DRAFT – Final Report

Myanmar National Electrification Plan (NEP): Least-Cost Geospatial Electrification Planning Results

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Executive Summary

Myanmar is estimated to have over 7 million households without electricity amidst the other 3 million that do have access. The poverty reduction and shared prosperity benefits for electricity access are abundantly clear to all. Yet Neighboring countries such as Thailand, Vietnam, Laos and China have managed to meet the challenge of a similar scale -- from 30% to nearly 100% electricity coverage -- within two decades; so there is reason to believe that Myanmar should be aspired and able to reaching universal access in a similar time frame.

To achieve universal access in Myanmar by 2030 will require an average annual electrification rate that is more than double the current rate. At the same time the investment requirements per household will continue to rise with increasing penetration of electricity towards less populated areas. **Recent experience in countries such as Rwanda shows that the most effective and efficient way to achieving a rapid increase in electrification is through a coordinated sector-wide approach.** Under this approach, implementation efforts will be channeled to solutions in line with a least cost planning strategy, and both financial and physical resources will be mobilized in a predictable and structured fashion over a number of years.

A two-pronged and planned approach is proposed under the Myanmar National Electrification Plan (NEP): an aggressive grid electrification rollout program and an ambitious off-grid program. The total investment requirements, not including additional generation and transmission capacity needed to support electrification rollout, are estimated to be US$5.8 billion. The investment requirements for generation and transmission expansion are addressed in the electricity master plan whose development is being led by JICA.

It is evident that even if electrification proceeds according to the initial grid rollout plan and the corresponding coordinated investments in generation and transmission continue apace, there will still be more than one million of households who will not be economically connected to the grid for 10 or more years. Myanmar incidentally has a large populated region in the central plains where the investment requirements per household are modest and will remain relatively low as grid penetration increases. However, in much of Shan or Chin states (as well as other highland and remote areas) where settlements are sparse, the investment requirements per household will rise sharply as the length of medium voltage wire required rises quickly as electrification proceeds in rural and remote areas (see **Error! Reference source not found. Error! Reference source not found.**). Throughout the country, approximately 300,000 households, with a total population of perhaps 1.5 – 1.7 million (3-4% of the population) reside in communities which, due to sparse and remote settlement patterns, are estimated to costs more than US$1,200 per household for grid connection.

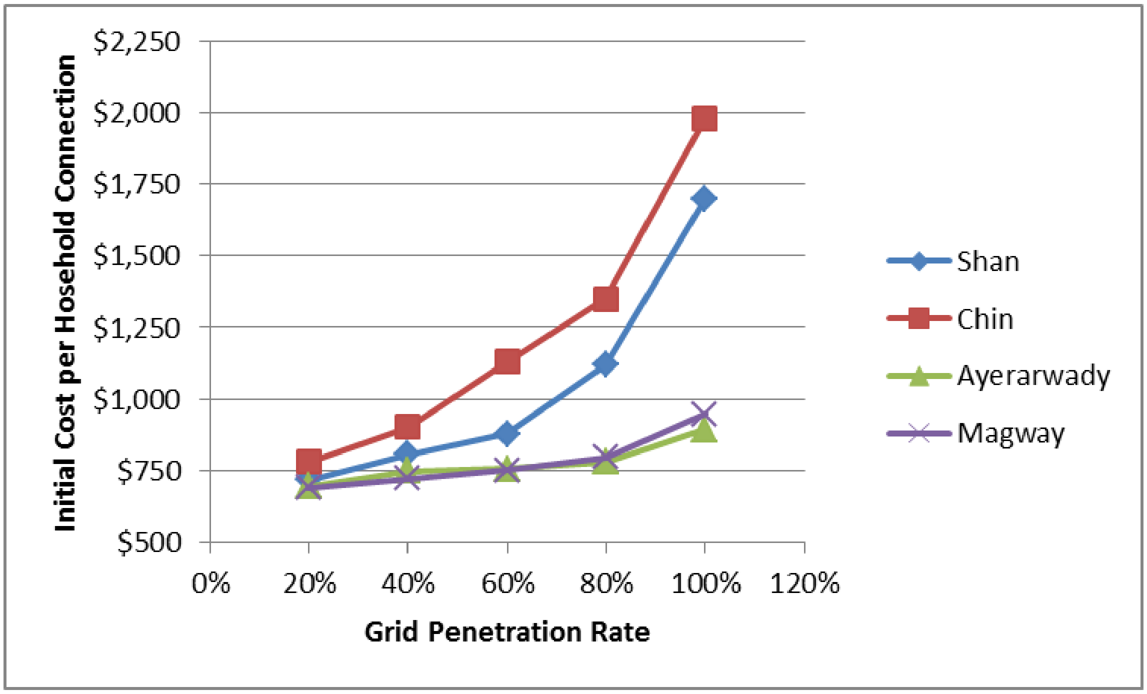

Figure 1: Initial costs per household connection with increasing penetration rate for four states / regions within Myanmar.

While in the long term, Myanmar's settlement patterns and demand aspirations suggests that grid provided power would dominate, there is need for a systematic off-grid program , consisting of solar home sytems and mini-grids, to bring basic electricity services sooner to a maximum number of households possible. An off-grid plan that operates concurrently with the grid expansion plan would ensure that basic electricity services are made available at affordable prices. On the basis of the currently available information, the immediate target population for the off-grid program will consist of those rural and remote populations that would have to wait an inordinate amount of time for grid expansion plans to roll out and where the cost of expansion is clearly high. Some of these populations would ultimately be served by grid, but needs could be met in the short-term with an off-grid system that attempts to mimic the functionality of a grid connection with reduced power capacity.

In order to expedite the process of access, a service profile that meets the most basic requirements (but does not permit electric cooking or a family refrigerator or a form of air-conditioning or ice making,) could be provided at a cost that is affordable to the consumer and to the government. This off-grid approach nevertheless requires a programmatic approach that can leverage scale and build on the emerging and new service delivery models such as pay-as-you-go.

A phased approach to implementing both grid rollout and off-grid programs under the NEP is recommended to ensure accountability and timeliness. The proposed NEP calls for the following roadmap and intermediate milestones to universal access: 50% in 2020, 75% in 2025 and 100% in 2030. Given that information available for planning the electrification roll-out in Myanmar is limited, the NEP will need to be adjusted dynamically to reflect the emerging information, such as the impending population census, as well as changing population patterns and demands.

Introduction

This is the draft final report for one part of the project for development of a Myanmar National Electrification Plan (NEP) funded by the World Bank Group. This report focuses on the project's geospatial electricity planning component ("Myanmar National Electrification Least-Cost Geospatial Planning (grid and off-grid)"). Another report, "Roadmap and Investment Prospectus," prepared by Castalia Advisors, focuses on financial and institutional factors, as well as project timelines. Together, the two efforts comprise the NEP, a comprehensive plan to achieve universal electrification in Myanmar by 2030.

The objective of this work is least-cost, geo-spatial electfication modeling for a national electrification plan. The plan will serve as a basis for accelerating national roll-out of grid, and off-grid systems in achieving universal access. Sub-goals of this work include building capacity among local energy practitioners within Myanmar to carry out similar work in the future both to update this plan and to extend this work to other areas as needed, and to identify, obtain, and best use domestically soucred data wherever possible.

The results in this report represent approximately one year of investigation and planning undertaken by several partners, including two Myanmar government ministries – the Ministry of Electric Power (MOEP), and Ministry of Livestock, Fisheries and Rural Development, Department of Rural Development (DRD) – and a consultancy funded by the World Bank Group and led by the Earth Institute at Columbia University (EI), including both local sub-contractors (Resources and Environment Myanmar) and international contributors (HOMER). The framework for the geospatial planning and related training is outlined in greater detail in ***Annex 1: Project Plan*** at the end of this document.

This report describes the least-cost electrification planning effort in two main sections. The ***Planning Approach*** section describes the sources of data, steps taken to prepare a national dataset, and analytical approaches to geospatial least-cost planning. (Additional detail for these sections can be found in the Annex at the end of this document.) The ***Results*** section describes the outputs of the analysis, including a "pre-electrification" strategy for locations that are planned for the final stages of grid connection.

Planning Approach

The approach used for this electrification planning work is described here in brief. For a more complete description with examples of data formats and key steps, see ***Annex 2: Detailed Methodology*** *at the end of this report****.***

A key objective of this project is to make electrification planning geo-spatially specific, both to reflect the geographic diversity of Myanmar, and to ensure that resources for electrification are used as effectively as possible. This project has used location-specific information for electricity demand and power infrastructure, along with cost and technical values from local sources. A substantial part of this work was the creation of a national geospatial dataset with three main types of information: i) geo-located populated places (referred to here as "settlements"), ii) medim-voltage grid line locations, and iii) technology costs, technical specifications, and other values used for modeling energy demand and system costs.

Compiling a national, geo-located population dataset

Geo-located populated places (villages, towns, and cities with latitude and longitude coordinates) provide information for electricity demand. The primary source for this data was the Department of Rural Development (DRD), which provided approximately 64,000 village locations with population from 2001, and 286 town and city locations with populations from 2013.

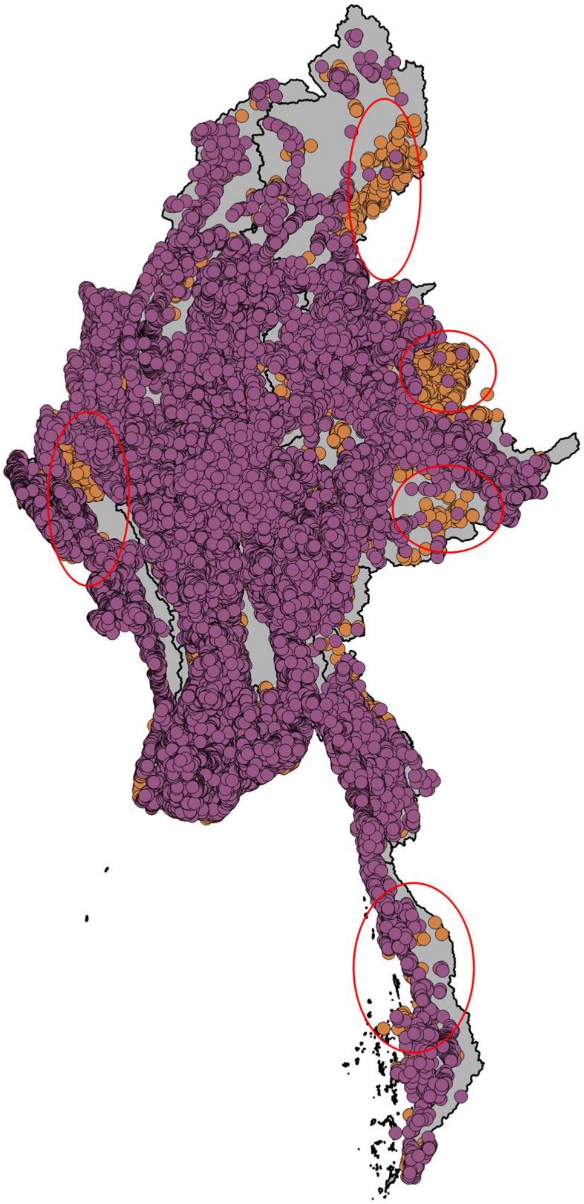

Figure 2: Violet points show village data from DRD with locations and population values. Orange points show locations from MIMU matched to other population data. For gray areas, data was unavailable, or location and population data could not be matched.

This data was cleaned and aggregated, creating a standardized national dataset that covered all states and regions, but with data gaps for some townships, particularly in Shan and Kachin states (see Figure 2 above). These data gaps were of two types: i) areas with simply no village points, and ii) locations marked as villags but with missing or zero population.

A combination of two other village datasets was used to address these gaps, where possible. Village data from the Ministry of Home Affairs, General Administrative Division (GAD) provided population values from 2013 (but no geo-spatial data). These points were joined with latitude and longitude information from MIMU (the Myanmar Information Management Unit). This supplemental DAD-MIMU village dataset was then combined with village, town and city data from DRD, to create the national geospatial dataset of populated places. The population values for all locations were then projected to a common year, 2011, using growth rates provided by the Central Statistics Office (CSO). The process for creating the national dataset of geo-located populated places is shown in Figure 3 below.

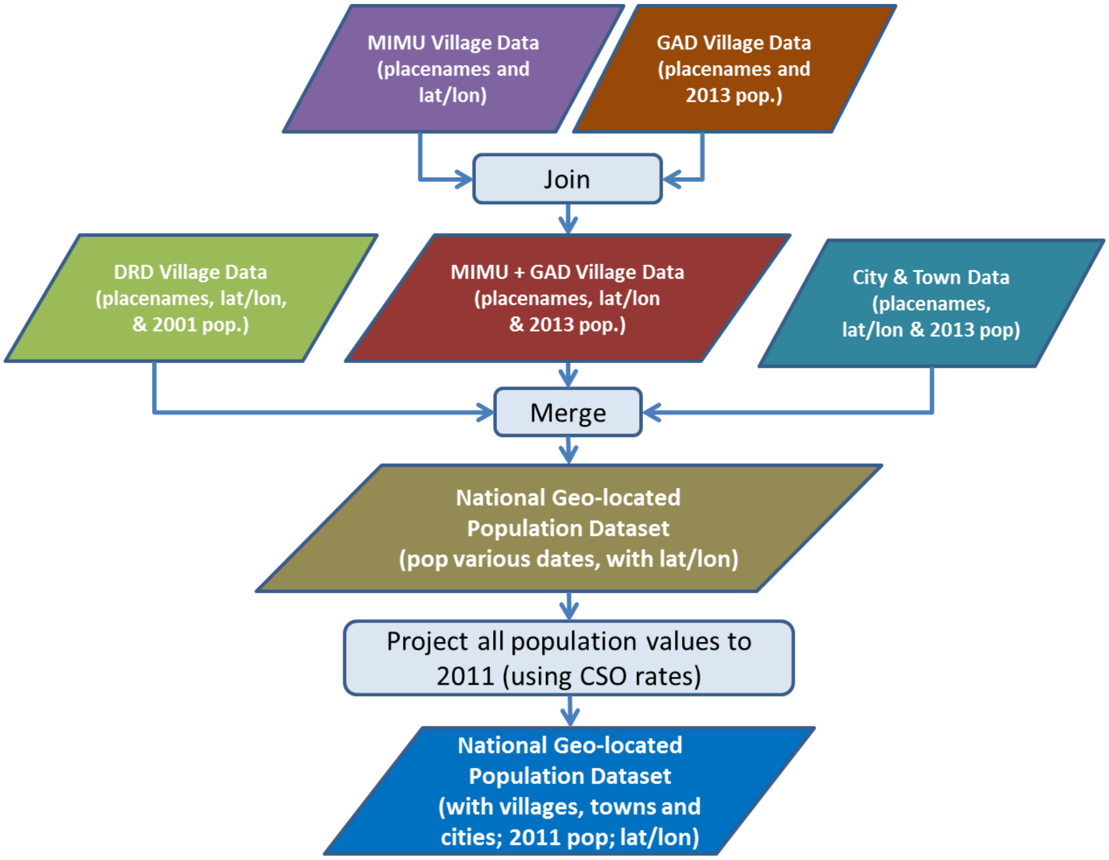

Figure 3: Method for creating a national, geo-located population dataset.

An effort of validation was made by comparing total population of our full national dataset projected to 2011 versus the CSO population figures, and the two agreed within 9% which is seen as acceptable, considering the uncertainty of domestic data source[1].

It is important to note that, although the population dataset obtained for this project was reasonably comprehensive, there are important data gaps. These gaps necessarily limit the accuracy of all resulting estimations related to number of households nationally, residential electricity demands, and related costs and technical conclusions. For this reason, model results and other conclusions of this document must be considered as estimates, indicative of overall costs and spatial trends, but requiring validataion at the local level.

Geo-spatial (GIS) files for utility electricity grid maps

The second important data category is geo-referenced information for electricity grid infrastructure. As preliminary investigation, a GIS comparison was made between high voltage (HV) transmission infrastructure (existing and planned) and populated places to provide a rough estimate of potential future access. A map of existing and future HV lines proided by Myanmar Electric Power Enterprise (MEPE) is shown in Figure 4 below. A comparison with populated places indicates that most (75-85%) of the Myanmar population lives within 25-50 km of existing HV infrastructure, while 90-99% will be within this range of existing and proposed HV extensions.

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[1] Discussions in with technical advisors to the census effort clarified that preliminary values are planned for release in Augst of 2014, and final results in March 2015 (UNFPA staff, Nay Pyi Taw, Myanmar, February, 2014).

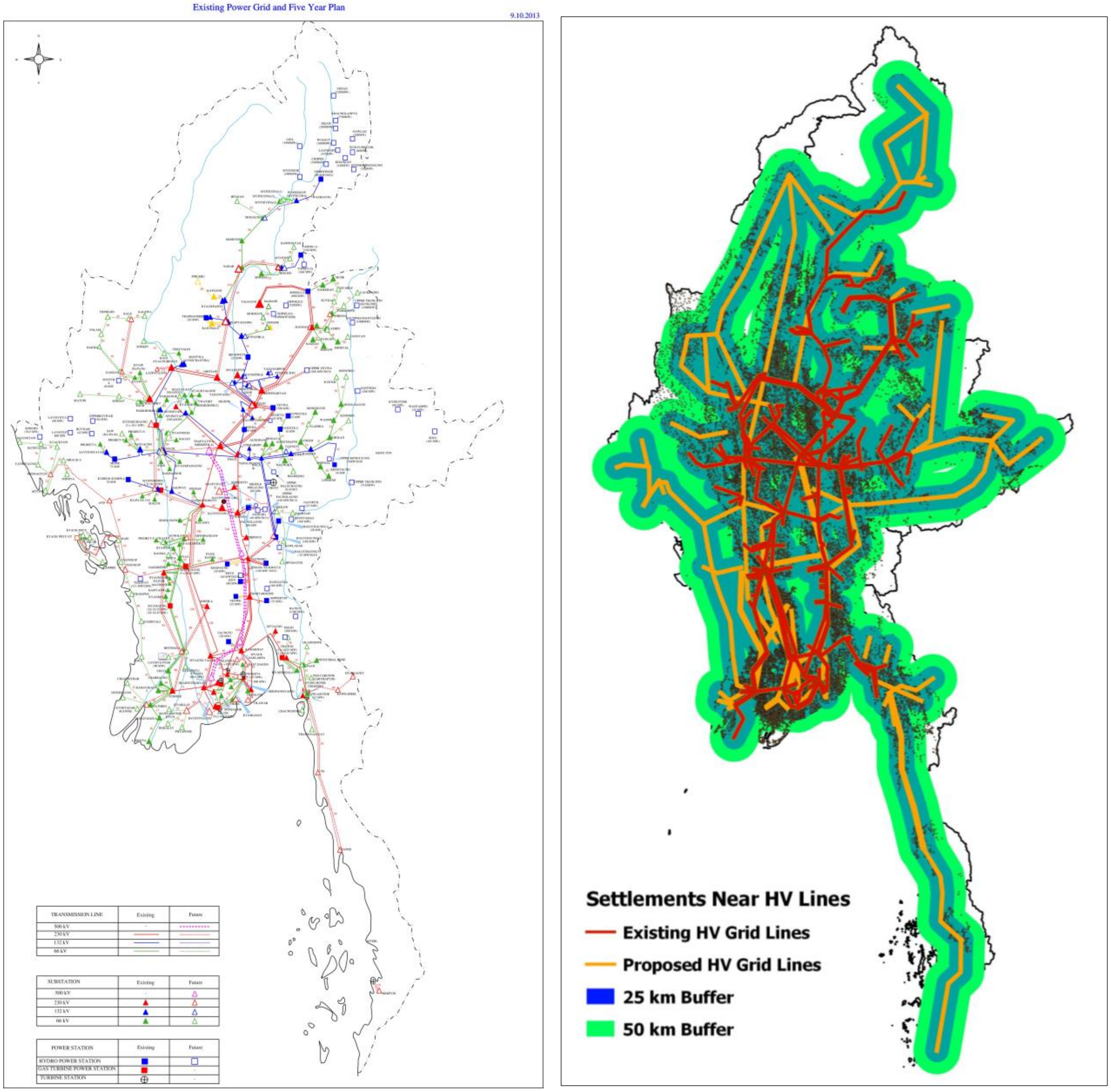

Figure 4: High voltage (HV) grid infrastructure map from MEPE (left) and 25 km and 50 km buffers surrounding existing and planned grid (right).

While HV lines indicate proximity to infrastructure at a very high level, examination of medium-voltage (MV) lines[2] is necessary for the more detailed, local analysis for this project. For this work, ESE and YESB provided hundreds of maps in various paper and electronic formats for existing MV lines, which were then geo-referenced to create GIS shapefiles (see Figure 5 below).

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[2] Throughout this document, "medium voltage" and "MV" refer to lines of 6, 11 and 33 kilovolts (kV) when referring to existing MV, and 11 and 33 kV when referring to planned extensions (since ESE plans to avoid construction of additional 6 kV lines in the future.).

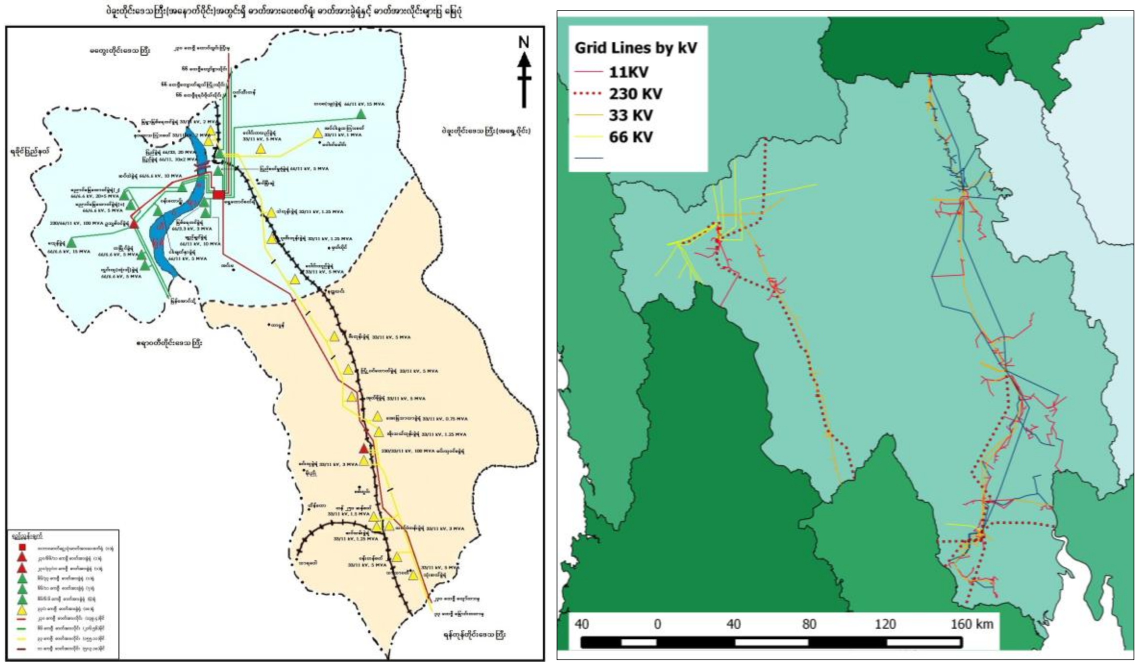


Figure 5: (Left) ESE drawn MV maps at the district level. (Right) Geo-referenced, digitized, GIS shapefiles for electricity grid lines for Bago Region.

After establishing the population dataset and the MV distribution line map, the two were used together to create a geo-spatial estimate of current access. (ESE and YESB have information for grid access, but it is not geo-located.) ESE indicated that communities within 1 km of the existing MV line are in range to obtain connection. This 1 km range was used for spatial analysis to identify villages with access to current MV lines. The difference in the number of electrified villages between this geo-spatial estimate and the ESE data is less than 5% for many states, and less than 15% for most.

Gathering modeling paramters from local sources

A third key type of information is the numerous parameters required for model calculation. These relate to equipment costs, technical specifications, growth rates, and numerous other details. The majority of these parameters were gathered directly from utility officials in Nay Pyi Taw, and various state / regional offices (Mandalay, Bago, Kayin, Chin). The value of parameters listed above were relatively consistent throughout the lowland areas of the country, while costs rose in remote, highland areas. Regional modifications were applied to the model calculations, to reflect this trend. Among the numerous modeling parameters, the most critical ones are listed below. (***Annex 2*** provides a more complete breakdown of parameter inputs, with variation by state.)

Probably the most important parameter is electricity demand per household. ESE officials and engineers provided current electricity demand values ranging from a low of 450-500 kWh per household per year, to a high of around 1,000 kWh/HH-year. This data was validated at the local level by an inspection of billing records. The ESE officials also reported 1,000 kWh as the average consumption per household per year for the residential customer, which included urban high-consumers, and, more importantly, confirmed that they expect rural consumers to rise to this average within a few years after connection. For this reason, 1,000 kWh per household per year was chosen as the conservative (i.e. low-end) household demand value, with ESE agreement.

Key grid cost and technical parameters are illustrated below (for the full list of more than 70, see *Annex 2: Detailed Methodology*):

- **MV line: $20,000 / km for lowland areas; $22,000 for highland areas (ESE).**
- **LV line: US$15,000 / km for LV line (ESE)**
- **Distribution losses: 15%**
- **Connection cost: US$300 ($100 household equipment and $200 "service drop")**
- **Cost of power: 130 kyat (13 US cents) per kWh (Castalia Advisors)**

The last of these cost parameters, the US$0.13 per kWh "bus bar" cost of power, is of fundamental importance, and is detailed more fully in the second part of this study authored by Castalia Advisors. Briefly, it represents all costs of generation and transmission to deliver power to the medium-voltage substation, considering the full mix of existing and new generaion, across all technologies including hydropower, gas turbines, and others, as well as all costs for existing and new transmission, including losses at this HV level. It represents the internal cost of power for the utility, not the final retail price of power to the consumer.

For diesel gensets, cost of fuel is a dominant recurring (and lifetime) cost:

- **Diesel Fuel per liter: 4,400–4,900 kyat (US$1.10-1.22/liter) varies by location (ESE)**

Costs for solar systems were obtained from vendors, with support from Dr. Aung Ze Ya, (Mandalay Technological University) and compared with international prices where quality was a key concern:

- **Solar PV panels: US$1.00 per Watt-peak.**
- **Batteries: US$150 per kWh; with 3 year lifespan.**

Household size was derived for each state or region using DRD data from 2001, which included both the number of households, and the total population for a given community.

Note: the full list of all cost, technical, financial and other parameters are presented in ***Annex 2.***

Least-Cost Electrification Planning for Each Demand Point

Once all data is prepared, the next step is a **least-cost comparison of on-grid, mini-grid, and off-grid electricity systems** for each settlement. The model first projects the expected population and electricity demand for each settlement (Figure 6, left panel).

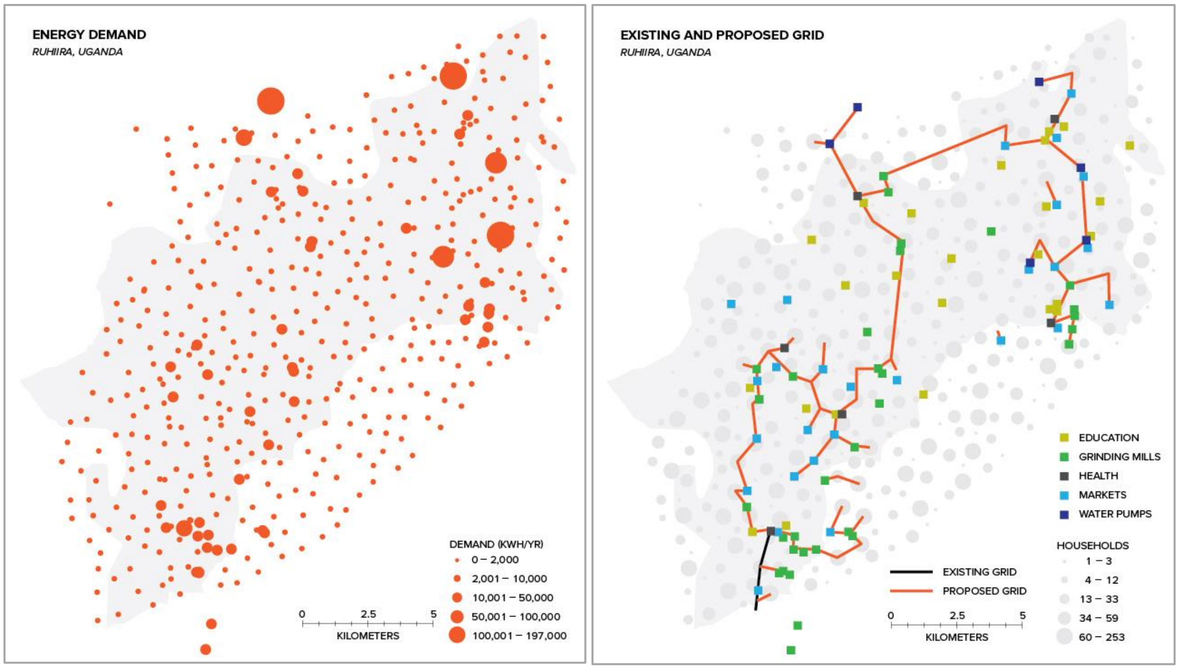


Figure 6: Map with magnitude of electricity demand for each point shown by circle size (left); algorithmically specified least-cost electricity grid network (right)

Cost calculations are then made, **incorporating all initial and recurring costs over the long-term (30 years)** for all system types (grid, mini-grid, off-grid). The model then uses a customized algorithm to select the lowest cost option for each location. Communities recommended for the grid are identified and the corresponding electricity network is mapped in Figure 6 (right panel). Locations where the grid is not recommended are instead assigned the least-cost non-grid alternative which may be mini-grid (solar, diesel, hybrid, etc.) or off-grid (typically solar photovoltaic home systems).

Key Metric: Meters of Medium-Voltage Line per Household (MV/HH)

Many costs related to electric power infrastructure are either the same for all households (e.g. the cost for an electric meter) or vary with electricity demand (the costs for transformers, solar panels, or a diesel engine). However, some costs related to electric grid infrastructure have spatial factors to incorporate, an important one being the length of medium-voltage grid line required to connect communities. A key metric which reflects this geo-spatial factor is ***meters of medium voltage line installed per household connection***, or **MV/HH** for short. MV/HH is a valuable metric, first, for understanding the cost-benefit trade-offs related to grid extension vs off-grid alternatives, and, second, for prioritizing grid extensions in a least-cost manner. In general, the medium-voltage line per household (MV/HH) is low in urban and per-urban areas, reducing grid extension costs on a per household basis, and higher in remote and rural areas. When the metric MV/HH is used to select which communities should be reached by grid, and then to algorithmically determine the most cost-effective pattern of connections, the result is typically to concentrate connections and prioritize sequential extension within denser areas, which are lower cost, and continue onto more remote, less dense, higher cost areas. MV/HH can be computded in a variety of ways, as dscussed in ***Annex 3.***

Preparation of Sequenced Roll-Out

This analysis also quantifies relative costs for different phases of grid extension in order to provide a sequenced grid roll-out plan. In this analysis, an algorithm prioritizes construction of lines that meet higher electricity demand with the shortest MV line extension. Figure 7 below shows an example of grid roll-out in five phases. Initial phases of grid construction reach communities that are closely spaced and nearer to the existing electricity grid, where less medium voltage line is needed per household. Later phases reach remote, rural communities where MV/HH is much higher.

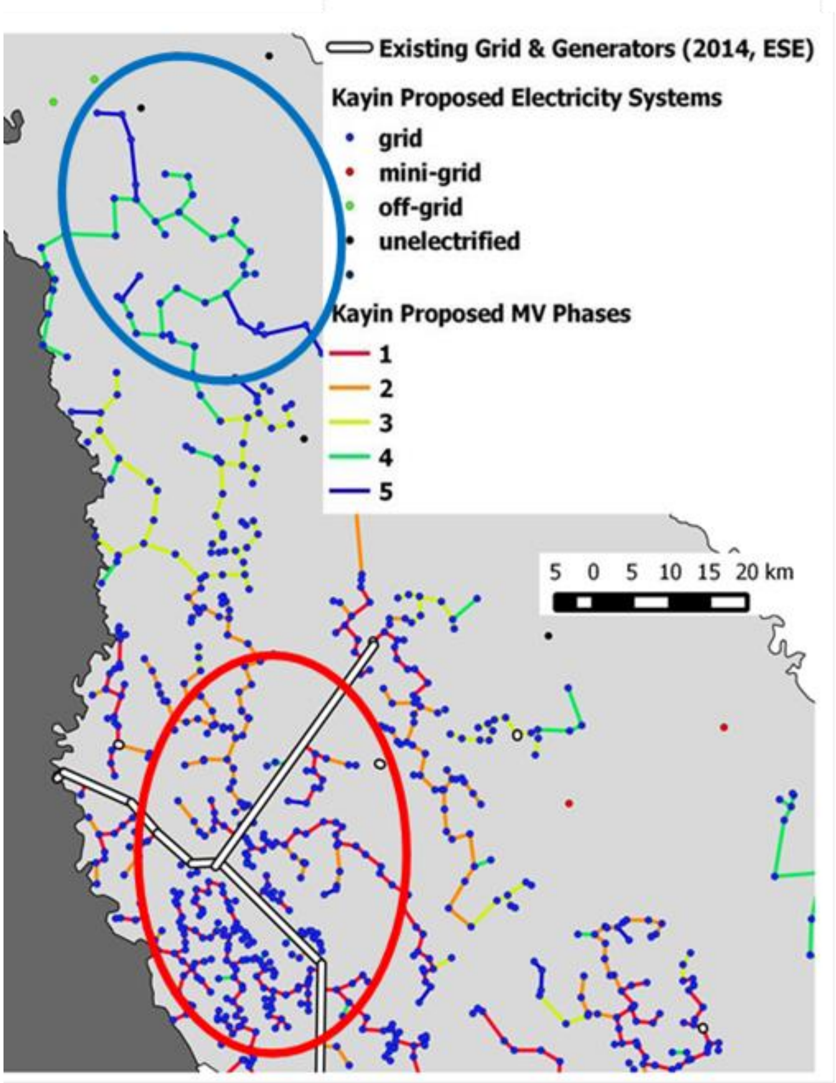


Figure 7: Five phase grid roll-out plan for part of Kayin State.

Results: National Least-Cost Electrification Rollout Recommendataions

Grid is the long-run, least-cost recommendation foralmost all Myanmar households

The most important recommendation of the geo-spatial least-cost electrification plan is that grid extension is the most cost-effective means of electrifying virtually all (99% or more) current and projected unelectrified households throughout Myanmar over the long-term (see Figure 8 below).

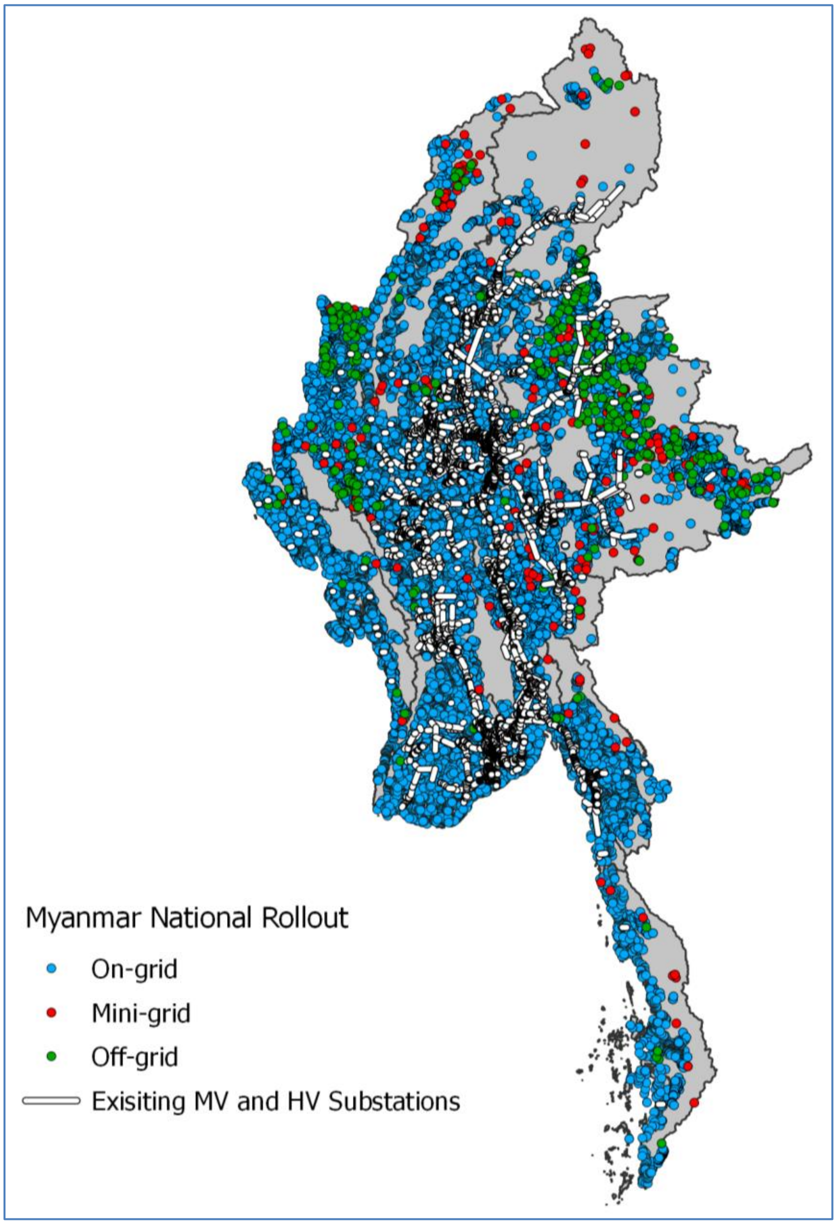


Figure 8: Geogrpahic distribution of communities recommended for different electricity system types.

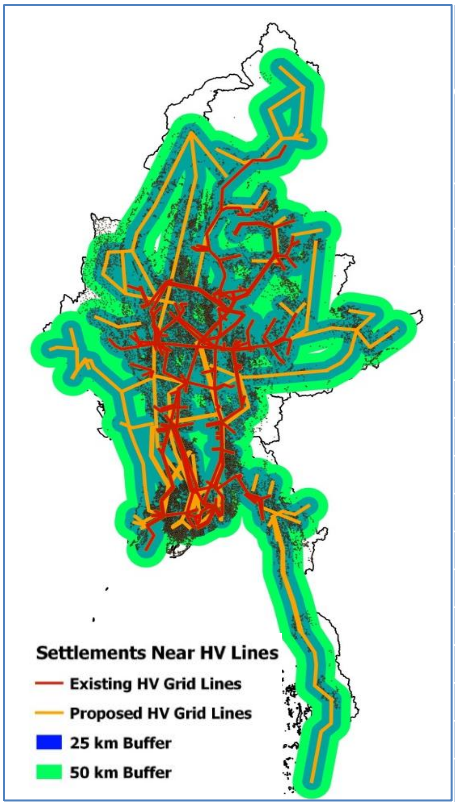
The penetration of grid throughout the country according to this least-cost plan would be very comprehensive, covering virtually all of the densely populated and lowland areas, as well as the majority of the highlands. Very rarely (1% of the time or less) mini-grid systems (in this case, village or town-scale systems) and off-grid systems (solar home systems) are recommended, typically for the smallest and most remote communities, predominantly in Chin, Kachin, Shan and other mountainous and border areas.

Quantitative data detailing this recommendation for all states and regions is provided in Table 1 below. Based on the best available data for this analysis, the national electrification program will connect around 7.2 million homes, of which more than 99% will be through electricity grid extension. It is important to note that, even though the Earth Institute model outputs report values to higher levels of precision, all population figures in this table have been rounded to the 10,000 unit, and all percentages are expressed in no greater accuracy than 1%. This is because of limits on the accuracy and completeness of the source data upon which this analysis is based – the population figures from a combinantion of DRD, MIMU and GAD. As has been emphasized before, the results of this analysis are estimates.

Table 1: Quantitative results for least-cost electrification planning by state / region.

	Population			Long-Term System Recommendation						
	(EI Est., round to 10,000)			Households and Percent						
States / Regions	**Total**	**Unelectrified**		**grid**		**mini-grid**		**off-grid**		**total**
Ayeyarwady	5,530,000	4,920,000		1,080,000	>99%	0	<1%	0	<1%	**1,082,000**
Bago	5,960,000	4,530,000		690,000	>99%	60	<1%	0	<1%	**688,200**
Chin	510,000	430,000		110,000	>99%	330	<1%	410	<1%	**112,600**
Kachin	1,260,000	920,000		120,000	>99%	250	<1%	280	<1%	**116,100**
Kayah	260,000	150,000		30,000	>99%	80	<1%	0	<1%	**27,060**
Kayin	1,590,000	1,370,000		380,000	>99%	80	<1%	30	<1%	**379,600**
Magway	5,200,000	4,310,000		810,000	>99%	130	<1%	0	<1%	**811,400**
Mandalay	6,740,000	4,250,000		720,000	>99%	10	<1%	0	<1%	**721,700**
Mon	2,680,000	1,820,000		260,000	>99%	30	<1%	40	<1%	**258,200**
Nyapitaw	650,000	200,000		100,000	>99%	0	<1%	0	<1%	**98,220**
Rakhine	4,300,000	4,040,000		980,000	>99%	50	<1%	0	<1%	**977,400**
Sagaing	5,830,000	4,490,000		910,000	>99%	630	<1%	20	<1%	**909,600**
Shan	5,990,000	4,490,000		500,000	~99%	1,100	<1%	1,100	<1%	**511,300**
Tanintharyi	1,220,000	1,110,000		330,000	>99%	30	<1%	0	<1%	**325,400**
Yangon	6,610,000	1,720,000		210,000	>99%	0	<1%	0	<1%	**208,000**
National Total	**54,320,000**	**38,740,000**		**7,220,000**	**>99%**	**2,700**	**<1%**	**1,900**	**<1%**	**7,230,000**

A rough analysis of MEPE's plan for high-voltage insfrastructure concluded that new transmission lines to be built are sufficient to support universal grid access in Myanmar. Figure 9 below shows a comparison of locations of existing and planned transmission lines, versus populated places. Buffer zones of 25 and 50 km around future transmission infrastructure will enclose 92% and 99% of Myanmar's population, respectively. While it is important to note that this is not an indication of grid access – distribution infrastructure is required to access power from transmission lines – it does illustrate that planned coverage of HV transmission lines is nationally comprehensive, and so will support MV grid extension to virtually the entire country.



		Existing & Proposed Transmission Lines	
State/Region	**EI total pop est (2011)**	**% within 25 km**	**% within 50 km**
Ayeyarwady	5,525,272	84%	98%
Bago	5,962,202	96%	100%
Chin	513,818	55%	89%
Kachin	1,257,257	92%	96%
Kayah	262,623	100%	100%
Kayin	1,588,067	84%	94%
Magway	5,196,998	88%	100%
Mandalay	6,744,796	97%	100%
Nyapitaw	648,236	100%	100%
Mon	2,675,187	97%	100%
Rakhine	4,296,507	90%	99%
Sagaing	5,827,408	87%	98%
Shan	5,985,389	92%	96%
Tanintharyi	1,220,319	95%	100%
Yangon	6,614,051	97%	100%
Total	**54,318,130**	**92%**	**99%**

Figure 9: Buffers of 25 and 50 km drawn around existing and planned HV transmission lines (left panel) include more than 90% of national population.

Key metrics by state / region

A variety of key metrics related to new grid infrastructure proposed by this modeling work are provided on a state by state basis in Table 2 below. These include the recommended number of new household connections, length of new MV grid line, and new generation capacity needed only for residential demands for new connections. Note that this capacity estimate excludes commercial, industrial, and other non-household demand types, as well as the growth in demand for all types of customers already connected to the grid.[3] Implementation of the recommendations will require approximately 62,000 km of MV line, or approximately 9 m of medium-voltage (MV) line per household on average. The total initial cost of this extension of the distribution lines and household connections is estimated at US $5.8 billion, an average of around US $800 per connection. Note that these investments would be *in addition to* other costs related to additional generation, transmission infrastructure or upgrades or improvements of existing distribution lines. These results show nearly negligible (<1%) contributions of mini-grid and off-grid (solar home system) systems to the electrification mix throughout the country.

Table 2: Proposed New Connections, MV Line, and Generation Capacity by State / Region

State / Region	Number of Household Grid Connections Proposed	MV Length Proposed (km)	Generation Capacity Proposed (MW)
Ayeyarwady	1,082,000	8,300	395
Bago	688,000	4,700	251
Chin	112,000	3,200	41
Kachin	115,000	2,000	42
Kayah	27,000	560	10
Kayin	379,000	2,900	139
Magway	811,000	6,400	296
Mandalay	722,000	4,400	264
Mon	258,000	1,300	94
Nyapitaw	98,000	670	36
Rakhine	977,000	5,000	357
Sagaing	909,000	7,800	332
Shan	504,000	11,000	184
Tanintharyi	325,000	2,300	119
Yangon	208,000	1,600	76
Grand Total	**7,216,000**	**62,000**	**2,636**

Considering only the Grand Total figure, because it best reflects the scale of the electrification challenge:

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[3] The limitation of this estimate to new, largely rural residential customers results in new electricity demand values substantially below those in similar large scale studies, such as the national electricity masterplan developed by NEWEC Inc. and Kansai Electric Power with JICA support.

- **New distribution infrastructure**. The question of how many connections must be added per year is dealt with in more detail by the Investment Prospectus (the complementary component of the NEP project, report authored by Castalia Advisors). However, simple arithmetic indicates that 7.2 million household connections over 16 years to 2030 requires nearly 500,000 new connections each year. This is equal to approximately ten times the current rate of ESE connections (at around 50,000 per year). The model results also recommend new construction of around 62,000 kilometers of MV grid lines, or more than 4,000 km per year of primarily 33 kV line. This highlights the magnitude of the task facing the utilities, most of all ESE.

- **New generation:** Myanmar would also require around 2.5 – 3.0 GW of new generation capacity, just to meet the needs of the 7.2 million new household connections under the assumed service standard of 1,000 kWh/HH-year. This is equivalent to doubling of **the current generating capacity, which stands at around 2.7 GW.** Because this represents only new residential demand – omitting commercial and industrial demand, as well as demand growth for currently connected customers – the objective of universal access clearly implies doubling the generation capacity ***at the minimum***.

Two of these metrics – the number of new connections and new generation capacity – relate directly to the population of a state or region. The MV line recommended, however, relates to a key geo-spatial factor, the distance between communities. For several states, but particularly Shan, Chin, Kachin and parts of a few others, the amount of MV line required is quite large compared to the total number of household connections. This indicates an unusually high MV/HH, which results in high costs for grid extension. A more detailed sub-national breakdown of MV/HH values is included in ***Annex 4****: Restuls by State / Region***.** The grid is still the least-cost option for all of these households compared to minigrids or off-grid systems on the basis of same service standards, but it is more expensive to connect each household in these states in comparison to other less rural and remote areas.

Targeting system types by size of community

An important part of this planning effort is to cost-effectively target different electricity system types – grid, mini-grid, and off-grid (solar home system)[4] – for specific communities. As seen previously, the overwhelming majority of the population (99%) is recommened for grid access eventually. For those very few communities that are recommended for non-grid systems over the long term, the size of the community plays an important role in determining which should be mini-grid or off-grid. Figure 10 below shows a breakdown of the recommened electricity system type based on village size, highlighting the non-grid recommendataions with red boxes. This figure shows that it is the smallest villages, those with 10 or fewer households, which are most often recommended for off-grid. Larger settlements – villages with 11-20 households and 21-50 households – are mainly served by grid, with a very small percentages from non-grid options, though the tranches are generally too small to discern.

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[4] Note that in this analysis, "mini-grid" systems have been defined and costed as diesel standalone systems, which "off-grid" have been defined as solar home systems. In practice, these systems, particularly mini-grids, are likely to involve hybrid technologies, combining diesel gensets, solar PV generaion, and even hydro or other renewables. This modeling work made these technology choices for the following reasons: ESE, the current operator of isolated grids currently only employs diesel generation, and provided cost estiamtes for this system type. While this may change in the future, it is not currently in the utility's plans. Also, for this modeling exercise, detailed geo-spatial data on precise locations of hydro and other renewables were unavailable at national scale. Most important, the results of this modeling work should not be seen as precluding other system types, but rather as setting a cost maximum. If other, lower cost renewable or hybrid options exist, they will likely reduce the long-run cost of mini-grid systems, and can be implemented on a local basis. Renewables also may be integrated into the grid, as local opportunities permit.

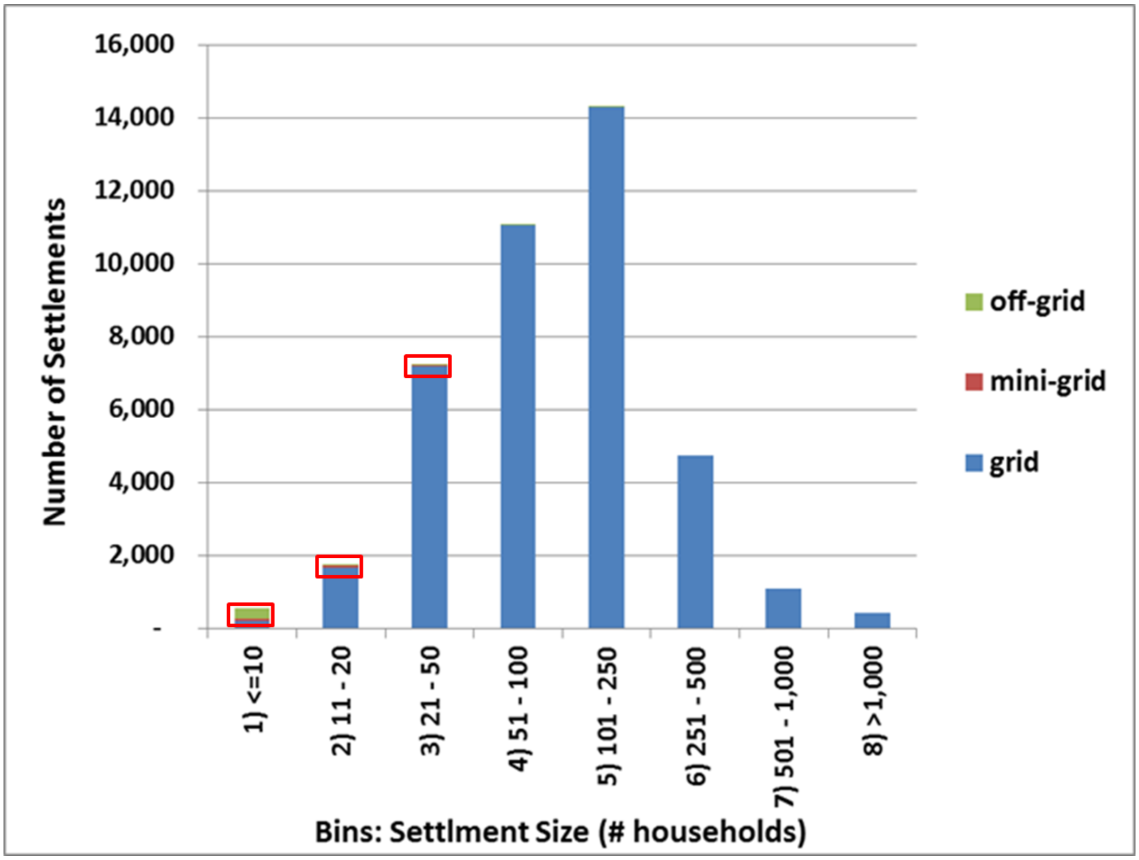


Figure 10: Number of Settlements for which each electrification technology is recommended, by Settlement Size (in number of households)

This figure offers a more general insight useful for electricity planning overall: small villages are much more likely to be cost-effective sites for solar home systems and mini-grids, particularly if they are remote. This is largely due to the high initial costs of extending MV lines between villages, and adding transformers. In Myanmar, only the smallest villages (10 households or fewer) are consistently recommended for non-grid electricity solutions. However, there is some uncertainty regarding the results, which is further explored in the later section of this report.

Sequenced grid roll-out shows high costs in later phases

In addition to providing least-cost system recommendations, an essential output of this planning process is the sequencing of grid connections in a manner that is also least-cost. The approach taken here plans grid “roll-out” as a sequence of grid extensions starting with lower cost areas where electricity demand is dense, such as urban, per-urban and nearby rural areas, and extending gradually toward higher cost areas where demand is typically less dense, such as remote locations where communities are smaller and more distant from each other. Throughout this document grid roll-out has been planned in five phases, each representing approximately 20% of the full medium voltage line extension. The map in Figure 11 below shows that in a five phase grid “roll-out” plan, it is most cost-effective to first elecrify lowland regions, such as Mandalay, Ayerarwady, and Mon, where populations are dense and grid is nearby (red and orange lines). However, highlandstates such as Chin, Shan, Kachin, and Kayah, are designated for later phases of grid roll-out (green and blue lines) because populations are less dense, communities are smaller and widely spaced, and grid extension costs are higher. In this way, if grid roll-out is considered only on a least-cost basis, it is most cost-effective to proceed from the lowland, dense areas, to the less dense highland and remote areas.

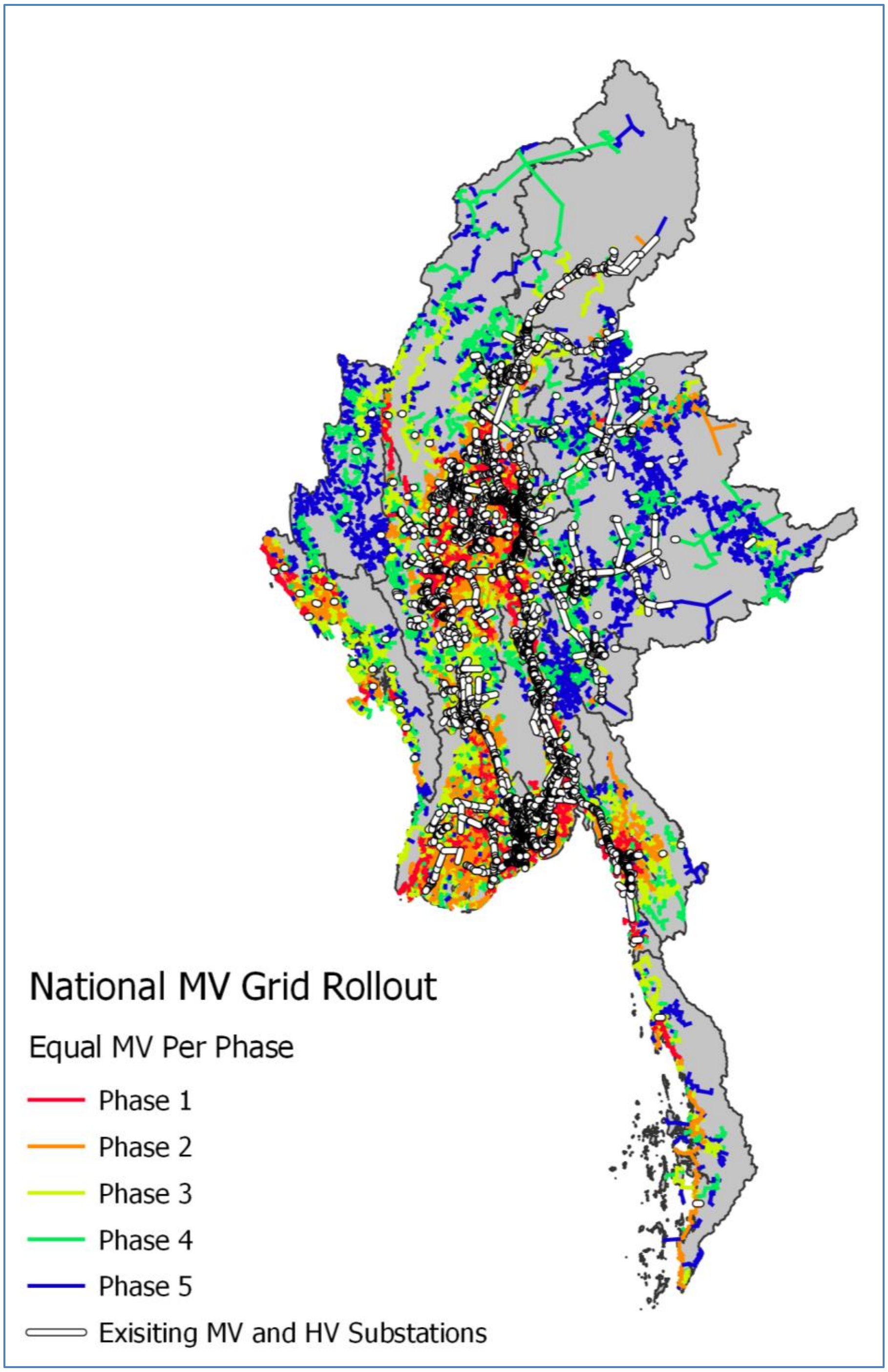


Figure 11: Grid "roll-out" in five phases for Myanmar

This geographic condition of high-cost grid in remote areas has been analyzed and expressed quantitatively. Metrics related to total cost, per household cost, and medium voltage line length for this five phase national roll-out plan are shown for the national dataset in Table 3 below (sub-national data is presented in ***Annex 4****: Restuls by State / Region*) . As grid is extended to more remote communities, the average length of MV line per household increases, causing per HH connection costs to increase. The MV line investment rises dramatically in Phase 4 to reach double the MV/HH average for the national program, then jumps in Phase 5 to exceed 5 times the average.

Table 3: Metrics for five phase national grid roll-out plan.

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
		km	USD	m
1	3,510,000	12,300	$700	4
2	1,750,000	12,300	$770	7
3	1,100,000	12,300	$850	11
4	615,000	12,300	$1,030	20
5	234,000	12,300	$1,710	53
Total	**7,220,000**	**61,700**		
Average	**1,440,000**	**12,300**	**$800**	**9**

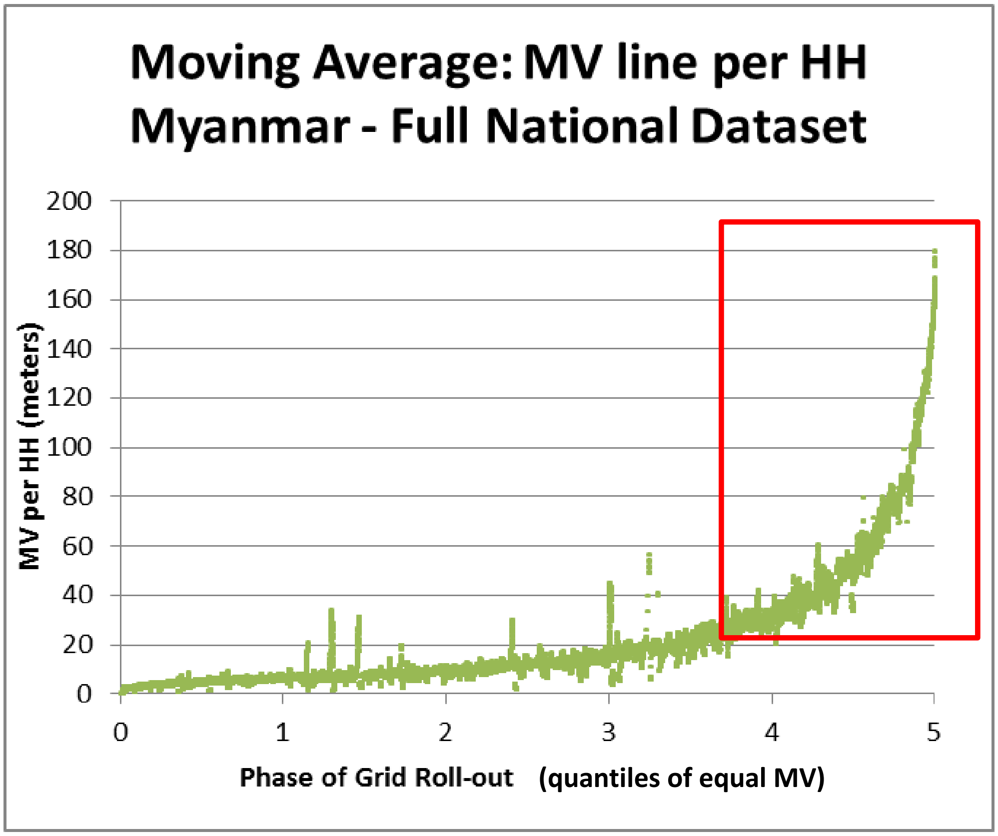


Figure 12: Increase in average MV/HH as grid "roll-out" progresses

Figure 12 above shows how this metric changes continuously throughout grid roll-out. The steep increase in the curve highlights the very rapid rise in MV/HH in the last (fifth) phase of grid extension which corresponds to a similarly rapid rise in cost to connect households in remote communities. In this figure the red box indicates “high cost” areas where more than 25 meters of MV/HH is required. This threshold is somewhat arbitrary and what is seen as “high cost” may vary from state to state. It is chosen at 25 meters for this illustration because, at US$20 per meter of MV line, this distance adds around $500 to every household connection, approximately doubling the cost per connection relative to what might be seen in dense, urban areas.

For the Myanmar dataset, application of a “high cost” threshold of 25 meters corresponds to the MV extensions that would serve approximately the final 250,000 households of phase five. This equals about 3.5% of the targeted population and perhaps 20-25% of the total national MV line extension. The quantitative and geographic analysis shown here indicates that these are communities that will cost substantially more to electrify per household. Moreover, geo-spatially, these areas fall disproportionately in states and regions such as Chin, Shan, Kachin and Kayah, and to a lesser extent Kayin, Sagaing, Tanintharyi.

The argument for "pre-electrification"

This analysis indicates that, in the long run, grid extension is cost-effective for virtually the entire population. However, full grid electrification will take 15 years, or longer. Costs to electrify remote locations rise rapidly for the last 5% or so of grid extension. Furthermore, other factors, aside from MV/HH, will likely contribute to increasing costs of serving these communities even more. These factors include challenges in electricity service provision that utilities experience, but which are often quite difficult to measure and model, such as:

i) demand density falls in more remote and poorer locations, since commercial loads of markets are reduced, and household consumption falls;

ii) transformer and distribution losses are higher as loads become more spread out, and loads tend to be more "peaky" when demand types are more limited;

iii) operation and maintenance (O&M) costs rise in remote areas since equipment is harder to access and replace due to poorer roads and longer distances, and management costs also rise as activites such as metering and bill collection become more difficult.

One of the most important factors to consider in electrification planning is timing of access. Full grid electrification is expected to take at least 15 years, perhaps longer depending upon the capacity of ESE to increase the rate of grid expansion. The highest cost areas of Myanmar are targeted for grid extension in the latest phases of grid roll-out, but they have urgent need for basic power to servicelighting for homes, and power for clinics and schools. One response to this issue is to plan temporary or transitional electrification option, which will provide electricity access in the short to medium term to the most remote rural areas that are targeted for grid extension in the later phases. Non-grid electrification technologies such as mini-grids and solar home systems can provide electricity in the short to medium term, which is referred to here as "pre-electrification" indicating that it is non-grid electrification that precedes grid extension.

“Pre-electrification”: Geography and Qunatitative Analysis

Figure 13 below shows the geographic areas that would be targeted for pre-electrification.

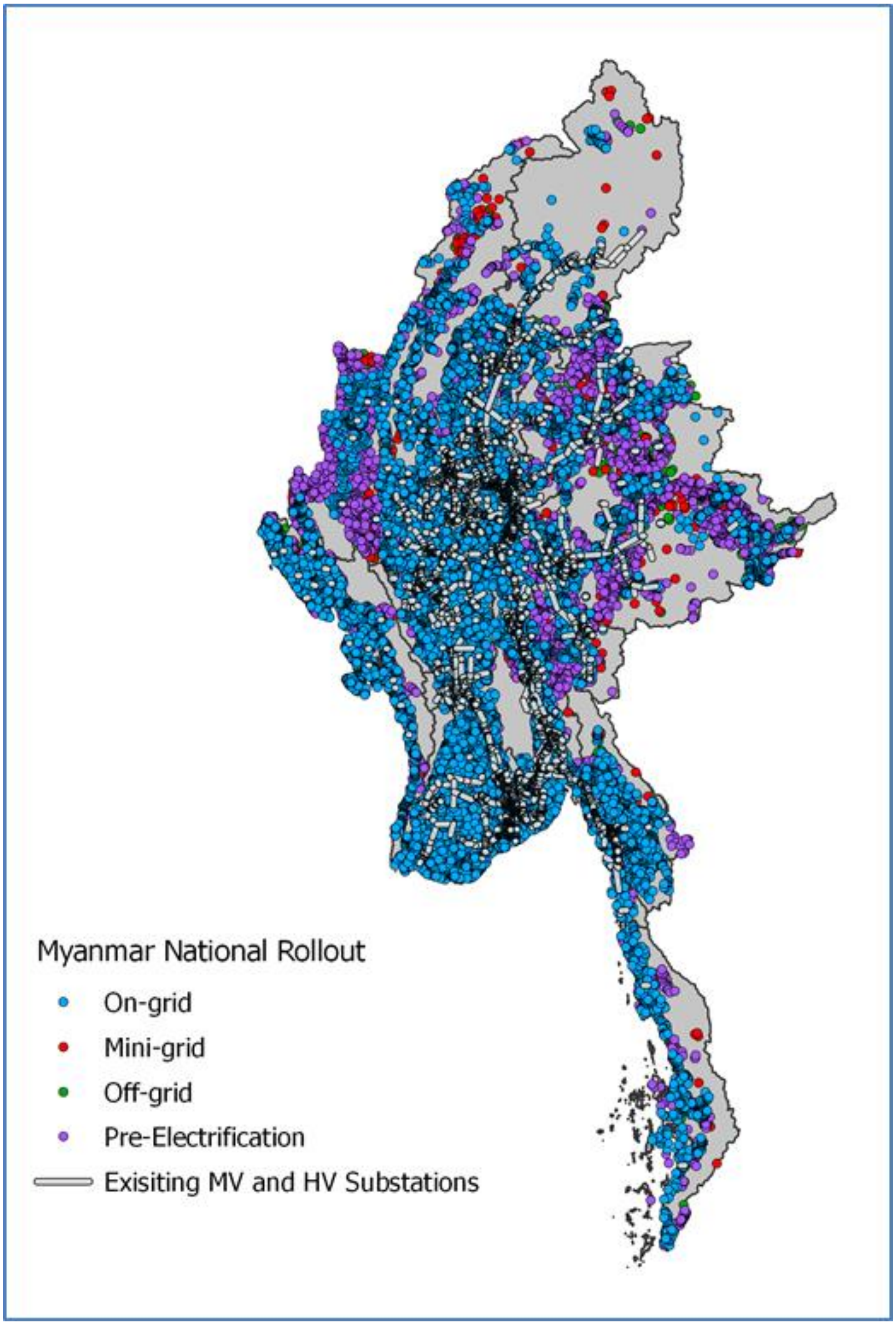
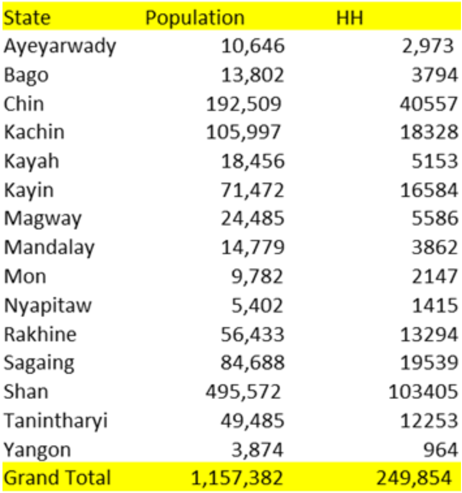


Figure 13: Locations proposed for grid and for "pre-electrification"

Clearly the violet areas targeted for “pre-electrification” – which fall mostly in Chin, Shan, Kachin and other highland states – show substantial overlap with the later phases of planned grid extension, as shown in blue previously in Figure 11.

Quantitative information on pre-electrification by state / region is provided in Figure 14 below. The last 3-4% of locations identified as “high cost” represent around 5,000 settlements, containing around 250,000 households. As the table and bar chart emphasize, the greatest needs are in Shan and Chin states, while other areas that are relatively rural and remote from the existing grid are also substantial.



State	Population	HH
Ayeyarwady	10,646	2,973
Bago	13,802	3794
Chin	192,509	40557
Kachin	105,997	18328
Kayah	18,456	5153
Kayin	71,472	16584
Magway	24,485	5586
Mandalay	14,779	3862
Mon	9,782	2147
Nyapitaw	5,402	1415
Rakhine	56,433	13294
Sagaing	84,688	19539
Shan	495,572	103405
Tanintharyi	49,485	12253
Yangon	3,874	964
Grand Total	1,157,382	249,854

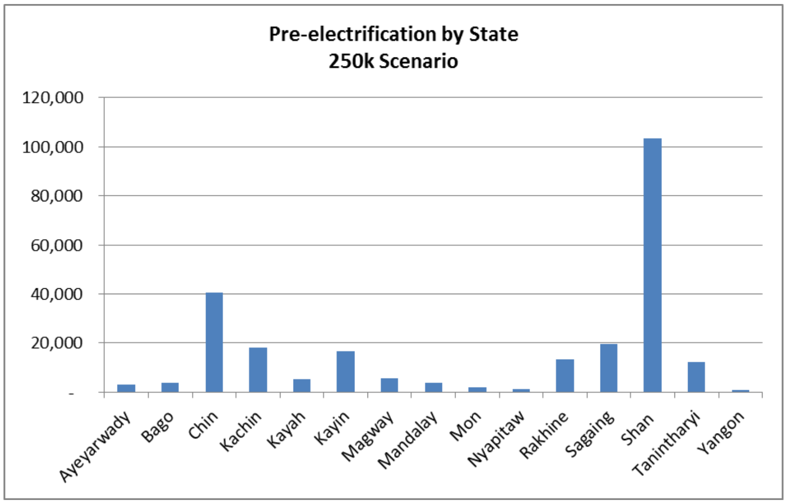
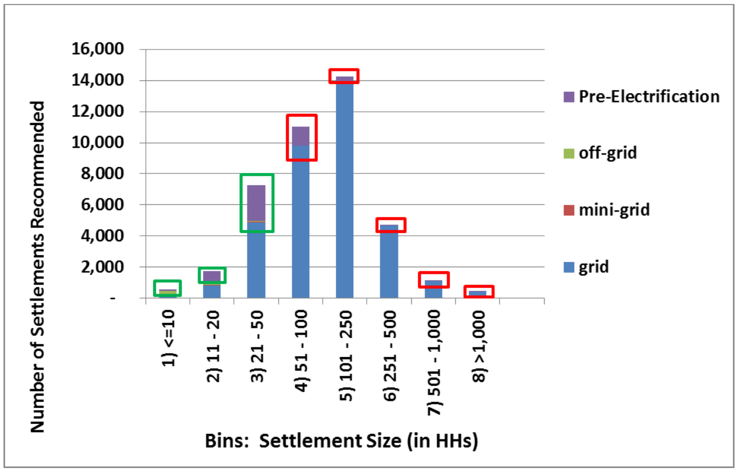


Figure 14: Number of households targeted for pre-electrification by state / region

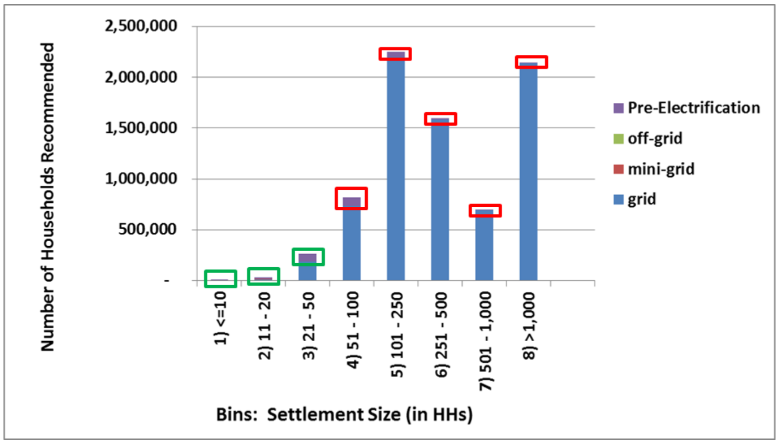
There is also size diversity among the settlements targeted for pre-electrification, and community size affects the relative cost-effectiveness of different non-grid technologies (see Figure 15 below). Off-grid / solar home systems are recommended for smaller villages below 50 households (highlighted by green boxes), while mini-grid systems are largely recommended for communities larger than about 50 households (see red boxes).



Settlement Size (in # HHs)	Number of Pre-electrification settlements
1) <=10	93
2) 11 - 20	850
3) 21 - 50	2,289
4) 51 - 100	1,241
5) 101 - 250	356
6) 251 - 500	40
7) 501 - 1,000	5
8) >1,000	3

Figure 15: Pre-electrification figures: by number of settlements

Pre-electrification would target about 3,250 small settlements (those with fewer than 50 HHs or 95,000 households in total), most likely with solar home systems, and about 1,650 larger settlements (155,000 households in total), which are better suited for mini-grids (see Figure 15 Figure 16). In total, the pre-electrification program would serve nearly 5,000 communities with a total of around 250,000 households.



Settlement Size (in # HHs)	Number of Pre-electrificat
1) <=10	830
2) 11 - 20	13,616
3) 21 - 50	78,902
4) 51 - 100	85,145
5) 101 - 250	49,807
6) 251 - 500	13,020
7) 501 - 1,000	3,422
8) >1,000	5,112

Figure 16: Pre-electrification figures: by number of households

It is essential to note that pre-electrification technologies – mini-grids and solar home systems – will necessarily deliver power at a lower service standard than the electric grid. It is simply not cost-effective to provide electricity services, in terms of kWh per year, equivalent to the grid using non-grid technologies. At reduced service standards, these technologies will be somewhat cheaper than the grid, perhaps by 20-50%. The some expected tradeoffs bewteen cost and service for various pre-electrification options can be described as follows:

- Mini-grids of various types (solar, diesel, hybrid, or renewables such as micro-hydro which is site-specific) could cost-effectively provide around 250 kWh per household per year, or about 25% of the grid standard. A system of this type could meet needs for lighting, ICT (particularly mobile phone charging), media devices (television/DVD/radio), and perhaps a fan or small refridgerator. Such systems might cost $1,400 per household, which is higher than local prices, as well as some internationally procured mini-grids in use in other countries. However, if built with local distribution infrastructure (LV lines, meters) built at, or near utility standards, this mini-grid can be connected directly to the grid later, saving on future distribution costs. This program would target approximately 155,000 households, costing a total of around US$220 million.
- Solar home systems sized between 80 and 100 peak Watts can provide perhaps 150-175 kWh per household per year, meeting needs for lighting, ICT/phone charging, and media devices at a cost of around US$450-500 per household. These are international prices, and though higher than local prices, quality is a crucial consideration in avoiding market spoiling in the initial period of the solar program. This program is recommended for around 95,000 households, costing a total of around US$50 million.

If these costs are applied to the national pre-electrification plan as a whole, assuming that around 250,000 households will be included in the program, the results are summarized in Table 4 below.

Table 4: Cost summary for a national pre-electrification program targeting 250,000 households

	250K
Households targeted for SHS	93,348
Total Initial Costs	$47,455,452
HHs targeted for mini-grids	156,506
Total Initial Costs	$219,108,400
Grand Total: Households	**249,854**
Grand Total: Costs	**$266,563,852**
Overall Ave per HH Costs	**$1,067**

Uncertainty analysis

The model used for this analysis employs more than 70 independent parameter inputs. In considering the impact of changing these parameters, it is important to distinguish between the majority of parameters that have only a small influence on final costs and electricity system recommendations, versus the few which are decisive. Because major infrastructure investments last for decades, planning must take into account the cost-benefit balance over decades. For this reason, the cost tradeoff between grid and non-grid electricity technologies depends crucially upon the ratio of fixed and recurring costs for different technologies at a given level of electricity demand. All of these costs are specific to a given country, or even region.

Myanmar has three overwhelmingly important planning factors for the purposes of this project.

- One is the pattern of human settlement throughout the landscape. This is not a parameter, per se, but rather a geographic fact, captured in geo-specific data, and so is addressed elsewhere in this report.
- The second is the relative abundance of hydropower generation potential, which leads to an important planning parameter. The estimate of recurring costs of new hydropower generation is at around 13 US cents per kWh, including financing costs. This can be compared to recurring costs for non-grid options such as diesel and solar, which are typically much higher. These costs are set by the costs of fuel and batteries on global

markets, and are in the range of 45-55 US cents per kWh, or more – a full 30-40 cents more per kWh compared to hydropower.

- The third is the assumed residential demand of 1,000 kilowatt hours per household per year. It is roughly the average of current residential customers on the grid nationwide, and a reasonably assumed average for poorer, newly connected households with demand growth after perhaps 5 years of grid service.

Considered together, these factors – settlement patterns, relatively low unit cost of grid versus non-grid power, and somewhat high household demand[5] – very strongly favor grid extension over non-grid options for virtually all of the country. To illustrate why, it helps to see how savings from low hydropower recurring costs, added over many years, can justify quite long MV grid extensions as a means of avoiding high recurring costs of solar systems and diesel fuel. If one considers the cost difference of 30 cents per kWh for grid and non-grid power, at 1,000 kWh per household per year, this equates to a savings of at least US$300 per grid-connected household per year – or $6,000 over 20 years. At US$20 per meter of MV line, these savings would justify an investment in up to 300 meters of MV line per home before MV costs become so high as to cause a shift in the recommendation to non-grid technologies. This is why, as can be seen in Figure 12 previously, settlements and households are recommended by the model for grid connection even at the latest phases of grid roll-out, when MV/HH values have climbed above 100 m. Only for unusually small and remote settlements, where high initial costs for long MV extnsions overcome the great additive cost advantage of inexpensive hydropower, does one see non-grid options recommended as least-cost over the long term. As the results for this geo-spatial analysis show, these situations are very rare in Myanmar, limited to less than 1% of all targeted communities and households.

For this same reason – the large difference in recurring costs between hydro-powered grid and non-grid alternatives – the system type recommended by this analysis is very stable. Despite changes in multiple input parameters, the overall result does not easily shift away from grid as the dominant technology recommendation. As show in Figure 17 below, the overall system recommendation results in only a very small reduction in the recommendation of grid, even

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[5] Most other cost and technical factors for Myanmar – such as costs of equipment for grid, solar and diesel systems, as well as population growth rates and other parameters – are within relatively normal ranges.

when household electricity demand, one of the model's most critical parameters, is reduced by as much as 50%.

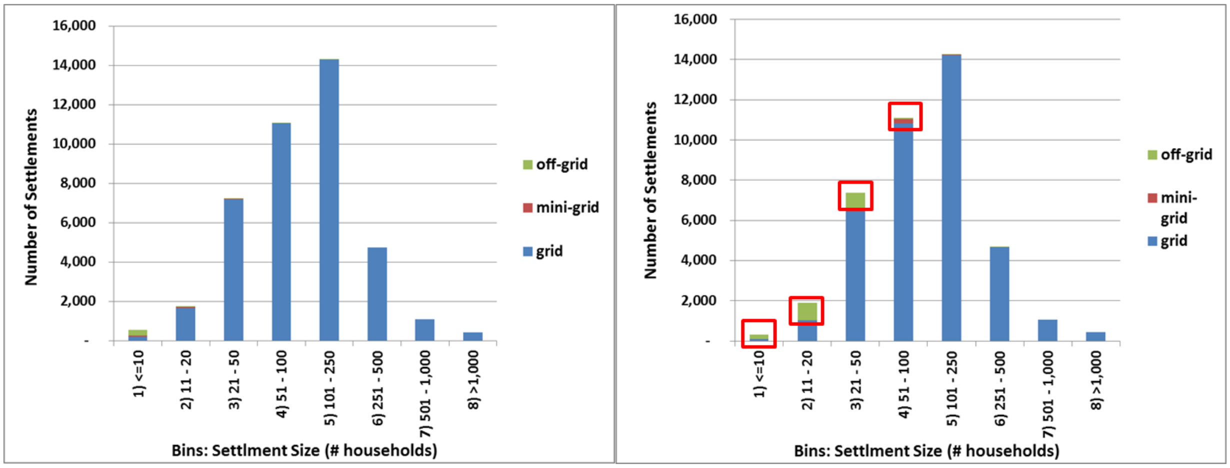

Figure 17: Distribution of grid, off-grid and mini-grid system recommendations at different demand levels for differently sized communities. Full demand (1,000 kWh/HH-yr, left); half demand (500 kWh/HH-year, right).

At half-demand, the number of very small settlements recommended for off-grid and mini-grid rises slightly (right panel), but the overall impact on household grid connections is minimal: both charts are overwhelmingly blue.

Results are similar for changes in other factors, including the main cost parameters for non-grid options. As shown above (Table 1) both solar off-grid and diesel mini-grid systems are recommended extremely rarely (less than one-tenth of 1%) in this modeling work, and it is worth examining whether change in these prices will affect penetration significantly.

Considering the likelihood and magnitude of cost changes for both types of non-grid options: Learning curve trends suggest that a 20% decrease in solar panel and battery costs over 20 years is plausible. This reduction would increase the cost-effectiveness, and presumably the penetration of solar systems as a least-cost recommendation in the model outputs. Currently, diesel prices in Myanmar are perhaps 10% below world and East Asia market prices, so the most likely change in fuel costs would be an increase, making diesel less cost-effective, and thus lowering the already very low penetration of diesel mini-grid systems in the model. Diesel mini-grid system recommendations are already so low in the model results that a further decrease is analytically uninteresting. So although it is relatively unlikely, the possibility of a 20% fall in diesel prices has also been examined.

The results for 20% decline in all three parameters – diesel fuel, photovoltaic panels, and batteries – are shown in Table 5 below for only Chin State. Chin State was chosen because, as one of the least densely populated stateswhich already has highpenetration of non-grid systems in the results, it is reasonable to expect that change in results would be unusually probably and visible here. This State was chosen in order to provide an estimate of the largest possible impact of these price changes.

Table 5: Effect on percent of settlements recommended for grid vs. non-grid options under assumed changes in recurring cost paramters

	Number of Settlements Recommended by Model			
System Types	**Normal Prices**	**20% reduction: Solar Panel and Battery**	**20% reduction: Diesel Fuel**	**20% reduction: Diesel, panel and battery**
Grid	2,070	1,981	2,031	1,977
Mini-Grid	27	5	79	38
Off-Grid	92	203	79	174
% Grid	**95%**	**90%**	**93%**	**90%**

The results show that, assuming a rather dramatic price drop of 20%, the penetration of non-grid options in Chin State may be expected to increase from 5% to perhaps 10% of settlements-- that is, the penetration might double. However, it is crucial to note that these values are expressed in terms of settlements, and the locations where non-grid options prevail tend to be the smallest villages. So, even if this doubling were seen throughout the country, and expressed in terms of population rather than number of settlements, then it would represent an increase from around 0.1% of all system recommendataions nationwide to about 0.2%. **Thus, even with a very substantial decrease in non-grid recurring costs, the impact on final resultsis virtually imperceptible, and well within the error range of this analysis.**

Annex 1: Project Plan

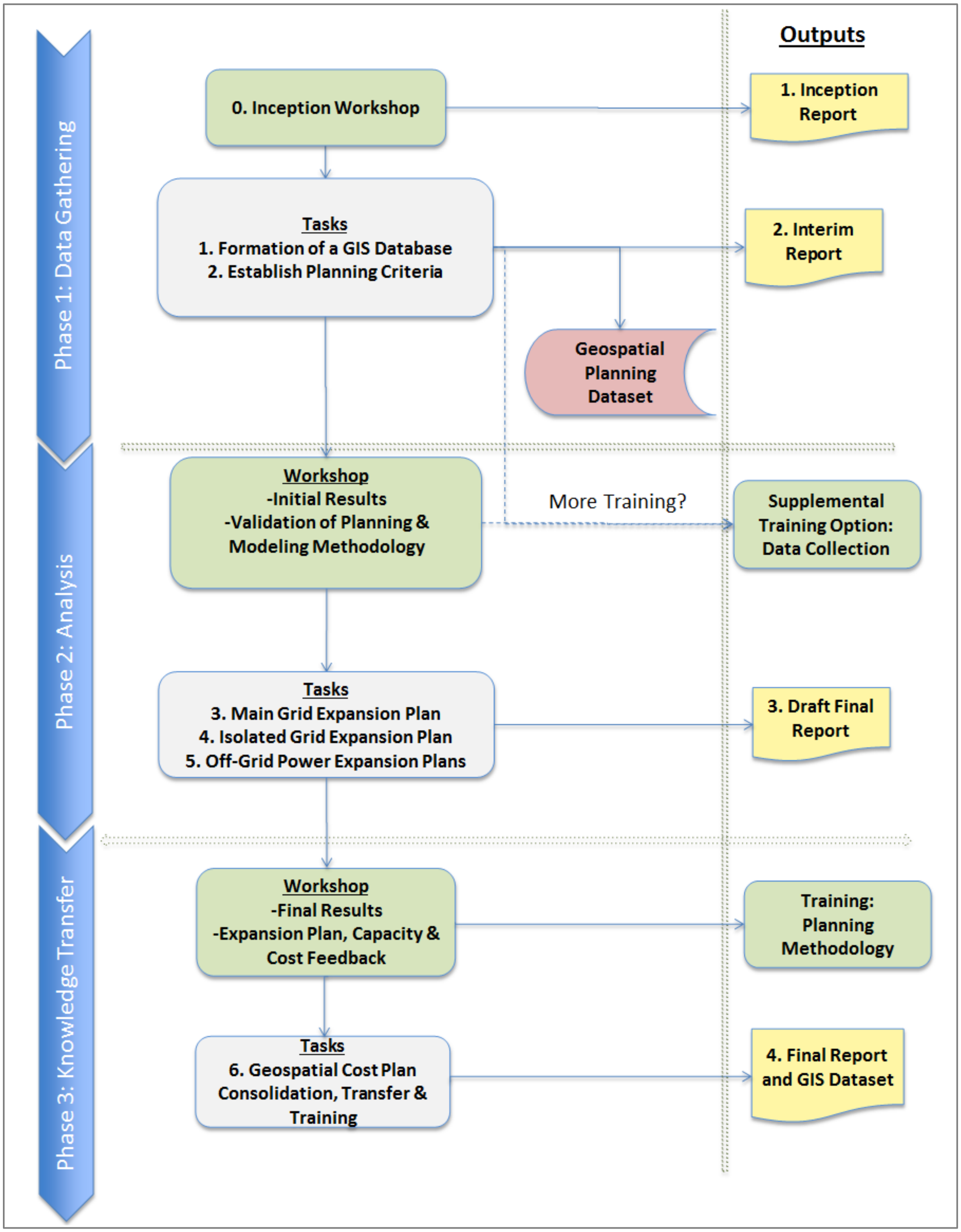

Figure 18: Earth Institute approach to developing a national plan with rollout for Myanmar

List of Tasks, Objectives and Activies

The basic objectives and activities of all tasks for this project are reviewed below (for more detail, see the Inception Report for this project).

Task 1 – Data collection and preparation of a structured GIS-layered database

- **Objective:** Create a national geospatial dataset including demand points, electricity infrastructure (primarily medium-voltage grid lines), and renewable energy resources.
- **Activities:** Collect key demographic and infrastructure datasets; Identify data gaps and develop approaches to fill these gaps.

Task 2 – Establishing planning criteria

- **Objective:** Create demand estimates and service standards for Myanmar consumers through 2030.
- **Activities:** Collect and assess data such as key demand, cost, service, socio-economic information, and integrate this information into a GIS database which will serve as input parameters in subsequent modeling steps.

Task 3 – Development of least cost main grid expansion and connections plan

- **Objective:** Create a cost-optimized national electricity grid network targeted for 2030.
- **Activities:** Apply modeling tools, and evaluate results designating electricity systems for each location (as grid, mini-grid or off-grid).

Task 4 – Development of least cost expansion plan for isolated network systems

- **Objective:** Ensure that grid and off-grid system selections also include cost-optimal specification of grid connection, even when grid systems may be small and isolated, which is often the case for location-specific, smaller-scale renewable resources.

- **Activities:** i) Working with partners to obtain and interpret renewable energy source information for Myanmar at a national scale. ii) Integrating existing data resources into electricity system planning such that both initial and recurring costs for renewable electricity generation are accurately refelected in location-specific cost calculations leading to system choice for all locations.

Task 5 - Development of least cost electrification plan for off-grid areas

- **Objective:** Produce a District-level plan identifying the least cost configuration, sizing, operating schema for communities with standalone power systems by 2030
- **Activities:** Establish a Minigrid and Off-grid plan, which includes costing summarized by District

Task 6 – Geospatial plan consolidation, transfer and training

- **Objective:** Transfer both results and methodology to local electricity planning specialists to prepare them to both interpret the outputs of the planning effort, and also to revise results in response to changing conditions, data, technologies and related costs.
- **Activities:** i) Creation of a final report providing a full description of the results of all planning efforts to the level of the District. ii) Provide a training workshop to local energy planners to ensure understanding and ability to implement the core features of our planning approach.

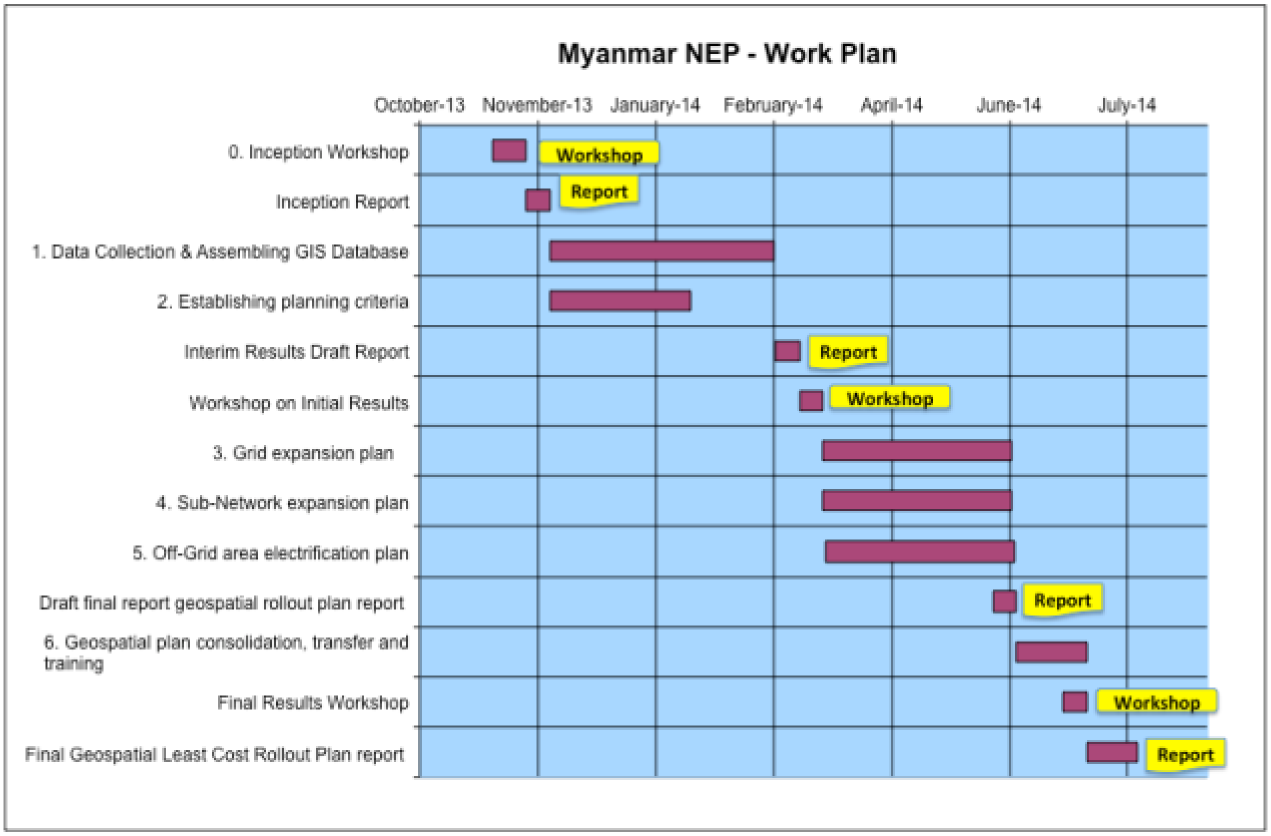

Figure 19: Initial workplan for the EI-led program for national electrification for Myanmar.

Annex 2: Detailed Methodology

The most fundamental and typically most labor-intensive task for this electrification planning work is to obtain and prepare key input data. In the context of Myanmar, this has included: obtaining geo-located populated places, and projecting the population values to a common year; obtaining maps of medium voltage (MV) electricity grid distribution lines and high voltage (HV) lines; digitizing these maps to create GIS compatible format files (shapefiles); and obtaining detailed model input parameters (initial and recurring costs, technical details for equipment and electricity demand, population growth rates, etc.). All of these steps are described in this section. For clarity, we have divided into three sub-sections:

- Population Data
- Data for Electricity Grid Distribution Lines
- Parameter Inputs

Population Data

The work focused on creating a geo-referenced[6] population dataset that is suitable for spatial scale modeling which is essential for electricity planning. This includes geo-referenced electricity demand locations which are typically obtained from a national statistics agency, or a reliable source with widely available data. This data is typically quite heterogeneous in format, scope, and resolution, thususually requires additional data gathering and GIS processing in preparation for geo-spatial electricity modeling. The challenge presented by the lack of recent census data for Myanmar adds to the complexity.

In Myanmar, the primary source for geo-referenced population data values was the Ministry of Livestock, fisheries and Rural Development (MoLFRD) which includes the Department of Rural Development (DRD). The data obtained consisted of:

- Approximately 64,000 points for villages with population from 2001.

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[6] In this context, geo-referenced means that a given location or feature is identified by latitude & longitude coordinates. Geo-referenced data may be in a variety of formats, most commonly shapefiles or spreadsheets. Maps in paper or digital formas (such as jpegs or pdfs) must typically be geo-referenced in order to be useful for analysis.

- 286 points for cities and towns, with populations from 2013.

The village level rural data was available by townships for each state and region. The urban dataset containing major cities and towns was made available for entire states or regions. An example of this data is showing in Figure 20 below.

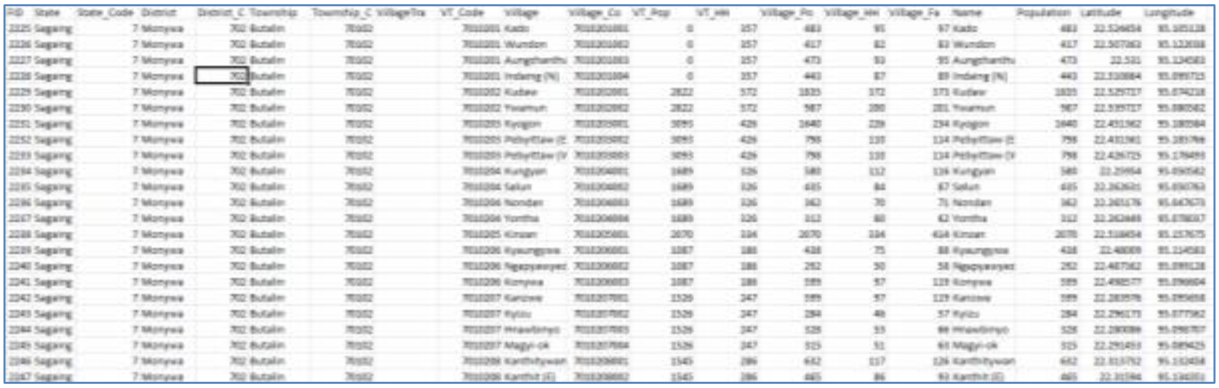

Figure 20: Village-level population data from DRD (example for Sagaing Region)

Compiling the rural dataset was the majority of the work, and this was done first. The original village level data from DRD was made available as GIS shapefiles. The original data was first cleaned according to procedure, such ensuring consistency in spelling, adding data, and deleting duplicate data. The result was a standardized dataset, a township level data file containing the same attribute data in a consistent format. The village level population data points for various townships were then merged into a single layer to create a state or regional level data file. This data was generally comprehensive in that the DRD dataset included village points that covered most of the states and regions.

However, the dataset had two key types of data gaps (see Figure 21 below):

- **Gaps in the village point dataset:** There are clear coverage gaps in the village dataset, particularly in some of the more highland states and regions, as well as areas bordering neighboring countries (e.g. Kachin and Shan).[7]

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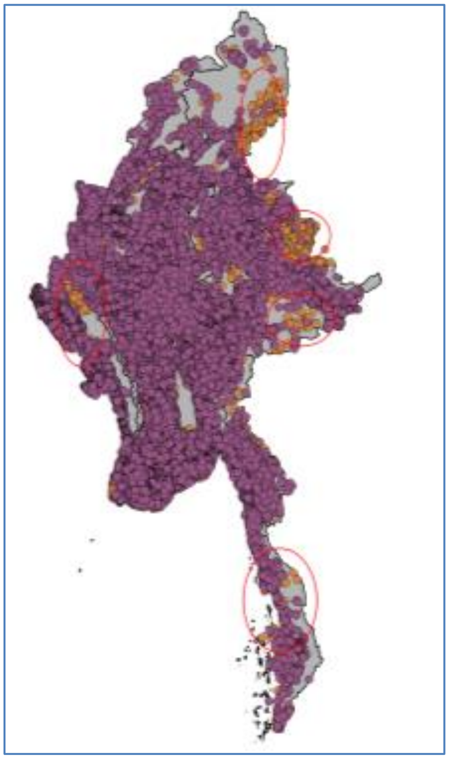
[7] This conclusion was reached by comparing externally obtained point data sources, such as village coordinates from the Myanmar Information Management Unit (MIMU) with the DRD point dataset.

- **Missing values in the population data column** For some locations, the DRD village dataset has good geo-location data (latitude / longitude coordinates) but has no corresponding population value (population is either zero or blank).



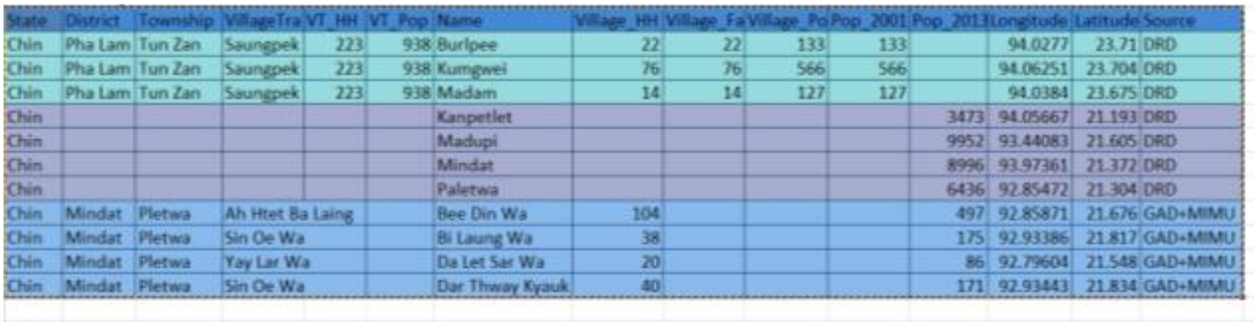
	Projected Popuation (2011)			
	Urban	Rural	Total	% of Villages w/ zero pop
Kachin S.	447,473	809,784	1,257,257	2.1%
Kayah S.	92,089	170,534	262,623	1.7%
Kayin S.	433,298	1,154,769	1,588,067	1.7%
Chin S.	92,589	421,229	513,818	0.2%
Mon S.	573,878	2,101,309	2,675,187	5.0%
Rakhine S.	1,362,634	2,933,873	4,296,507	0.0%
Shan S.	3,419,850	2,565,539	5,985,389	9.3%
Yangon R.	4,543,461	2,070,590	6,614,051	5.0%
Mandalay R.	2,007,372	4,737,424	6,744,796	0.5%
Nyapitaw	648,236		648,236	0.4%
Sagaing R.	1,123,241	4,704,167	5,827,408	1.6%
Bago R.	1,683,706	4,278,496	5,962,202	1.9%
Magway R.	793,583	4,403,415	5,196,998	0.2%
Ayeyar. R.	1,064,573	4,460,699	5,525,272	0.8%
Tanin. R.	333,348	886,971	1,220,319	1.9%
Total	**17,971,095**	36,347,035	54,318,130	**2.5%**

Figure 21: At left, violet points show settlements with population values from DRD. Organge points show settlement points present in the MIMU data, but not in DRD data. At right: The total population by state, with percent of points in DRD data with zero population.

In response to these gaps, a sustained effort was made to supplement the DRD village-level dataset from 2001 with other village datasets, which included both geo-locations (latitude . longitude points) and population values. Because there was not a single source which had both attributes among the existing data, required merging one data source with population values to another with geo-spatial information.

A population dataset from 2013 obtained from the Ministry of Home Affairs, General Administrative Division (GAD) was obtained for as many states and regions as possible. The GAD dataset included village names and administrative units (townships, districts); however, it lacked geo-coordinates. Location data for villages was available from the Myanmar Information Management Unit (MIMU). The GAD and MIMU data were combined by matching names in several stages. Frist, the two datasets were matched and merged using an automatic "join", which required that placenames in both datasets to match exactly. Due largely to spelling differences in placenames between the MIMU and GAD data, this matching process created results that were inadequate since it did not encompass the majority of the villages from the GAD data, nor did it help fill gaps in the DRD data. In the second stage, the two datasets were examined by visual inspection on the township level, which allowed much better village name matching than had been possible with automatic matching. This manual process allowed village records from the GAD data, which contained the population values, to be matched with corresponding records in the MIMU latitude / longitude data for dozens of additional townships. This also allowed for exclusion of things like urban wards from the village dataset.

This supplemental village dataset, combining GAD population information with MIMU location information, was then combined with the larger village dataset from DRD, as well as similar data for cities and towns[8], to create a single, national geospatial dataset of settlements (see Figure 22 below). For each record, the dataset includes fields for state or region, village name, population (from varying years, 2001 for DRD-sourced data, and 2013 for GAD-sourced data), and geo-location (latitude / longitude coordinates sourced from either DRD or MIMU) among others. Gaps are visible for some secondary fields, particularly administrative units such as townships and village tracts, due to the heterogeneity of original data sources.



State	District	Township	VillageTra	VT_HH	VT_Pop	Name	Village_HH	Village_Fa	Village_Po	Pop_2001	Pop_2013	Longitude	Latitude	Source
Chin	Pha Lam	Tun Zan	Saungpek	223	938	Burlpee	22	22	133	133		94.0277	23.71	DRD
Chin	Pha Lam	Tun Zan	Saungpek	223	938	Kumgwei	76	76	566	566		94.06251	23.704	DRD
Chin	Pha Lam	Tun Zan	Saungpek	223	938	Madam	14	14	127	127		94.0384	23.675	DRD
Chin						Kanpetlet					3473	94.05667	21.193	DRD
Chin						Madupi					9952	93.44083	21.605	DRD
Chin						Mindat					8996	93.97361	21.372	DRD
Chin						Paletwa					6436	92.85472	21.304	DRD
Chin	Mindat	Pletwa	Ah Htet Ba Laing			Bee Din Wa	104				497	92.85871	21.676	GAD+MIMU
Chin	Mindat	Pletwa	Sin Oe Wa			Bi Laung Wa	38				175	92.93386	21.817	GAD+MIMU
Chin	Mindat	Pletwa	Yay Lar Wa			Da Let Sar Wa	20				86	92.79604	21.548	GAD+MIMU
Chin	Mindat	Pletwa	Sin Oe Wa			Dar Thway Kyauk	40				171	92.93443	21.834	GAD+MIMU

Figure 22: Sample from comprehensive geospatial dataset of populated places, including state or region, village name, popluation (varying by year) and geo-location (lat / lon)

Deriving 2011 Population by Projection based on CSO data:

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[8] This city and town data was provided by DRD employees, but the ultimate source is likely GAD.

Heterogeneity of dates presented another issue. The DRD village data included population values from 2001, the GAD values were from 2013, and the NEP required planning from the present forward to the year 2030. To resolve this issue, our work employed the most widely accepted source of aggregate population data for the country: the 2011 Statistical Yearbook published by the Central Statistics Office (CSO). This Yearbook was the most recent version available, and included rural and urban growth rates by year for each state / region (see Table 6 below).

Table 6: Tabular data with Urban and Rural growth rates, by year, for Myanmar states and regions.

State	Rural Growth Rate	Urban Growth Rate
Kachin	1.38%	2.17%
Kayah	2.28%	2.36%
Kayin	1.50%	3.29%
Chin	1.15%	1.76%
Mon	1.99%	1.77%
Rakhine	1.51%	1.60%
Shan Total	0.99%	1.71%
Yangon	1.01%	1.81%
Mandalay	1.76%	1.80%
Sagaing	1.77%	1.87%
Bago Total	1.50%	1.47%
Magway	1.83%	1.66%
Ayeyarwady	1.45%	0.95%
Tanintharyi	1.83%	2.53%
Total	**1.55%**	**1.74%**

Summary and Validation of the Population Dataset

The full process for creating the national dataset of geo-located populated places is shown in Figure 23 below, which indicates the original data sources, attributes present in each, reference years for population values, and all steps (join, merge, project) required to combine them into a single national dataset.

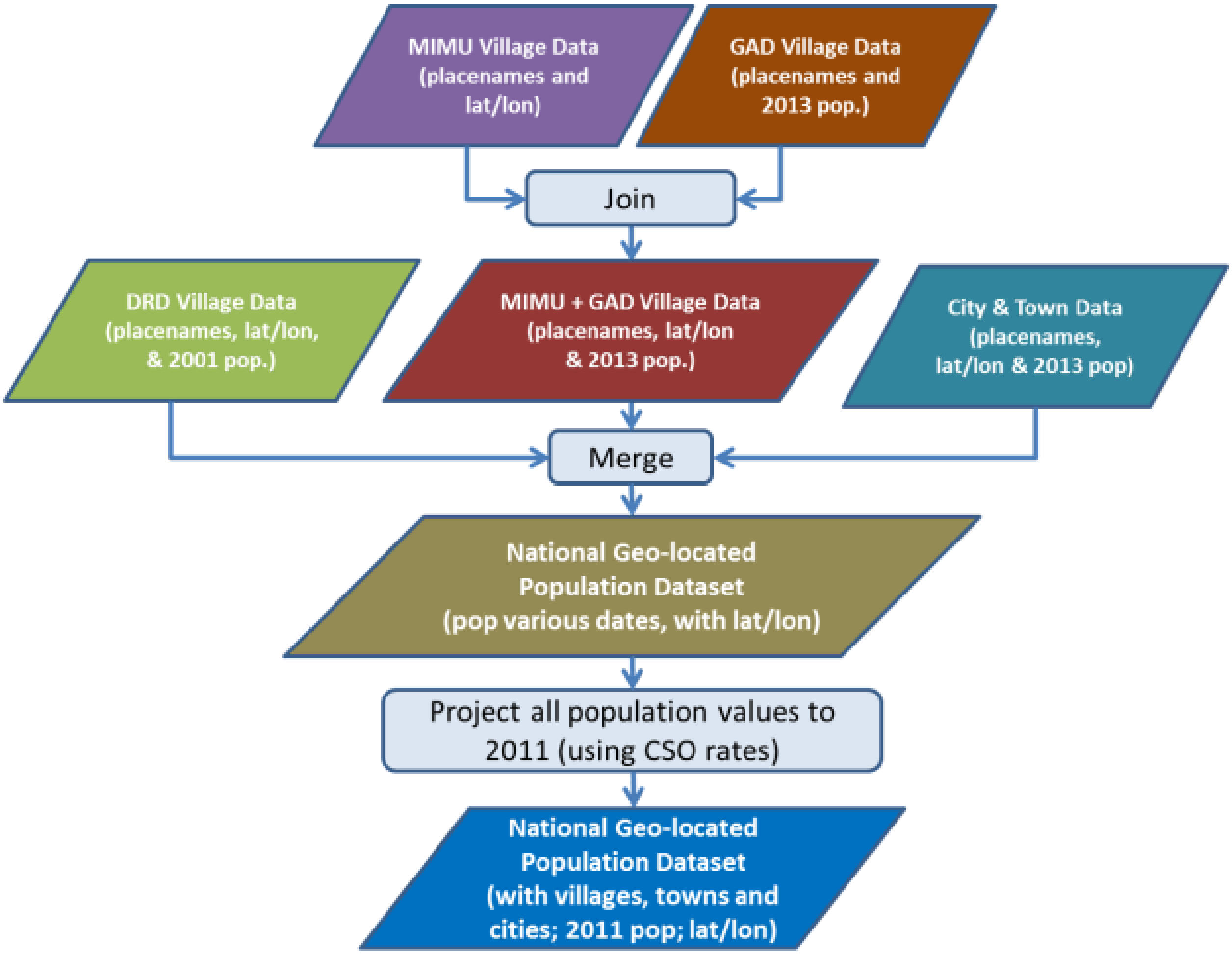

Figure 23: Flowchart showing population and geo-location data sources and workflow for creating a composite population dataset for each of the states and regions.

Though there are few reliable population sources in Myanmar, an effort of validation was made by comparing total population of our full national dataset – both the DRD data alone, and the dataset combining DRD and GAD data – versus the CSO population figures for rural and urban areas, and national total, with all data projected to 2011. Results of this are shown in Table 7 below

Table 7: Difference between Projected and CSO population figures (urban, rural and national total)

	Total National	**Urban**	**Rural**
Only DRD data	20%	2%	27%
DRD & GAD-MIMU data	**9%**	**2%**	**12%**

It is essential to note that the reliability of all of these data sources is limited, given that Myanmar has just undertaken the first national census in over thirty years. Nonetheless, if one accepts the CSO data to be a reference value, the addition of GAD+MIMU data to the DRD dataset appears useful for two reason: 1) The addition of DRD-MIMU data to the national dataset reduces the difference between the projected values used in this analysis and the CSO reference by more than half (from 20% difference to 9% for the national totals, and from 27% difference to 12% for the rural data). Rural values perhaps deserve extra attention throughout this analysis, since these are the areas with lowest electricity access and highest costs for electrification. 2) This comparison may provide some insight into the overall completeness of the village dataset obtained from DRD, suggesting that it under-estimates the national population by perhaps 15-20%, on average. Considering that all of these population values, including those from the CSO, are estimates or projections, and thus highly uncertain,[9] an agreement of +/- 10% is considered quite acceptable as a basis for broad costs estimates at the state / region and national level.

In summary, the population dataset assembled for this modeling effort is nationally comprehensive, with coverage of both villages and urban areas (towns and cities) for most townships throughout the country. All values are projected to the same year, 2011, based on the best available data from DRD-GAD-MIMU (settlement points) and CSO (growth rates). It has been noted that it is important to recognize that the compiled dataset and subsequent analysis bear the limitations of the original source data.

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[9] Brief discussions in with technical advisors to the census effort clarified that preliminary values are planned for release in Augst of 2014, and final results in March 2015 (UNFPA staff, Nay Pyi Taw, Myanmar, February, 2014).

Deriving Household Size by State:

Because electrification occurs at the level of the household, it is important to create cost estimates that translate overall population figures into the number of households. The average household size was determined for rural areas on a state-by-state basis using the DRD data from 2001, which included both the number of households, and total population for a given community. These values, thenumber of households, were used as input parameters for model runs during electrification cost and network planning. As a separate calculation, the average household size was calculated first for each village in a state, then the results were averaged across all villages in each state. For Urban Areas, CSO provided distributions of household sizes for each state by different categories from 2006. Here, households were divided into 4 categories: 1-2 people, 3-7 people, 8-10 people or over 11 people. Each category, across the state, equaled to approximately 100% such that the percentage of households in each category was given for each state and for the union. To calculate the average urban household size by state, each percentage was multiplied by the average of the class (1.5, 5, 9, 11) to determine the total number of people in 100 households. This was then divided by 100 to determine average household sizes. The results are shown in Figure 24 below.

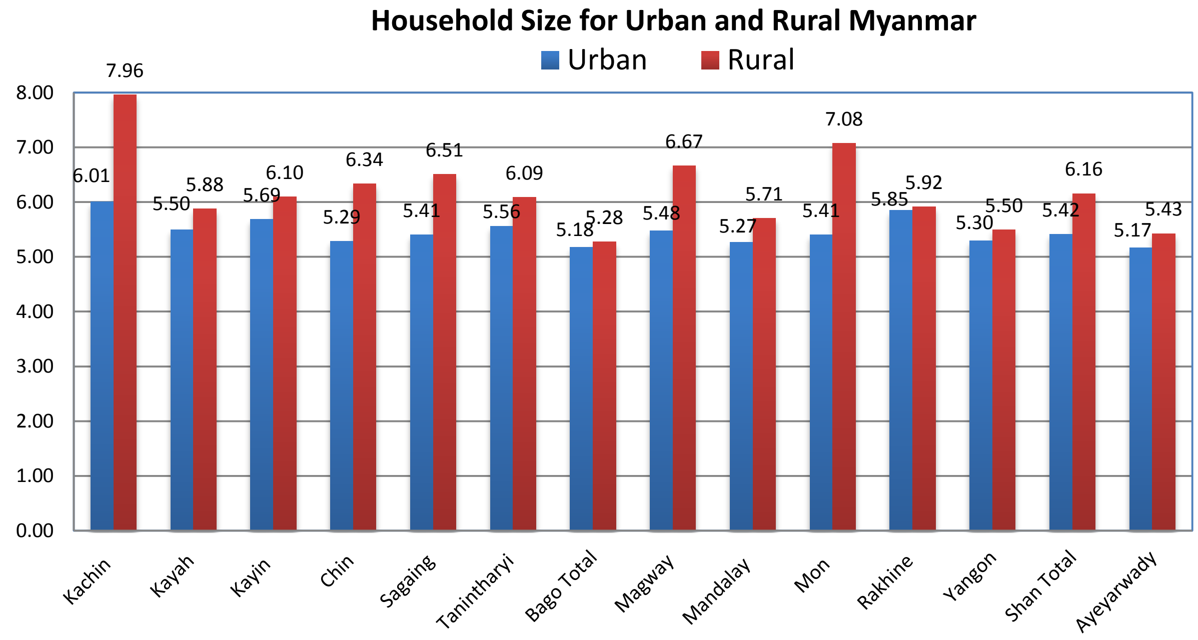


Figure 24: Urban and Rural household size for Myanmar states and regions.

Data for Electricity Grid Distribution Lines

Use of utility maps to create geo-referenced shapefiles for grid lines

The second fundamentally important data category for this national electrification planning effort is **geo-referenced data for electricity infrastructure, primarily the existing – and planned, if available – electricity grid network and related generation.** Various offices within the Ministry for Electric Power, and utilites such as Electricity Supply Enterprise (ESE), and Yangon City Electricity Supply Board (YESB) were good sources for this information. Hundreds of maps in jpeg, pdf and other formats for existing MV lines were provided by ESE and YESB for the state, district, and township level grid distribution systems, as well as maps for existing and planned HV lines along with generation and sub-station points were obtained from Myanmar Electric Power Enterprise (MEPE). These maps were then geo-referenced and digitized to create GIS compatible files (shapefiles) by Earth Institute working with our local partner Resources and Environment Myanmar (Yangon).

The general workflow for digitizing the paper based maps of MV Lines and HV Lines is outlined below:

1) The maps for different admin levels of Township, District, and State were examined and any needed spatial adjustments were made for inter-connections at the edges of separate maps for different administrative areas.
2) Village tract polygon data (from MIMU) and Village point data (collected from DRD/MIMU) was used for georeferencing.
3) The MV and HV lines along with the generation and substation locations were digitized and encoded with related attribute information. The attribute data includes: KV_type, Cable_type, Ext_from, Ext_to, length, region/division.
4) Two versions of the MV lines were digitized; one based on District/State level maps, and a more detailed version based on Township level maps. The latter was the one used in the geo-spatial modeling for electricity planning.

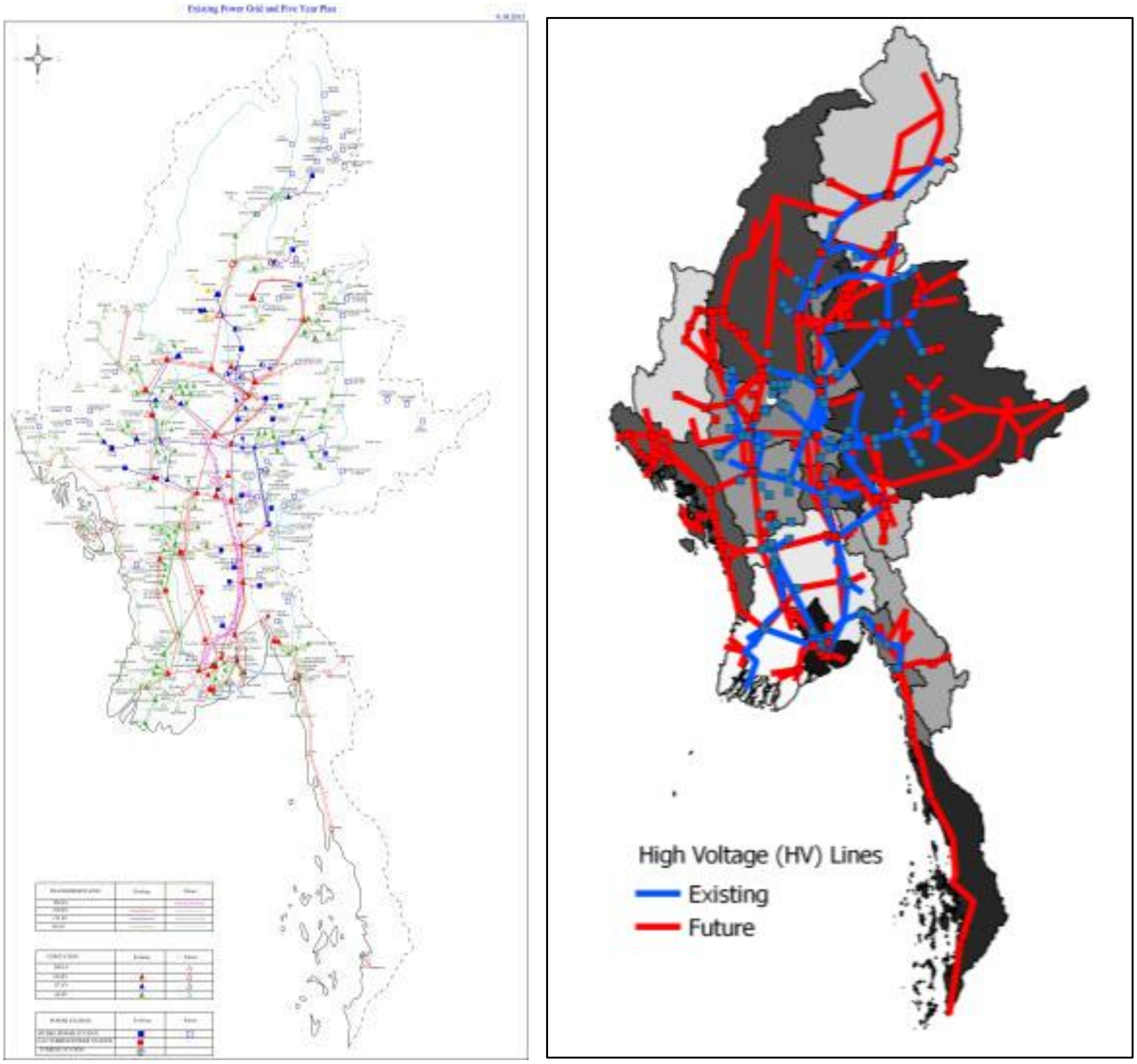


Figure 25: High voltage (HV) grid infrastructure map from MEPE (left) and geo-referenced digitized map by EI (right).

A GIS comparison of existing and planned high voltage (HV) electricity grid infrastructure relative to settlements (Figure 26 below) provides a rough estimate of potential access.

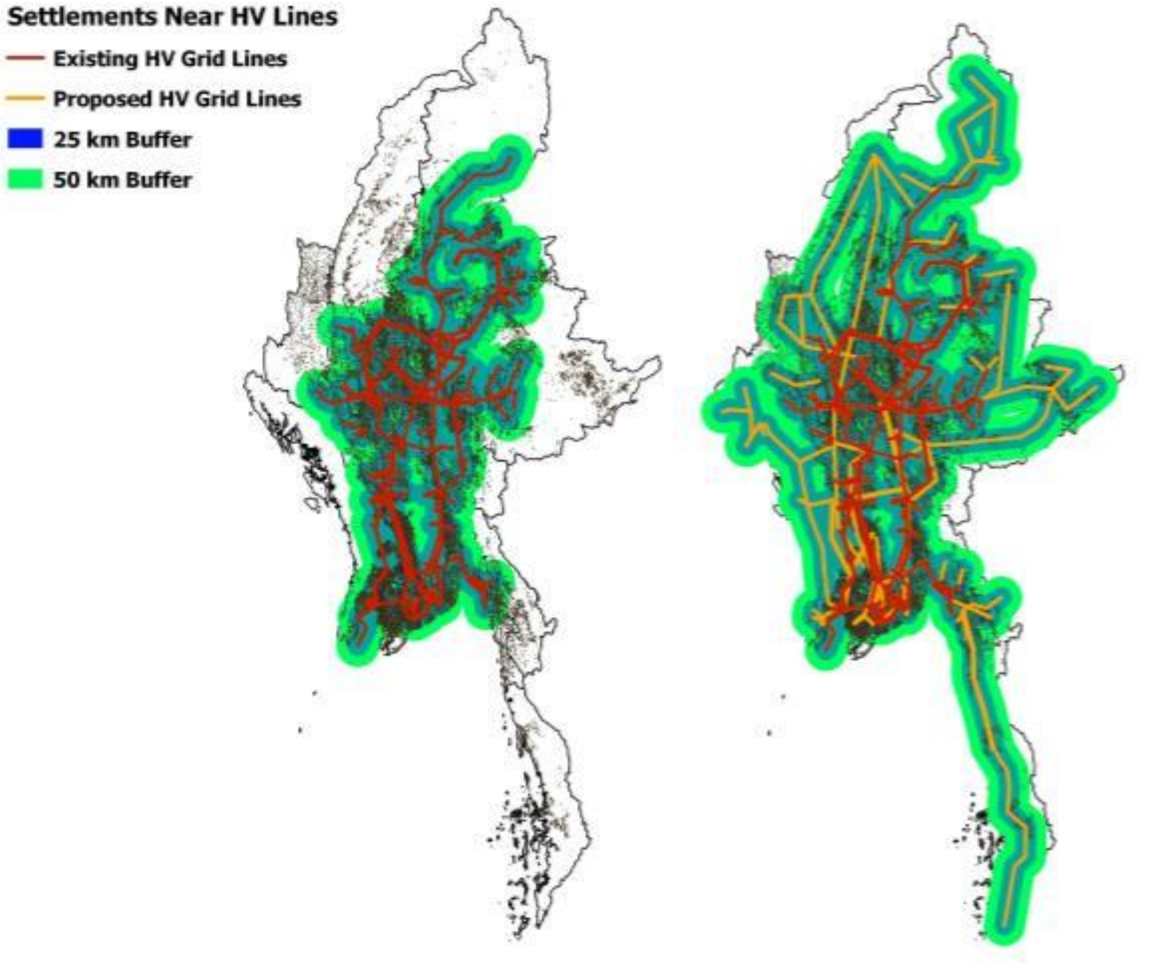


Figure 26: 25 and 50 km buffers surrounding existing (left) and proposed (right) high voltage (HV) grid infrastructure; small black points are settlement (points are not scaled by population).

These maps clearly indicate that most of the population that resides within the central, lowland areas is already roughly within 25-50 km of existing high voltage grid infrastructure. Once planned extensions of HV lines aretaken into account, the majority of the country falls within this range. This general conclusion is supported quantitatively by the data in Table 8 below, which shows that rougly 75-85% of the country's population is within 25-50 km of existing HV infrastructure, while 90-99% will be within this range of proposed HV extensions.

Table 8: Percentage of population within 25 or 50 km of existing and proposed high voltage (HV) grid lines.

		Existing HV lines		**Existing & Proposed HV lines**	
Name	**EI total pop est (2011)**	**% within 25 km**	**% within 50 km**	**% within 25 km.**	**% within 50 km.**
Ayeyarwady Region	5,525,272	56%	81%	84%	98%
Bago Region	5,962,202	95%	100%	96%	100%
Chin State	513,818	0%	5%	55%	89%
Kachin State	1,257,257	81%	90%	92%	96%
Kayah State	262,623	83%	89%	100%	100%
Kayin State	1,588,067	39%	58%	84%	94%
Magway Region	5,196,998	63%	91%	88%	100%
Mandalay Region	6,744,796	93%	100%	97%	100%
Nyapitaw	648,236	96%	100%	100%	100%
Mon State	2,675,187	65%	81%	97%	100%
Rakhine State	4,296,507	0%	0%	90%	99%
Sagaing Region	5,827,408	40%	72%	87%	98%
Shan State	5,985,389	77%	85%	92%	96%
Tanintharyi Region	1,220,319	0%	0%	95%	100%
Yangon Region	6,614,051	93%	100%	97%	100%
Total	**54,318,130**	**66%**	**79%**	**92%**	**99%**

A more targeted modeling and planning effort relies on geo-located information for medium voltage (MV) grid distribution infrastructure. Figure 27 below provides and example of high-level maps of MV lines at the district level. Figure 28 shows more detailed township level grid maps. Finally, Figure 29 shows maps from GIS shapefiles created using both District and Township level drawn maps.

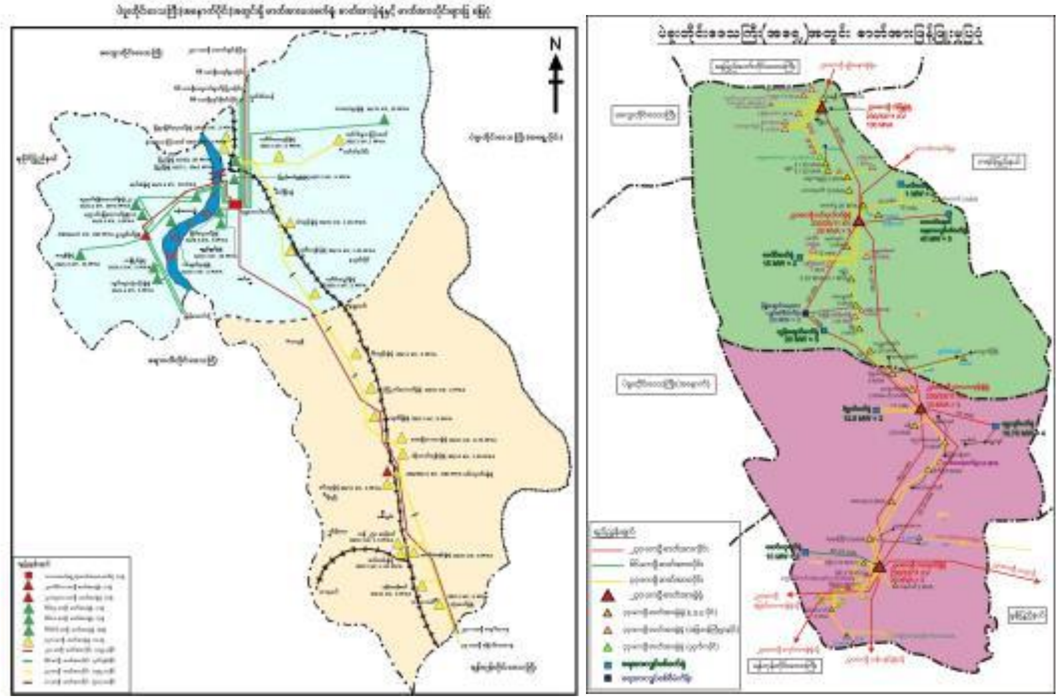


Figure 27: Grid distribution lines, source files: ESE drawn maps (ESE) at the district level.

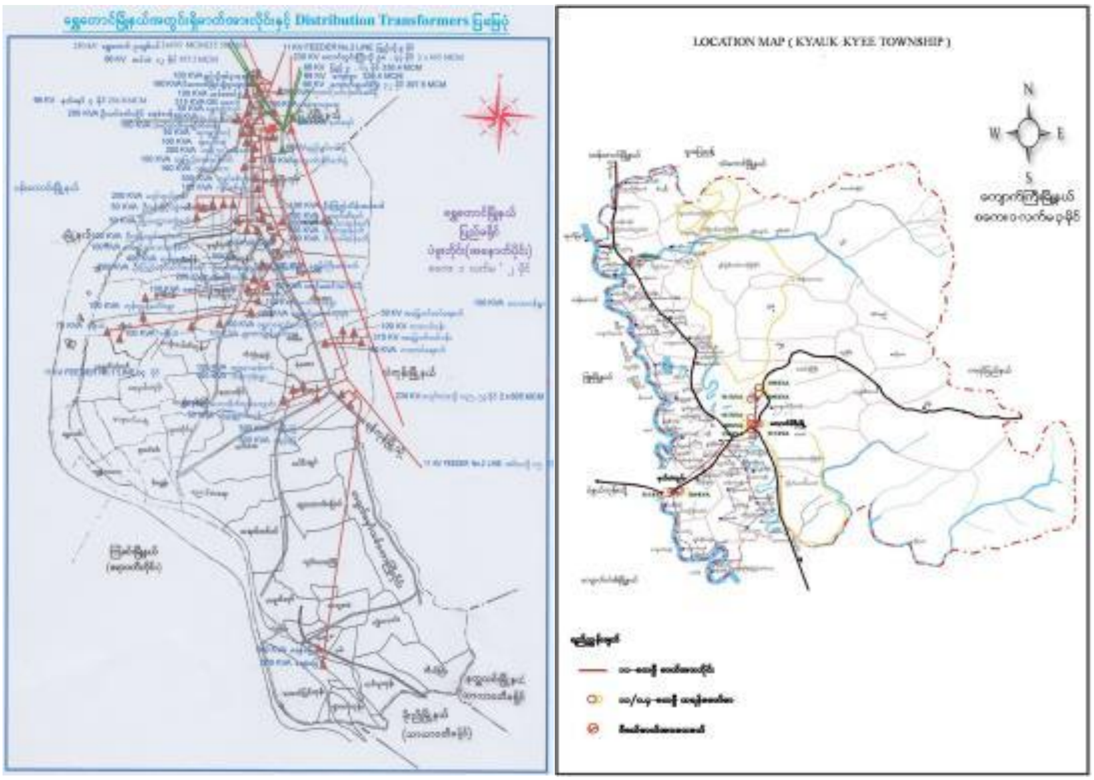


Figure 28: ESE drawn maps at the Township level provide a greater level of local detail.

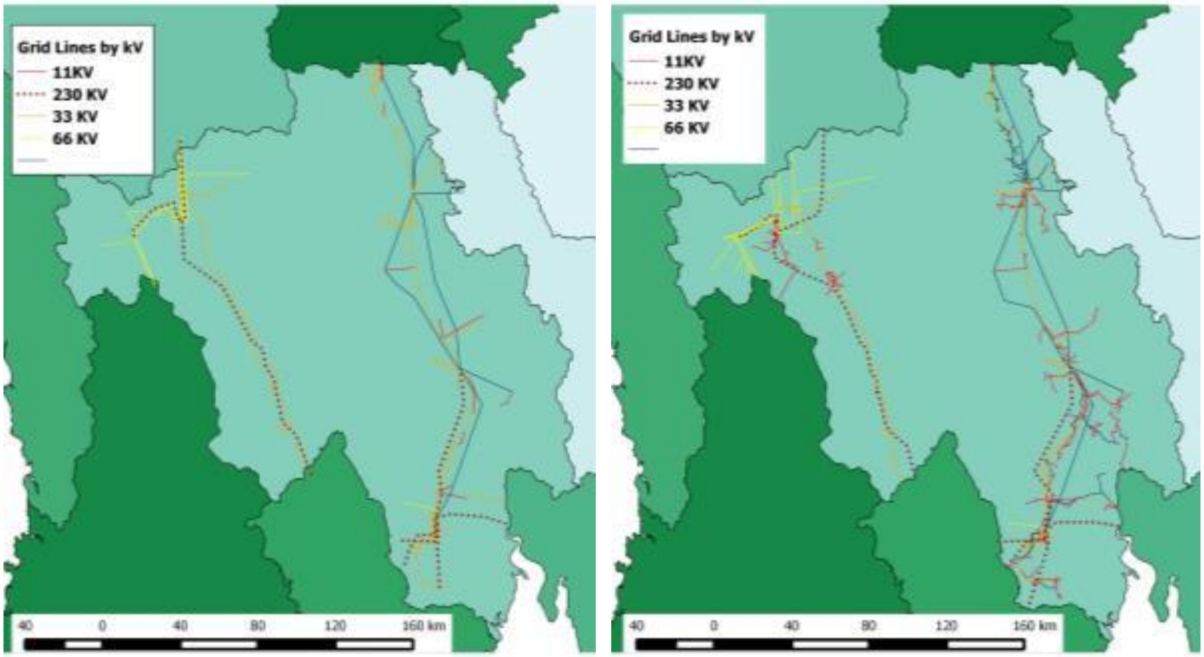


Figure 29: Geo-referenced, digitized, GIS shapefiles for electricity grid lines for Bago Region. Left: shapefile created using district-level drawn maps; Right: using township level drawn maps for greater detail.

GIS "buffering" to select locations within 1 kilometer of existing low-voltage grid

Discussions with ESE indicated that communities within approximately 1 km of the existing MV line are considerd in range to obtaingrid connection, for free. Based on this, Earth Institute performed a spatial analysis by creating a "buffer" surrounding the existing grid, and used this as a basis for identifying those villages with LV access to current MV lines (see Figure 30 below).

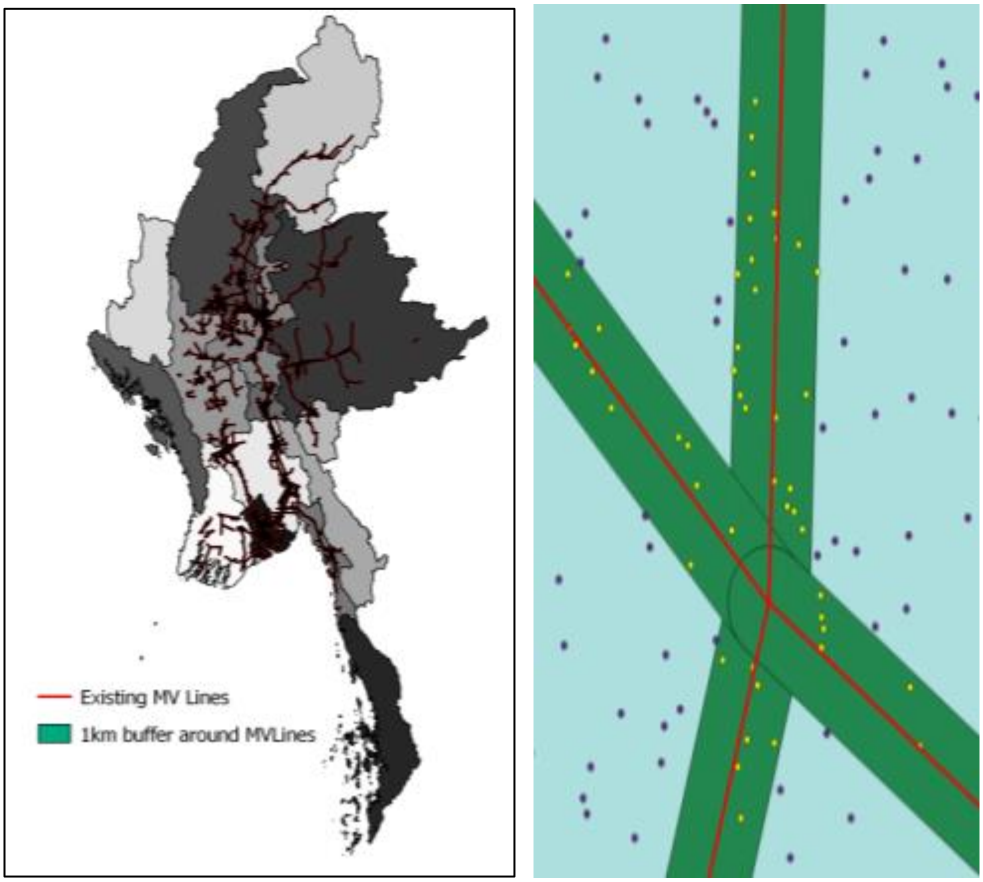


Figure 30: Village points in yellow fall within the 1 km zone (dark green) near existing MV line (red). ESE policy is to electrify these first, at no cost to the consumer beyond the ~$100 charge for meter and other connection equipment.

A comparison of the Earth Institute estimate of those within close range of existing MV lines versus the ESE values for those already electrified agreed within around 5% for many states, and within about 15% for most (see Table 9 below). For those states where figures diverged the most, population data issues – specifically gaps in the settlement data – were important. Other important caveats relates to both uncertainty in the accuracy of the MV Lines, and the lack of information regarding the percent of households connected to grid in communities within range of grid.

Table 9: Comparison of EI estimate of population within 1 km of existing MV grid lines vs the ESE provided values.

Name of State / Region	Population	Area	Electrification Rate	
			EI Computed	ESE Reported
	2001 Est.	km²	(from 1 km buffering)	(Grid + Diesel Gen Supply)
Ayeyarwady R.	6,663,000	35,138	8%	10%
Bago R.	5,099,000	39,404	30%	23%
Chin S.	480,000	36,019	0%	16%
Kachin S.	1,270,000	89,041	11%	26%
Kayah S.	259,000	11,670	32%	41%
Kayin S.	1,431,377	30,383	2%	23%
Magway R.	4,464,000	44,819	13%	8%
Mandalay R.	7,627,000	37,021	24%	35%
Mon S.	2,466,000	12,155	26%	31%
Naypyidaw (UT)	925,000	2,724	No data	No data
Rakhine S.	2,744,000	36,780	0%	6%
Sagaing R.	5,300,000	93,527	19%	22%
Shan S.	4,851,000	155,801	10%	9%
Tanintharyi R.	1,356,000	43,328	0%	9%
Yangon R.	5,560,000	10,170	85%	74%

Parameter Inputs

Alongside the population and grid line information, the third key source of information for modeling is the numerous parameters required for model calculations. These parameters include over 100 metrics related to equipment costs, technical specifications, growth rates, and numerous other technical, cost demographic, and financial details.

The overwhelming majority of the these parameters were gathered directly from utility officials. The first step of this process was discussion with high-level planners in Nay Pyi Taw. These officials provided costs, technical specifications, and planning rules related to details like distance of line runs and household demand levels. These were a combination of national "standard" values, as well as values indicating regional variation, which may be important particularly for the most remote (and least electrified) parts of Myanmar. The regional variation includes aspects such as: the cost of transport as a percentage of total project costs; and the variability of some recurring costs, such as diesel fuel, by state / region.

To provide a more complete picture of these regional differences, the EI and REM teams followed-up with visits to several ESE site offices in Bago, Kayin, Mandalay, and Chin states/regions. In general, our investigations found that costs and technical parameters were relatively consistent throughout the flatter, lowland areas of the country, while costs rose in the highland and remote areas, particularly those with rugged terrain. Insights from these visits outside of Nay Pyi Taw were used to apply regional modifications throughout the country.

Because the moedling parameters are numerous, we emphasize below those that are typically most important for determining the outcome of modeling efforts:

Probably the single most important parameter is the electricity demand for residential sector (kWh per household). Through discussions with ESE officials, we obtained values ranging from 30 kWh/HH-month (or 360 kWh per year) for the poorest households, up to perhaps a few thousand kWh/HH-month in cities like Mandalay and Yangon. The best value for current household demand in poor, rural areas is most likely in the range of 450 - 500 kWh/HH-year.

However, a very important factor to consider will be increasing consumption patterns, which is estimated to increase from the current year to 2030 (the final date for the NEP). The combined factors of low tariff in Myanmar, the general trend of increasing household demand as residents become accustomed to new connections, and economic growth makes it safe to estimate increasing demand. Overall, we expect household demand to approximately double from this 480 kWh base, and so have set household demand to be:

- **Annual Household Demand: 1,000 kWh per Household, per year (ESE)**

For grid extension, a key concern is the costs for LV and MV grid lines. This discussion addressed several issues: the difference in cost between various voltage lines (0.4, 11, 33 kV), as well as structural elements (single vs. double-pole design). Given ESE engineers statements that they would generally be installing 33 kV, double-pole systems for the spans connecting between villages, we estimated MV costs per km as follows:

- **MV line: $20,000 / km (base); $22,000 (~20% higher) for remote / rugged areas (ESE).**
- **LV line: US$15,000 / km for LV line (400 V, same for lowland and highland areas)**
- **Cost per "connection": approximately US$300 (broken into two componenets: i) around $100 forhousehold level equipments, such as meters, and ii) around $200 for the "service drop" from the nearby LV line)**

Recurring costs for a grid connection in the EI model, including long-term costs of installed new generation, are represented by the the future "bus-bar" cost of power, which Castalia estimated at:

- **"bus bar" cost of power: 130 kyat (13 US cents) per kWh (Castalia Advisors)**

Cost of diesel fuel is a dominant recurring (and lifetime) cost for diesel mini-grids:

- **Diesel Fuel: 4,400 – 4,900 kyat (US$1.10 - 1.22/liter) varying by location (ESE)**
- **Liters of diesel consumed per kWh generated: 0.4 l/kWh**
- **Minimum running hours of diesel gensets: 3 hours per day (1,095 hours per year). (ESE practice is to run gensets for 2-3 hours per day)**

"Threshold" sizes – the smallest equipment of certain types likely to be installed and maintained in a national scale electrification effort – were also important, since it helps to establish lower limits of the types of technology best suited for serving small and isolated communities:

- **Smallest diesel generator used: 25 kVA (ESE)**
- **Smallest transformer: 50 kVA (ESE)**

Costs for solar systems were obtained from vendors in Yangon and Mandlay:

- **Costs for solar PV panels: US$1.00 per Watt-peak (as a conservative estimate; prices ranged from ranged from about US$0.70 – US$1.00 per Wp).**
- **Costs for batteries (the dominant long-term cost of a solar system): US$150 per kWh**
- **Costs for lifespan of batteries: 3 years**

The tables below provide a more complete breakdown of all parameter inputs. Table 10 below lists the values, by state or region, for a few key parameters which were found to vary throughout the country. On subsequent pages, Table 11 through Table 14 provide the full list of other parameters which were constant throughout the country. These tables emphasise (in bold) those parameters which are particularly important and note which parameters show variation by state or region and so are listed in Table 10.

Table 10: Key scenario inputs that varied by state or region

State / Region	Growth Rate (Urban)	Growth Rate (Rural)	Household Size (Urban)	Household Size (Rural)	Diesel Cost (USD/liter)	MV Cost (USD/meter)
Chin	0.0117	0.0077	5.29	6.34	1.28	21
Kachin	0.0144	0.0091	6.01	7.96	1.28	21
Shan (east)	0.0114	0.0066	5.20	5.44	1.14	20
Shan (north)	0.0114	0.0066	5.59	6.98	1.14	20
Tanintharyi	0.0168	0.0122	5.56	6.09	1.14	20
Kayin	0.0218	0.0100	5.69	6.10	1.14	20
Sagaing	0.0124	0.0118	5.41	6.51	1.14	20
Kayah	0.0157	0.0151	5.50	5.88	1.14	20
Rakhine	0.0106	0.0100	5.85	6.20	1.14	20
Yangon	0.0120	0.0068	5.30	5.50	1.00	19
Ayer	0.0063	0.0096	5.17	5.43	1.00	19
Mon	0.0118	0.0132	5.41	7.08	1.00	19
NPT					1.00	19
Mandalay	0.0120	0.0117	5.27	5.71	1.00	19
Magway	0.0110	0.0122	5.48	6.67	1.00	19
Shan (South)	0.0114	0.0066	5.46	6.05	1.00	19
Bago / Pegu	0.0098	0.0100	5.18	5.25	1.00	19
Average	**0.0125**	**0.0099**	**5.43**	**6.20**	**1.09**	**20**

Table 11: Grid Power Modeling Parameters (cost and technical) – no variation by state / region

MV Grid	available system capacities (transformer)	1,000 – 50
	distribution loss	0.15
	electricity cost per kilowatt-hour	0.13
	installation cost per connection	200
	MV line cost per meter	**See table 5**
	MV line lifetime	30
	MV line O&M cost per year as fraction of line cost	0.01
	transformer cost per grid system kilowatt	50
	transformer lifetime	10
	transformer O&M cost per year as fraction of transformer cost	0.03
LV distribution	**LV line cost per meter**	**15**
	LV line equipment cost per connection	100
	LV line equipment O&M cost as fraction of equipment cost	0.01
	LV line lifetime	30
	LV line O&M cost per year as fraction of line cost	0.01

Table 12: Diesel Mini-Grid Power Modeling Parameters (cost and technical) no variation by state / region

G	available system capacities (diesel generator)	1,000 – 25

	diesel fuel cost per liter	**See table 5**
	diesel fuel liters consumed per kilowatt-hour	**0.4**
	diesel generator cost per diesel system kilowatt	170
	diesel generator hours of operation per year (minimum)	1095
	diesel generator installation cost as fraction of generator cost	0.25
	diesel generator lifetime	10
	diesel generator O&M cost per year as fraction of generator cost	0.1
	distribution loss	0.15

Table 13: Off-Grid (Solar Photovoltaic) Modeling Parameters (cost and technical) no variation by state / region

Off-Grid (solar)	available system capacities (PV panel)	1.5 - 0.05
	diesel generator hours of operation per year (minimum)	1,095
	peak sun hours per year	1,320
	PV balance cost as fraction of panel cost	0.75
	PV balance lifetime	10
	PV battery cost per kilowatt-hour	150
	PV battery kilowatt-hours per PV component kilowatt	8
	PV battery lifetime	3
	PV component efficiency loss	0.1
	PV component O&M cost per year as fraction of component cost	0.05
	PV panel cost per PV component kilowatt	1,000
	PV panel lifetime	30

Table 14: Other Modeling Parameters, including demand, demographic, distribution, and finance.

Demand	household unit demand per household per year	1,000
	target household penetration rate	1
	peak electrical hours of operation per year	1,095
Demographics	mean household size (rural)	6
	mean household size (urban)	5
	mean interhousehold distance	20
	effective population growth rate per year (rural)	**See table 5**
	effective population growth rate per year (urban)	**See table 5**
	urban population threshold	5,000
Finance	economic growth rate per year	0
	elasticity of electricity demand	1.5
	interest rate per year	0.1
	time horizon	30

Annex 3: Key Metric: Meters of Medium-Voltage Line per Household (MV/HH)

A key metric for understanding and evaluating outputs for this geo-spatial electricity planning approach is ***meters of medium voltage line installed per household connection***, or **MV/HH** for short. This metric is particularly important for geo-spatial least-cost planning because it varies according the spatial distribution of electricity demand.

Most costs related to both on-grid and off-grid electric power are either the same for all households (such as cost of a “service drop” or electric meter, which tends to be essentially the same for any household within a km or so of the grid), or vary in direct proportion with electricity demand (such as costs of transformers, costs of photovoltaic panels, or costs of diesel gensets, all of which are sized by the W or kWh and so scale directly with electricity demand for a given household or community). In contrast, the medium voltage line required to connect a household varies with two key spatially-dependent factors: 1) the distance between communities and 2) the population of a given community. While both of these values are related to population density, the relationship is not simple or predictable since both can show enormous local variability due to variations in human settlement patterns.

For this reason, MV/HH is in many ways the essential metric for understanding the cost-benefit tradeoffs related to grid extension or off-grid alternatives. In a very general sense, low MV/HH values indicate that extension of the electric distribution grid is inexpesive for a given electric line, while high MV/HH values indicate that grid extension is costly for a given line, and therefore off-grid alternatives (such as solar photovoltaics, diesel gensets and other options) should be considered as alternatives. There is no fixed rule for what is “high” or “low” MV/HH values, because the tradeoffs between on-grid and off-grid systems depend upon price, distance, and population that vary for different countries.

It is also important to note that MV/HH can be computed in a variety of ways. One way is to compute the MV/HH for an extension of the electric grid from one community to the next, i.e. for a grid segment. Another approach to consider is the MV/HH value for several line segments and communities that are part of the same branch or feeder line. Two simple examples below illustrate these alternative computations:

MV/HH by Segment

The length of MV line to connect one community is divided by the number of households served in a single community. Figure 31 below shows a small and very simple MV grid extension beginning at point X (on the existing distribution line) to community A, and on along two branches to connect various communities of different sizes.

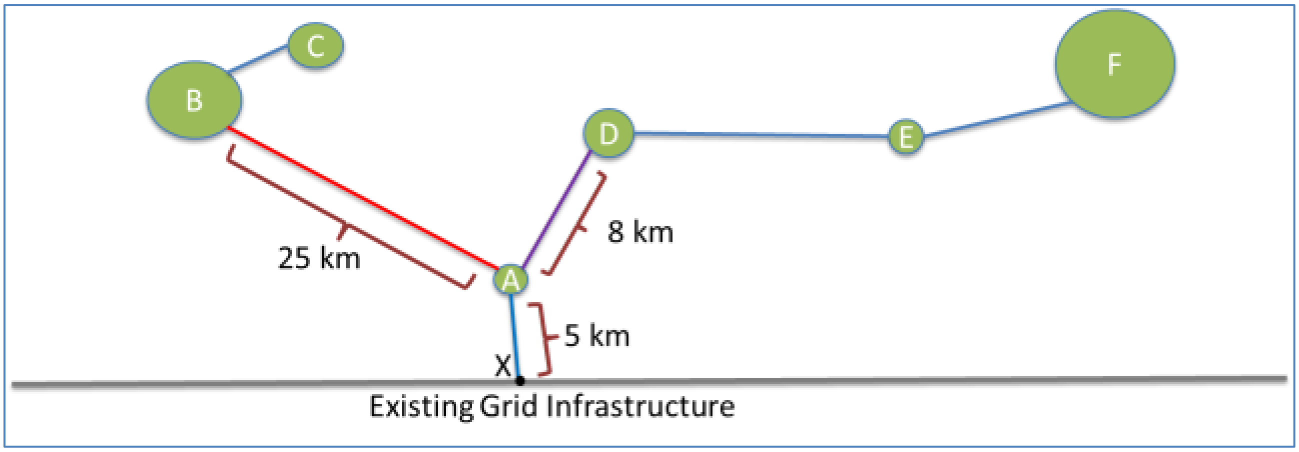


Figure 31: MV/HH can be computed for three different grid segments in isolation.

Segment from X to community A:

- Community A (pop. of 100 households)
- Segment: 5,000m of MV / 100 HH
- 5,000 m/100 HH = **50m MV/HH**

Segment from Community A to Community B

- Community B (pop. of 2,000 households)
- Segment: 25,000m of MV
- 25,000m / 2,000 HH = **12.5m MV/HH**

Segment from Community A to Community D

- Community D (pop. of 500 households)
- Segment: 8,000m of MV

- 8,000m / 500 HH = **16m MV/HH**

This computation can be repeated, segment by segment, for the rest of the segments in the network.

MV/HH by Branch:

The length of MV line needed to connect all communities in a branch or feeder is divided by the total number of households served in all communities along that line. Figure 32 below shows the same small grid extension, however in this computation the calculation focuses on the entire branches stemming from Community A.

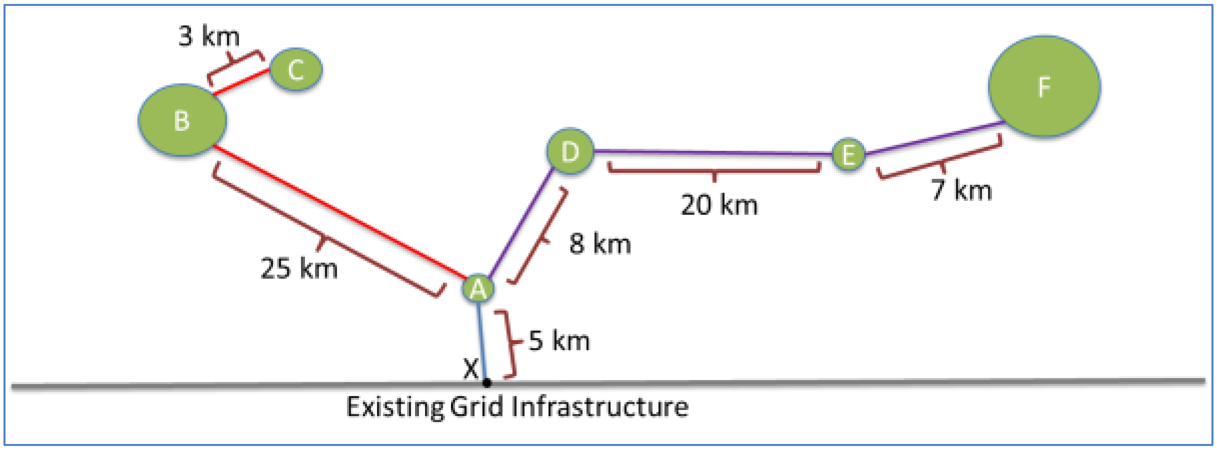


Figure 32: MV/HH can be computed for a branch or feeder

Branch from A-to-B-to-C

- Total population of communities on branch: 100 + 2,000 + 500 households: 2,600HH
- Total branch length: 25,000 + 3,000m of MV = 28,000m/MV
- 28,000m / 2,600 HH = **10.8m MV/HH**

Branch from A-to-D-to-E-to-F

- Total population of communities on branch: 100 + 500 + 300 + 10,000 households: 10,900HH
- Total branch length: 8,000 + 20,000 + 7,000m of MV: 35,000 m of MV
- 35,000m / 10,900 HH = **3.2m MV/HH**

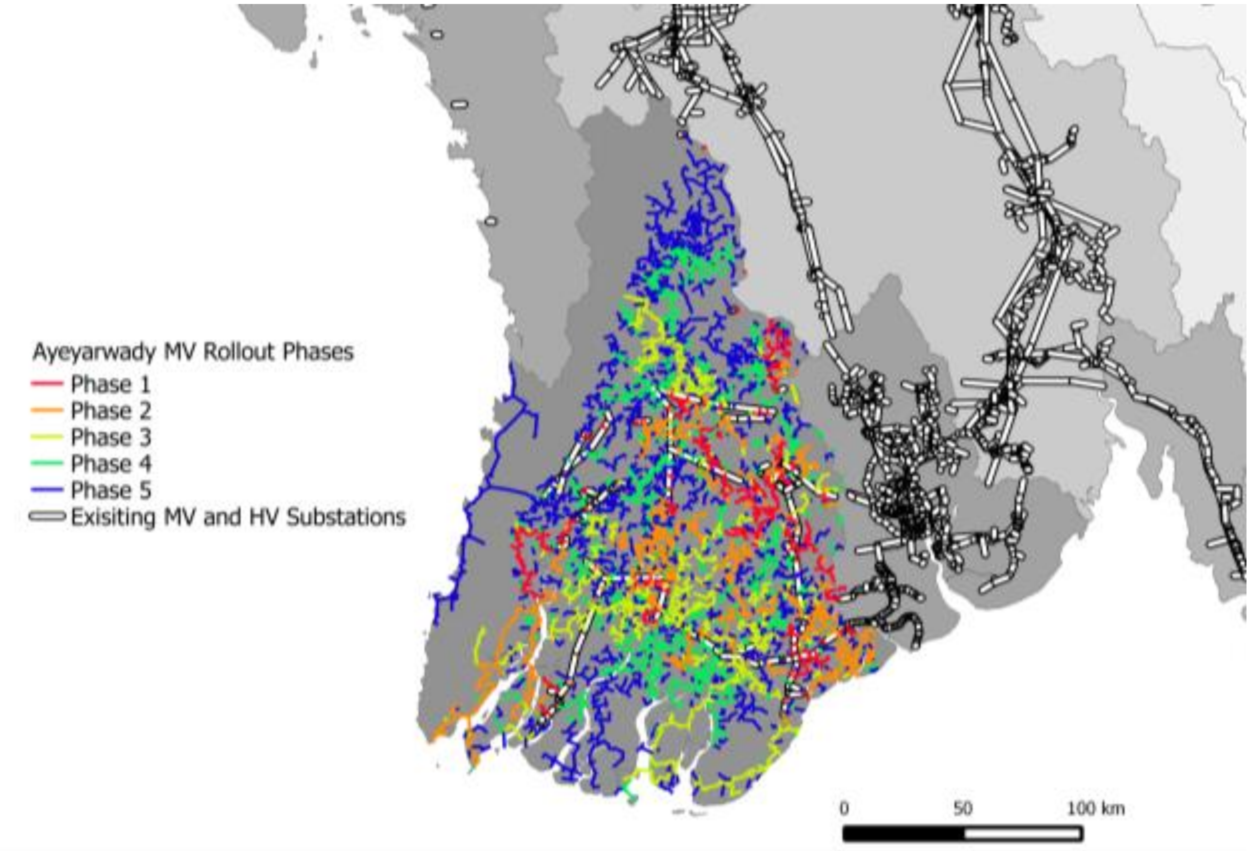
A few aspects of the MV/HH metric emerge from this example:

- Because MV/HH allows evaluation of the cost of grid extension ***on a relative basis, comparing one area to another,*** it offers a valuable tool for priorizing grid extension. For this reason, it is the key metric for algorithmically determining the sequenced grid "roll-out", in other words, the recommended pattern of connections from the exisiting grid and onward from one community to the next**.**
- Since power in real electricity systems must flow from the existing grid, generation sites, or substantions outward, grid roll-out cannot simply prioritize the least expesive grid segments wherever they occur. Instead, the grid must be constructed in sequence, starting from power sources. For this reason, MV/HH is used in an algorithm which considers cost-benefit tradeoffs for both branches, and segments.
- Computations of MV/HH for small amounts of data (such as single communities or very short grid branches) tend to be "noisy", with widely ranging values even for locations that may be only a few km apart. This is because unusually small or large communities, or unusually long or short MV spans between communities, can result in extreme MV/HH values. In the first example, the MV/HH values for segments range from 12.5 to 50, a factor of 4 difference.
- Computations of MV/HH for long branches with many communities tend to be less noisy, and MV/HH values tend to be lower. This is because averaging across many communities tends to smooth out values, and because large cities or towns have a disproportionate effect in reducing MV/HH values. In the second example, MV/HH values for branches are 3.2 and 10.8, both lower, and with somewhat less variation than the values by segment.

Annex 4: Restuls by State / Region

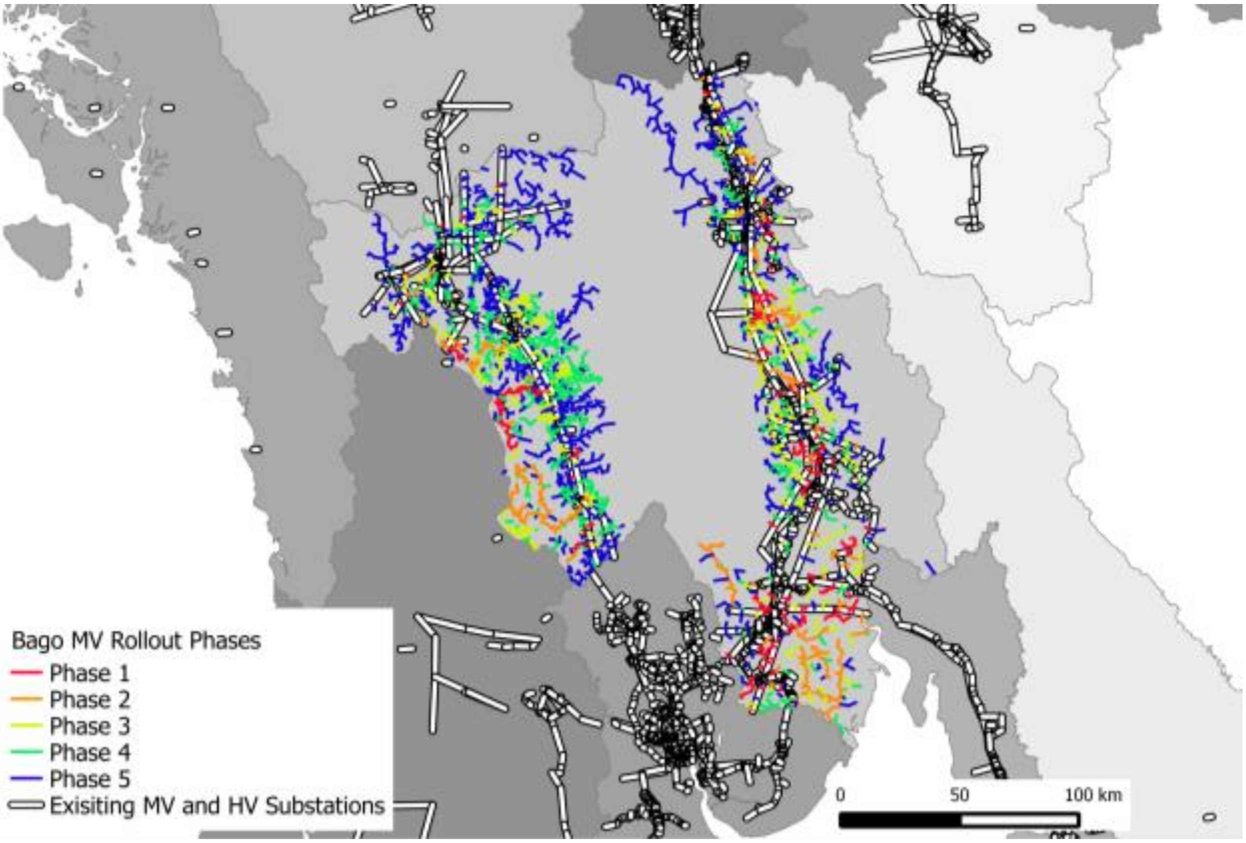
Ayeryarwady

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	218,000	782	$694	4
2	218,000	1,350	$747	6
3	218,000	1,450	$755	7
4	219,000	1,720	$780	8
5	219,000	2,990	$895	14
Total	**1,090,000**	**8,290**		
Average	**218,000**	**1,660**	**$774**	**8**



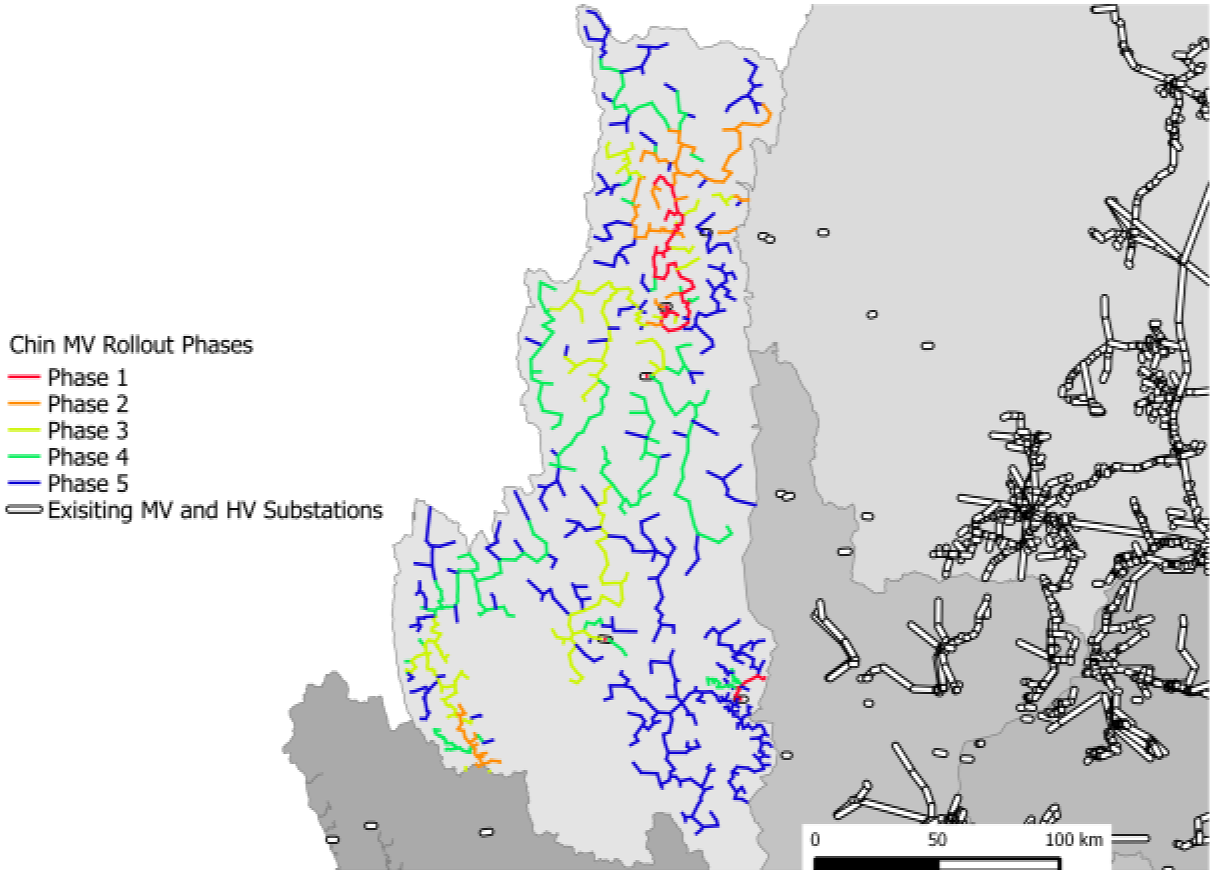
Bago

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
0	(Qty)	km	USD	m
1	137,000	363	$675	3
2	137,000	611	$710	4
3	137,000	775	$735	6
4	137,000	1030	$772	7
5	137,000	1870	$891	14
Total	686,000	4640		
Average	137,000	929	$757	7



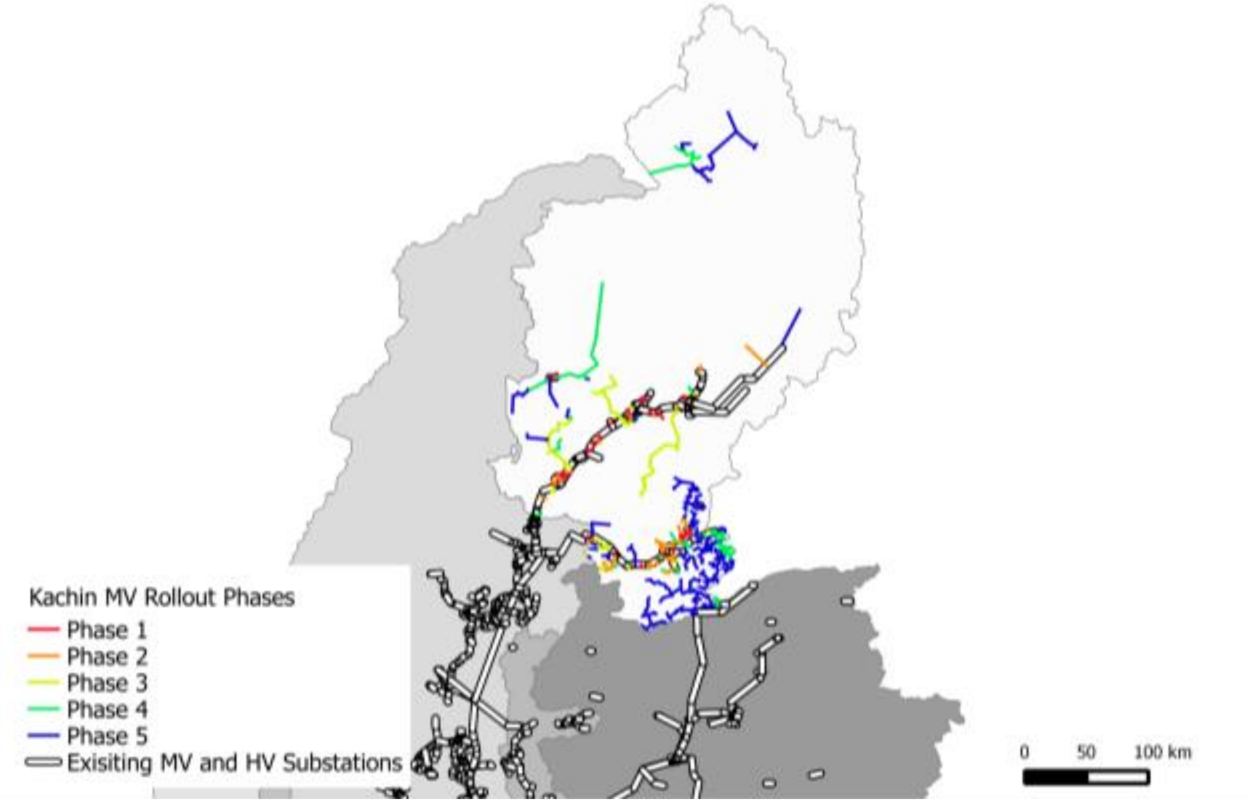
Chin

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	23,600	174	$780	7
2	23,400	304	$901	13
3	24,600	580	$1,130	24
4	23,800	808	$1,350	34
5	24,100	1520	$1,980	63
Total	**120,000**	**3,390**		
Average	**23,900**	**678**	**$1,230**	**28**



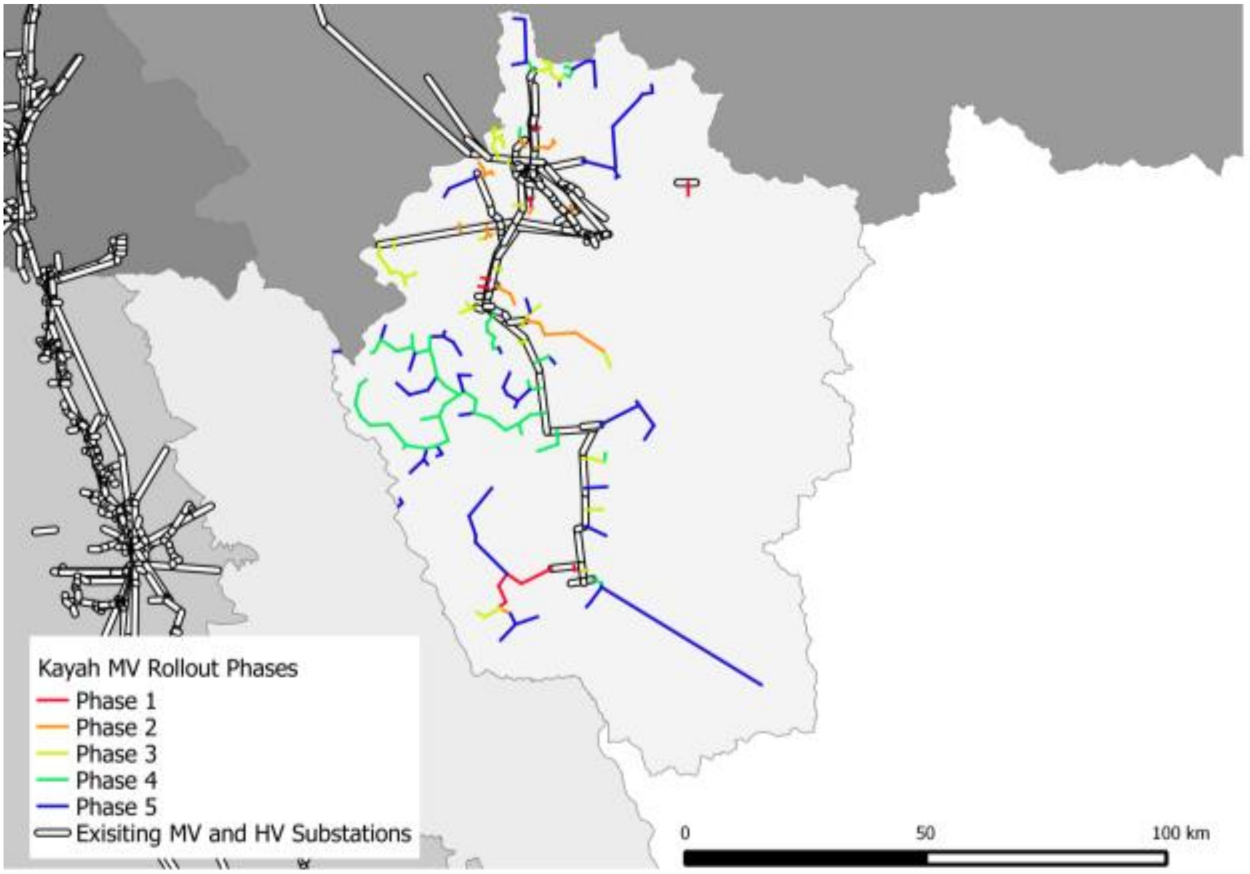
Kachin

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	23,100	78	$695	3
2	23,000	182	$793	8
3	23,100	311	$909	13
4	22,800	458	$1,060	20
5	23,500	949	$1,490	40
Total	**115,000**	**1,980**		
Average	**23,100**	**396**	**$989**	**17**



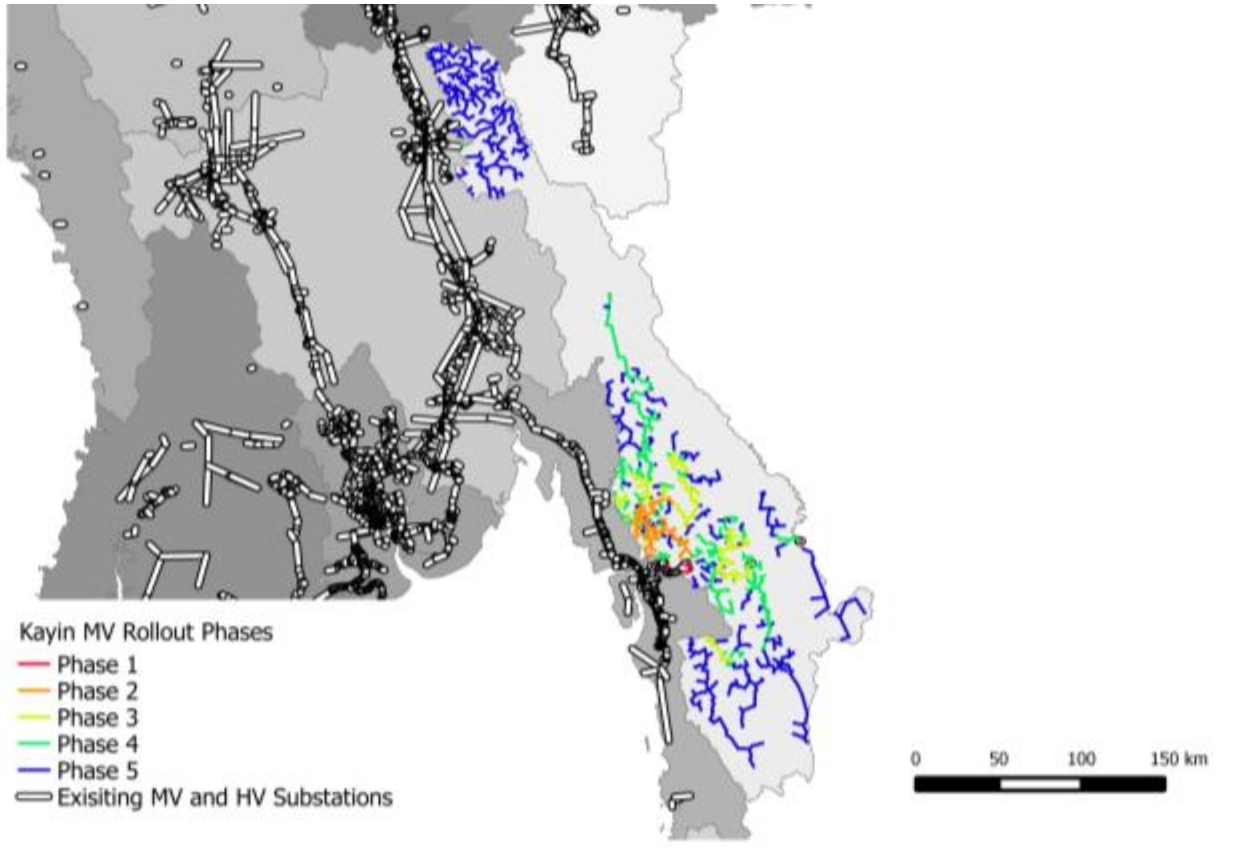
Kayah

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	5,100	30.8	$745	6
2	5,480	50.2	$810	9
3	5,550	79.1	$918	14
4	5,420	144	$1,160	27
5	5,400	251	$1,560	46
Total	**27,000**	**555**		
Average	**5,390**	**111**	**$1,040**	**21**



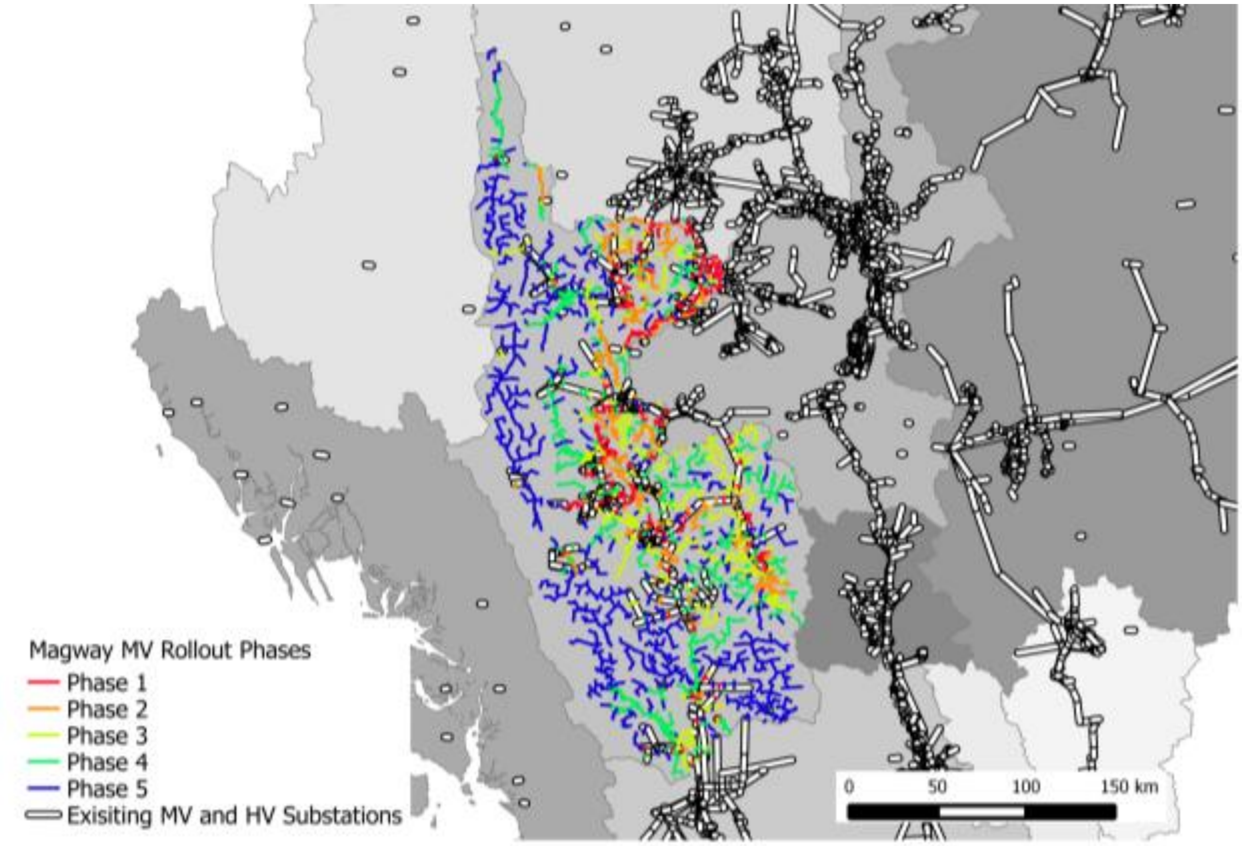
Kayin

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	75,900	11	$625	0
2	75,800	220	$682	3
3	75,600	355	$718	5
4	76,200	632	$792	8
5	76,000	1710	$1,080	22
Total	**379,000**	**2,930**		
Average	**75,900**	**585**	**$780**	**8**



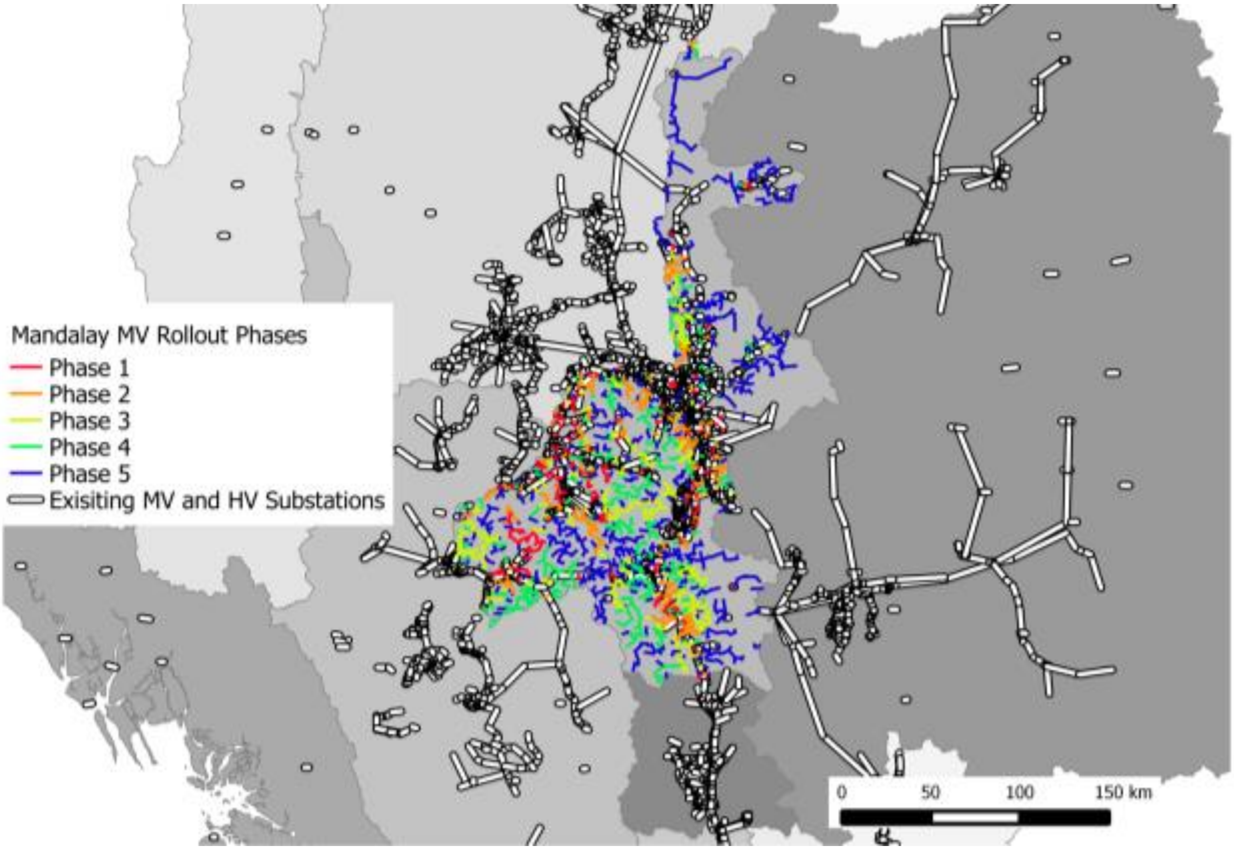
Magway

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	157,000	525	$689	3
2	158,000	788	$721	5
3	158,000	1040	$752	7
4	158,000	1410	$797	9
5	158,000	2630	$946	17
Total	**789,000**	**6,390**		
Average	**158,000**	**1,280**	**$781**	**8**



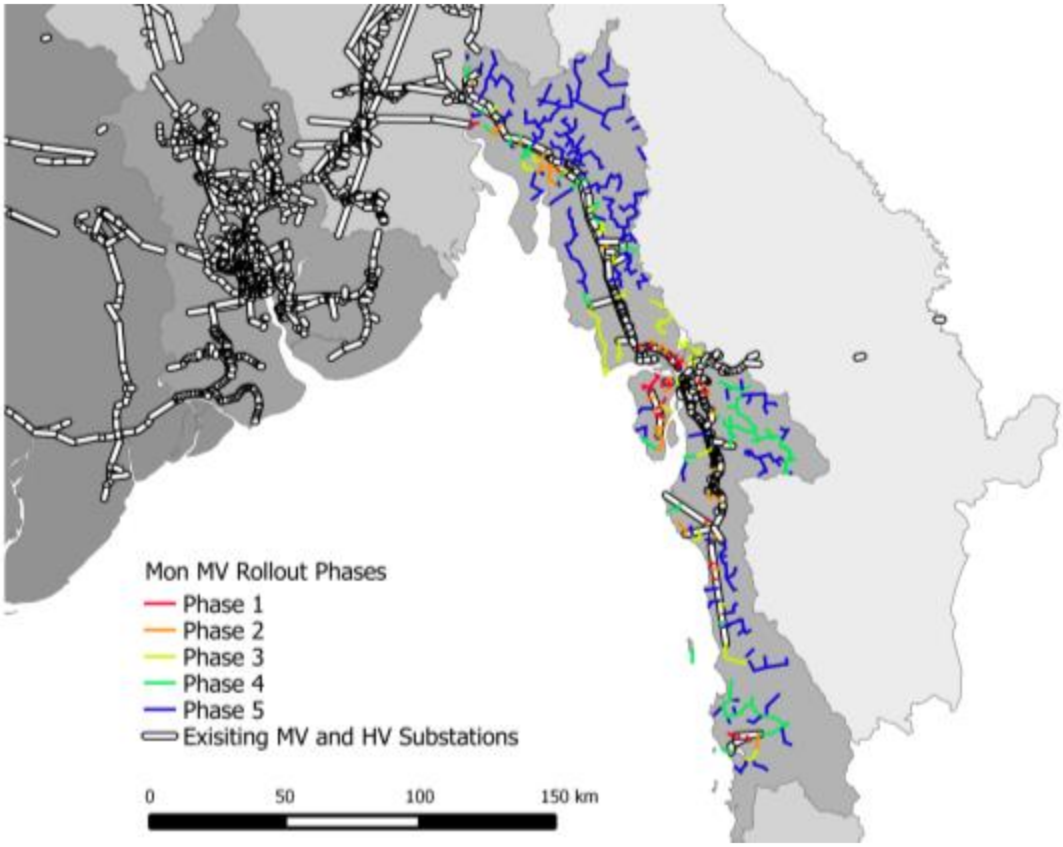
Mandalay

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	145,000	372	$673	3
2	144,000	610	$706	4
3	145,000	746	$724	5
4	145,000	951	$751	7
5	145,000	1700	$851	12
Total	**724,000**	**4,380**		
Average	**145,000**	**875**	**$741**	**6**



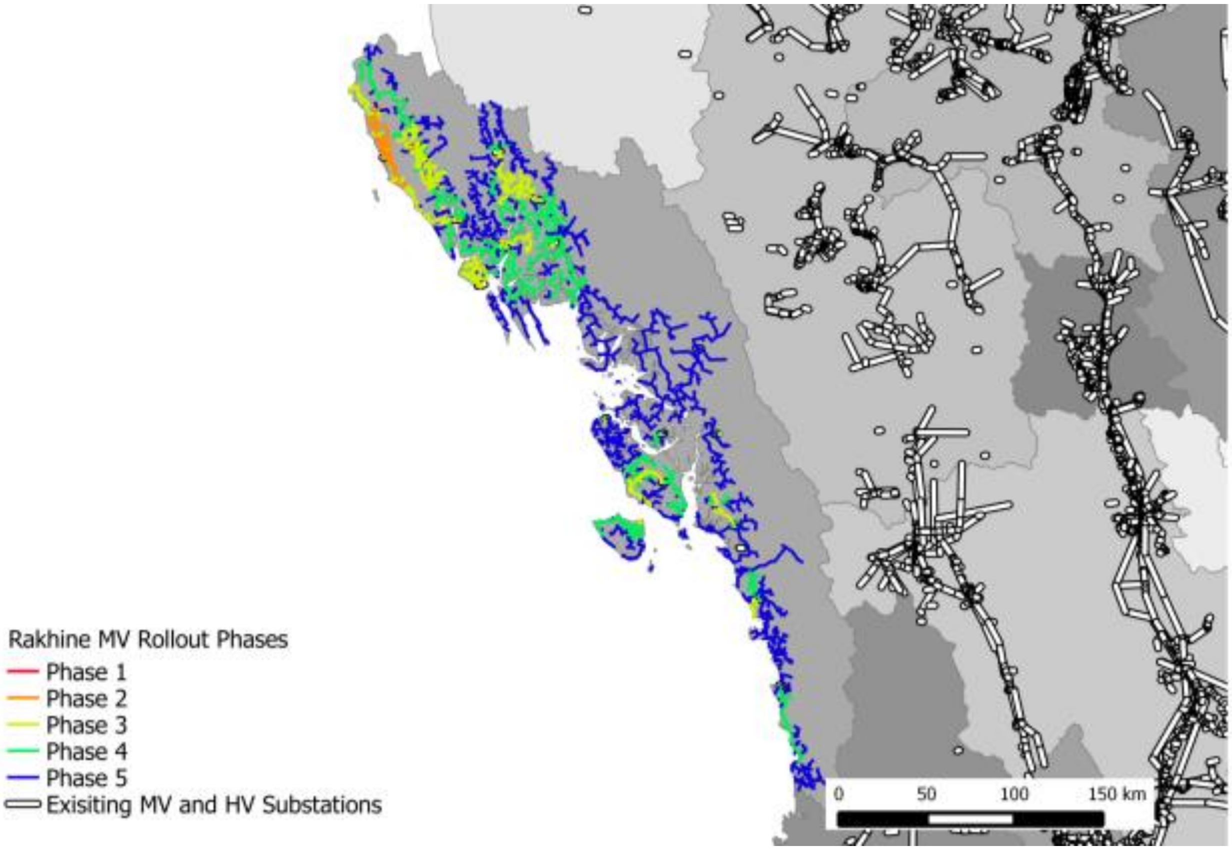
Mon

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	50,800	52	$642	1
2	51,200	101	$661	2
3	51,800	168	$685	3
4	51,300	245	$715	5
5	51,400	720	$895	14
Total	**256,000**	**1,290**		
Average	**51,300**	**257**	**$720**	**5**



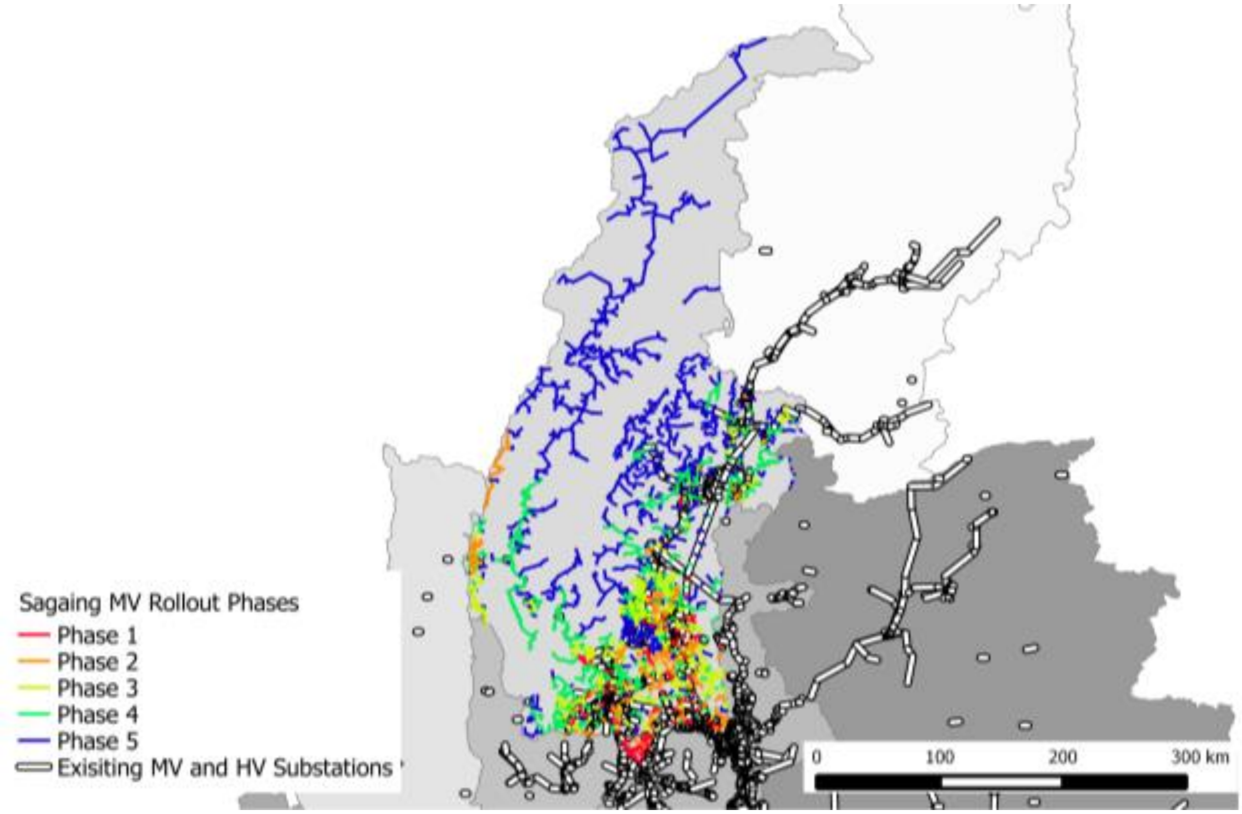
Rakhine

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	194,000	68	$629	0.4
2	194,000	68	$629	0.4
3	194,000	664	$694	3
4	194,000	1220	$754	6
5	194,000	2720	$913	14
Total	**970,000**	**4,740**		
Average	**194,000**	**949**	**$724**	**5**



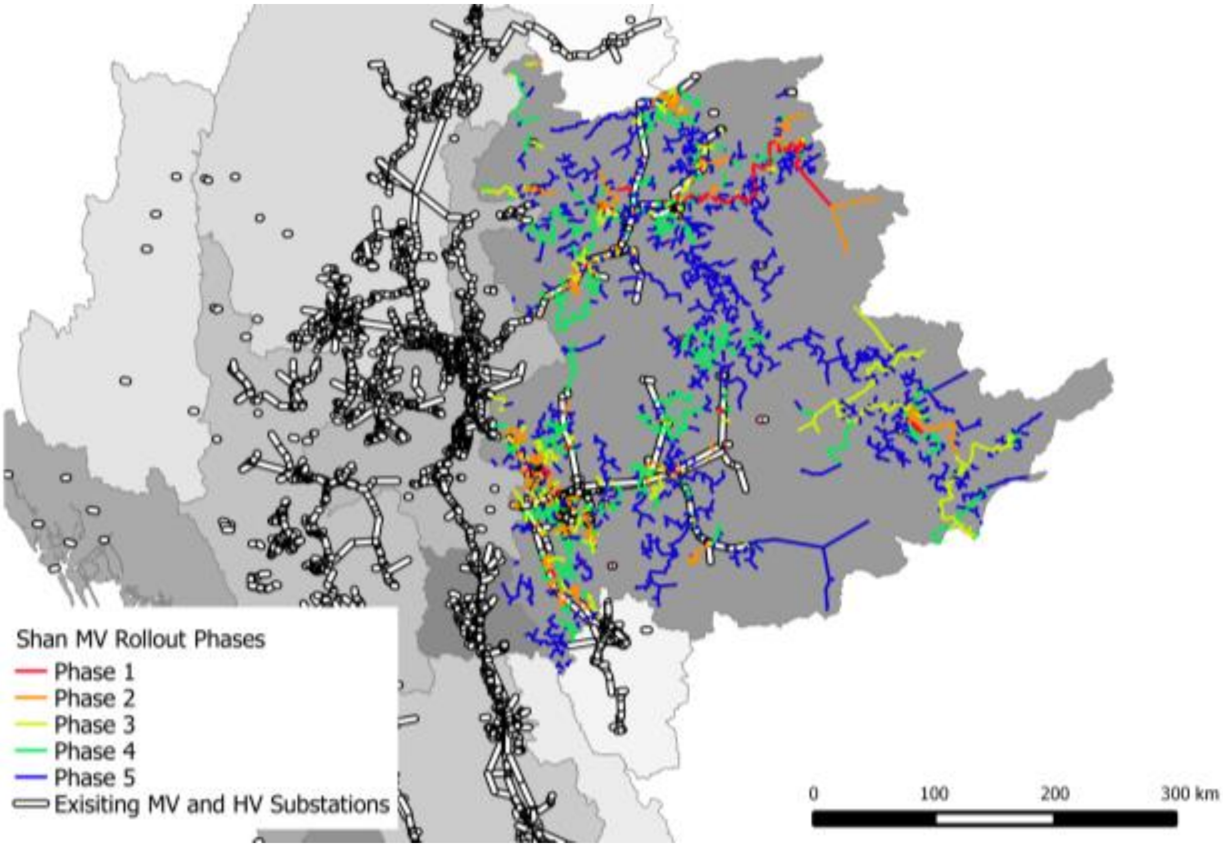
Sagaing

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	182,000	295	$655	2
2	181,000	732	$705	4
3	182,000	1140	$751	6
4	182,000	1790	$825	10
5	182,000	3740	$1,040	21
Total	**909,000**	**7,690**		
Average	**182,000**	**1,540**	**$796**	**8**



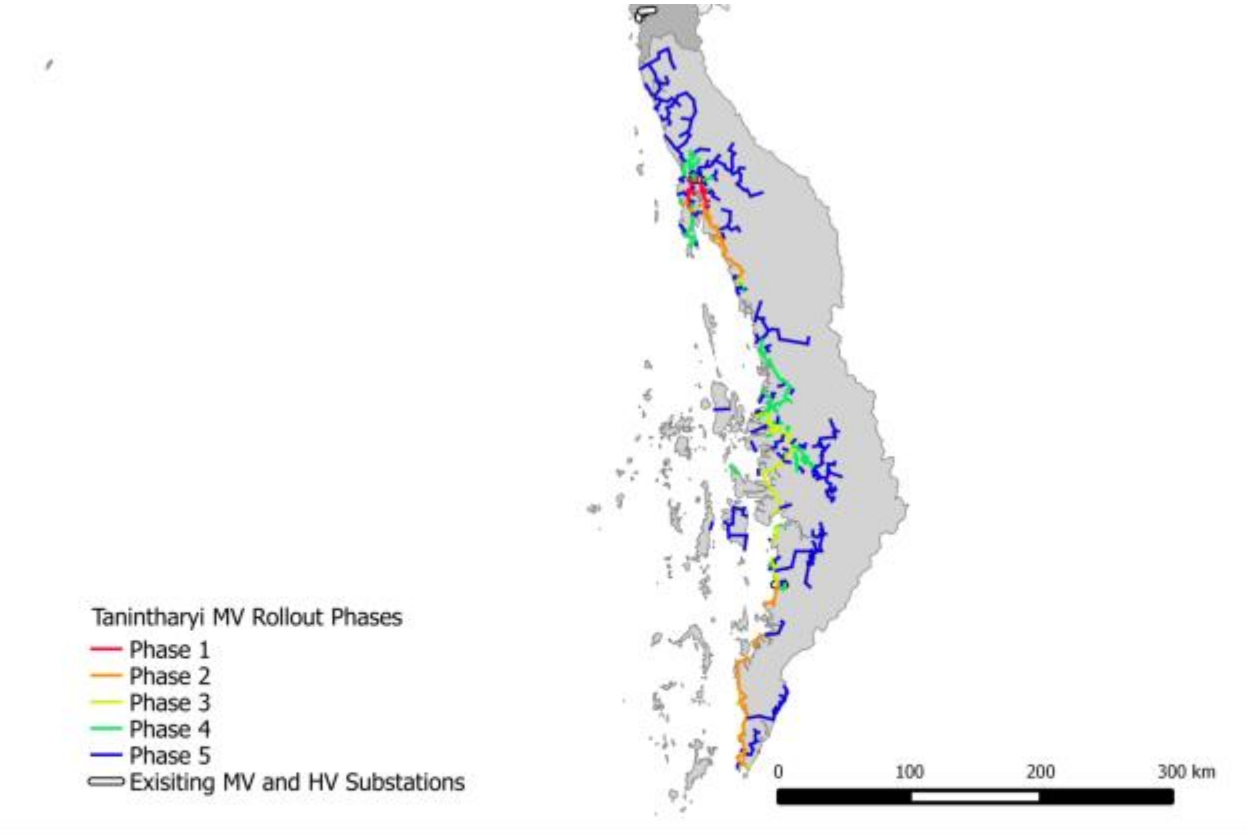
Shan

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	85,700	390	$717	5
2	116,000	1,030	$806	9
3	101,000	1,250	$877	12
4	99,000	2,380	$1,120	24
5	103,000	5,390	$1,700	52
Total	**505,000**	**10,400**		
Average	**101,000**	**2,090**	**$1,040**	**21**



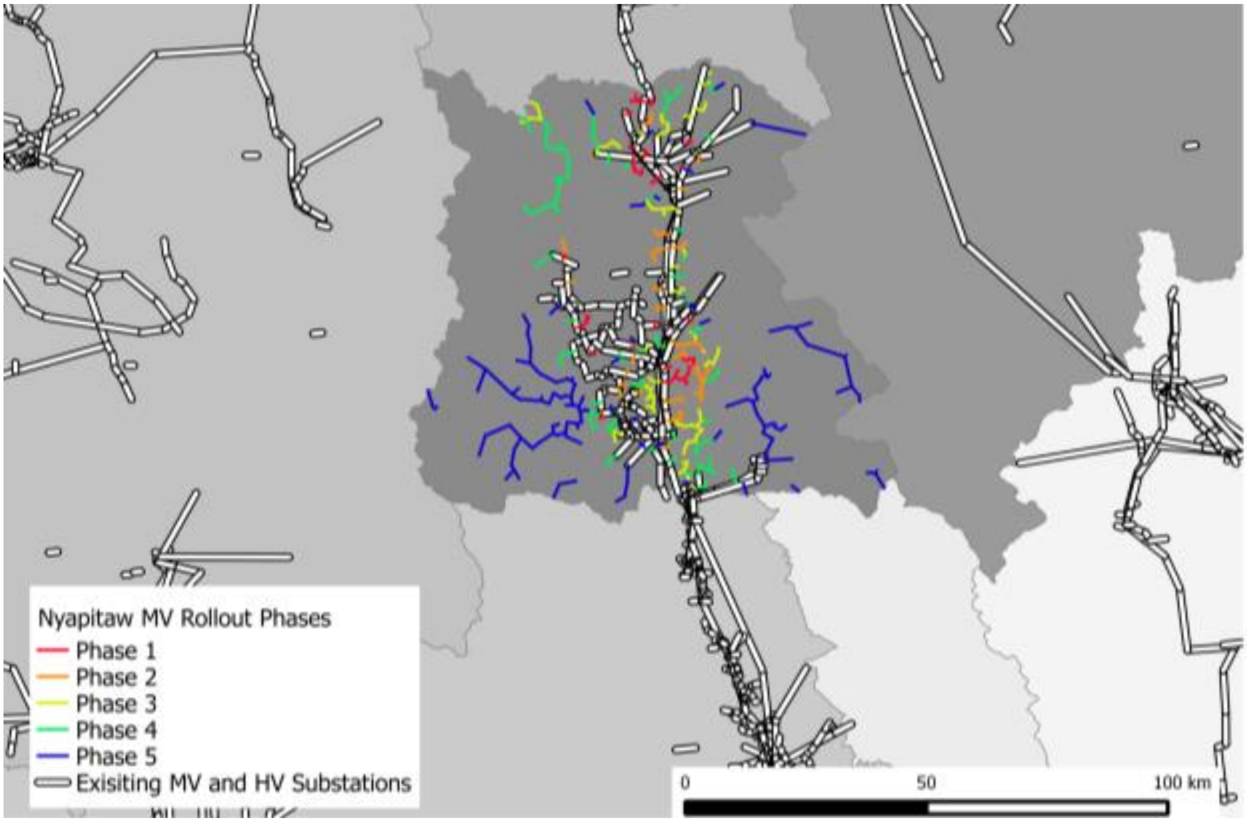
Tanintharyi

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	63,800	78	$647	1
2	44,900	275	$747	6
3	85,000	227	$676	3
4	64,500	361	$736	6
5	64,700	1290	$1,030	20
Total	**323,000**	**2,230**		
Average	**64,600**	**447**	**$767**	**7**



Nay Pyi Taw

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	19,600	47	$670	2
2	19,700	75	$699	4
3	19,400	102	$725	5
4	19,900	144	$765	7
5	19,800	297	$915	15
Total	**98,200**	**666**		
Average	**19,600**	**133**	**$755**	**7**



Yangon

Phase	Number of Households Connected	Total New MV Line Installed	Per HH Cost of Phase	MV Line Installed per HH
	(Qty)	km	USD	m
1	41,500	117	$678	3
2	41,400	222	$728	5
3	41,800	281	$755	7
4	41,600	345	$787	8
5	41,600	613	$916	15
Total	**208,000**	**1,580**		
Average	**41,600**	**315**	**$773**	**8**