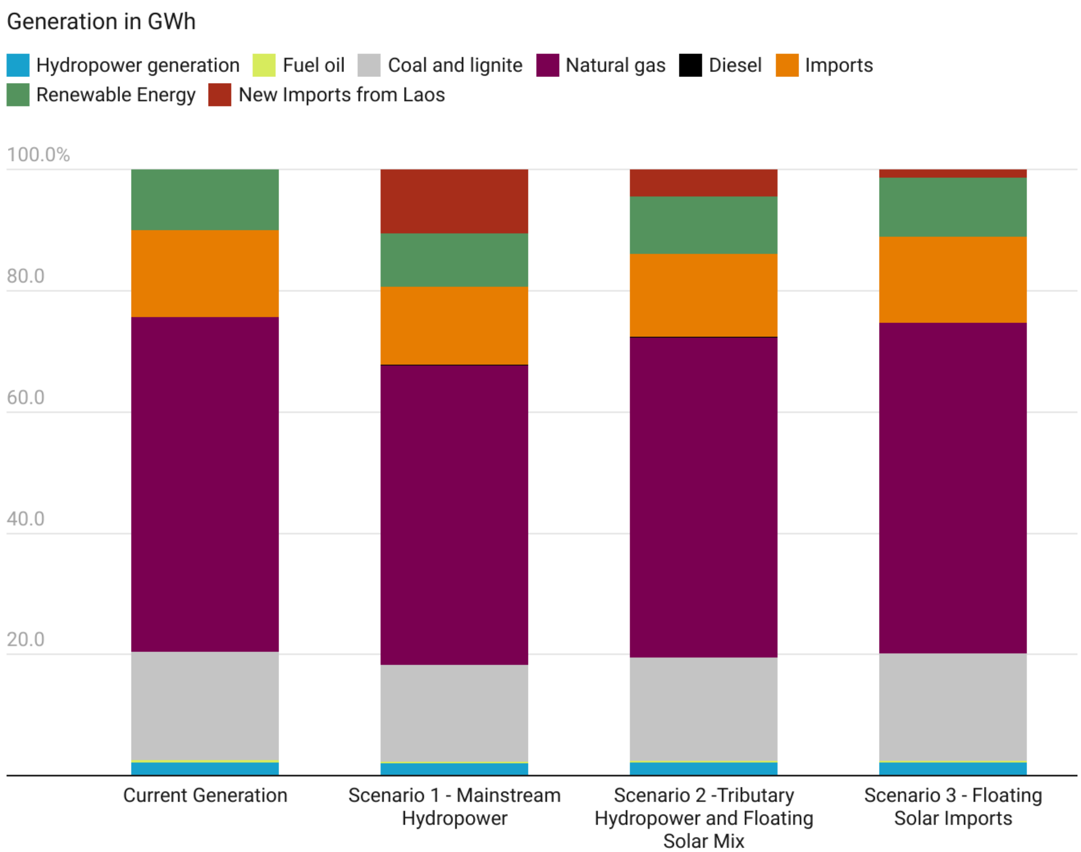
As seen in the attached figure, floating solar electricity follows a daily cycling pattern. If Thailand were to pursue the import of floating solar electricity from Laos during the afternoon when demand peaks in lieu of hydropower, it would reduce peak demands. The floating solar generation could effectively reduce afternoon electricity demand and provide some extra generation capacity to offset the need to run natural gas turbines that utilize imported natural gas from abroad. In this sense, it could provide a hedge over the volatility of future natural gas prices. If a renewable certification program is implemented, renewable energy projects such as floating solar could potentially bid into larger power markets such as the Lao-Thai-Malaysia-Singapore cross-border power trade plan.

Other Considerations

Rooftop solar may cost more on an LCOE basis, however, there are advantages that may not be included in an initial calculation. The upfront investment would be significantly lower, and many of the rooftop solar installation costs are funded privately by companies or individuals. The grid connection would be managed by the Metropolitan Electricity Authority or Provincial Electricity Authority, depending on the location of the rooftop. Rooftop solar also allows for self-consumption of electricity, which could reduce overall demand from large industrial, commercial, or residential users. The above approach could reduce pressure from EGAT to maintain or increase its overall supply. This would increase the share of SPP (small power producer) and IPP (independent power producers) under EGAT's management. Equally this would reduce overall system costs, but it would likely also require additional investment at the distribution network level. Further detailed cost-benefit analysis is necessary.

Rooftop solar could help Thailand move toward NDC targets and set up renewable energy certification programs that would eventually allow for other utility-scale power trade with potential customers such as Singapore that may have more stringent environmental requirements on imported electricity. Substituting domestic rooftop solar in Thailand for imports from Laos would require less coordination between national electricity transmission operators and address Thailand's variable electricity demand, but would likely cause friction in the bilateral relationship because it would not meet Thailand's existing commitment to purchase power from Laos.

THAILAND'S FUTURE ELECTRICITY MIX IN 2037



This chart shows generation across each of the first three scenarios in GWh by 2037 when the scenarios end. Because Scenario 4 is based primarily off of rooftop solar, the impacts would largely be behind the meter. A direct comparison would not be accurate and so for this reason Scenario 4 is not included in this graphic.

Figure 6: Thailand's Future Electricity Mix in 2037. This chart was created by Courtney Weatherby in DataWrapper.

ENVIRONMENTAL AND GEOSPATIAL IMPACTS

Environmental and Geospatial Impacts by Scenario				
Scenario	**Sediment Impacts**	**River Connectivity Impacts**	**Fisheries Impacts**	**Land Impacts**
Scenario 1: Business-as-Usual Mainstream Dam Scenario	Loss of 10 megatons of sediment flow	Retains 8.8% connectivity in the entire Mekong basin	Impacts habitat for 5 of 9 key fish species	Reservoirs could inundate 430 sq km, including 60 sq km of farmland and 170 sq km of forest, and 27 sq km of protected area. Up to 17,869 people and 235 land species could be impacted by the reservoir footprints.
Scenario 2: Tributary Hydropower	Loss of 2 megatons of sediment flow	Retains 10.3% of connectivity in the entire Mekong basin	Impacts habitat for 8 of 9 key fish species	Reservoirs could inundate approximately 680 sq km including approx. 35 sq km of farmland, 470 sq km of forest, and 33 sq. km of protected area. Up to 9,630 people and 524 land species could be impacted by the reservoir footprints.
Scenario 3: Floating Solar	None	No connectivity reduction	No impact on migratory fish or key fish species. Studies necessary on reservoir ecosystem impacts.	No additional impacts, as all dams which would export to Thailand under this scenario already exist and impacts have already been felt.
Scenario 4: Domestic Renewable Energy	None	No connectivity reduction	None	No modeled impact, although there could be land-use changes inside Thailand depending on size and location of distributed solar.

This table shows the modeling results for each of the four scenarios across key indicators of sediment, river connectivity, fisheries impacts, and land impacts. For further information on Methodology, please review Appendix B.

Before analyzing the impacts of the scenarios, it is important to note that the existing construction of dams and other infrastructure projects in the broader Mekong basin has already significantly reduced connectivity, sediment flow, and fish migration from the basin's natural state. Connectivity allows longitudinal (up and downstream) processes to occur in a river system, such as the downstream flow of sediment and nutrients and the up and downstream movement of organisms such as migratory fish. Dams and their associated reservoirs disrupt connectivity, as reservoirs trap sediment and dam walls block upstream movement of fish. There are already 140 hydropower dams in the Mekong system: 11 are mainstream dams on the upper Mekong mainstream in China, 2 are mainstream dams in Laos, and the remaining 127 are tributary dams in China, Thailand, Laos, Cambodia, and Vietnam.[50] Seventy-four of these dams have sufficient details from the Mekong River Commission dataset for inclusion in this model. These existing barriers have already reduced the basin's overall connectivity by 90%. As of 2021, only 5,504 km of an original 29,533 km in the entire Mekong river system remain connected to the ocean.

Within this context and depending on the sites chosen, additional dams will not only have land impacts but could reduce the remaining sediment and connectivity that are crucial for the Mekong River system's natural productivity.

Connectivity

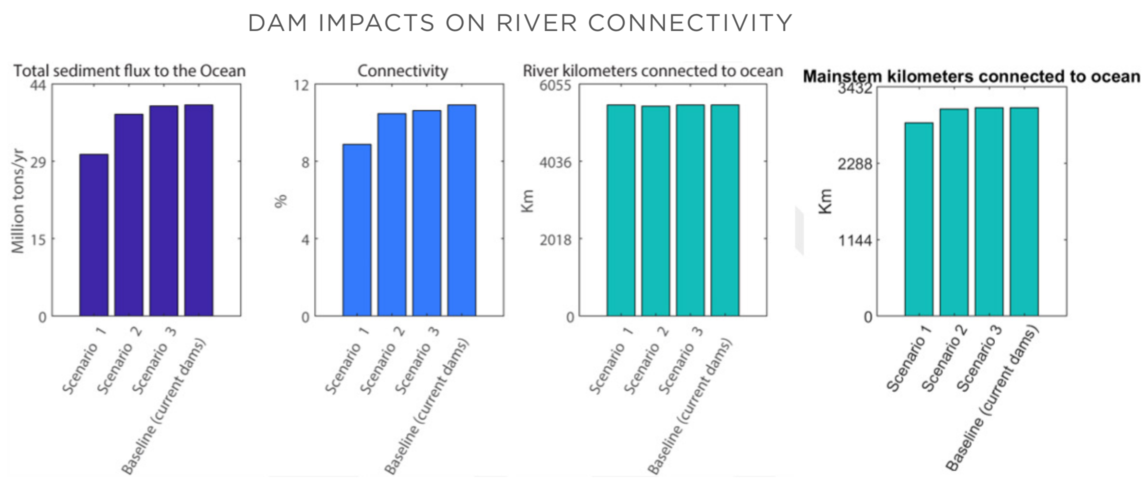


Figure 7: Dam impacts on river connectivity in terms of sediment delivery to the ocean and thus the Mekong delta, connectivity, and length of mainstem river which remain connected to the ocean. These three figures look at the entire river network. The chart on Mainstem kilometers connected to the ocean only looks at rivers with a drainage area of over 10,000 km2 in order to help differentiate between losses to the entire network—which includes small rivers—and the larger rivers. This chart is courtesy of Dr. Rafael Schmitt.

River connectivity enables the movement of aquatic species and is a proxy for many processes which depend on natural flow of water, matter, and organisms throughout the river system such as fish migration. Connectivity can be measured in two ways: first, the kilometers connected to the ocean, which captures how many kilometers of the river flow with no barriers below the most downstream dam. In the Mekong, "connected to the ocean" is a proxy for "connected to the Mekong Delta and Tonle Sap" because of their geographic nearness to the delta. The second type is basin-scale linkage, which measures the percentage of river length in the basin which still exists as a connected system that is not fragmented by dams. Basin-scale linkage captures whether tributary rivers remain connected internally even if they are disconnected from the main river.

The legacy of 74 existing dams considered in this modeling means that there is a limited difference between the three scenarios in terms of the total percentage of the Mekong basin remaining connected. Most of the impacts are already visible: basin-scale linkage has been reduced to only 10.8% of the entire river network as of 2021 due to existing dams. The model indicates that the Business-as-Usual Mainstream Dam Scenario (Scenario 1) does slightly worse (maintains 8.8 % residual connectivity) than the Tributary Dam Scenario (Scenario 2) (which maintains 10.3 % residual connectivity). Scenario 1 and 2 are actually quite similar in terms of kilometers connected to the ocean, with Scenario 2 actually losing 32 km more than Scenario 1 due to significant losses in tributary river linkages. If only large rivers with over 10,000 sq km of drainage area are considered then Scenario 1 has 210 km less of kilometers connected to the ocean than Scenario 2. The Floating Solar Scenario and Domestic Renewable Energy Scenarios (both represented by Scenario 3 in the model given that neither adds new dams or influences land use) have no impacts on connectivity apart from existing impacts of dams that are already operating or are currently under construction.

Sediment Delivery

Rivers naturally connect sources of sediment in upstream areas to downstream sinks, e.g., floodplains and deltas where sediment is deposited. Hydropower dams change this connectivity between sources and because some of the incoming sediment will be retained in the reservoirs behind the dams. Thus, sediment transport in the downstream river network and delivery to downstream sinks will be lower than in natural conditions. Such a reduction can lead to severe impacts on downstream rivers. For example, the Mekong Delta depends on sediment delivery to build shorelines and delta land against rising sea levels. When sediment transport is reduced in river channels, those channels can incise, reducing water surface levels and thus the lateral connectivity between the mainstem of the Mekong and its floodplains, as well as with the Tonle Sap. This lateral connectivity is important for fish spawning and access to habitats and has already been reduced by droughts and operation of upstream dams. Thus, channel incision induced by reduced sediment transport can exacerbate the loss of this important lateral connectivity.

The natural sediment transport in the lower Mekong was around 160 million tons (Mt) per year.[51] Existing dams have already reduced that number to around 50 Mt/yr,[52] and with dams that are under construction this value might fall to 40 Mt/yr. Adding more mainstream dams in Scenario 1 would reduce sediment transport in the lower Mekong to 31 Mt/yr, while under Scenario 2, sediment transport would fall to 38 Mt/yr.

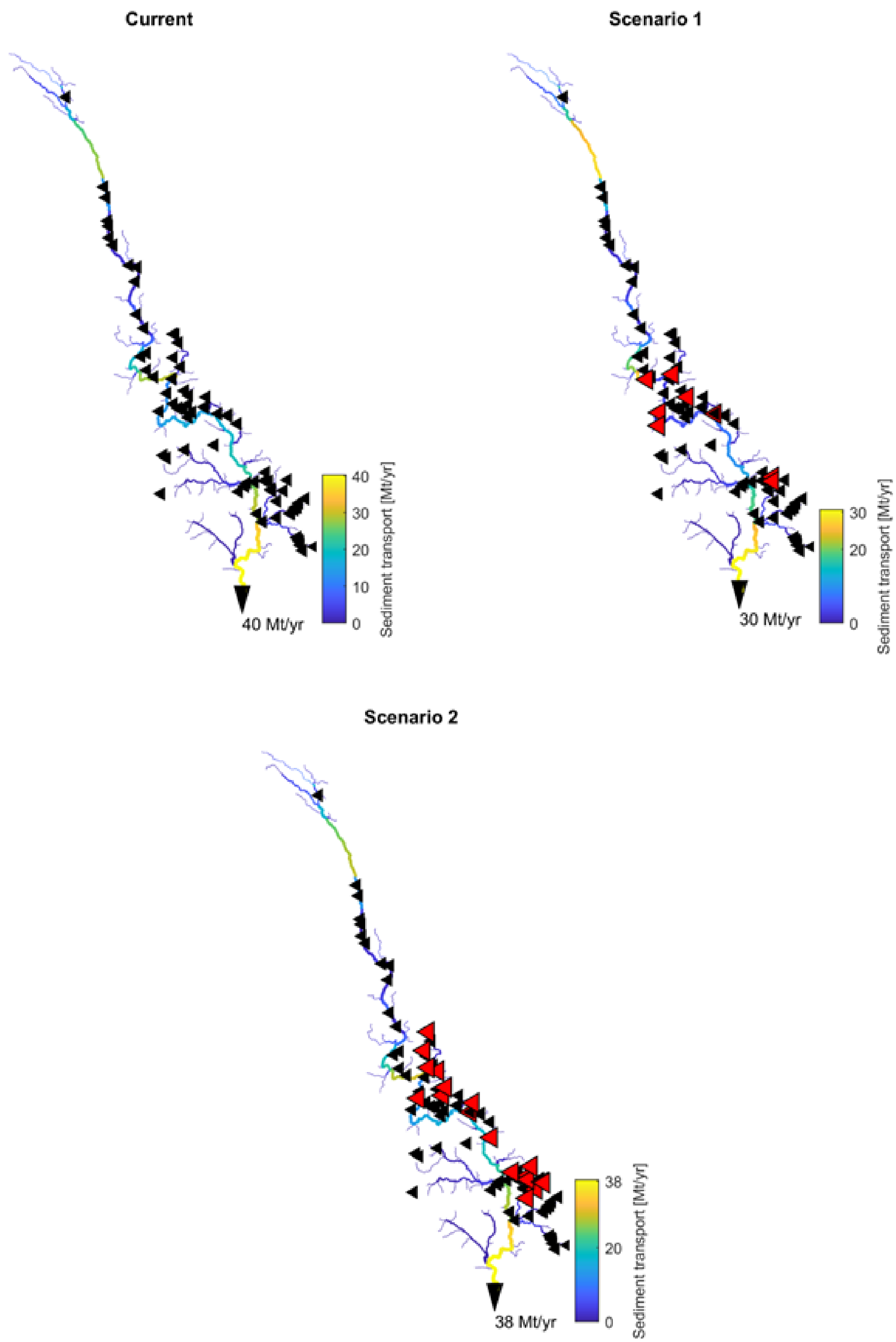


Figure 8: Network sediment transport in the Mekong for current conditions (top left) and for each scenario. Black markers show existing dams and red markers show the dams included in each scenario. These modeling maps are courtesy of Dr. Rafael Schmitt.

Fisheries

Connectivity is a good proxy for fish migratory pathways, but local fish habitats are also directly impacted by dam placement. As with connectivity, existing dams already impact fish habitat for 500 species in the Mekong. As a result, dams added in Scenarios 1 and 2 only impact an additional 2 and 9 species respectively. The status quo of existing dams has already impacted an average of 41% habitat area across all species, and this increases to 43% for scenario 1 and to 47 % for scenario 2. However, these average numbers might mask larger differences between scenarios for individual species.

The model considers nine species which are important for regional food security, and Scenario 2 impacts 8 of these key species compared to only 4 in Scenario 1. In some cases, the difference is significant: Thicklipped Barb, the Thinlipped Barb, and the Laotian Shad habitat impacts are up to 10 % higher for scenario 2 as compared to scenario 1, as those species have important habitat in the tributaries in Scenario 2. For some other species like the Mekong Giant Catfish and Julien's Golden Carp, both Scenario 1 and 2 results increase the habitat area impacted by dams by several percent. While the increase in percent numbers seems small, most species in the Mekong suffer from multiple environmental pressures. Thus, even a small increase in impacts on existing habitats might significantly impact the abundance and survival of species.

DAM IMPACTS ON KEY SPECIES

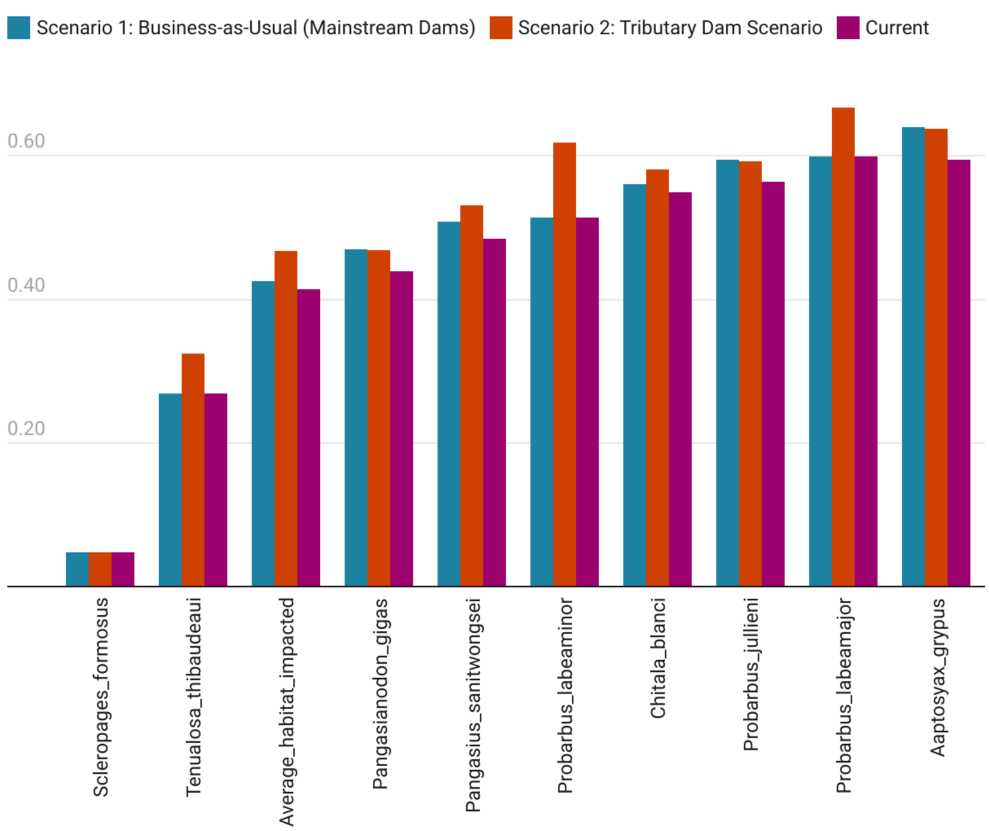


Figure 9: Dam impacts on nine key species. Each bar shows the area of each species' habitat within the impact range of a dam.

Chart: Rafael Schmitt & Stimson Center Southeast Asia Program • Created with Datawrapper

SUMMARY ECONOMIC CONSIDERATIONS

It is difficult to do an exact comparison of cost effectiveness across scenarios due to different time frames and different amounts of total electricity generation and imports. The variance in overall electricity production has been discussed above, but it is possible to broadly compare the performance of various scenarios through an assessment of direct costs of capital investment, electricity produced, and the impacts on other resources and sectors.

The Business-as-Usual scenario (Scenario 1) is probably the least attractive due to not only the high capital investment but also the significant negative impacts from forecasted impacts to fish species and the flow of sediment and nutrients. Numerous research papers show that the costs of these negative impacts outweighed the benefit from electricity sales.[53] This scenario is also likely to face social resistance in Thailand due to the associated and irreversible environmental impacts and major riverbank erosion. Addressing these impacts on local communities would have high mitigation costs and could also incur legal costs. Thailand has already spent millions of dollars to stabilize the Mekong river banks due to increasing erosion, and estimates from the Mekong River Commission indicate that it could require up to $6 billion in additional investment along the entire river system.[54]

The Tributary Dam Scenario (Scenario 2) is more attractive than Scenario 1 in terms of upfront capital investment and a lower range of electricity costs. Tributary hydropower projects are smaller and have shorter construction times than larger mainstream dam projects, which allows Thai decision makers more flexibility in terms of when they need to make a decision about power purchases. Another benefit of this scenario is that about 10% of the import electricity would be supplied by solar at a lower cost than tributary hydropower, providing a more diverse electricity supply than either Scenarios 1, 3, or 4. The direct negative environmental impacts in terms of fish catch and sediment impacts is likely to be lower for Thai communities due to the location of most of the tributary dams in southern Laos, but the impact on the basin is potentially larger in terms of fish species impacted and fragmented connectivity to the Tonle Sap.

The Floating Solar scenario (Scenario 3) has a lower capital investment and slightly lower LCOE compared to Scenarios 1 and 2. The minimal cost of land acquisition, relatively low cost of connecting to the existing grid, and lack of further land use disruption are all advantages. Compared to the previous two scenarios, the construction time and the payback period are shorter because solar projects are modular and can be built within a year or two depending on size. This scenario does produce significantly less electricity than Scenarios 1 and 2 in terms of gigawatt-hours per year. The negotiation of a PPA for this scenario would be relatively complex given the need to adapt historical PPA terms to manage the variability of solar, but it may be politically easier because of advantageous returns on investment and clear mutual benefits for Thailand and Laos. Scenario 3 also lacks some of the externalities associated with

Electricity lines near Kampong Khleang Village near the Tonle Sap, Cambodia.
Photo courtesy of Courtney Weatherby.

Scenarios 1 and 2: because there would be no new dams under Scenario 3, there would be no further impacts on fisheries, sediment delivery, or agriculture. The model explored only floating solar installations which were 1% or less of the total reservoir area. Larger installations are possible and should likely include separate analysis on potential reservoir fishery impacts of floating solar plants.

The Domestic Renewable scenario (Scenario 4) is probably the most economically attractive for Thailand, as utility scale solar is already the lowest cost generation option and is forecast to become even cheaper in coming years. As most of the electricity through this scenario would be provided by rooftop solar, there would be indirect benefits for the grid. Distributed energy from rooftop solar decentralizes the grid and reduces the risk of blackouts due to localized disruptions such as a downed cross-border transmission line. Rooftop solar also is invested in primarily by private companies and citizens, which would reduce the need for government investment in generation capacity. Scenario 4 could be even more attractive in terms of lower capital investment and LCOE if it utilizes a combination of utility-scale solar, floating solar, and rooftop solar, all of which would have no direct externality risks in terms of fisheries or riverbank agriculture. However, scenario 4 would reduce or postpone a significant portion of Thailand's committed power imports from Laos. Such a policy decision would invariably have non-monetary impacts on the bilateral relationship and could impact revenue generation for the government of Laos, and therefore should be carefully considered.

Solar Power Project in Thailand, used courtesy of the Asian Development Bank's Flickr account under a Creative Commons license.

TAKEAWAYS AND RECOMMENDATIONS

There are thousands of different combinations of potential projects which Thailand could consider purchasing power from in coming years, and the scenarios in this study only explore four. This study therefore does not provide concrete recommendations for or against individual projects or portfolios but rather aims to identify trends and inform decisions about the broad policy pathways that Thailand could pursue when importing electricity from Laos. The scenarios analyzed herein are carefully constructed to include the most practical and likely projects under differing baseline assumptions. In an exhaustive study, each scenario would be benchmarked against all possible dam portfolios from which Thailand could buy energy.

This study includes the following key takeaways:

- **In terms of price per kilowatt-hour, the lowest cost electricity option for Thailand is likely to be a solar-oriented portfolio**. This reflects general global trends of rapidly dropping prices for solar power, but it holds true even when looking at the costs of floating solar. The Floating Solar (Scenario 3) had estimated LCOE of $30-$40/MWh compared against costs of up to $50/MWh for projects under Tributary Dams (Scenario 2) and up to $140/MWh for some projects under the Mainstream Dam (Scenario 1). While Scenario 2 did include a few hydropower projects with estimated costs of under $30/MWh, most had estimated price points starting at $50/MWh and up. The inclusion of some cheaper solar projects in Scenario 2 led to a lower average LCOE compared to what it would be if it consisted entirely of similarly sized hydropower projects.

- **A majority solar portfolio could be used to effectively meet afternoon demand even if it produces significantly less overall electricity**. If Thailand is primarily seeking to expand reserve capacity and prioritizes dispatchability, then hydropower projects under either a Business-as-Usual Scenario 1 or Tributary Dam Scenario 2 would produce significantly more in GWh/year than the solar-heavy Scenarios 3 and 4. However if Thai policymakers are looking primarily to purchase electricity from Laos to help meet afternoon demand-- when air conditioning demand spikes and when solar production is highest--then Scenarios 3 and 4 would likely produce sufficient electricity for Thailand's needs. Additional investment in energy storage such as batteries or additional pumped hydropower facilities could help ensure reliability to meet evening demand when the sun is no longer shining. Additionally, the purchase of solar imports during the day could reduce the overall carbon footprint of Thailand's electricity generation by displacing afternoon generation by natural gas and coal.

The analysis also identified a series of potential gaps over the coming decade in terms of regional electricity trade and sustainable infrastructure development. These provide an opportunity for Thailand to proactively take steps now that would lay the groundwork for future sustainable electricity trade and the clean energy transition. Recommendations include:

- **Thailand's Ministry of Energy could incorporate the results of this scenario analysis and use a scenario-based approach in the next Power Development Plan in 2022 and future power purchase agreements with projects in Laos.** This scenario-based study identifies clear economic benefits in terms of both direct cost and mitigation of externalities for Thai communities under the three scenarios which depart from the historical Business-as-Usual approach. There is no urgency in signing PPAs for new projects in Laos given the near-term surplus electricity. While the scenarios explored in this study are illustrative, the Ministry of Energy (MOE) could adopt similar assessment methods in coming years as it considers further agreements. MOE and EGAT have real-time access to the proposed portfolios of projects that are currently under consideration or proposed over the coming decade. Utilizing a scenario-based approach in the Power Development Plan 2022 would help Thailand ensure the direct costs and external impacts on Thai communities associated with any future power purchase agreements are fully and cumulatively considered.

- **Given the increasing economic argument for solar projects, Thailand may wish to reconsider the exact terms of the MOU with Laos and work to establish clear standards for PPAs for variable solar electricity from Laos**. Thailand's electricity imports from Laos to date have come from coal and hydropower, and the power purchase agreement terms and requirements are written with these types of traditional dispatchable electricity production in mind. Thailand has experience adjusting PPA terms to better distinguish between peak and non-peak demand and differentiate between the wet and dry season production of hydropower, showing that there are opportunities for flexibility and pragmatic updates.

- Given the likelihood that prices of solar technology and energy storage technologies continue to drop, it is likely that Laos may eventually look to export non-hydropower electricity. This is already being discussed within the context of electricity trade with Vietnam, as Vietnam's Draft Power Development Plan 8 explicitly considers purchasing from a series of wind projects in Laos. Vietnam has already begun negotiating the price and terms for potential wind imports. If Thailand wishes to maintain access to competitively priced projects in the medium-to-long term and not lose out to Vietnam—the other major electricity market for Lao exports—Thailand should take initial steps to explore alternative power purchase agreement structures. Reconsideration of the exact PPA terms could also be folded into discussions on how to manage PPAs when the goal is to resell electricity to neighboring markets, some of which like Singapore are interested in specifically buying renewable energy to reduce fossil fuel reliance.

- **If Thailand is importing electricity primarily for resale to neighboring markets rather than for domestic use, it would be beneficial to establish a clear process for managing renewable energy certification for cross-border power trade**. As Thailand looks to establish a role as an electricity trading hub, it is important to consider what the sourcing requirements and targets are for end-countries. Myanmar and Cambodia may not prioritize renewable energy imports, but Singapore as an end-market needs to diversify from natural gas and is in a position where renewable energy certificate (REC) system would be desirable.

- RECs have been used elsewhere to facilitate regional electricity trade: in the United States, there are 10 regional REC tracking systems that can manage the creation and retirement of individual RECs. Tracking systems ensure that each REC is assigned a unique serial number to specific megawatt-hours of renewable electricity generation. Recently, regional REC tracking systems have begun interacting with one another more, allowing RECs to be imported and exported across a broader geography.[55] In Europe, RECs are known as guarantees of origin (GOs). Several countries within and outside the EU have their own mandatory compliance schemes that drive the development of renewable energy generation and create demand for the resulting certificates. In these quota-based systems, governments need to set requirements for a minimum percentage share of renewable sources in the energy mix of electricity suppliers or large electricity consumers. Certificates are created by generators when electricity is produced, and they are sold to parties that are subject to renewable purchase quotas. The Swedish Quota system is an example of this type of Mandatory Compliance Scheme in Europe. The United Kingdom, Belgium, Italy, and Poland have used similar systems.[56]

- Thailand is already experimenting with a domestic REC system and could share lessons from this experience with Laos to explore trading electricity and RECs. This could still have benefits even if the electricity is intended for a domestic audience rather than for resale to neighbors. Due to rising international pressure, many industries are now facing internal requirements or company-level targets to ensure that a certain percentage of their electricity is supplied by renewable energy. Thailand needs to prepare a business environment, such as third-party access to the grid, institute verifying renewable energy credit or certificate, to be ready for demand for renewable energy in the near future. The renewable energy certificate system is still at an initial stage for Thailand and uncertainty over managing ownership of renewable energy certificates is one of the main challenges. The Ministry of Energy has conducted a study to gather the information on implementation from other countries and investigate the most suitable way to broadly implement the use of renewable energy certificates. Development partners may be able to further assist with this process.

- **Thailand has an opportunity to work with multinational development banks to pursue strategic investment portfolios in Laos which limit impacts, meet high ESG standards, and support sustainable regional power trade**. The International Finance Corporation Bank has in recent years used similar system-scale analysis in its assessments in Myanmar and Laos to help inform investment. Of particular note is the IFC's *Cumulative Impact Assessment and Management of Renewable Energy Development the Sekong River Basin, Laos*, which studied multiple power generation scenarios to explore potential outcomes and impacts in the transboundary tributary basin with consideration of exports to Vietnam. Exploring multiple and cumulative project impacts can help to identify and avoid expensive and controversial externalities relatively early in the development process, thereby reducing risk for individual projects in the long-term. This study and other targeted studies done directly in conjunction with regional power purchasers like Thailand and Vietnam could inform initiatives like ACMECS, the Japan - US Mekong Power Partnership, and potentially attract investment from multinational development banks like the US Development Finance Corporation, Asian Development Bank, World Bank, and others.

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APPENDIX A: METHODOLOGY AND DATASETS FOR GEOSPATIAL ANALYSIS

1. Overview—study objectives and approaches

The objective of this assessment is to gain insight into the impact Thailand's energy choices have on hydropower development in its neighboring countries, and thus on possible impacts related to the portfolios of future dams required to deliver that power. This assessment aims to demonstrate the overall feasibility of such an approach both with regards to analyses methods to rapidly screen different dam portfolios, but also with regards to the availability of relevant freely available, global or regional data.

Regarding the impacts, dam impacts mostly fall in **three domains:**

- **River connectivity impacts**
  Dams interrupt the longitudinal connectivity of rivers from upstream to downstream and vice-versa, e.g., regarding sediment connectivity (the transport of sediment from upstream sediment sources to downstream deltas and floodplains), the migration of aquatic species (mostly fish, but also mammals), and hydrologic connectivity (e.g., the timing and magnitude of flood pulses travelling downstream). These impacts will vary between dam sites as a function of the location in the river network, its design, the adaptation of mitigation measures, and dam operations.

- **Terrestrial Impacts**
  Terrestrial impacts of dams result mainly from the inundation of floodplains and hillslopes in the reservoir formed by a dam. This immediately impacts nature and people by destroying habitats of species as well as agricultural land and settlements. Additional impacts might be created through auxiliary infrastructure, e.g., access roads and transmission lines.

- **Aquatic impacts**
  Impacts of dams on aquatic species, and specifically fish are manifold. Most importantly, dams hinder the movement of migrating fish, alter the flow regime of rivers and thus access to spawning habitat (e.g., on floodplains) and feeding grounds. Dams also convert flowing rivers into standing reservoir water bodies, a very different kind of habitat. Dam impacts on fish are of key concern for the Mekong, given the role of fish for livelihoods. However, the life cycle of many fish species and how they will be impacted by dams is poorly studied for most species.

Modelling impacts in these three domains will use distinct approaches. Impacts of dams on river connectivity use a spatial representation of the river network and analyze how adding barriers to that network might change the transport of sediment. Terrestrial impacts of dams are instead better modelled by representing a river basin as a set of grid cells. Each grid cell can be assigned multiple values, e.g., population or species richness. Overlaying a footprint of future reservoirs then enables quantifying which ecosystem and human values are lost through inundation. The following sections give a high-level overview over the different modeling approaches and list data sources, data quality and data gaps. For dam impacts on fish, we resort to an analysis on the scale of small hydrologic basins on which the occurrence of more than 590 species has been recorded in the basin. The area considered for all modelling includes the drainage area of the Mekong River.

2. Approaches

Dam impacts on rivers

Impacts on rivers are modelled using a river network that was extracted from a Digital Elevation Model (DEM) with 250 m elevation and considering a 250 km^2 threshold for initialization of the channel network. The network is then split at all confluences so that the river network is represented as a set of distinct features ("reaches"). Each dam site is then assigned to the nearest reach in the network. Impacts of dams on river connectivity always require modeling all dams that are present in a basin. Thus, for each scenario we model the impact of existing and newly added dams.

Impacts on river connectivity

River connectivity describes how well the different parts of a network are connected. If dams are built, the river network is divided in multiple disconnected fragments and river connectivity is reduced. This reduction in connectivity is commonly referred to as fragmentation. A fragmented river network has many consequences on biophysical processes, e.g., on the movement of aquatic species and the transport of sediment. We measure fragmentation based on a metric modified by the metric proposed by Grill et al. (2015) for the Mekong. The river fragmentation index is defined as

$$RF = 100 - \sum_{i=1}^{n(P)} \frac{l_i^2}{L_{tot}^2} * 100$$

Where n is the number of river fragments, i.e., stretches of river separated from the rest of the network by dams, l is the length of one of these segments and L_{tot} is the total length of the river network. A value of 0 indicates natural conditions, i.e., that a river network is not fragmented.

Additionally, we also calculate the length of river network that stays connected to the ocean for each scenario.

Impacts on sediment transport

We model natural sediment transport by assigning a specific sediment yield to different regions of the Mekong basin (described in Kondolf et al. (2014)). We then track the sediment from each region through the river network to determine natural sediment transport in each part of the Mekong network (Schmitt et al., 2018, 2016) using a simplified version of the CASCADE sediment routing model (Schmitt et al., 2019).

Terrestrial impacts
All terrestrial impacts of dams are modelled with a 250m resolution. All analyses are underpinned by a digital elevation model (DEM), i.e., a digital representation of the basin's topography. The first step of analysis for a given dam portfolio is to first determine the reservoir footprint of each reservoir. The reservoir footprint is determined from the DEM and the reported dam height. Note that the reservoir footprint might be variable over the year as the water level in the reservoir fluctuates. Though some recession farming might be possible on reservoir shores when the water level is lower, it is unlikely that parts of the reservoir are only inundate part of the year can support healthy ecosystems.

We then overlay the determined reservoir footprint over different rasters that represent the spatial distribution of different human and ecosystem values. These rasters are henceforth referred to as "impact rasters". For this study, we consider the following terrestrial impacts:

- Impacts on people
- Impacts on agricultural land
- Impacts on forest
- Impacts on the habitat of endangered mammals, birds, and amphibians
- Impacts on protected areas and wetlands protected by the Global Convention on Wetlands (Ramsar sites)

Each raster is resampled to match the 250 m resolution of the underlying DEM. Below, this document lists data sources, references, and a short assessment of data quality for each of these impact rasters.

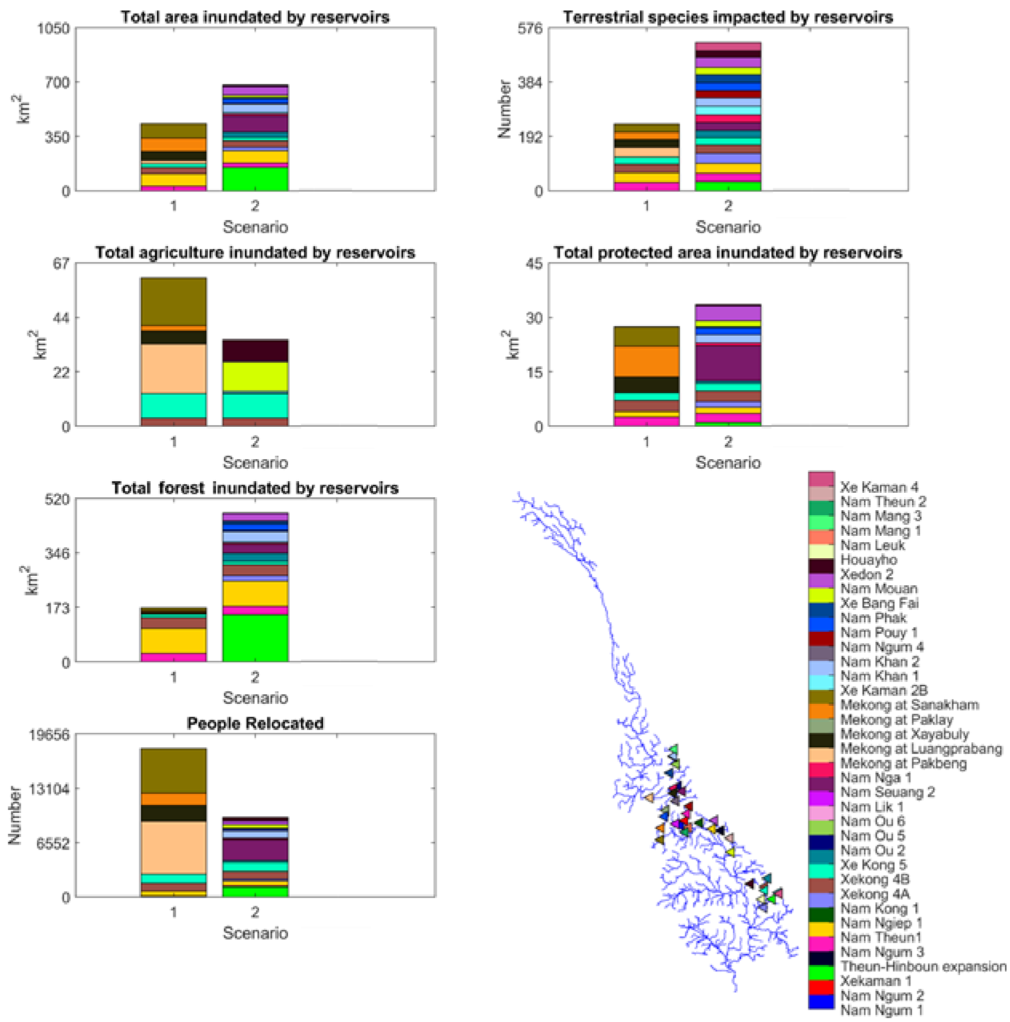

Figure 10: Reservoir impacts on people and terrestrial ecosystems in terms of total inundated area (first row, left), species impacted (first row, right), inundated agricultural lands (second row, left), inundated protected areas (second row, right), inundated forest (third row, left) and people displaced by reservoir (fourth row, left). Bar heights indicate the total impact of each scenario. Each colored slice indicates how much of the total impacts can be associated to a specific dam (map, bottom right for dam locations and color legend).In this chart, Scenario 1 is the Business-as-Usual Scenario with mainstream dams. Scenario 2 is the Tributary Dams Scenario. There are no additional land impacts from Scenarios 3 and 4, and so they are not included. This modeling visualization is courtesy of Dr. Rafael Schmitt.

3. Data sources for impact rasters

Impacts on people	
Data sources, References	Worldpop (2016) projected values for 2020. https://www.worldpop.org/geodata/summary?id=140
Native resolution	0.00833333 degree, equivalent to 1km at the equator
Quality, comments, additional processing	Data indicate a population of 74 million for both the Mekong and Salween. This is realistic, given that the population of the Mekong is estimated to be around 60 – 70 million people (Kondolf et al., 2018; MRC, 2010), and the Salween basin is relatively sparsely populated.
Impacts on agricultural land	
Data sources, References	European Space Agency Climate Change Initiative Land Cover (CCI-LC) layer (2015). http://maps.elie.ucl.ac.be/CCI/viewer/download.php
Native resolution	300 m
Quality, comments, additional processing	Land use and landcover are derived from multiple satellite sensors and classified into ~30 classes using a data driven approach. Here, we consider the following landuse types to represent agricultural land: • Class 10 (Cropland, rainfed) • Class 20 (Cropland irrigated or post inundation) • Class 30 (Mosaic cropland (>50%) / natural vegetation)
Impacts on forest	
Data sources, References	European Space Agency Climate Change Initiative Land Cover (CCI-LC) layer (2015). http://maps.elie.ucl.ac.be/CCI/viewer/download.php
Native resolution	300 m
Quality, comments, additional processing	Land use and landcover are derived from multiple satellite sensors and classified into ~30 classes using a data driven approach. Here, we consider the following landuse types to represent forest: • Class 50 • Class 60, 61, 62 • Class 70, 71, 72 • Class 80, 81, 82, • Class 90 • Class 100 These classes indicate forest cover with various density and of different types (broad vs. needle leafed, deciduous vs. evergreen). Note that not all of these types actually occur in the study area. For a detailed description see here: http://maps.elie.ucl.ac.be/CCI/viewer/download/ESACCI-LC-QuickUserGuide-LC-Maps_v2-0-7.pdf

Impacts on endangered species	
Data sources, References	Jenkins, et al. (2013), https://biodiversitymapping.org/wordpress/index.php/download/
Native resolution	10 km
Quality, comments, additional processing	Data are mostly based on Jenkins, et al.'s (2013) paper in the *Proceedings of the National Academy of Science*, which use range maps of species to get an aggregated count of species in each cell. Species are counted for three animal classes (mammals, birds, amphibians) and different sub-classes, as well as endangered species in each class. Here, we sum the number of endangered species from each class to derive an indicator about the overall abundance of endangered species in each cell. We then calculate the average over all cells inundated in reservoirs. Note that this data set does not cover aquatic species (fish or aquatic mammals) and that there are no independent datasets for comparison.
Impacts on protected areas	
Data sources, References	Protected areas are derived from protected planet https://www.protectedplanet.net/ (data)
Native resolution	None, shapefile
Quality, comments, additional processing	Data are available as vectorized polygons in a shapefile. We extract all polygons in the study area and rasterize them to match the resolution of the DEM (250 m).
Impacts on wetlands	
Data sources, References	Global data on protected wetlands under the Ramsar convention are available here: https://rsis.ramsar.org/. However, there are only few wetlands in the study area that could be impacted by dams. These are identified visually.

Dam impacts on fish

Dam impacts on the habitat of fish are modelled using a global dataset of fish occurrence records (Barbarossa et al., 2020). Species occurrence is reported on the scale of small watersheds (hydrosheds) derived from the global HydroSheds dataset (Lehner and Grill, 2013). For each watershed, many distinct species can be reported. In total the used data set reports the occurrence of 592 species for the whole Mekong.

Our understanding of how dams will impact fish is still rudimentary for the Mekong. Especially, we lack an understanding of migration patterns of important fish species throughout the basin. If such information would be available, a network model similar to what we use for sediment could be used to derive more detailed estimates of dam impacts on the fragmentation of fish habitat.

Thus, this analysis resorts to a high-level screening approach with two different indicators:

1. The habitat of how many fish species is potentially impacted by dams
2. Which fraction of the habitat of each species is impacted by dams. For indicator 2, we report two subindicators:
    - The average over 592 species
    - The impact on the habitat of nine selected 'flagship' species which are of priority for conservation or fisheries.

To calculate impacts, we first select an 'impact radius' around each dam. We select all hydrosheds falling into that impact radius of each dam included in a specific dam portfolio. We then record which species occur in those hydrosheds. Then we compile a unique list of all species which have been recorded in impacted hydrosheds.

For indicator 2, we determine in how many hydrosheds each species occurs. We then determine how many of those hydrosheds are within the impact radius of a dam, allowing us to calculate which fraction of each species' habitat is potentially impacted by a dam. We repeat this process for each species. The indicator is then calculated as average over all species (2a) but can also be reported for any species in our database, e.g., species of special interest (2b).

The impact radius is a sensitive parameter and setting it to a single value is a gross simplification. In reality, some species might migrate over hundreds of kilometers, thus a dam in the migratory pathway might impact the lifecycle of faraway populations. Other species might be more local and thus less impacted by even nearby dams. Ideally, we would adopt a different impact radius for each dam and each fish species. Some dams might interrupt long distance migration of fish for hundreds of kilometers, while others might just interfere with local habitat. Those difference are because of both differences in dams (large, small, fish passage) and different migratory traits of fish species. For this illustrative analysis we selected an impact radius of 25 km, but higher or lower values can easily be implemented.

Name	Common name
Aaptosyax grypus	-
Chitala blanci	Royal Featherback
Pangasianodon gigas	Giant Catfish
Pangasius sanitwongsei	Pla Thepa
Probarbus jullieni	Jullien's Golden Carp
Probarbus labeamajor	Thicklip Barb
Probarbus labeaminor	Thinlip Barb
Scleropages formosus	Asian Bonytongue
Tenualosa thibaudeaui	Laotian Shad

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APPENDIX B: LCOE CHARTS

Project Name	Generation Type	Current Status	Capacity (MW)	Capacity Sold to Thailand (MW)	Year of Completion	Projected Annual GWh	Estimated Capital Expenditure	Estimated LCOE ($/MWh)
Nam Ngum 3	Hydro	Under Construction	480	480	2020	2,345	$1 billion	20-50
Pak Beng	Hydro	Planned	912	912	2025	4,765	$2.7 billion	40-80
Pak Lay	Hydro	Planned	770	770	2029	4,124	$2.2 billion	40-80
Sanakham	Hydro	Planned	700	700		3,803	$2 billion	40-80
Luang Phrabang (Nam Sang)	Hydro	Planned	1410	298		7,400	$3 billion	60-270
Xekong 4A	Hydro	Planned	165	165	2025+	820	$400 million	50-100
Xekong 4B	Hydro	Planned	175	175	2025+	820	$400 million	50-100

Table 1. Business-as-usual generation and levelized cost of electricity.
Background data for individual projects is taken from the Mekong Infrastructure Tracker. Projected Annual GWh, Estimated Capital Expenditure, and Estimated LCOE are drawn from the energy modeling for this project led by Noah Kittner.

Project Name	Generation Type	Current Status	Capacity (MW)	Capacity for Thailand (MW)	Year of Completion	Projected Annual GWh	Estimated Capital Expenditure ($)	Estimated LCOE ($/MWh)
Nam Ngum 3	Hydro	Under Construction	480	480	2020	2,345	$1 billion	20-50
Xekong 4A	Hydro	Planned	165	165		820	$400 million	50-100
Xekong 4B	Hydro	Planned	175	175		820	$400 million	50-100
300 MW Attapeu & Borikhamxay	Solar	Planned	250	250		25	$250 million	30-35
300 MW Attapeu & Borikhamxay	Solar	Planned	50	50		5	$250 million	30-35
EDLGEN – Solar Power First Project - 68 MW Phase 2	Solar	Planned	68	68		9.5	$80 million	25-30
Xekong 5	Hydro	Planned	330	330		2,190	$850 million	20-50
Floating Solar Nam Ngum 1 Reservoir	Solar	Planned	1200	928	2026	950	Up to 1 billion	30-40
Nam [KN1] Mouan	Hydro	Planned	100	100		439	$300 million	60-70
Xe Kaman 4	Hydro	Planned	96	96		N/A	N/A	N/A
Xe Bang Fai	Hydro	Planned	110	110		N/A	N/A	N/A
Nam Nga 1	Hydro	Planned	100	100		N/A	N/A	N/A
Nam Kong 1	Hydro	Under Construction	150	150	2021	469	$336 million	70-80
Xekaman 2B	Hydro	Planned	180	180		500	N/A	N/A
Nam Puoy	Hydro	Planned	60	60		160	N/A	N/A
Nam Ngum 4	Hydro	Planned	240	240	2023	640	$700 million	N/A
Xedon 2	Hydro	Planned	54	54	2021	150	N/A	N/A

Table 2: Tributary Hydropower Projects
Background data for individual projects is taken from the Mekong Infrastructure Tracker. Capacity for Thailand (MW) is estimated by scenario for the amount of power that is available for sale to Thailand, specifically referencing that the Floating Solar Nam Ngum 1 Reservoir project would have a total capacity of 1200 MW but would only be utilizing 928 MW of this power for sale to Thailand. Projected Annual GWh, Estimated Capital Expenditure, and Estimated LCOE are drawn from the energy modeling for this project led by Noah Kittner.

Project Name	Subtype	Current Status	Year of Completion	Surface Area (km²)	Estimated Capacity (1% surface area coverage)	Estimated Capital Expenditure ($)	Max Annual Generation (GWh)	Estimated LCOE ($/MWh)
Nam Ngum 1	Hydropower	Operational	1971	474	Up to 1000 MW+	Up to 1 billion	950	30-40
Nam Theun 2	Hydropower	Operational	2010	377	UP to 1000 MW+	750 million – 1 billion	750	30-40
Nam Ngum 2	Hydropower	Operational	2010	100	Up to 1000 MW+	200 million+	200	30-35
Theun-Hinboun exp.	Hydropower	Operational	2010	97	Up to 1000 MW+	950 million +	195	30-35
Xayaburi	Hydropower	Operational	2019	47	Up to 900 MW	900 million	100	30-35
Nam Ngiep 1	Hydropower	Operational	2019	45	Up to 900 MW	900 million	90	30-35
Nam Khan 2	Hydropower	Operational	2016	30	Up to 600 MW	600 million	70	30-35
Nam Lik 1	Hydropower	Operational	2016	26	Up to 500 MW	500 million	60	25-30
Houay Ho	Hydropower	Operational	1999	20	Up to 400 MW	400 million	50	25-30
Nam Ou 2	Hydropower	Operational	2017	18	Up to 360 MW	350 million	40	25-30
Nam Ou 6	Hydropower	Operational	2017	17	Up to 350 MW	350 million	40	30-35
Nam Ou 5	Hydropower	Operational	2017	16	Up to 330 MW	330 million	40	30-35
Nam Leuk	Hydropower	Operational	2000	11	Up to 240 MW	240 million	25	30-35
Nam Mang 1	Hydropower	Operational	2018	10	Up to 210 MW	200 million	20	30-35
Nam Mang 3	Hydropower	Operational	2005	10	Up to 200 MW	200 million	20	30-35

Table 3: Scenario 3 Floating Solar Development Project List
Background data for individual projects is taken from the Mekong Infrastructure Tracker. Estimated Capacity, Estimated Capital Expenditure, Max Annual Generation, and Estimated LCOE are directly taken from the energy modeling for this project led by Noah Kittner.

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