CHAPTER 13 PLANNING METHODOLOGY OF RURAL ELECTRIFICATION

13.1 Work Flow of the Master Plan

In order to formulate the master plan for rural electrification, the baselines for the power systems and the related data, review years, and basic inspection items for the system determination were set up as shown below:

- Baselines of the power systems and related data:
  - Baseline: the end of May, 2004
  - Sub-baseline: the end of 2007 (when ADB/RE-3 in 9th Five Year Plan (FYP) is completed)
- Review years:
  - in 2012 (when 10th FYP is completed)
  - in 2017 (when 11th FYP is completed)
  - in 2020 (the last year of the master plan: 100% electrification is to be accomplished)
- Basic inspection items for system determination:
  - System structure by review year (e.g. electrified/non-electrified, on/off grid)
  - System analysis by review year (Basically, the demand considered for system analysis is supposed to be the estimated demand for the review year. As for analysis for the year 2020, the estimated demand for the year 2025 is also to be used in addition to that of 2020.)

The overall flow of the formulation of the Master Plan for rural electrification is shown in **Figure-13.1.1** below.

The location of all the non-electrified villages was recorded by the village reconnaissance and the positional coordinates (X, Y, and Z) of those villages were indicated on a GIS map. Similarly, all the existing distribution line routes and the routes of distribution lines to be constructed under 9th FYP were indicated on the GIS map. The new distribution lines will be extended to the target non-electrified villages from the end points of the existing lines or the lines that will be constructed during 9th FYP. Firstly, the Study Team connected all the non-electrified villages by the extension of the distribution lines. This was done in order to gain an understanding of the extant and cost of the 100% on-grid electrification scenario; this case is named "Option-1". The routes of the distribution lines were selected by using the GIS map.

The potential sites for mini/micro hydro power generators were selected and map studies were done. For environmentally protected areas, the selection of the conductor to be adopted was done by taking into account the cost and environmental impact.

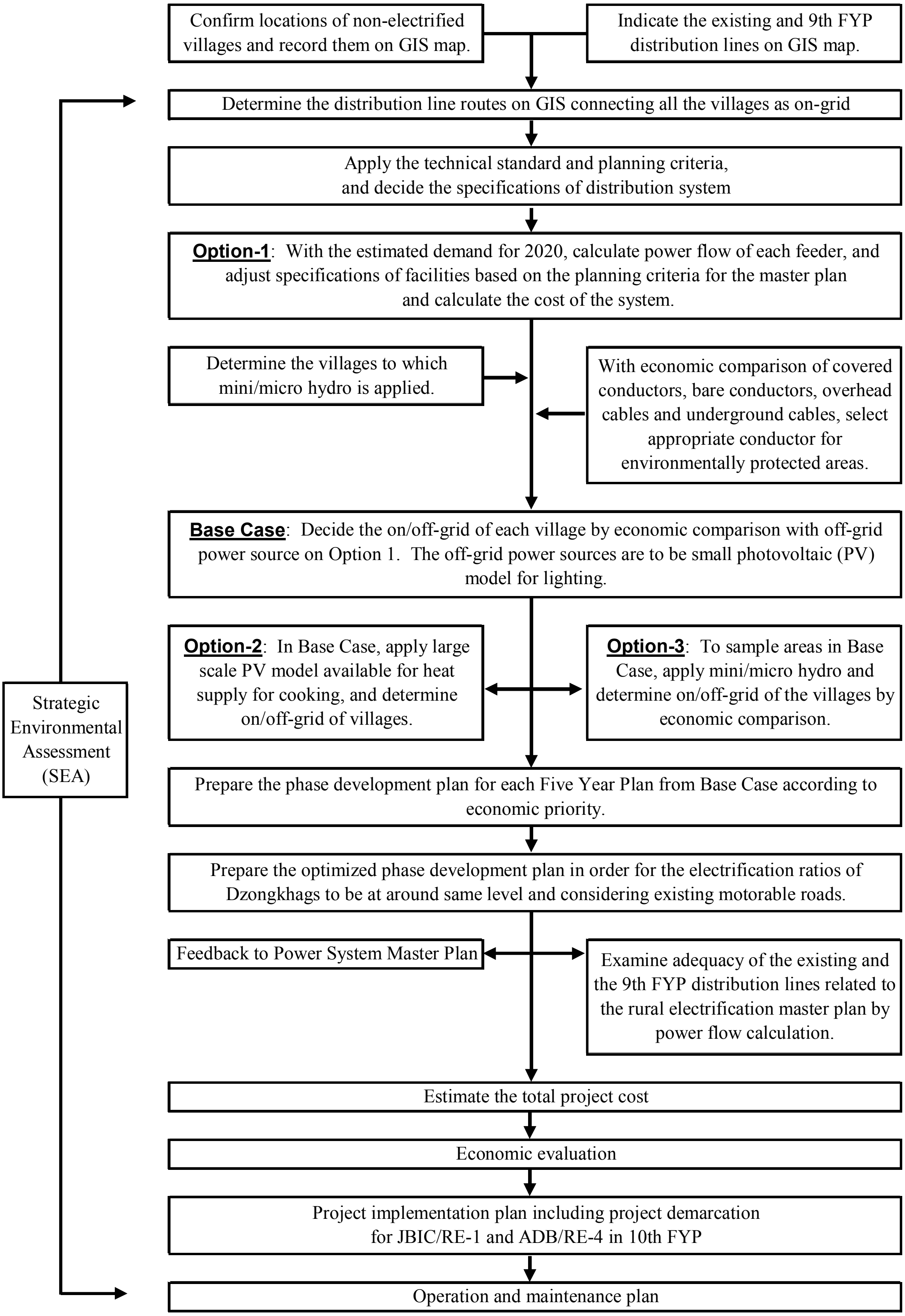

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Figure-13.1.1 Flow of the Formulation of the Master Plan for Rural Electrification

The allocation of all the non-electrified villages to either on-grid or off-grid status was decided by economic comparison of on-grid and off-grid. On-grid costs were estimated from the result of Option-1 and the particular type of conductors selected for environmentally protected areas. The off-grid power source is a small PV model for lighting. This case was named “Base Case”.

Another two option studies were conducted using Base Case. One option studied was for on/off-grid decision to be made with large scale PV model as the off-grid power source, which had enough capacity to supply electricity for cooking heat: Option-2. The other option studied was done for sample villages using the same mini/micro hydropower generators as the off-grid power source: Option-3.

The Study Team prepared the phase development plan for each FYP from the Base Case. The implementation order was decided according to economic priority. Equal development of the country is a policy of the RGoB. Therefore, the Study Team optimized the phase development plan in order for the electrification ratios of Dzongkhags to be at around same level in the early phase of FYPs. Furthermore, the priority was given to the feeders near the existing trafficable roads.

The result of the formulated optimized master plan for rural electrification was fed back to the Power System Master Plan. The adequacy of the existing and 9th FYP was examined on the optimized phase development plan.

Finally, the total project cost was estimated, economic and financial evaluations were done, and the project implementation and the operation and maintenance plans were prepared. In addition, for the implementation plan, the Study Team showed the project demarcation for JBIC/RE-1 and ADB/RE-4 in 10th FYP.

13.2 Criteria for Implementation Priority

To establish the phase development plan up to 2020, the implementation priority of the feeders and villages had to be decided.

At the starting time of the study, the following criteria for diciding the priority were considered.

- Economic efficiency
- The distance between existing trafficable roads and the targeted village
- Trafficable road expansion plan
- Willingness of villagers toward electrification, and the level of preparation for contribution

Needless to say, economic efficiency is the most significant criteria. The closer the targeted village is located to existing roads, the easier it is to construct power lines, and the cost becomes lower. Therefore, the existing roads and the road expansion plan for the future have to be considered, and the villages that are near the planned roads should be given priority. However, because of the reasons mentioned in the Section 13.3 below, the expansion plan was not based on these criteria.

On the other hand, the attitude of the villagers and the level of preparation for contribution are really important factors to sustain electrification projects. Therefore, the villages that were evaluated as having a high ranking for these criteria should correspondingly be given a high priority for electrification. However, when the local consultant collected the data required to evaluate these matters as part of the non-electrified village survey work, it was found to be difficult to obtain reliable and objective data that could be used to decide the priorities of the villages. Therefore these criteria were omitted from actual decision of priority, and the trial evaluation that was carried out was only used for reference.

Finally, the following criteria were adopted to decide the implementation priority.

- Economic efficiency
- The distance between existing trafficable roads and the targeted village

13.3 Road Development Plan and Consistency Level

At the moment, there is a lack of information about the precise location of existing roads, which results in a lack of precision when the road location is mapped in GIS. However, the villages that are near the existing roads are given higher priority for electrification because it was assumed that the roads do exist. This was done even though it is acknowledged that the available information of existing road is not reliable. It is expected that the accuracy of the road location information will be improved as the master plan is reviewed.

In contrast, although there is a master plan for the planned road expansion, the budget has not been set and it is not clear when the plan is to be put into practice. Also, there are no maps that indicate precise routes of the extended roads; rather there is a list in which village names indicate the start point and end point of the planned road. Accordingly, the locations of the planned roads are considered only as a guide.

13.4 Network Optimization Method in Determining Grid Extension

13.4.1 Grid Extension Network

In Bhutan, it is expected that a grid extension will cover the majority of the future rural electrification needs, while some remote areas will employ independent electrification systems because of prohibitive economic costs.

Figure 13.4.1 shows the conceptual model for Rural Electrification in Bhutan.

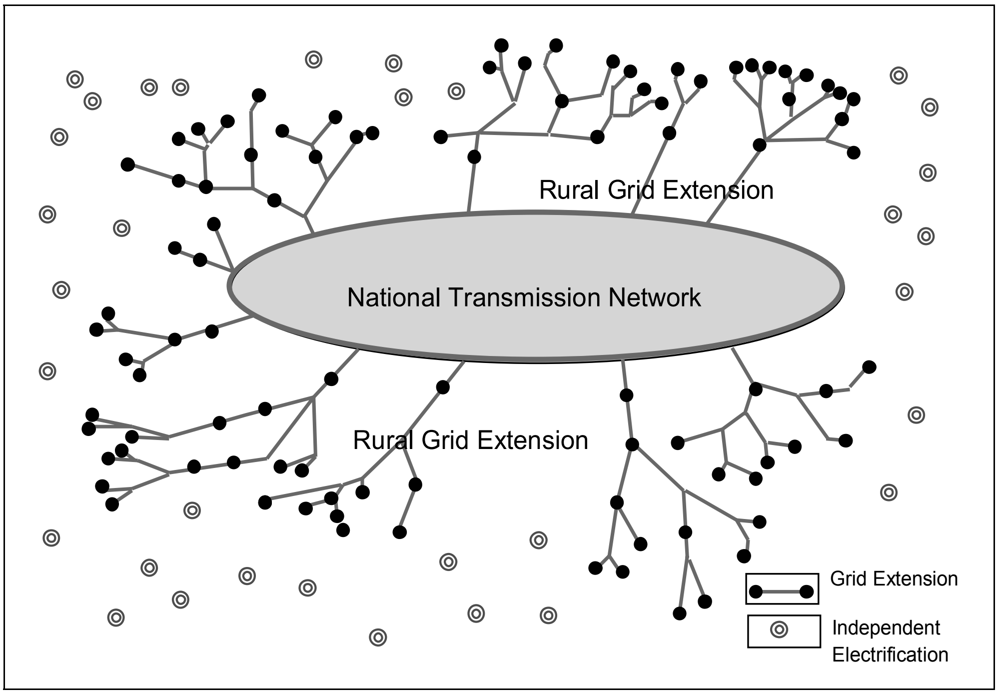

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Figure-13.4.1 Conceptual Model for Rural Electrification in Bhutan

One of the major tasks of the rural electrification master plan is to inquire the extent of distribution network. It is easy to understand the rationale for the judgment of not extending a grid in the extreme cases such as the one to a village of a few houses with tens of km distance away or the one to extend the grid to a village of hundred houses only few hundred meters away from an existing grid. The problem of grid extent determination exists in the middle ground where the distance to a village with 20 to 30 households may be a few km. The drawing line would be difficult at any point in the middle area without clearly predetermined rationales. The issue becomes further complicated since most feeders will have several villages connected along the extension and there are linkage dependency going backward and forward within the network that will make it a piecemeal evaluation not applicable to the overall evaluation. Instead a feeder-wide evaluation in light of every possible tree-configuration needs to be conducted for optimization.

13.4.2 Inter-dependency of Distribution Network

The judgment becomes even more difficult since power distribution network chains villages as the grid extends outwards. If economic analysis is conducted separately for each settlement, it could lead to strange outcomes of leaving a distant village with economic viability without linkage to the trunk line.

It is easy to understand that a village that are located at the end of the distribution network will depend on the on/off grid determination of the preceding villages in the chain. This is backward linkage dependency within a network. The dependency is purely physical so it is easy to see.

There is another direction, forward linkage dependency. This is more economical, thus not visible. The economic benefits of a inner connection of the network to provide links to the subsequent peripheral linkages extends to all the linkages enabled by the linkage. Therefore the justification of cost of the inner links will depend on the benefits of all the subsequent dependent links. Even if the inner link to one settlement does not justify itself independently with a negative net economic benefit, if the outer locations have large enough positive economic net benefits to offset the negative net benefits in the inner node, then the linkage can be justified. Theoretically, the economic justification of an inner extension depends on the sum of the net benefits brought by all the subsequent forward linkages.

As **Figure-13.4.2** shows, a village near to the center can share the cost with the villages that connect to the grid at further distances. The optimization of a network needs to take into account a linkage effect that is pertinent to a network. For instance Village B in **Figure-13.4.2** in the middle network configuration may have a negative value in its own economic net benefit. If there are additional villages such as Villages C that connect in the extension of the grid beyond the village in question, may lead to a case where the total net benefit may exceed the total net benefits offered by off grid systems.

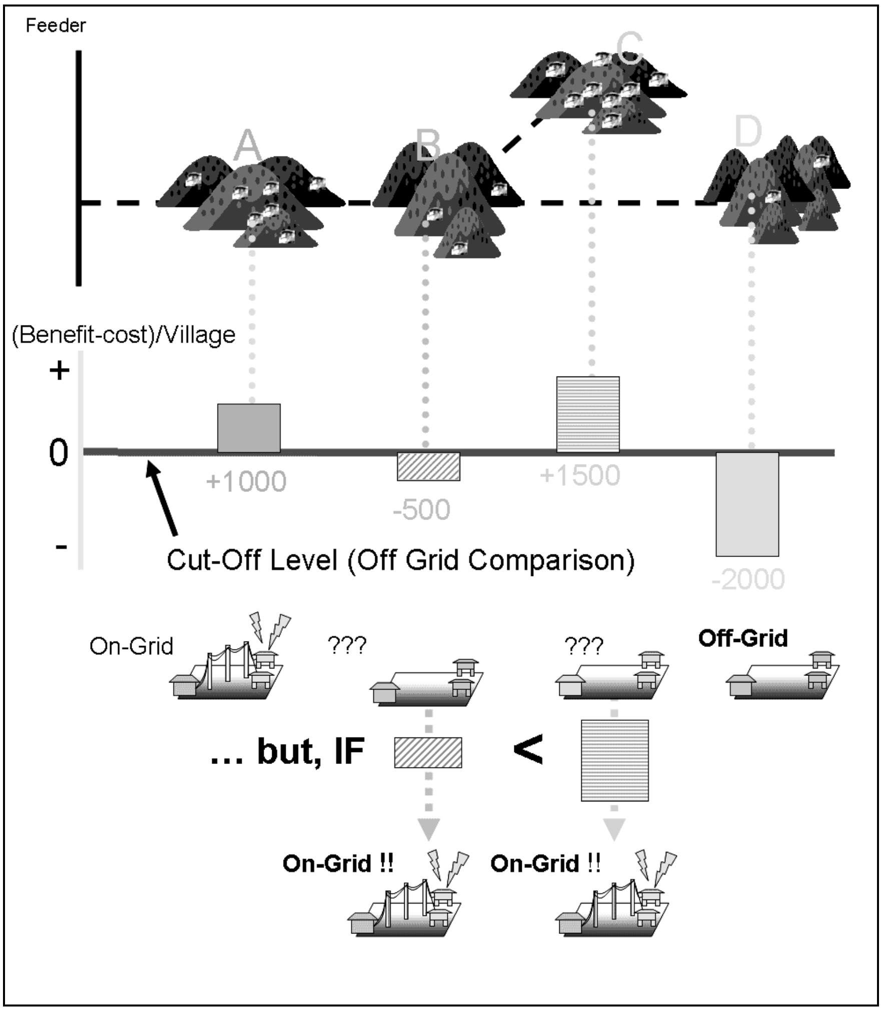

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Figure-13.4.2 On-grid Additional Cost Comparison

13.4.3 Basis of Optimization of Grid Extension

The interdependencies of linkages within a network require an overall optimization in economic sense to determine the extension of the grid. The first step of optimization is to define the objectives of optimization. Though in the end the procedure presented in this study is mathematically defined, the process of defining optimization goal involved dialogs with policy makers. Reflecting the national motto of “Gross National Happiness”, Bhutan pursues more egalitarian approach in providing basic social services regardless of locations. There are tw o goal options to take for the master plan:

1) Maximization of Efficiency of Investment, and

2) Maximization of Social Welfare Derived from Rural Electrification.

The adopted approach for the master plan is the second option of maximization of social welfare, i.e. the net economic benefits[1].

Values of social welfare for grid and solar are compared in determining on/off grid so as to maximize overall social welfare of rural electrification. The definition of social welfare is exactly same as that of the net economic benefit (economic benefit minus economic cost) as defined for economic analysis for the study[2]. The determination of on/off grid extent is done according to the technical criteria to maximize the net benefits from electrification, by grid extension or an independent solar home system.

In principle, the judgment to extend the grid to a particular village will be based on a comparison of the two alternatives of 1) grid extension and 2) an independent power system, a small-scale solar home system in Base Case. Simply, the choice of a system is the one that brings a larger net benefit than the other.

Though the larger grid increases the total cost, in absolute terms, the unit cost may be lower if the user base increases more than the total cost. So called economy of scale takes place because a larger user base makes it possible to reduce user-wise unit investment cost by sharing common installation investment cost among a larger denominator. However, as the size becomes even further, the density of the users becomes sparse, and the cost per user will be increased.

Figure-13.4.3 shows the tendency of user-wise unit investment cost along grid extension.

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1 In deciding the staging plan for the feeders(200 in all), the return on investment played the most critical role. Thus the plan mixes the efficiency and welfare maximization to a large extent.

[2] See Appendix B-1-1

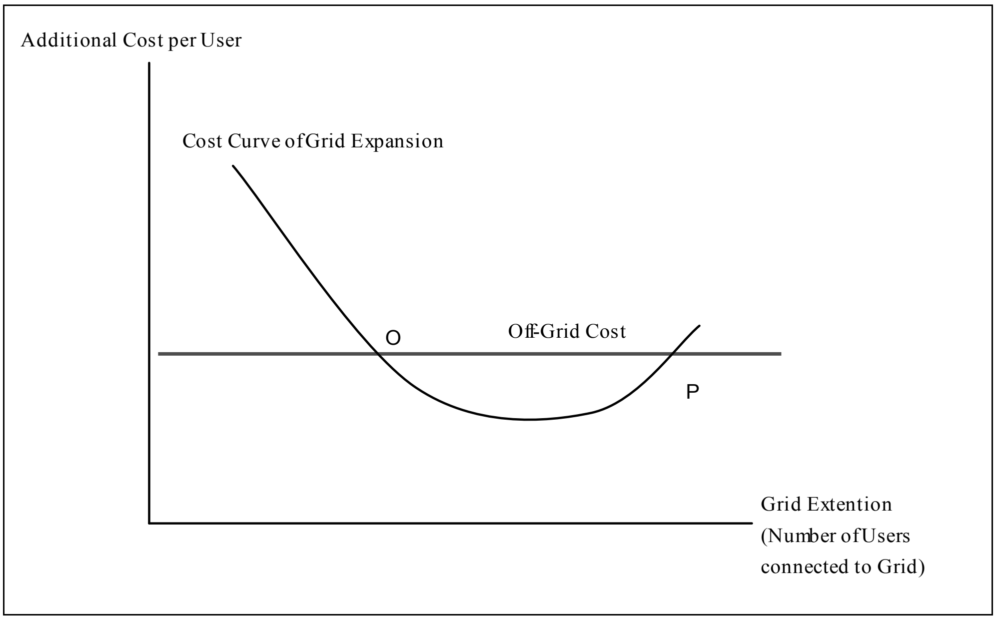

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Figure-13.4.3 Technical Criteria for Grid Extension

The extent of the economy of scale needs to be examined as a whole. For detailed description of the method and actual estimation, please refer to economic analysis method section **Appendix B-1-1.**

13.4.4 On/Off Grid Calculation Criteria Procedure

The economic dependency of the inner connection to the outer connections necessitates initiating the optimization process from the largest possible network. Starting from the farthest village, piece-wise additional net benefit calculations and comparisons need to be done between on-grid and off-grid. If the difference between the net benefits of the two alternatives is positive for grid extension, the village or tap-off node (hereafter called a node) is judged as “potentially on”. If the difference is negative, the node is judged “off”. The comparison of the combined net benefit to the net benefit of off grid system determines whether the node in question is “potentially on”, or “off”. Note there is a clear difference between “on” and “off”. The determination of “off” is a local one. So long as the node cannot justify grid connection, i.e. the node is having only negative contribution to the network; the node needs to be taken off. For a potentially “on” node, the difference of net benefits is added into a total feeder account called “cumulative net benefit” to feedback as part of additional net benefit of grid extension to the nodes that precede the particular node (*Forward Linkage*). After completing the evaluations of all the nodes in the last tier, the evaluation moves up to the second to last tier, i.e. the nodes that connects to the last tier. The calculation of the net benefit for any node should include the cumulative net benefits that all the forward linkage would bring on.

If any node along the linkage becomes “off”, all the succeeding nodes that depend on the linkage becomes instantly “off.” Since the decision to figure “potentially on” or “off” is determined at every subsequent node and any decision takes into account of all the subsequent cumulative net benefits (*Backward Linkage*). The final "on" decision, a switch from "potentially on" to "on" or "off", is carried out at the root of the network (feeder). If the root is determined "on", all the subsequent nodes with "potentially on" become "on". This backward trimming and optimization process, and final feed forward linkage finalization are based on the optimization method called "Dynamic Programming."[3]

Algorism for Calculation

Figure-13.4.4 shows a schematic algorism for the calculation of the node (village)-wise net benefit comparisons.

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[3] In optimizing grid extension, choice of villages are not independent but dependent on the choices for the preceding nodes. Such dependency between nodes are best dealt with Dynamic Programming.

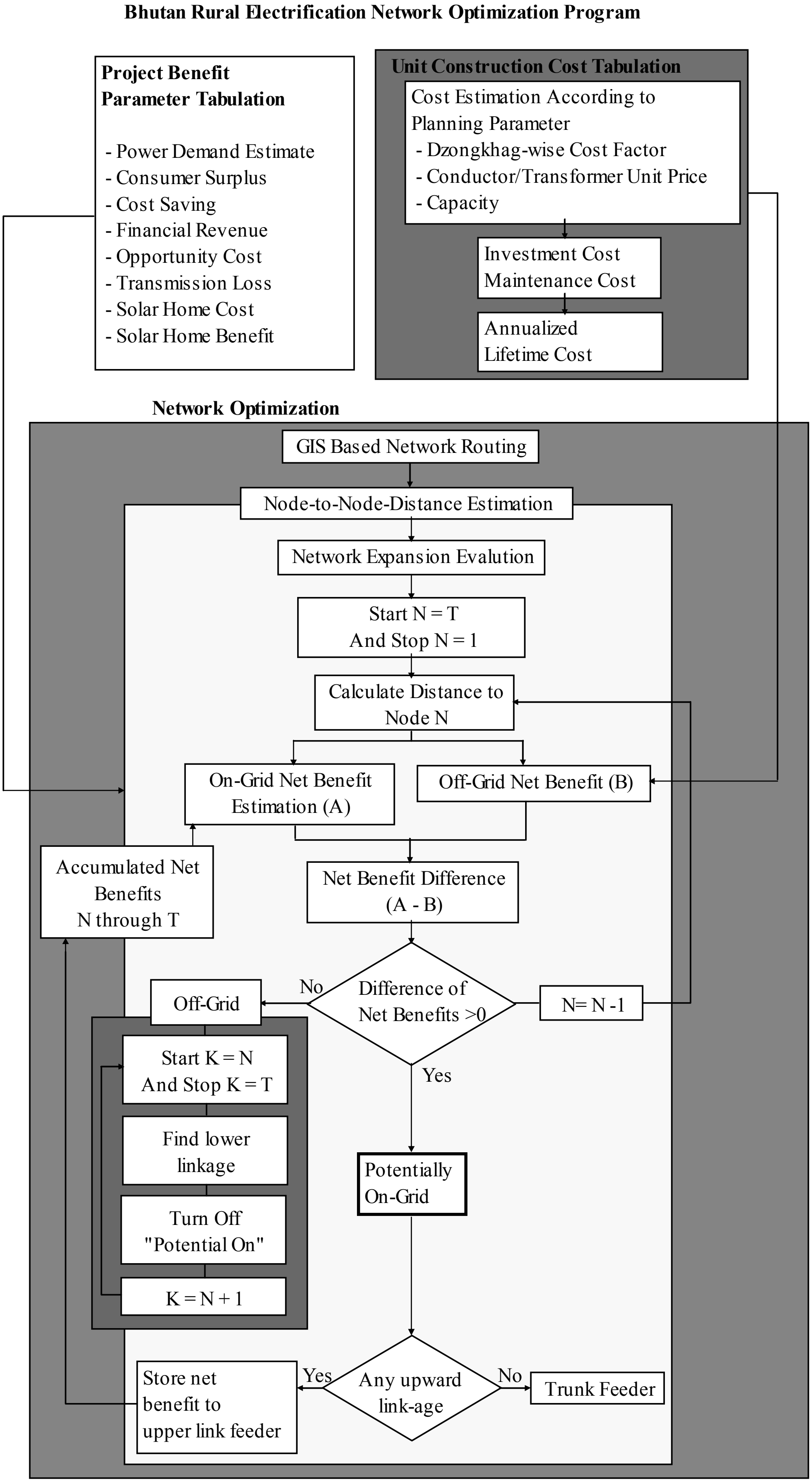

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Figure-13.4.4 Grid Extension Optimization Algorism

13.5 Method of Designing Distribution Lines

13.5.1 Method of Distribution Line Expansion

The distribution lines were designed as an expansion of existing lines, planned ADB/RE-3 lines, and planned new transmission substations. Expanding from existing the 11 kV lines, designs of voltage conversion into 33 kV and installation of voltage regulators were considered.

The distribution lines were designed for installation alongside roads, otherwise they were designed to avoid large differences in elevation and undulating terrain as much as possible.

The conductors of the lines are designed in consideration of voltage, basically adopting ACSR Dog and Wolf conductors for trunk lines and Rabbit conductors for branch lines. In 33 kV lines, Rabbit conductors, which are cheaper than Dog or Wolf, were mainly designed. Covered conductors were designed for environmentally protected areas.

As for distribution substations, it was decided that the maximum capacity of the transformers should be 25 kVA for mountainous areas considering easement in transportation. As a consequence, most of the capacities of the designed transformers became 25 kVA. The single phase lines and transformers were adopted by estimating the demand of each village. The switches for distribution lines were designed at suitable locations, approximately 10 km apart, wherever necessary.

The distribution facilities were designed based on the demand estimated for the year 2020. Therefore, for villages where rural electrification projects are planned for a later time, the capacities of facilities that are designed in feasibility studies should consider future demand.

13.5.2 Work undertaken in GIS

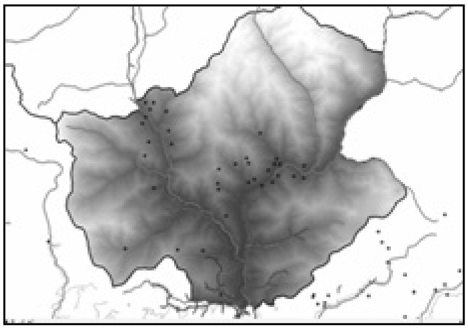
In this study, GIS was used in order to select the route of new distribution lines. The advantages of using GIS are summarized in the following four points:

- It is possible to display both the location of facilities (e.g. existing distribution lines, ADB/RE-3 distribution lines, roads, rivers, non-electrified village positions, contours, etc.) and database information which are required to draw up a distribution line extension plan on one digital map.
- Experimentation by trial and error can be easily done, because GIS uses a rewritable digital map.
- It is possible to create and deliver data which is required for the distribution system analysis.
- It is possible to calculate the cost estimation in master plan because GIS can provide attribute data which is required for estimation.

In this study, two training programs were carried out during the field survey of the project. The first training program was the training for power distribution system analysis technology. This involved an explanation of the rural electrification technique, an introduction of GIS technology, and training in the use of the system analysis program. The second training program was GIS training for the GIS and the system analyst counterpart members. This training allowed the counterpart members to independantly formulate the distribution line extension plan using GIS.

The work procedure flow for the distribution line extension planning which uses GIS is shown below. As explained above, the distribution line extension planned by GIS was initially planned without considering the separation of on-grid and off-grid villages. Firstly, all the non-electrified villages were connected to the existing grid so that the extent of the network could be conceptualized. Economic evaluation determined the on-grid and off-grid villages. After doing this, the on-grid and off-grid villages, and the corresponding electrification network, could be mapped.

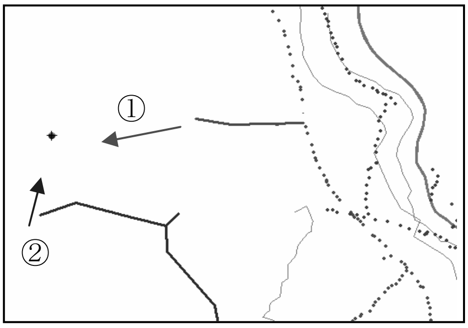
1



Data display in GIS

Existing distribution lines, ADB/RE-3 distribution lines, non-electrified village positions, rivers, roads, environmental protected area, contour lines, etc., are displayed in GIS.

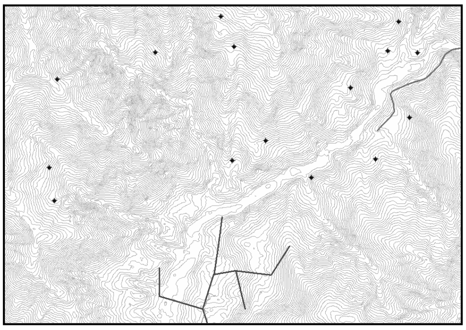
2



Selection of the feeder extension to non-electrified villages

The distance to non-electrified villages, line voltages, and conductor size are considered for selecting distribution lines to extend.

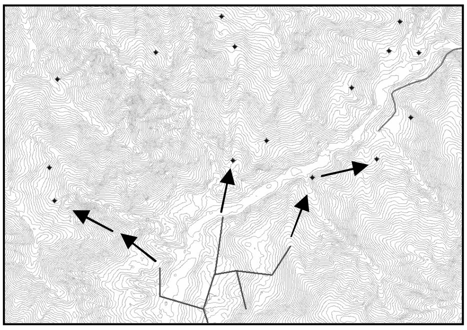
3



Printing the data on a paper

GIS data are printed as a topographical map. The distribution line extension is considered using this paper map. The contour lines are displayed at intervals of 20 m.

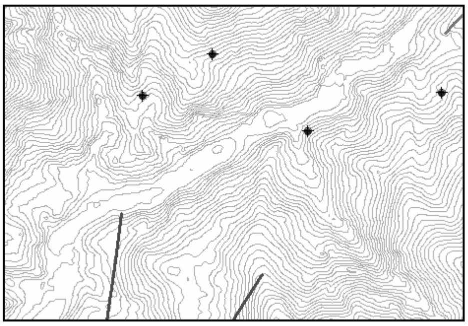
4



The distribution line extension plan

- When there is a road, the plan should be along the road.
- The plan should be along with the contour. The steep geographical feature and inclination are avoided.
- The plan should be avoid the crossing of a river.
- Entry in environmental protection areas should be minimized in the plan.

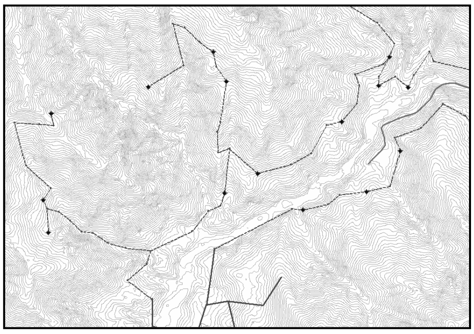
5



Calculation of the transformer capacity for the substations

Transformer capacity of substations is calculated based on assumed demand.

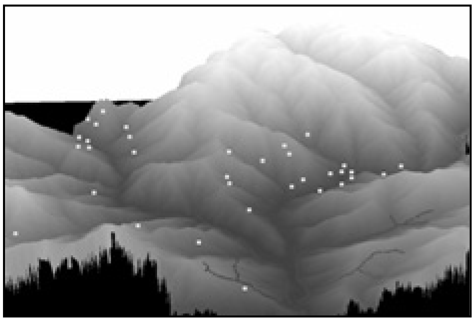
6



Data input to GIS, and calculaion of distance

The distribution line extension plans drawn up on the paper map are input to GIS. Calculation in consideration of geographical feature of distance is performed like the existing distribution lines and ADB/RE-3 distribution lines. Data are created for the system analysis.

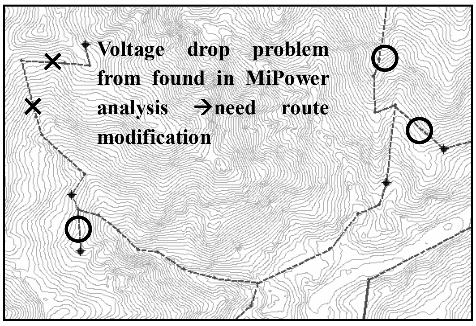
7



Checking the data using 3D Analyst

The created data are displayed using the 3D Analyst GIS module to check whether the created route is suitable.

8

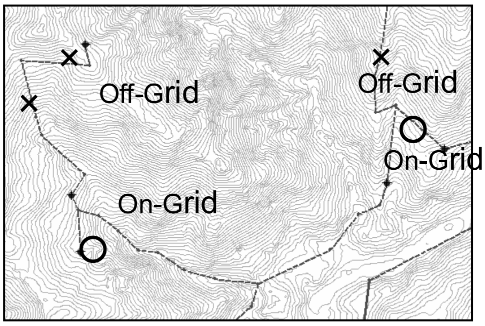


Data updating and Finalization of Option-1 (All-on)

The data are transferred to a power flow analysis program (MiPower) and power flow analysis is done. When issues relating to voltage and current were identified, the route and line selection are modified.

→ When modification of route is required, return to Step "1".

9



Preparation of Base Case(On/Off) and phase development plan by economic analysis

Based on Excel data exported from GIS, economic calculations are carried out and village on/off status is evaluated.

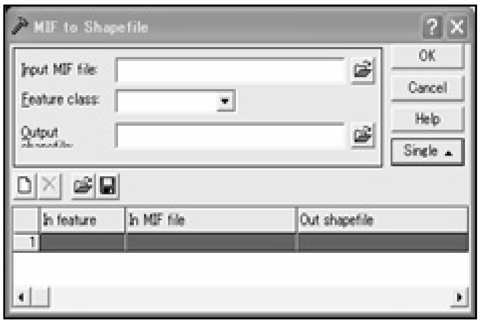
→ The result of on/off evaluation is transferred from Excel back to GIS.

10

Base Case Mapping 1 – Preparation of MIF/MID GIS files

Based on the result of economic calculation, line data are prepared based on the on/off Excel data by a program. The line data is prepared by feeder. The output file type of the GIS data is "MIF/MID" (MapInfo Interchange Format)

11

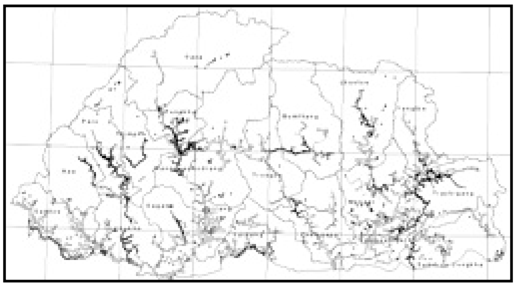


Base Case Mapping 2– Preparation of Shape file

Convert MIF/MID file to ESRI Shapefiles using a module in the ArcGIS ArcToolBox.

→ Prepare Shapefiles with on/off attribute

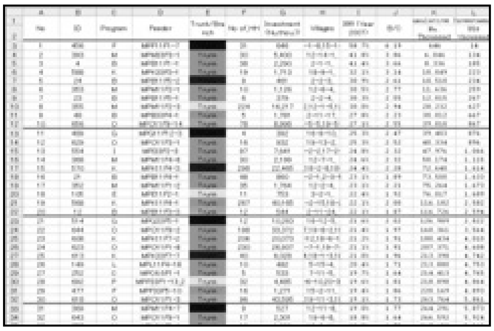
12



Base Case Mapping 3 – Mapping

Display the prepared line data in GIS and check on/off-grid villages using GIS. Repeat the work from Steps “9” to “12” every time the economic calculation is carried out, and update the data.

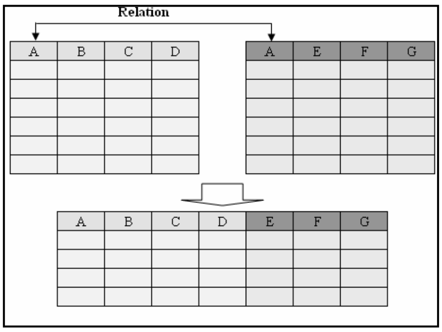
13



Preparation of each FYP – Phase-wise planning by economic calculations

Calculate the IRR of each feeder and sort into order of IRR. Allocate the feeders in 10th FYP, 11th FYP, and 12th FYP by a criteria such as budget limit or target on-grid electrification household number.

14

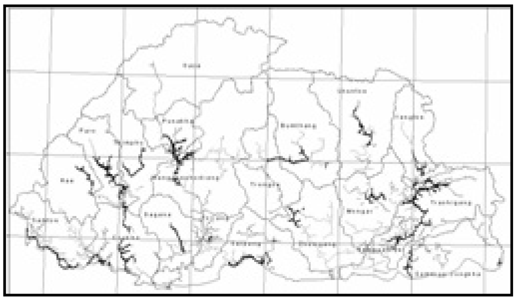


Mapping of each FYP 1 – Addition of phase attributes

Open the line data prepared in Base Case (on/off) with GIS. Set the relation of the data table prepared in Step “13” by feeder name and add feeder attributes to the existing database.

→ Addition of phase information to the line data prepared by Base Case.

15



Mapping of each FYP 2 – Mapping

Using the function of attribute display, prepare the map and data table for each FYP. When data are modified, repeat the work from Step “13” to “15” every time the phase calculation is carried out, and update the data.

If it is needed to prioritize the feeder development using another development priority (other than IRR evaluation), modify Steps “13” to “15” according to the new priority.

13.6 Inspection Items, Criteria and Inspection Methods by Power System Analysis

Distribution system analysis using the power system analysis program called MiPower was carried out in order to technically verify both the distribution line for non-electrified villages and the connected existing distribution lines, which are mapped in GIS.

For conventional distribution system planning previously done in Bhutan, the type and voltage of distribution lines had to be decided without using the power system analysis program. For example, in the case of 33 kV lines with 150 mm^2 aluminum conductors, the maximum length of lines was arbitrarily set to 25 km. In the case of 11 kV lines with 100 mm^2 aluminum conductors, the length of lines was arbitrarily set to 10 km. Now, the most suitable system configuration which minimizes costs can be proposed by doing power system planning utilizing the MiPower power system analysis program.

The following sections, (1) and (2), describe the power system planning inspection items, criteria and inspection methods.

(1) Inspection Item Criteria

Table-13.6.1 shows the inspection items and criteria required for power system analysis.

Table-13.6.1 Inspection Items and Criteria for the Power System Analysis

Inspection Item	Criteria
Voltage at the end of the distribution lines	Within ±5% of reference voltage (Target value)
Power flow of distribution lines	Within the rated capacity of distribution lines

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(2) Inspection Methods

The inspection methods are to collect power system data required for MiPower in terms of line distances, types of conductors, voltage levels, demand, and so on, for the distribution lines. Those are planned in GIS toward non-electrified villages, and then to analyze the power flow. From the results of this analysis, the voltage at the end of distribution lines and power flow of distribution lines planned for non-electrified villages are inspected.

If the voltage at the end of the distribution lines or the power flow is outside standard values, some countermeasures should be considered, depending on the situation. For example, changing the type of conductors, selecting another route, upgrading the voltage, and so on. Then, some feedback should be sent back to the GIS. The power flow analysis and the inspection of the validity of the planning need to be carried out again.

Table-13.6.2 shows the inspection methods used by the power system analysis program.

Table-13.6.2 Inspection Methods by the Power System Analysis Program

Work Sequence	Work Contents
1. Acquiring the data from GIS	Acquire the data[*1,2] for distribution lines which are planned in GIS for non-electrified villages. *1: Detail information of distribution lines Pole numbers, Distance between distribution lines, Type of conductor (Wolf, Dog, Rabbit), Voltage (33 kV or 11 kV), Demand (kVA), Type of load (three-phase or single-phase), Distribution diagram. *2: No need for information of all distribution poles. Acquire the data of branched poles, transformer poles, the poles in locations where the type of
2. Making power system diagrams	Make[*3] power system diagrams using the power system analysis program MiPower, according to the acquired data. *3: Data input method for the single-phase load MiPower can handle a single-phase load in power flow analysis. But, the calculation result cannot be displayed by the diagram. Therefore, for easy management, the data input for the single-phase is assumed to be input data
3. Power system analysis	Conduct power flow analysis using MiPower.
4. Evaluating the result of power system analysis	Evaluate the calculation result of MiPower according to **Table-13.6.1**. If the voltage at the end of distribution lines or power flow is outside standard values, some countermeasures should be considered depending on the situation. For example, changing the type of conductor, selecting another route, upgrading the voltage and so on. Then feed back the result to GIS, and conduct the procedures from Work Sequence 1 again.

Prepared by JICA Study Team

13.7 Methodology for Economic Analysis

13.7.1 Outline of Economic Analysis

In the economic analysis for the master plan study, the economic benefits for electrification are quantified on the basis of consumer surplus. The consumer surplus is defined by the cumulative willing price for the consumer to pay, represented by the integral of the demand curve for power. The benefits or costs of the project in question need to be measured as differences between doing the project and not doing the project, the so-called "With/Without" analysis. Then the derived cost and benefit flows are summed into the net present values to derive an internal rate of return on the investment.

There are three types of rural electrification methods: connection to the grid, an independent grid and a solar home system. While a solar home system simply replaces kerosene lamps with fluorescent lamps that give much brighter lights, full-fledge electrification gives more capacity and options in the use of electricity. A higher output capacity enables the use of TV or radio, and rice cookers. A typical solar home system that provides a limited use of electric appliances bestows a lower level of benefits than grid-based electrification.

13.7.2 With/Without Approach

An alternative to the electrification of most villages in Bhutan is the choice between grid-based or solar home electrification, since 100% electrification by the year 2020 is one of the national goals. The choice of grid connection or solar home system is examined on a feeder basis. The method of choosing between grid and off-grid is explained in 13.4 in greater detail. The mini/micro hydropower method is only possible where there is hydro potential and substantial demand in the vicinity. Therefore the general choice really is between grid connection and a solar home system. In grid connection evaluation, With/Without analysis needs to compare grid connection and the solar home system. One important issue in comparing grid connection to solar home systems is the significant difference in consumer benefit.

In the economic evaluation of the rural electrification program as a whole, With/Without analysis will compare the differences in benefits and costs of post electrification vs. pre-electrification. Electrification would include all the components of grid connection, solar home and mini/micro hydropower systems.

<Project Economic Evaluation>

With	Without
Grid Connection, or	Non-electrified (Kerosene Lamp)
Solar Home System	
Small Hydropower	

13.7.3 Data Collection for Benefit Estimation

The data required to calculate benefits is based on the output expected from the Village Baseline Surveys conducted under the master plan. The estimate of benefits will be based on the data dealing with household energy consumption (comprising kerosene, diesel oil, candles, batteries, LPG, fuel wood, and electricity).

13.7.4 Calculation Method of Economic Benefits

In principle, the estimation of the benefits will be based on an estimate of the household demand curve for energy. The area under the demand curve is the estimated sum of the consumer benefit (**Appendix B-1-1**). In electrified villages the demand for energy was surveyed for grid connection, mini/micro hydropower and solar home systems. In non-electrified villages, converting the brightness of kerosene lamps into the energy required by fluorescent lamps to achieve equal brightness represents the demand for energy.

13.7.5 Calculation of Economic Costs

The basis for the economic cost is the notion of proper market prices after removing the distortions. For traded products, border prices are employed as the economic costs. At present the standard international prices for conductors, poles, and transformers are collected. Non-traded products usually have a large component of labor. domestic resources, or immobile inputs. Therefore the prices for non-traded products differ from country to country. Non-traded products are calculated in local currency (Nu.) while traded products in US dollars. For economic analysis conversion into one currency is necessary. However, there is a known distortion in the foreign exchange market due to trade barriers, such as import duties. A shadow exchange rate is calculated to remove the distortion and to convert the local currency costs into U.S. dollars.

13.8 Economic Benefit Calculation

13.8.1 Economic Benefit of Grid Extension-Overview

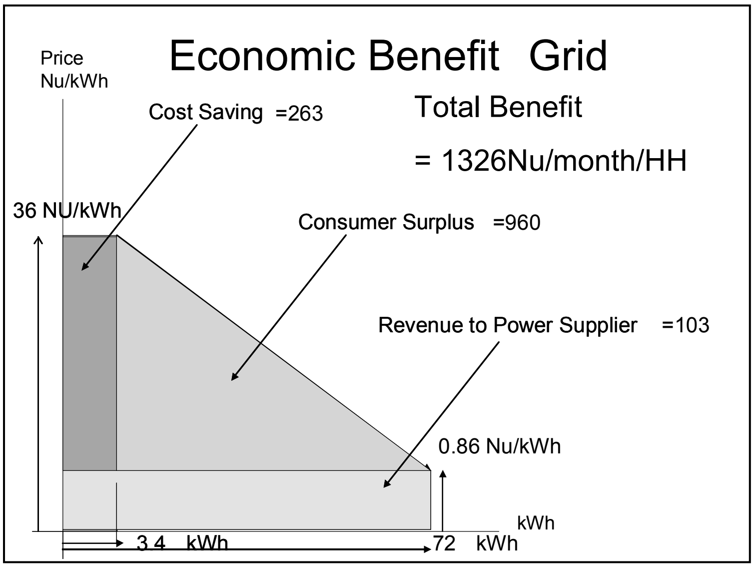
As described in the section for the methodology for the estimation of economic benefits, there are three components in rural electrification projects. Those are 1) consumer surplus, 2) energy cost savings, and 3) revenue to the power distributor.

The overall economic benefits estimate is 1,326 Nu. per month per household based on the current demand levels[4]. **Appendix B-I-1** is for more detailed estimation procedure.

Table-13.8.1 Total Economic Benefit in Grid Extension

	Unit	Grid Benefits
Consumer Surplus	Nu./month	960
Cost Saving including heating	Nu./month	263
Revenue to BPC	Nu./month	103
Total		1,326

Prepared by JICA Study Team



Prepared by JICA Study Team

Figure-13.8.1 Economic Benefits of Grid Extension

Consumer Surplus

The consumer surplus is the triangular area shown above in **Figure-13.8.1**. The consumer surplus by grid extension is measured by comparing two status: pre-electrification and post-electrification. In the pre-electrification status, the principal lighting source used in Bhutan is kerosene lamps. The lumen equivalent kWh value for the average kerosene consumption of 4.7 liter per month per household is translated the lumen equivalent kWh value for the average kerosene consumption of 4.7 liter per month per household is translated to 3.37 kWh/month/HH power consumption and that for dry cell battery is 0.02 kWh/month/HH. Since the average expenditure for kerosene is 51 Nu./month and that for

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[4] For the purpose of economic analyses, the future benefits that increases as the demand increases are estimated by applying the unit benefit per energy consumption unit (kWh) to increased energy consumptions.

dry cell batteries is 71 Nu./month, a total of 122 Nu/month. The payment is tantamount to the price of 36 Nu./kWh. After the grid extension, the estimated power consumption 120 kWh/month per household. The consumption of firewood is estimated to reduce by 238.7 kg, converted to 48 kWh to be substituted by electricity . Thus pure power demand excluding heating is estimated to be 72 kWh/month per household. Taking the current average price of 0.86 Nu./kWh by BPC and after applying convex factor of 0.8, the triangular part, the consumer surplus of 960 Nu./month is derived.

Cost Saving

The cost saving in energy consumption is based on the findings of the Village Survey conducted by the JICA Study Team as described in Chapter 7. The saving is estimated by comparing the energy consumption patterns of non-electrified households and electrified households, as shown in **Table-13.8.2** below. Electrified households are estimated to save 60 Nu./month for dry cell batteries, 33 Nu./month for kerosene, and 172 Nu./month for firewood. The consumption of candles is estimated to increase by 2 Nu./month to allow for the possibly of power outages. However the difference in candle consumption is negligible. The overall energy cost saving per household is estimated to be 263 Nu./month.

Table-13.8.2 Comparison of Household Energy Balance Sheets between Grid-Electrified and Non-Electrified Areas

	Energy Source	Consumption/Month		Expenditure Nu/Month	Price Nu/Unit	kWh/month equivalent	Equivalent Price Nu/kWh
		Unit	Quantity				
Without Project	Dry cell Battery	No.	5.26	70.59	13.41	0.016	4470
	Kerosene	L	4.7	51.2	10.9	3.37	15.2
	Candle	No.	0.6	3.8	6.1	-	-
	Firewood	Kg	626.4	450.6	0.7	125.3	3.6
	Total			576.2		128.7	4.5
With Grid Extension Project	Dry cell Battery	No.	0.78	10.5	13.41	0.0024	4470
	Kerosene	L	1.7	18.5	10.9	1.2	15.2
	Candle	No.	0.9	5.7	6.1	-	-
	Firewood	Kg	387.7	278.9	0.7	77.5	3.6
	Electricity	kWh	120.0	103.2	0.9	120.0	0.9
	Total			416.9		198.8	2.1
Difference Between With/Without	Dry cell Battery	No.	4.48	60.08	13.41	0.013	4470.1
	Kerosene	L	3.0	32.7	10.9	2.2	15.2
	Candle	No.	-0.3	-1.9	6.1	-	-
	Firewood	Kg	238.7	171.7	0.7	47.7	3.6
	Electricity	kWh	-120.0	-103.2	0.9	120.0	-0.9
	Total			159.3		169.9	0.9

Prepared by JICA Study Team

Revenue to BPC

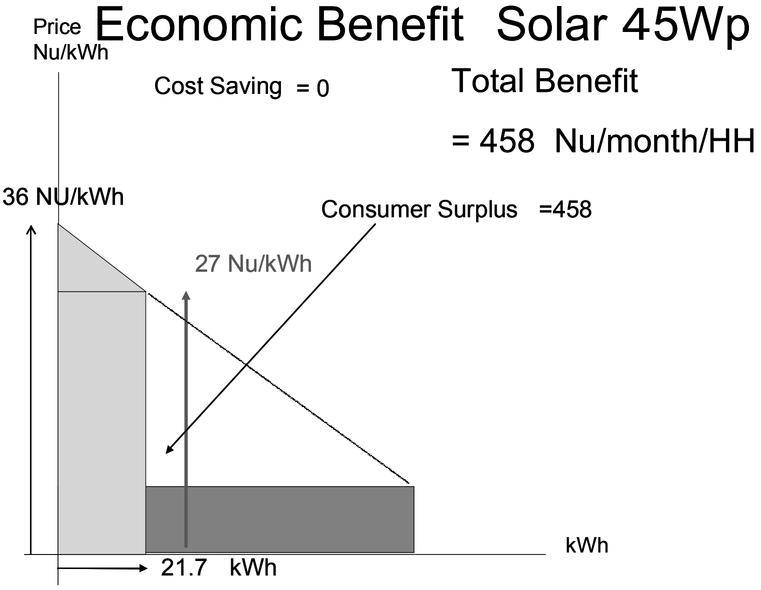
The estimated post-electrification revenue to BPC is 103 Nu./month per household. This was determined by applying the average tariff of 0.89 Nu. to the average monthly electricity consumption of 120 kWh.

13.8.2 Solar Home System

In the case of small scale solar home system of 45 Wp, the benefits are presumed to be limited to the consumer surplus without any substantial energy cost saving and no revenue to BPC[5].

The demand curve for power is assumed to be identical to the one estimated for grid connection[6]. Thus the price that the consumer is willing to pay is determined to fall on the line that connects kerosene energy consumption and grid energy consumption level.

Similarly the energy conversion to kWh is done in terms of lumens since the proposed LED lamps use much less power than standard bulbs or florescent lamps. In terms of lumen equivalence, the kWh value is estimated to be 21.7 kWh worth for the system.



Prepared by JICA Study Team

Figure-13.8.2 Economic Benefits of Small Scale Solar Home System

13.8.3 Difference in Economic Benefits between Alternative Systems

For on/off grid evaluation, the difference of economic benefits is also incorporated as foregone cost not using grid extension. Based on the above economic benefits calculation, the difference between grid extension and small scale solar system is tabulated as below.

Table-13.8.3 Difference in Economic Benefits of on/off-grid

	Benefit (Nu./Month)
Grid Benefit /HH 2003	1,326
Solar Benefit /HH	410
Benefit Difference /HH	916

Prepared by JICA Study Team

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[5] In undertaking an extensive off-grid program, there will be a need for establishing an institution to market, install and maintain individual systems but no firm plan or tariff is examined at this stage.

[6] It might be possible to insert another point between grid and kerosene energy consumption to increase the accuracy of the demand curve estimation. However, there are only few experimental cases of solar home systems in Bhutan yet.

13.9 Cost Data Used for Economic Evaluation and the Analysis

13.9.1 Types and Analysis of Cost

There are three types of costs associated for project evaluation. Those are:

- Investment costs,
- Operation and maintenance costs, and
- Opportunity costs

The cost estimates for investment follows conventional cost estimation by estimating the quantities and unit prices.

The opportunity costs are the costs that may not be accounted for financially but nevertheless it is economic costs such as foregone incomes and loss during transportation. In the case of grid extension to rural areas in Bhutan, such opportunity costs are loss of power export sales to India and also transmission and distribution losses. Before electricity reaches the project areas, the losses on the way are incurred.

13.9.2 Estimation of Grid Investment Quantity

Transformer

Based on the peak demand forecasts of all the non-electrified villages projected over the year 2020, the capacity of requirements for the transformers are established for each village.

Distribution Line Length

The distribution line length is estimated based on the measured route length of each feeder/branch designed over GIS map for each Dzongkhag. However, the route length is not equal to the line length because each node in the GIS map does not represent the actual electric poles. GIS nodes rather represent geographic route feature. In other words, the actual line length will be much longer than the GIS route lengths. The estimated increase that is needed to fill the gap between the map distance and actual distance is assumed 15%.

The conductor sizing, voltage, and phase are determined after evaluating the voltage drop and loss of energy based on the power demand distributions on the GIS maps.

Three Phase

The choice between three phase and single phase at the consumer level is determined by the size of the community. Communities larger than 20 households are given three phase. This general rule is something of convention to derive overall construction cost but not for implementation principle. At the time of implementation, the choice needs to be based on the actual needs regardless of the size of the community.

13.9.3 Estimation of Construction Cost

The BPC provided construction unit price tables for the construction cost estimation for the master plan. The estimate concerning the total construction cost is composed of the costs of materials, labor, transportation, and contingency. The total content is divided by distance into the unit construction costs for each unit construction cost, e.g. Nu./km for each conductor size of 33 kV, 11 kV and LV. The unit construction costs of distribution transformer are classified according to voltage and capacity. The unit construction costs of underground distribution lines are classified by voltage. In the past construction work were estimated by this conventional standard unit prices and then are confirmed by the international bid. The method proves to be sufficiently accurate for the purpose of economic analysis.

The construction items for the master plan are as follows.

(1) Expansion of Equipment for Distribution Substation

- The construction of switchgear equipment and connection between equipment and distribution line for supply to new consumers

(2) Development and Expansion of Distribution Lines

- New construction of 33 kV and 11 kV distribution lines for power supply to new customer.
- Extension from 33 kV and 11 kV existing distribution lines for power supply to new customer.
- Conductor size up-grade of the existing conductors required by distribution line extension from existing distribution line.
- Construction of poles mounted with distribution transformer.
- Construction of section switches.

(3) Unit Construction Cost Table for Distribution Line

The unit construction cost table was prepared with the adoption of the new and existing power distribution material. It was discussed and decided with DOE and BPC referring to the price estimation from manufacturers. **Appendix B-1-2** shows the comparison of material cost of bared conductors (ACSR) and covered conductors (AAAC) from different countries. The unit construction prices of distribution line are shown in **Appendix B-1-2**.

13.9.4 Operation and Maintenance Cost

For the rural electrification project in Bhutan, maintenance and operation costs share a large portion of a total life cycle cost of the project as a whole. Therefore having an accurate estimate is an important work in cost estimation. In operation and maintenance (O&M), the labor cost required for tariff collection and inspection constitutes a large proportion of the operation and maintenance cost. The O&M cost also depends on the spatial distribution of the users. If the users are spread over a large area, it means that the total distance of conductors and poles is greater and the labor requirement for covering the area is larger, regardless of the energy consumption. There is no standard cost such as a percentage ratio of investment in estimating the O&M cost. Rather, it is necessary to reflect the local conditions, i.e., an analysis of region-based cost data. Almost all the Dzongkhag have sales offices, called ESD, or electricity dispatching stations. The next table shows the O&M cost for each ESD of BPC. Comparison of sales revenue and expenditures shows that in most ESD the expenditure exceeds the revenue. The unit expenditure, i.e., the total O&M expenditure divided by the total energy sales shows a range of 0.66-1.69 Nu./kWh with an average of 1.3 Nu./kWh. It is obvious that the O&M cost alone exceeds the tariff.

Table-13.9.1 Operation and Maintenance Cost of BPC Sales Office, July 2002 through December 2003

COMPARISION OF OPERATION & Maintenance Cost (million Nu.)						Energy Sales* (kWh)	kWh cost** (Nu./kWh)
ESD	Operation & Maintenance	Employee cost	OM & Employee	Value of Job	OM & Employee cost as Percentage of Job done	Total	
Bumthang	5.46	5.55	11.00	3.16	348.00	3,209,655	0.66
Dagana	0.55	1.70	2.25	0.75	299.91	554,996	0.90
Gelephu	5.68	6.56	12.24	7.73	158.34	5,515,428	0.93
Punakha	1.43	2.78	4.21	5.73	73.51	4,353,523	0.88
Samdrup	1.59	5.76	7.35	5.40	34.74	4,179,337	0.86
Samtse	1.78	4.39	6.17	73.07	8.45	58,120,812	0.84
Trashiyangtse	1.64	1.89	3.53	1.34	264.13	991,019	0.90
Trashigang	5.79	13.91	19.70	8.76	224.94	7,074,839	0.83
Trongsa	3.06	1.50	4.55	1.55	294.56	716,463	1.44
Tsirang	1.16	1.47	2.62	0.97	269.30	665,691	0.97
Wangdue	2.06	6.51	8.58	7.11	120.60	5,253,355	0.90
Zhemgang	0.76	2.52	3.28	1.91	171.37	961,527	1.33
Haa	0.63	2.98	3.61	5.24	68.90	4,162,224	0.84
Lhuntse	1.19	2.94	4.13	0.89	464.71	739,603	0.80
Mongar	3.05	4.91	7.96	3.06	259.78	2,534,498	0.81
Paro	3.25	7.60	10.86	14.47	74.99	12,017,342	0.80
Pemagatshel	1.44	7.60	4.04	1.90	212.55	1,156,687	1.10
Thimphu	4.30	13.17	17.47	75.92	23.01	29,887,641	1.69
Phuentsholing	6.20	10.33	16.52	480.42	3.44		
CTD-Gelephu	-	8.45	8.45	0.92	923.17		
WTD-Phuentsholing		35.88	35.88	6.61	542.59		
Total	**51.01**	**148.37**	**194.39**	**706.91**	**27.50**	**112,206,998**	**1.30**

Note: * figure for kWh sales is that of year 2002.July -2003 June.
** kWh cost is adjusted for difference in durations between cost and kWh sales.

Source: BPC

Dzongkhags such as Trongsa, Tsirang, and Dagana have an independent grid of mini/micro hydropower and their supply capacity falls short at peak loads. Therefore they run a diesel power generation set at peaks. At such independent grids, the operation costs become much larger due to fuel cost. In Trongsa, the O&M cost is 1.4 Nu./kWh and 0.9 Nu./kWh in Dagana. For some unknown reason, Thimphu has a high cost of 1.69 Nu./kWh.

13.9.5 Estimation of O&M Cost

In order to estimate the operation and maintenance costs for the distribution of power, the Study Team collected data on O&M costs of all the electricity dispatching stations. Then the relationship between the costs and other parameters such as the volume of installed facilities, number of consumers, and sales of energy was analyzed (**Appendix B-I-3**). According to the results of the co-relation analysis, the correlation with energy sales has the lowest value and the highest in the distance of distribution lines. Other variables such as Log (Sales) and Log (Number of Consumers) have an equally high correlation. Judging from the fact that there are high correlations between O&M costs and other variables, a liner equation would have a higher explanatory power. Thus a regression analysis was conducted with different combinations of variables. With an initial combination of all the variables, the R^2 was 0.94. However, the significance level of each coefficient proved to be less than a threshold. Thus finally a more robust linear function of a constant and distance of distribution line extension as shown below was chosen as an estimation formula (**Appendix B-I-4**).

$$\textit{O\&M Costs}\text{ (million Nu.)}$$
$$= 1.557036 + 0.039032 \times \textit{Length of Distribution Lines}\text{ (km)}$$

13.9.6 Economic Cost Conversion

Economic costs differ from financial costs because of the market imperfections such as tax burdens and unemployment. Standard element in such differences are cased by the distortion of foreign exchange markets and labor market. In conducting economic analyses and on/off grid evaluation, the local currency of Nu. is used.

Investment Costs

In deriving economic costs for investment the following conversion factors are employed.

Table-13.9.2 Conversion Factors of Investment

Item	Conversion Factor
Imported Goods	1.1
Unskilled Labor	0.75
Administration	0.85
Transportation	0.9

Note: Economic analysis is conducted in local currency, thus the conversion factor becomes larger than 1.
Prepared by JICA Study Team

O&M Cost

Based on the analysis of the current operation and maintenance cost actually borne by BPC, the marginal short run cost, the unit O&M cost per MV line distance is set at 39,000 Nu./km. The standard conversion factor for O&M cost is set at 0.9

Opportunity Costs

For the identified opportunity costs, the following parameters are adopted.

- Transmission loss: 20%
- Opportunity cost of power supply: 2 Nu./kWh

Since an accurate estimate of transmission and distribution losses are not available at this point, the loss is assumed to be at 20%. The opportunity cost of power consumption for rural consumers is defined as the loss of revenue by selling power to India. The current average revenue per unit is around 1.7 Nu./kWh. The recent adjustment of tariff for Chuka Hydro Power with India has led to an increase to the price of 2 Nu./kWh. When the Tala Hydropower is commissioned, the average revenue is expected to rise very close to 2 Nu./kWh. Taking into account of such future opportunities, the opportunity cost is set at the future price.

13.9.7 Cost for Small Scale Solar System

The investment outlay for the proposed small scale solar system is as follows.

Table-13.9.3 Small Scale Solar System Investment Cost

	No.	Unit	Unit Price (Nu.)	Failure Rate	Overall Cost	Life	Annualization Factor	Annual Cost
PV module	45	Wp	152	15%	7,866	25	0.11	895
LED lamps 2W	5	pieced	1,400	5%	7,350	8	0.18	1,321
Charge Controller	1	10 amp	1,250	15%	1,438	8	0.18	258
Battery	1	50Ah	3,200	25%	4,000	4	0.29	1,176
Total					20,654			3,651

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Animalization is based on 12% annual interest.

Annualization, i.e., the conversion of one-time investment into annual cost flow over the life of the invested equipment is carried out by deriving the annualization factors that considers the discount rate of 12% of the capital shown in the above table[7].

Table-13.9.4 kWh cost for Small Scale Solar System

Item	45 Wp Solar System
Annualized Solar Investment (Nu./Year)	3,651
Solar OM Cost (Nu./Year)	500
Total Financial Cost (Nu./Year)	4,151
Shadow Exchange Rate	1.1
Total Economic Cost (Nu./Year)	4,566

Prepared by JICA Study Team

13.10 Power Sector Policy

There are three focal issues for power sector policies in Bhutan:

1) Contribution to Poverty Reduction
2) Efficient Use of Resources
3) Contribution to Environmental Protection

Poverty reduction is one of the main motives for the promotion of rural electrification, the basis for the master plan. In terms of efficiency, as ADB often points out, Bhutan's power tariff level is one of the lowest in the world, lower than the cost of delivery of power to the consumer. However, these two policy goals often come in conflict with each other. The construction of transmission and distribution lines does not have major negative impacts on the environment when compared to other infrastructure developments. In fact, such activity has the positive impact of reducing the consumption of fuel wood, thereby preserving forests. However, the total length of transmission and distribution lines is quite extensive and

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[7] Annualization factor is calculated as factor that equates the sum of annual cost flow over the life to the investment cost on a net-present value basis. The discount factor employed is 12%.

cumulative impacts on forests can be significant. In addition, the Bhutanese government gives a high priority to environmental conservation.

(1) Social Equity and Electricity Tariff

Since the master plan for the rural electrification targets 100% electrification for households, even difficult areas will not be left without electricity. An option might be any one of several types of electrification, be it connection to the grid, solar home systems, or an independent grid with mini/micro hydropower. In general, network service (such as power supply) has an economy of scale from the demand side in concentrated urban areas where the marginal cost of supply is low. However, the delivery of service becomes more and more expensive as the coverage of the network becomes larger. From an economic viewpoint, the service should be provided up to a point where the marginal cost equals the marginal revenue or benefit.

However, there is an issue that goes beyond simple economic optimization in a management perspective. In an area with minimal access to power, long-term productivity growth may be lower, and local population may dwindle with emigration. Conversely, with a supply of power, the local economy may grow faster and the population may increase. A long-term productivity growth that generates an increase in income for the local population may make it more economically attractive to expand the power supply by increasing the demand and affordability of a higher tariff. In sum, the supply of power offers an option value to the local economy for an unspecified economic upturn. An investment in option value is a necessary condition for long-term economic development where the odds are not predictable.

(2) Poverty Reduction

The general understanding in rural electrification is that electrification is a necessary condition but not sufficient alone for poverty reduction. Together with the expansion of road access and telecommunication, electrification may have a major impact in isolated villages within the mountains. Access to the market stimulates the development of cash crops and handicrafts, or some other forms of business. The possibility for income increase of rural household is expected only when those factors are fulfilled. In 9th FYP the bulk of the development budget is allocated to the development of rural power and roads for their synergy effect.

What the Village Survey revealed was that there was a lack of information, even about existing road networks, not to mention future road construction plans. If information on existing road networks and projected plans were readily available, it would be possible to prioritize the installation of distribution networks to areas where synergy effects could be maximized, as well as reducing the cost of installation of distribution lines utilizing the road networks. Though the survey on road networks in rural areas is definitely outside the scope of the master plan, nevertheless it is an important piece of information.

(3) Revision of the Electricity Tariff

There is an efficiency problem with the current electricity tariff level in Bhutan because the tariff charged for the service is much lower than the cost to deliver the service. The power generated at Chukka Hydropower brings in revenue of 2.0 Nu./kWh and Kurichhu brings 1.75 Nu./kWh to Bhutan. However, the average consumer in Bhutan pays 0.9 Nu./kWh. If the cost of delivery, i.e., transmission and distribution, were added to the generation cost, the cost at the consumer end would be 4Nu./kWh. The recovery gap is 3 Nu./kWh. International donors are pressing for the elimination of this cost recovery gap.

However, a simple revision of the tariff leads to a contradiction with other policy goals. The Poverty Assessment Report shows that the majority of the poor reside in remote rural areas. The Bhutanese government regards supplying power as a means of distributing wealth gained through utilizing the country's abundant hydropower. The policy issue is to find an equilibrium point between the two contradictory policy goals.

(4) Environmental Protection and Rural Electrification

In general the installation of distribution lines does not cause major environmental destruction. A right of way is secured to protect the lines and to secure easements for maintenance. For instance, the right-of-way for 33 kV lines is 6 m on both sides and 4 m when covered conductors are applied for the trees within this width need to be felled. At the same time rural electrification is expected to reduce the consumption of fuel wood, reducing the pressure on forests. Therefore, there are some positive impacts on environment. Bhutan is internationally recognized for its abundant and well-conserved forestry resources. Therefore it is a top issue for its diplomatic policy. The problem is that for every single distribution line project, a full EIA may be required. This requirement adds significant costs to the development process. At the same time, there is no established causal relationship between rural electrification and fuel wood saving or the reduction of forestry resources. A better understanding through scientific research is much needed.

13.11 Possibility and Limitation of Information and Telecommunication Network Development

13.11.1 Possibility of Information and Telecommunication Network Development

Now RGoB is developing the kingdom under the philosophy of "Gross National Happiness" and policy of decentralization. Only some area can be developed and digital-divide will be larger if they don't have communication infrastructure, therefore, in working on the development of infrastructures such as information and telecommunication networks, the Government should make an effort to give citizens opportunities for equal access to the information without letting certain Dzongkhags or Gewogs be improved more than others. Consequently, in designing development plans for information and telecommunication networks in the future, it has to be evaluated not only from the economic aspect but also from the public aspect.

As for the possibility of expansion for information and telecommunication networks, there are 4 alternatives as listed below:

- ➢ Alternative 1 Overhead fiber-optic ground wires (OPGW) are installed to connect the transmission networks with the regular switching center for information and telecommunications. They are connected to the local governments, certain companies and other public facilities by the private fiber-optic circuit.

- Alternative 2 Fiber optics are to be installed to connect the local Gewogs as well as OPGW for the transmission networks, making use of the transmission and distribution lines.
- Alternative 3 Fiber optics are to be distributed throughout the entire network and for the villages in the grid.
- Alternative 4 Fiber optics are to be installed for each household.

Bhutan Telecom targets to finish the expansion of existing telecommunication systems in all the Gewogs by the end of 2007, however, Bhutan Telecom (BT) does not have the plan to substitute fiber optic cables for the telecommunication lines to be expanded at present. BT will apply fiber optic for replacement of existing microwave trunk lines to enhance the reliability and capacity and future replacement of local telecommunication lines to Gewog centers. In the master plan, the Study Team proposes Alternative demands can be expected at Gewog centers.

The following are the demands for information and telecommunication:

- Actual demand

Though actual demand already exists, undeveloped demands are seen in:

1. Telephone communication
2. Internet

- Potential demand - Though it does not exist at this stage, the possible demands are seen in:

3. Distribution of TV/movie programs via internet as an alternative for TV transmission
4. Advanced public services such as remote medical care and education
5. Advanced services by the private sector such as Internet banking/e-commerce

As for 1 and 2, the questionnaire survey was conducted with gewog offices and officials. 3-5 needs to be estimated on the certain assumptions, and regarding 3, interviews have been conducted with the cable television companies that distribute VTR copies of BBS programs.

13.11.2 Optical Fiber Use Demand Survey

Telecommunication Survey

Since there was no established statistical data for the use of telephone and other communication methods by local administrations, the Study Team conducted a brief questionnaire survey with gewog offices and officers. **Table 13.11.1** shows the format of the questionnaire and the results. 200 forms were distributed to each Gewog office and 30 returned the response. In addition, at the time of national assembly, the forms were handed out to the representatives of Gewog's and 96 responses were collected.

Cable TV

Interviews have been finished with nine (9) companies so far. **Table-13.11.1** shows the results. Eight (8) out of the nine (9) companies seem to be interested in fiber optics, however, the amount they are willing to pay is not large.

As for distance education needs, we've interviewed Ministry of Education and teachers in rural area. The Study Team quantified the magnitude of benefit assuming the improvement of quality of education equals to additional one teacher per Gewog.

As for health service needs in rural, the Study Team have interviewed Ministry of Health, JDWNR Hospital, it's the largest general hospital in Bhutan, and BHU (Basic Health Unit) in rural area and we identified the qualitative benefits. The Study Team quantified the magnitude of benefit assuming the travel cost of staffs to get information or knowledge per month equals to the benefit per Gewog. **Table-18.2.1** shows comments and benefits expected from bodies concerned and **Table-18.2.2** shows benefit s and demand expected. The result of quantified benefit is shown in **Chapter 18**.

Table-13.11.1 Telecommunication Demand Survey with Local Administrators

Questionnaire

Outline Currently we are making a plan for rural Internet Communication System combined with power distribution. Please answer the questions below to help us identify the needs for rural telecommunication and the Internet.

			Answers		
			Geog	Gup	Average
Q 1	Do you know the functions of the Internet?	Q1			
	a very well aware of it	a	20%	12%	16%
	b aware of it	b	17%	25%	21%
	c vaguely aware of it	c	33%	28%	31%
	d do not know	d	43%	53%	48%
Q 2	What is the current yearly budget for telecommunication, e.g telephone postage, messengers?				
	Nu. year	Q2	3504	5763	4633
Q 3.	Is telephone available in your office?				
	Yes No	Q3	17%	18%	17%
Q 4	If not available how far do you have to travel to use it? km	Q4	24	20	22
Q5	How often does your office need to use telephone per month?				
	times per month	Q5	7.9	318.	20
Q 6	In your Gweog, how do people communicate over a long distance at the time of emergency?	Q6			
	a goto a nearest place to use STD %	a	53	37	45
	b goto a officer who has a walkie-talkie %	b	12	5	8
	c goto the destination in person %	c	39	58	48
Q 7	How often such emergency occurs for a typical villager?				
	times per year	Q7	-	29	14
Q 8	If a telephone service is available at a gewog centre how much would a villager be willing to pay for it?	Q8	194	99	147
	a 50 Nu				
	b 100 Nu				
	c 150 Nu				
	d 200 Nu				
	e 250 Nu				
	f 300 Nu				
	g 400 Nu				
	h more				
Q 9	What function do you think the Internet would be very useful for?	Q9			
	a electronic mails	a	64%	64%	64%
	b data transfer	b	43%	37%	40%
	C information search on the WEB	c	64%	67%	65%

Prepared by JICA Study Team

Table-13.11.2 Interviews with the Cable Television Companies

No	Name Cable TV	Person Contacted	Interest in receiving Optical Fiber Broadcasting	No. Subscribers	Potential Customer Base	Price willing to Pay to pay in Nu.	Cost of Tape From BBS
1	Sigma Cable Services	Rinzy Dorji	NO	600	1000	Own Dubbing	nil
2	Norling						
3	M/s Barjam Cables	Mr Phuntsho	YES	400	1000	Depends Customer	nil
4	Nidup Cables	Mr Tshering	YES	260	700	15000 per month	3000 (not directly)
5	Nakchung Cable						
6	M/S Cable Sat Club	Sonam W Tobgyel	YES	850	100 or 200 more	not sure	1500 (not directly
7	M/s Tshela Cable Services	Karma Jurmi	YES	900 to 1000	not much Potential	4000	2000 not directly
8	M/s Tobgyel Sat Club	Kalden Jumptsho	YES	150-200	100	5000 to 10,000	2000 to300
9	M/s Khang Rung Cable	Tashi Dendup	YES	300	200	1000	1000

Prepared by JICA Study Team

Proposal for OPGW Expansion Plan

The development of the transmission and distribution networks underlies that of the information and telecommunication networks, therefore, the plan for the transmission and distribution networks affects that of the information and telecommunication networks. Besides, the political intensions of RGoB, which cannot be judged by cost and demand, should be considered. At this moment, the Government (Ministry of Information and Communication) has a concept of having two systems of fiber optics that connect east with west, but neither a specific plan nor policy has been set up.

One of the two systems starts in Simtokha and runs through Gelephu and Tintibi, and there is a development plan for the transmission networks for this route. The other route starts in Thimphu and runs through Trongsa, Bumthang, Mongar and Trashigang, which is along the national road. However, there are currently no plans for the transmission and distribution networks between Bumthang and Mongar where the roadways are blocked due to the landslides every year. Installing one system only is considered reasonable and proper if we consider costs and demands. The existing and planned transmission network was shown in the **Figure-5.2.1.**

Since installation plan of OPGW is planed by BPC and Bhutan Telecom Ltd. as another plan of the master plan, the installation plan is not included in the master plan.

Approaches to the Development Plan for Information and Telecommunication networks by Distribution lines

Fiber optic network on distribution network is expected to be the replacement of rural telecommunication radio network by rural telecommunication project in future. Radio network allows the transmission of only a small amount of information and is easily influenced by geographical and meteorological constraints.

Since life span of radio system installed by rural telecommunication project is around 10 years, installing fiber optic network in the near future might be overlapping investment. However, fiber optic cables can meet future demand and offers stable data communication. Additionally installation cost can be reduced if distribution line and communication line are installed in the same time. Department of Information Technology, Ministry of Information and Communication wants to see early installation of the network.

As previously mentioned, it is proposed that the fiber optics should be installed at least along with the distribution lines to the center of the Gewogs in which the distribution lines are planned to be extended. Economic evaluation of the proposal is done in Chapter 18.

13.12 Analysis of Rural Life Standard

Poverty Alleviation Analysis Methodology

The poverty impact analysis follows the standard method employed by ADB. The purpose of the analysis is to derive the proportion of benefit and cost that are to be born by the poor for the project in question. First, the analysis clarifies the percentage contribution to each sector in the institutional makeup for the project, for each item composing the benefits and costs of a project, and second, the analysis finds out the share of the poor in each sector and derives the ultimate percentage share for the poor. For the detailed methodology, please refer to ADB' reference manual[8].

Poverty reduction is one of the chief goals of the Bhutanese government in its pursuit of Gross National Happiness. In 2000 the Bhutanese government conducted a pilot survey of Household Income and Expenditure Survey (HIES 2000). In 2003 a full scale version of Bhutan Living Standard Survey (BLSS 2003) collected information on housing, employment, health, education, access to public facilities in addition to income and expenditure of the nation.

Although HIES 2000 generated only preliminary estimates for the incomes and expenditures, the survey attempted to set the two levels of poverty thresholds, i.e. lower poverty line (food poverty line) of 612.1 Nu./capita/month and upper poverty line (income poverty line) of 748.1 Nu./capita/month as shown in **Table 13.10.1**. The application of the lower poverty line would classify 29% of the rural population as poor while the upper poverty line would take 41.3% of the population under the threshold.

Table-13.12.1 Poverty Incidence in Bhutan 2000

Item	Lower Poverty Line (Food Poverty Line)	Upper Poverty Line (Income Poverty Line)
Threshold Expenditure	612.1 Nu./capita/month	748.1 Nu./capita/month
Population Poor		
Urban	2.9 %	6.4%
Rural	29%	41.3%
Total	25.3%	36.3%
Poverty Gap	6.6%	11.1%

Source: Dpt of Planning, M of Finance, *Poverty Reduction Strategy Paper*, 2004

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[8] Economics and Development Resource Center
(EDRC) "Handbook for Integrating Poverty Impact Assessment in the Economic Analysis of Projects", ADB, July 2001

The average income level estimated in HIES 2000 is 1,075 Nu./capita/month while that from BLSS 2003 is 1728 Nu./capita/month, showing a sharp upward revision as shown in Table 13.10.2. It does not attempt to define poverty thresholds yet though poverty profile is one of the main objectives of the survey to begin with. Following the logics employed in HIES 2000, it might be a case that the poverty population's proportion may be somewhat curtailed.

Table-13.12.2 Average Expenditure Per Capita by HIES and BLSS

Area	HIES 2000 (Nu./Capita/month)	BLSS 2003 (Nu./Capita/month)
Bhutan	1,075	1,728
Urban	1,945	2,982
Rural	1,075	1,358

Source: RGoB, HIES 2000, draft BLSS 2003 report

According to the Living Standard Survey 2003, the unemployment rates in Bhutan are 6.53% in urban area and 2.32% in rural area.

13.13 Policy of Optional Studies

13.13.1 Option-1 (All On-grid)

Option-1 was designed to assume the case that all villages are connected to the grid. Prior to the on/off evaluation, option-1 shows the total cost and power distribution network if all villages are electrified

13.13.2 Option-2 (Solar for Cooking in Off-grid Villages)

Option-2 was designed on the assumption that all villages are electrified by grid or a solar home system (SHS) that has enough capacity to meet demand predicted by the economic evaluation.

The clearest comparison of on/off grid can be obtained by using the same benefit criteria, like quantity. In the case of on grid power supplies, it includes the demand for cooking. Therefore, a SHS that has enough capacity will be a much bigger one than a SHS that is only required to supply power for lightning.

The purpose of Option-2 is to make the result of on/off evaluation clear if a larger SHS (that has enough capacity to accommodate the cooking demand) is used.

On the basis of the system deign parameters mentioned in **Table-11.3.3** of Chapter 11, Section 11.3.2, the size and cost of the system would be as follows:

PV Optimum Amp (Ipm):	3.0 Amperes and above
PV total capacity:	550 Wp
Number of Modules in Series:	1
Battery Capacity (Deep Cycle):	450 Ah (438 Ah and above at 10 hours rating)
Charge Controller Capacity:	40 Ah (34 Ah and above, 12V DC)
Inverter Capacity (Sine Wave):	1 kW (Out put 220 VAC, 50 Hz)
Total System Cost:	US$4,128

13.13.3 Option-3 (Mini/Micro Hydro Power for Off-grid Villages)

Option-3 utilizes a mini/micro hydro for off-grid power where applicable. The cost of electrification by mini/micro hydro was estimated for Option-3. Economic comparison was curried out between the off-grid electrification by mini/micro hydro and that of grid extension. Outlines of the studied sites selected as mini/micro hydro candidate villages are as follows

(i) Selection and Installed Capacity of Development Site and Target Villages

The candidate mini/micro hydro sites were selected by studying 1/50,000 scale topographic maps in conjunction with the proposed existing site study. The result of peak demand forecasts for villages in 2020 determines the required installed capacities (kW). When the hydro power potential estimated from the topographic condition can not satisfy the demand, the number of target villages to be electrified was reduced. Also, it is noted that long transmission line distance cause the cost increase. This also limited the number of target villages to be electrified.

(ii) Basic Design of Construction Quantity

As for the estimation of construction quantity, the predicted quantity was referred to and the installed capacity was modified to meet the revised demand forecast where past studies had already designed those items. When there were no existing studies for the sites, construction quantity was estimated using 1/50,000 scale topographic maps to determine factors such as such as stream head, length of water ways, access road location, transportation requirements, and the extension of distribution lines. Preliminary design was carried out to determine the scale of facilities by referring the standard design guidelines used in Japan, examples of existing mini/micro hydropower stations in Bhutan, and general specifications used for mini/micro hydro power plants in developing countries.

As for the method of construction and selection of types (see **Table 13.13.1**) of a intake weir, water way, penstock, and turbine, two cases were studied: implementation by a construction company applying international standards; and construction of micro hydro for village level applications with community participation. As for the type of turbine, an appropriate type was selected, based on the head and discharge.

Table-13.13.1 Classification of Project and Facility of Mini/Micro Hydro

Type of Project (Construction)

1	by Constructor
2	Community Participate

Type of Penstock Pipe

1	Steel Pipe
2	PVC Pipe

Type of Intake Weir

1	Concrete Weir
2	Tyrolean
3	Sand-bag

Type of Turbine

1	Cross-Flow (Local made)
2	Pelton (Imported)
3	Turgo Impulse (Imported)
4	Flancis (Imported)
5	Reversed Pump (Imported)
6	Pico-Hydro (Local made)

Type of Headrace Channel

1	Bare Soil/Rock
2	Concrete Open Channel
3	Steel Pipe
4	PVC Pipe

The designed discharge of each power house is determined from the mean value of dry season river flows (January to April) and catchment area at the intake of the candidate site. **Table-13.13.2** shows the specific discharge ($m^3/sec/100km^2$) prepared from the result of dry season discharge measurement carried out by DOE for 75 small rivers located all over the country.

Table-13.13.2 Specific Discharge in the Dry Season by Dzongkhags

No.	Dzongkhag Name	Ave. Specific Discharge ($m^3/s/100km^2$)
1	Thimphu	0.70
2	Chukha	0.85
3	Haa	1.04
4	Paro	*0.87*
5	Samtse	*1.75*
6	Tsirang	0.92
7	Dagana	1.14
8	Punakha	2.01
9	Gasa	*2.01*
10	Wangduephodrang	1.30
11	Bumthang	1.26
12	Sarpang	1.28
13	Zhemgang	1.60
14	Trongsa	1.43
15	Lhuntse	1.63
16	Mongar	1.12
17	Pemagatshel	*1.19*
18	Samdrup Jongkhar	*1.28*
19	Trashigang	1.26
20	Yangtse	1.91

Prepared by JICA Study Team (based on DOE Lean Discharge Obs.Data)

(iii) Construction Cost

Construction costs and material unit costs come from the result of a unit cost study done in October 2004 by the Study Team and the price escalation of the construction unit cost for a mini/micro hydro feasibility study (F/S) done by UNDP/GEF in 2000.

Regarding the transportation cost of construction materials, horses, donkeys, yaks, and manpower were considered in addition to trucks and helicopters. Also, the distances and transportation costs defined by Dzongkhags were reflected in the unit cost. Construction unit costs for transmission lines and low voltage lines were calculated from the grid cost of Option-1 (all villages on-grid) for economic comparison.

A review of the construction cost and unit cost will be needed in future if the master plan is modified, and also for the feasibility study and detailed design phases of the project.

The results of cost estimation and economic analysis of the proposed mini/micro hydro sites compared with grid extension will be described in the next chapter (***Chapter 14***). Basic data and detail evaluation results are attached in **Appendix C-II**.

CHAPTER 14 ANALYSIS OF RURAL ELECTRIFICATION

14.1 Overview of the Rural Electrification Master Plan

14.1.1 Master Plan for the Year 2020

An on/off-grid evaluation program was specifically developed for the master plan. This program determined whether a particular electricity distribution line will be extended (on-grid) or not (off-grid) from a village or tap-off point. The basis of the program is an economic calculation that compares the difference of benefits and costs for grid extension and installing a small scale solar home system.

Out of the 1,716 villages that were analyzed, it was found that grid extension was more economically beneficial than solar for 1,267 villages. The number of households to be connected to the grid was calculated as 39,085 out of a total of 44,218 households that were projected to exist in 2020[1]. The grid connection percentage under this plan is 73.8% in terms of the number of villages and 88.4% in terms of the number of households. On-grid villages will be connected to the grid, where as off-grid villages will be provided with electricity using solar home systems here in this chapter.

Table-14.1.1 shows the evaluation results for on/off-grid connection of villages and households in each Dzongkhag. **Figure-14.1.1** shows a map of the nation-wide distribution lines in Bhutan and the on-grid and off-grid villages defined for the Base Case[2]. The on/off-grid figures for each Dzongkhag are shown in **Appendix C-III-2.**

The total route length of the 11kV and 33 kV medium voltage distribution lines that will be constructed or replaced[3] was determined to be approximately 2,322 km. Covered conductors are to be used in protected areas (PAs)[4] in order to reduce the width of the right-of-way that needs to be cleared. The length of the distribution lines in the protected areas is approximately 286 km, which is equivalent to 12.3% of the total length. The additional cost of incorporating of this environmental protection measure into the master plan is US$0.6 million.

The total on-grid electrification cost is estimated to be US$71.4 million and that for the off-grid electrification is estimated to be US$ 2.54 million. Total investment for the combined on-grid and off-grid electrification is US$73.9 million.

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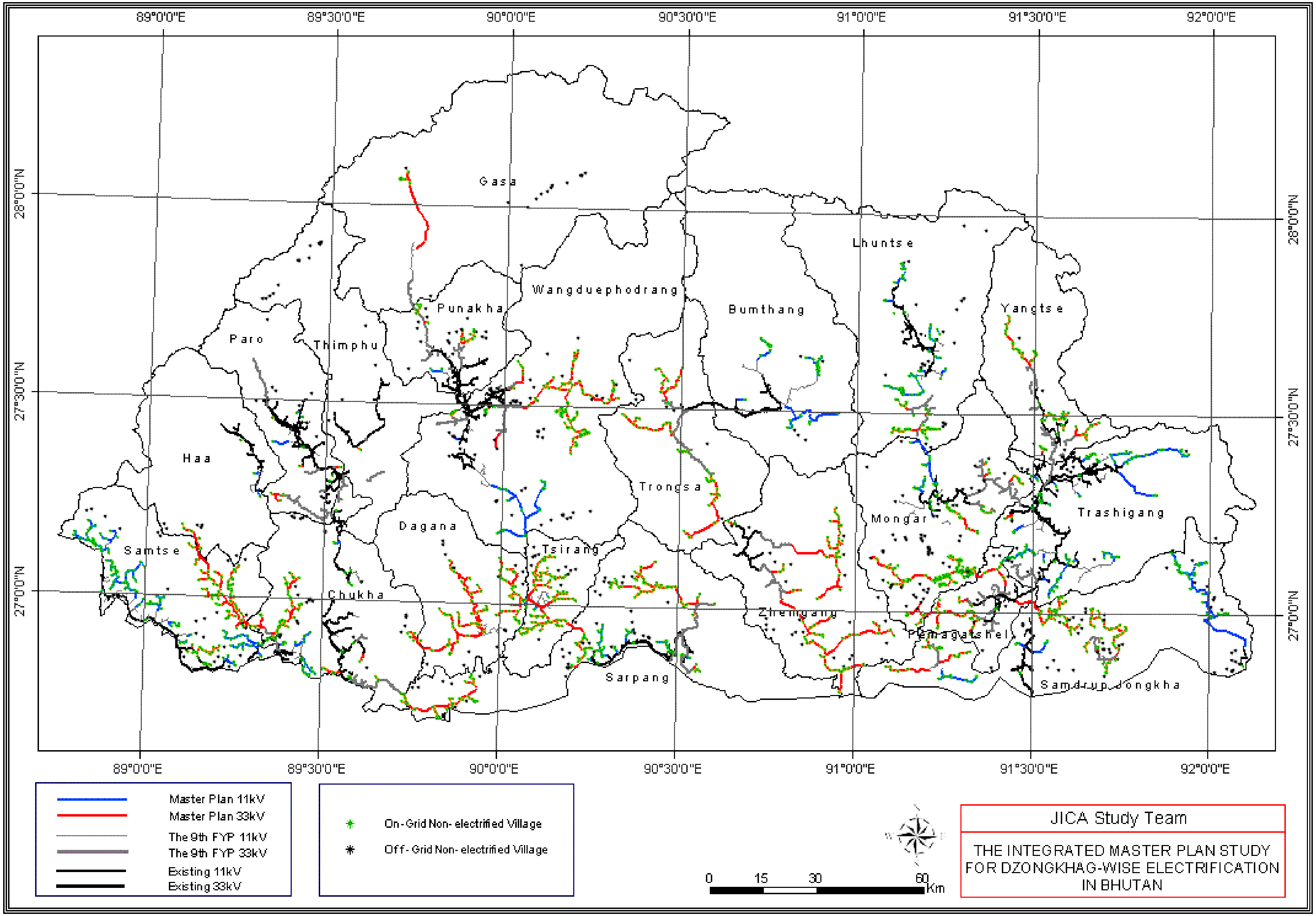
[1] The number of Households currently supplied from existing Dagana small hydro will be 545 forecast for 2020. Due to additional demand, the distribution lines of 6.6 kV from the small hydro is to be upgraded to 33 kV in the master plan lines. Then, the 545 households were assumed to be in one village and evaluated together with the non-electrified villages for the economic calculation. Accordingly, in Dagana, the actual number of non-electrified villages is 64 and the number of on-electrified households is 2,488 forecast for 2020, and similarly in Bhutan, the actual number of non-electrified villages is 1,716, and the number of non-electrified households is 43,673 forecast in 2020. The number of non-electrified households is slightly different from the result of the demand forecast described in Chapter 12, on account that the program automatically rounds off the numbers of households, while demand forecast did not round off the number.

[2] The Base Case is defined in Chapter 13.

[3] Line lengths in Dagana and Samtse include the length of replacement of existing line due to demand increase.

[4] Protected areas are defined in Chapter 9.



Prepared by JICA Study Team

Figure-14.1.1 Distribution Lines and On/off-grid Villages for the Base Case

Table-14.1.1 On/off-grid Villages by Dzongkhag

	Nos of Village			Nos of Household in 2020			Line Distance	Investment of Lines in On/Off-Grid Areas		
Dzongkhag	On-Grid	Off-Grid	TOTAL	On-grid	Off-Grid	TOTAL	On-Grid (m)	On-grid (1000Nu.)	Off-Grid (by Solar) (1000Nu.)	TOTAL (1000Nu.)
Bumthang	30	5	35	653	28	681	64,454	64,605	624	65,229
Chukha	78	30	108	2,312	387	2,699	125,562	153,734	8,626	162,360
Dagana*	65	18	83	3,033	280	3,313	174,711	248,982	6,241	255,223
Gasa	7	14	21	243	233	476	32,039	30,255	5,193	35,448
Haa	10	5	15	302	100	402	24,389	26,472	2,229	28,701
Lhuntse	73	30	103	1,484	368	1,852	87,755	145,632	8,202	153,834
Mongar	126	57	183	3,044	642	3,686	174,019	292,221	14,309	306,530
Paro	11	11	22	142	92	234	17,874	14,182	2,051	16,232
Pemagatshel	26	7	33	595	48	643	55,273	71,311	1,070	72,381
Punakha	17	18	35	219	112	331	27,565	25,023	2,496	27,520
Samdrup Jongkhar	128	49	177	4,335	507	4,842	250,358	377,180	11,300	388,481
Samtse	160	21	181	6,193	348	6,541	300,488	351,573	7,756	359,330
Sarpang	123	39	162	3,791	555	4,346	198,443	258,053	12,370	270,423
Thimphu	1	15	16	16	141	157	1,482	1,604	3,143	4,747
Trashigang	82	23	105	2,471	192	2,663	133,197	219,653	4,279	223,932
TrashiYangtse	51	5	56	1,632	46	1,678	65,265	142,444	1,025	143,469
Trongsa	44	5	49	1,355	49	1,404	95,641	135,827	1,092	136,919
Tsirang	70	16	86	3,488	198	3,686	120,851	238,099	4,413	242,512
Wangduephodrang	102	53	155	1,844	461	2,305	195,975	206,563	10,275	216,838
Zhemgang	64	28	92	1,933	346	2,279	176,493	207,599	7,712	215,311
Total nos	**1,268**	**449**	**1,717**	**39,085**	**5,133**	**44,218**	**2,321,837**	**3,211,010**	**114,407**	**3,325,417**
Ratio (%)	73.8%	26.2%	100.0%	88.4%	11.6%	100.0%	66.0%	96.6%	3.4%	100.0%
in 1000 US$								**$71,356**	**$2,542**	**$73,898**

* Dagana data includes the villages connected with upgraded line from 6.6 to 33 kV, which were counted as one village. The concerned household is 545 in 2020.

Prepared by JICA Study Team

Power flow analysis was carried out for the 2020 master plan system using the MiPower software package. The assumed demands in 2020 and 2025 were used for this analysis. As a result, it was found that some of the on-grid extensions can not be implemented by just extending the existing distribution lines due to unacceptable voltage drops. Accordingly, the required countermeasures were applied as follows:

1) Lauri and Serthig Gewogs in Samdrup Jongkhar

The areas of Lauri and Serthing Gewogs are surrounded by many steep mountains in Samdrup Jongkhar. It is planned to supply electricity from the Kanglung substation in Trashigang via the Khaling power station by 11 kV lines. The master plan lines were designed to cross some mountain areas, and the length of the lines will be more than 60 km from the transmission substation. Because of this, the voltage drop at the on-grid Gewogs was going to be approximately 50% of the nominal voltage (11 kV) according to the results of analysis by MiPower. For this reason, the following countermeasures were studied:

a) Adopting Dog conductors for the trunk lines and installing some voltage regulators.

b) Converting nominal voltage from 11 kV into 33 kV.

c) Supplying power from an Indian transmission substation.

Consequently, it was concluded that countermeasure (c) is the most feasible for on-grid plan because it is not realistic to install heavy voltage regulators in the steep mountainous areas. In this case, the existing Rabbit conductors had to be replaced by Wolf conductors and one voltage regulator will had be installed because the voltage drop would otherwise be more than 50%. Other countermeasures, in addition to these, will be required in 2025 because the predicted voltage will drop 13% lower due to the increased demand.

The high demand in the area will influence the voltage of the line. In the feasibility study stage, it will be necessary to examine countermeasures such as installation of a voltage regulator near the border between India and Bhutan with the measurement of the voltage at the receiving point from India.

As the areas have to import the electricity from India, alternative method of overcoming the problem would be preferred using mini/micro-hydro with a mini-grid to provide electricity to those areas. Possibility of mini/micro hydro schemes is discussed in the later section, 14.2.3.

2) Namgyel Chholing Gewog in Samtse

Namgyel Chholing Gewog in Samtse was planned to be supplied from the Samtse substation. However, the voltage drop at the Gewog was more than 50% in the original design. Therefore, the conductors on the existing trunk lines will have to be changed from Rabbit to Dog or Wolf. In addition, two voltage regulators will need to be installed on the lines. This work will be implemented when required, based on projecting the increase of demands.

3) Hiley Gewog in Sarpang

Areas on the outskirts of Belkhola and Kharpani in Hiley Gewog, Sarpang were designed to be supplied from the Golephu substation in the plan. A voltage regulator was required for the plan in order to compensate for the voltage drop because it will be approximately 15% at the end of the line, unless some countermeasures are applied.

4) Tseza Gewog in Dagana

Since Tseza Gewog in Dagana is to be supplied from the planned Goshi substation. It was necessary to upgrade the capacity of the existing 6.6 kV lines from the Dagana hydro power station. These lines was replaced with 33 kV in the plan. The cost of doing this work has been included in the total electrification cost.

5) Bara and Tendu Gewogs in Samtse

The Bara and Tendu Gewogs in Samtse are designed to be supplied from the Jaldhaka substation in India. Information about the parameters of the Indian power lines and power demands in Indian areas was not available. Therefore, power flow analysis usin

Therefore, power flow analysis using MiPower was performed using the boundary between India and Bhutan as the starting point. According to the results of the analysis, the voltage drop at the end of the line became 11% in 2025. Therefore, some countermeasures have to be taken. For this reason, the design must be examined in the feasibility study stage by taking such conditions into consideration and also measuring the voltage at the receiving point from India.

6) Sakteng Gewog in Trasigang

As the voltage drop at the end of line in the area of Sakteng Gewog in Trasigang was estimated to be approximately 18%, a voltage regulator should be installed according to the increase in demand.

DOE suggested using a 33 kV system instead of an 11 kV system with a voltage regulator. There are technical merits in using a 33 kV system, including power loss reduction. The investment cost of an 11 kV and a 33 kV system was compared, and it was found that an 11 kV system costs 39 million Nu. and a 33 kV system costs 45 million Nu. As an 11 kV system has an investment cost advantage, the master plan proposed using an 11 kV system. However, it is recommended that a thorough examination be conducted from an overall perspective in a feasibility study.

7) Kangpara Gewog in Trasigang

As the voltage drop at the end of line in the area of Kangpara Gewog in Trasigang was estimated to be approximately 15%, a voltage regulator have to be installed for the plan according to the increase in demand.

8) Tading Gewog in Samtse

The voltage drop was expected to be approximately 10% in 2020 in Tading, Samtse. It will drop down further to approximately 12% in 2025. So, some countermeasures may have be considered in the future.

Appendix B-II-1 shows the analysis results for all distribution feeders related to the master plan study. As a result of discussions between the Study Team and counterparts, it was decided to allow voltage drops at the end of distribution lines down to 10 % in the power system analysis.

Appendix B-II-2 shows the power system diagram for each Dzongkhag. This diagram is was prepared in collaboration with the counterparts.

14.1.3 Issues Relevant to Existing Lines and 9th FYP Feeders

With regard to the influence on the existing transmission grid due to distribution load fluctuations, an investigation of the type of loads that will be placed on the distribution system is needed. It is recommended that these investigations be conducted in the detailed design stage of each project.

Bhutan's electricity transmission grid is connected with that of India by 220 kV and 132 kV transmission lines. In future, both grids will be connected by new 400 kV transmission lines. If some faults occur in Bhutan's distribution system, such as distribution line faults, this will have no effect on both Bhutan and Indian grid, considering the scale of the transmission grids of both countries. However, further studies regarding the installation of protective relays for the transmission and distribution lines will be needed in the detailed design stage.

A rough calculation for the influence on transformer capacity of transmission substations by this master plan was conducted. In this calculation, the loading of each transmission transformer was calculated by simply summing up the load of each distribution feeder. Therefore, the diversity factor of each feeder needs to be checked, and a detailed verification of transformer capacities needs be done in the detailed design stage of the study.

From the approximate calculation result, it turns out that there is a possibility that the loadings of four transmission substations may exceed their rated capacities. **Table-14.1.2** shows the result of the rough calculations for these four transmission substations. In particular, it was found that the Dhajay substation in Tsirang Dzongkhag will probably require some countermeasures to be taken, such as adding another transformer. **Appendix B-II-3** shows the rough calculation results for all transmission substations.

Table-14.1.2 Transmission Substations which may Exceed Capacity after addition of the Master Plan Line Extensions

Dzongkhag	Substation	Voltage Ratio	Transformer Capacity (MVA)	Load (MVA)	Ratio (%)	Remarks
Paro	Olathang	66/11	5	5.2	104	Existing S/S
Samtse	Gomtu	66/11	5	5.1	102	Existing S/S
	Samtse	66/11	3	3.3	110	S/S Under Construction
Tsirang	Dhajay	66/33	2.5	7.3	292	Proposed S/S

Source: BPC

14.1.4 Feedback to the Power System Master Plan

(1) PSMP High Voltage Transmission Line Facilities

The Power System Master Plan (PSMP) proposed scales and locations of future high voltage (HV) transmission lines and substation facilities. These will be needed both for exporting energy to India and for delivery of energy to domestic users. Planning for these facilities was done on the basis of results of the examinations of various alternatives. Details of the planned transmission line routes and substation locations will be examined further through site reconnaissance in the implementation design stage. This will require consideration of access conditions, convenience of construction and maintenance, and natural and social environments.

In the PSMP, HV major and trunk transmission line and substation facilities in Bhutan are planned to be completed by 2012,. This would be quite reasonable, based on the demand forecast and other rural electrification studies. New substations planned in the PSMP are listed in **Table-14.1.3** below.

Table-14.1.3 New Substations planned in PSMP

Dzongkhag	Planned Substation	Voltage (kV)	Commission (during)
Bumthang	Jakar (Gorpang)	66/33/11	9th FYP Period
Chukha	Malbase	400/220	9th FYP Period
Dagana	Goshi (Dagapel)	66/33	9th FYP Period
Lhuntse	Tangmachu	132/33	9th FYP Period
Sarpang	Chowabari	132/33	10th FYP Period
Sarpang	Sarpang	400/132/66	10th FYP Period
Thimphu	Jemina	66/33	9th FYP Period
Thimphu	Pangrizampa	66/33	9th FYP Period
Thimphu	Motithang	66/33	9th FYP Period
Trongsa	Trongsa	33/11	9th FYP Period
Trongsa	Mangdechhu	132/33	9th FYP Period
Tsirang	Dhajay (Damphu)	220/66	10th FYP Period

Source: DOE and BPC

A 400 kV transmission line from Punatsangchhu-I power station to Indian grid will be constructed in 2012 via a new substation (400/132/33 kV) around Sarpang. Then, interconnection of the eastern and western power systems is to be formed at the Sarpang substation by 132 kV transmission line. Although transmission capaciy of the line is limited (thermal capacity of approximately 80 MW), power supply to the eastern system is secured. With the reason that interconnection of both power systems of Bhutan is formed at present through Indian Grid, PSMP suggests that further interconnecion will not be needed. While, DOE has several alternative plans of additional internal interconnection line beween both system. If the plan would be materialized, reliability of the Bhuan’s power system will further increase.

(2) Effects on the Distribution System of the HV System in the Master Plan

Effect of load fluctuation in distribution networks to a transmission grid depends on types of loads concerned in the distribution network. Therefore in detailed design stage of the network it is necessary to analyse the effect of faults and/or voltage fluctuaion in the distribution network for various cases, and to achieve a careful study on protective devices to be provided both for the distribution network and transmission line sides.

Bhutan’s power system is connected with the India’s huge scale power system through 132 kV and 220 kV systems at present, and it will be connected through a 400 kV system in a few years time. Accordingly, it is anticipated that load fluctuations and faults which occur in Bhutan’s distribution network will not cause any serious trouble in either the Bhutan or Indian power systems.

(3) Supply of Power to New Loads of Industrial Estates

It may seem that the PSMP is negative to consider the power supply related to new and additional loads of industrial estates. However, this is due to vagueness of implementation programs for the estates.

The Study Team's demand forecasts modeled two cases: a high growth scenario, with 100 % implementation of the approved estate development program, and a medium growth scenario, with 70 % probability that development of each estate may occur 5 years later than the approved schedules. Against the case, DOE plans an alternative of energy supply the estate by a new transmission line from Tsirang Dzongkhag. In any case power to those factories will be supplied from the nearest MV or HV subsation by an exclusive feeder.

14.1.5 On-grid Extension Priority

The national goal is to supply electricity to all by 2020, In order to achieve this goal, a phase development program is required. Which of the currently non-electrified villages are to be electrified in 10th FYP (2007-2012), 11th FYP (2012-2017), and 12 FYP (2017-2020) needs to be determined. The following criteria were considered when undertaking the evaluation of village electrification priority:

a) Economic evaluation
b) Target village road access
c) Village contribution and willingness (reference study)

a) Priority based on Economic Evaluation

Priority based on economic evaluation was prepared for each power line feeder. Technically, it is also possible to do the evaluation for each non-electrified village. However, the figure for the independent village-wise evaluation would be isolated from the actual figure of the overall economic evaluation, since the network-based connection is inseparable from the economic evaluation. Thus, feeder-wise prioritization was applied, as it has the consistency with the overall figure. The results of the evaluation are presented in the Chapter 15.

b) Priority based on Existing and Planned Road

The closer a village is to a road, the easier it is to construct the power line and the lower the cost expected for transportation of equipment and construction. Road access greatly contributes to the economic development of villages, and this is enhanced when electric power is supplied there too. Accordingly, the selection of high priority areas was based on the location of existing roads and planned road construction information. The selected Gewogs are listed as in **Table-14.1.3 b**elow.

Table-14.1.4 Priority Areas by Road

Dzongkhag	Areas
Samtse	a) Chargarey and Jhatey in Tendu Gewog
Tsirang	a) Areas from Kapasing in Tsirangtoe Gewog to PatalaTharey in Patala Gewog b) Areas from Khorsary to Lhamoilum in Dunglegang Gewog c) Areas from Beteni Gewog in Tsirang to Hiley Gewog and Senge Gewog in Sarpang supplying from Dhajay substation
Wangduephodrang	**a) Areas connecting Whalka in Bjnea Gewog, Rachowa in Nyisho Gewog, Nobding and Tabeding in Dangchu Gewog, and Taphu and Chimulo in Phobji Gewog** b) Jetshokha in Daga Gewog
Bumthang	a) Areas from Sarmith to Tandingang in Tang Gewog **b) Areas on the outskirts of Tangshibi in Ura Gewog**
Trongsa	a) Areas from Lower Tashi to Umdong in Tangsibji Gewog b) Areas from Thrisar to Pangzor in Langthil Gewog
Mongar	a) Areas on the outskirts of Takhambi in Tsakaling Gewog b) Areas from Dukulung to Upper Yakpogang in Mongar Gewog
Samdrup Jongkhar	a) Areas from Dungphu Goenpa to Dechhenling in Dechhenling Gewog

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The above data are illustrated in **Appendix B-IV-1**. As a result, many of these areas were included in the priority feeders evaluated by economic calculation. Two areas, indicated by **bold characters** in **Table-14.1.3**, were identified for construction with the feeders for 11th FYP, based on economic evaluation. However, these areas were expedited to be constructed in 10th FYP due to road prioritization.

c) Village contribution and willingness (reference study)

The evaluation criteia, "Village development priority sector and willingness of electrification contribution", that was once proposed, was here evaluated just for reference as explained in Chapter 13.2. This priority was spatially examined by using GIS separately for five stages by 20% in order by the numbers of village by ranking of the contribution level based on village contribution and willingness survey result. The result is shown with the figure of location of and willingness index of villages in **Appendix B–IV-2**.

14.2 Optional Studies

14.2.1 Option-1 (All On-Grid)

Option-1, the electrification of non-electrified villages by all on-grid connection, was studied to compare the cost with Base Case, and other options. The cost and features for Option-1 are summarized in **Table-14.2.1** below. The total electrification investment was calculated to be US$91.4 million when all households are connected by on-grid extension. While the off-grid investment in Base Case was US$2.54 million, it becomes US$20 million in Option-1. The difference of US$17.4 million is the cost saved by on/off-grid separation in Base Case.

Figure-14.2.1 below shows the national grid extension map for Option-1.

Table-14.2.1 Household, Village, Distance, and Cost for Option-1 (All On-grid)

Dzongkhag	Nos of Village	Nos of Household in 2020	Line Distance in On/Off-Grid Areas			Investment of Lines in On/Off-Grid Areas		
			On-Grid in Base Case (m)	Off-Grid in Base Case (m)	TOTAL (m)	On-grid in Base case (1000Nu.)	Off-Grid in Base Case (1000Nu.)	TOTAL (1000Nu.)
Bumthang	35	681	64,454	9,607	74,061	64,605	6,245	70,850
Chukha	108	2,699	125,562	63,017	188,579	153,734	46,799	200,533
Dagana*	83	3,313	174,711	55,601	230,312	248,982	47,218	296,199
Gasa	21	476	32,039	95,884	127,923	30,255	62,971	93,225
Haa	15	402	24,389	13,201	37,590	26,472	11,272	37,744
Lhuntse	103	1,852	87,755	88,012	175,767	145,632	81,160	226,792
Mongar	183	3,686	174,019	138,509	312,528	292,221	124,957	417,178
Paro	22	234	17,874	40,360	58,234	14,182	23,940	38,122
Pemagatshel	33	643	55,273	16,505	71,778	71,311	12,859	84,170
Punakha	35	331	27,565	40,935	68,501	25,023	28,097	53,120
Samdrup Jongkhar	177	4,842	250,358	98,723	348,942	377,180	79,001	456,181
Samtse	181	6,541	300,488	62,601	354,232	351,573	37,056	388,629
Sarpang	162	4,346	198,443	96,969	295,412	258,053	61,957	320,010
Thimphu	16	157	1,482	64,701	66,183	1,604	40,329	41,933
Trashigang	105	2,663	133,197	46,416	179,613	219,653	37,388	257,040
TrashiYangtse	56	1,678	65,265	9,848	75,113	142,444	9,571	152,014
Trongsa	49	1,404	95,641	9,455	105,096	135,827	8,410	144,237
Tsirang	86	3,686	120,851	36,508	157,359	238,099	29,186	267,285
Wangduephodrang	155	2,305	195,975	125,208	321,183	206,563	88,723	295,285
Zhemgang	92	2,279	176,493	82,981	259,475	207,599	63,914	271,513
Total nos	1717	44,218	2,321,837	1,195,040	3,507,880	3,211,010	901,052	4,112,063
Ratio (%)	100.0%	100.0%	66.2%	34.1%	100.0%	78.1%	21.9%	100.0%
in 1000 US$						$71,356	$20,023	**$91,379**

* Dagana data includes the villages connected with upgraded line from 6.6 to 33 kV, which were counted as one village. The concerned household is 545 in 2020.

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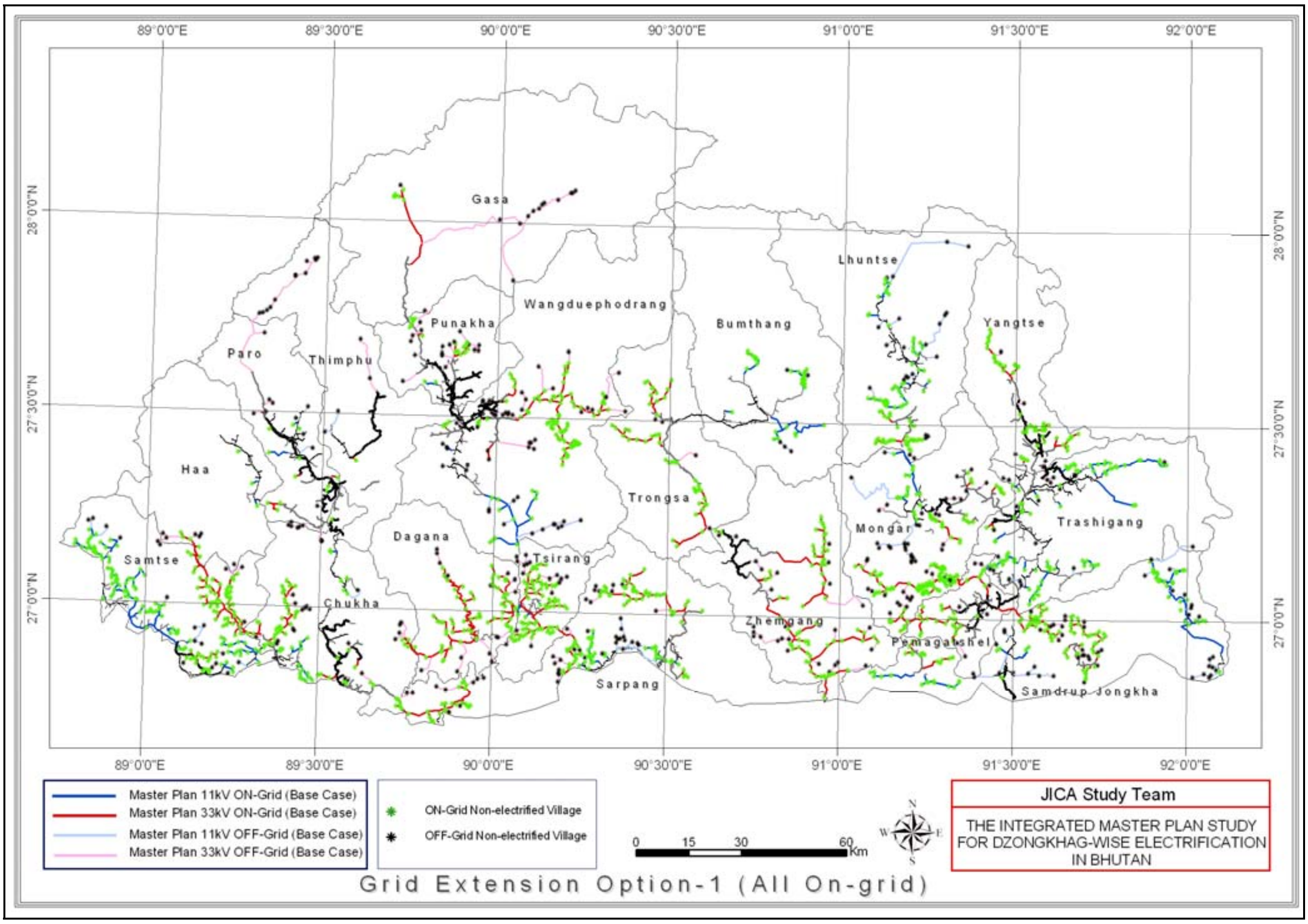

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Figure-14.2.1 Option-1 Grid Extension (All On-grid)

14.2.2 Option-2 (Large Scale SHS, including Cooking Heat Supply)

A large scale solar home system (SHS) with the capacity of 550 Wp solar panels was defined for Option-2. This system is capable of providing power to meet the needs of both lighting and cooking. Option-2 is examined in order to compare the grid and a PV system which provides almost grid-equivalent level of utility. However, there are still some limitations in the use of electrical appliances. However, the cost of such a large scale solar home system is also quite high as there is not much economy of scale in solar home systems.

The results of the Option-2 study are shown in **Table-14.2.2** below. In terms of household connection, 99.1% of households, i.e. 43,803, out of 44,218 would find grid connection more beneficial than having a large solar home system. Provision of a large solar home system was evaluated to be feasible for only 82 villages, with 415 households. The investment cost of Option-2 is US$88.1 million, which is US$3.3 million lower than Option-1 of the all on-grid.

Table-14.2.2 Household Grid Connection with Option-2 of Large Scale SHS

	Nos of Village			Nos of Household in 2020			Line Distance	Investment		
Dzongkhag	On-Grid	Off-Grid	TOTAL	On-grid	Off-Grid	TOTAL	On-Grid (m)	On-grid (1000Nu.)	Off-grid by Solar	TOTAL (1000Nu.)
Bumthang	34	1	35	678	3	681	71,368	69,674	637	70,311
Chukha	107	1	108	2,692	7	2,699	188,215	200,343	1,486	201,828
Dagana	78	5	83	3,239	74	3,313	202,418	276,011	15,706	291,717
Gasa	19	2	21	462	14	476	98,624	78,166	2,971	81,138
Haa	15	0	15	402	0	402	37,590	37,859	0	37,859
Lhuntse	97	6	103	1,787	65	1,852	125,404	189,092	13,796	202,889
Mongar	173	10	183	3,643	43	3,686	291,680	403,289	9,127	412,415
Paro	18	4	22	230	4	234	53,937	36,134	849	36,983
Pemagatshel	30	3	33	631	12	643	63,695	78,595	2,547	81,142
Punakha	27	8	35	312	19	331	46,335	39,914	4,033	43,947
Samdrup Jongkhar	171	6	177	4,811	31	4,842	329,227	406,896	6,580	413,476
Samtse	181	0	181	6,541	0	6,541	352,060	382,688	0	382,688
Sarpang	160	2	162	4,336	10	4,346	288,655	316,964	2,122	319,086
Thimphu	13	3	16	146	11	157	44,894	31,731	2,335	34,065
Trashigang	98	7	105	2,624	39	2,663	155,614	234,676	8,278	242,954
TrashiYangtse	55	1	56	1,677	1	1,678	73,360	150,734	212	150,946
Trongsa	49	0	49	1,404	0	1,404	105,096	144,900	0	144,900
Tsirang	84	2	86	3,670	16	3,686	150,953	263,215	3,396	266,611
Wangduephodrang	139	16	155	2,259	46	2,305	280,186	271,161	9,763	280,924
Zhemgang	87	5	92	2,259	20	2,279	243,674	262,239	4,245	266,484
Total nos	1635	82	1717	43,803	415	44,218	3,202,985	3,874,281	88,083	3,962,363
Ratio (%)	95.2%	4.8%	100.0%	99.1%	0.9%	100.0%	91.3%	97.8%	2.2%	100.0%
in 1000 US$								$86,095	$1,957	**$88,053**

Dagana does not include existing villages connected to the upgraded line from 6.6 to 33 kV

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14.2.3 Option-3 (Micro-Hydropower)

Desktop studies for 39 potential mini/micro-hydro (MHP) schemes were carried out for the Option-3 of off-grid electrification plan. The locations of the studied MHP sites are shown in **Figure-14.2.2** below. Economic evaluation and comparison with on-grid electrification was also conducted.

The results of the desk top studies for the 39 sites in both 28 off-grid and on-grid areas in the Base Case are listed in **Table 14.2.3** below. Alternative site studies within the same target areas were included for these MHP schemes. The results of these alternative studies are also included in **Table 14.2.3** below. The following paragraphs summarize the results of the economic comparison between the plans for the MHP sites and the grid extension plan.

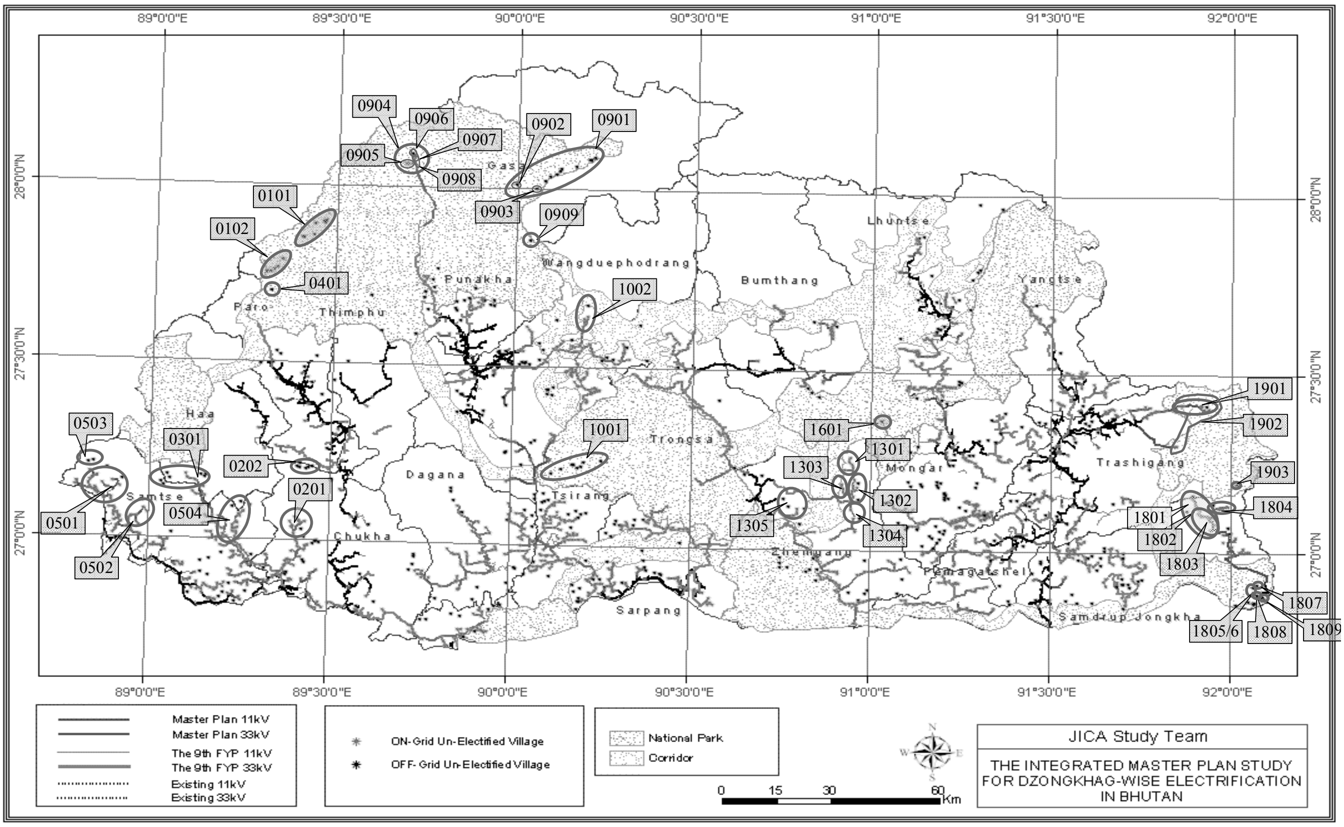

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Figure 14.2.2 Location of Desktop Study Sites of Off-Grid MHP (Option-3)

The results of economic evaluation of benefit-costs (B-C) for the year 2020 show that 5 MHP schemes were evaluated as being more economically feasible than on-grid electrification. These MHP schemes are: i) Lingshi (Thimphu), ii) Jangothang (Thimphu), iii) Laya (Gasa), iv) Sengor (Mongar) and v) Khelphu (Trashigang)

The cost of distribution lines (MV, LV) and the benefit in the target area have the same value for the MHP scheme and comparative grid extension plan. Consequently, if the cost of the power plant is higher than the cost of MV grid extension for the subject area, it is clear that the MHP scheme is not economical when compared to grid extension. Only sites that are far from an existing grid, or far from a grid scheduled for construction in 9th FYP, become comparative candidates for MHP when compared to grid extension.

Furthermore, almost the entire power source in the national grid in Bhutan is provided by large hydropower systems, which makes the cost feasibility of mini/micro hydropower comparatively lower than that of other countries that have alternative energy for thermal power.

Among above 5 economically feasible schemes, the Sengor MHP project is to be started in 2005 with UNDP/GEF funding support. For the other 4 schemes, and some additional sites where grid extension is technically difficult or the supply power from Indian grid is not reliable (such as Shingkhar-Lauri in Samdrup Jongkhar Dzongkhag), further detailed survey and feasibility studies are recommended.

In this study, most of the proposed MHP sites were examined at the desktop study level by using 1/50,000 scale topographic maps. Therefore, more detailed field survey (such as topographic surveys, geological investigations, etc.) and a hydrological survey (installation of stream gauges, discharge measurement and rainfall observation, etc.) will be required for the priority sites. Updating the unit price of construction and equipment will also be required.

Due to the high power demand growth in Bhutan, most of the existing MHP sites are faced with power supply shortages. Therefore, the power demand forecast for the off-grid MHP planning must be conducted carefully. The design and planning should consider the ease of increasing the capacity in the future. This is essential for power demand augmentation.

Operation and maintenance is important for the sustainability of micro-hydropower systems. Institutional strengthening and capacity building, as proposed in the master plan, is required. It is desirable that village people, supported by DOE/BPC/NGOs, undertake the operation and maintenance of micro-hydropower sites. For easy implementation of this, the community participation in the planning and construction stage is also required.

Details of the desktop study results for the proposed MHP sites are attached in **Appendix C-II**.

Table-14.2.3 Comparison of Identified Micro Hydropower Schemes (Option-3) with Grid Extension by Economic Analysis

Micro Hydro Power Scheme																	Grid Extension (for Comparison)								Comparison
Sch. No.	Area No.	Dzongkhag	MHP ID	Name of MHP	Installed Capacity (kW)	Projected Total HH (2020) (HH)	Total Investment Cost (MHP) (US$)	Unit Cost US$/kW (US$/kW)	Unit Cost US$/HH (US$/HH)	Annualized Investment Cost (MHP) (US$/year)	Annual O&M Cost (MHP) (US$/year)	Annual Economic Benefit (2020) (US$/year)	Annualized B-C (2020) (US$/year)	(B-C)/HH (2020) (US$/yr/HH)	EIRR for 30 years (MHP) (%)	Rank by EIRR w/o Alt.	Project-ed Total HH (2020) (HH)	Total Investment Cost (Grid) (US$)	Unit Cost US$/HH (US$/HH)	Annualized Investment Cost (Grid) (US$/year)	Annual O&M Cost (Grid) (US$/year)	Annual Economic Benefit (2020) (US$/year)	Annualized B-C (2020) (US$/year)	(B-C)/HH (2020) (US$/yr/HH)	MHP vs. Grid by (B-C)/HH
1	1	Thimphu	0101	Lingzhi (Nogang Chu)	160	87	784,000	4,900	9,047	94,000	12,000	76,006	-29,994	-346	6.0%	14	135	637,744	4,716	98,000	58,000	109,000	-47,000	-348	MHP
2	2	Thimphu	0102	Jangothang	60	32	311,000	5,183	9,571	38,000	6,000	26,698	-17,302	-532	3.6%	17	49	272,902	5,618	51,000	23,000	33,000	-41,000	-844	MHP
3	3	Chukha	0201	Metapkha	530	395	2,002,000	3,777	5,070	224,000	36,000	249,847	-10,153	-26	9.0%	5	395	594,572	1,506	75,000	72,000	250,000	103,000	261	GRID
4	4	Chukha	0202	Papali	80	55	459,000	5,738	8,294	51,000	8,000	24,489	-34,511	-624	0.6%	20	55	150,438	2,718	17,000	13,000	24,000	-6,000	-108	GRID
5	5	Haa	0301	Sangbay	460	369	2,213,000	4,811	5,998	247,000	38,000	188,381	-96,619	-262	5.7%	15	369	667,031	1,808	94,000	64,000	188,000	30,000	81	GRID
6	6	Paro	0401	Yaksa	26	16	370,000	14,231	23,009	45,000	8,000	6,669	-46,331	-2,881	Error	X	32	120,327	3,741	54,000	9,000	13,000	-50,000	-1,555	GRID
7	7	Samtse	0501	Upper Tendu	1,120	943	3,376,000	3,014	3,578	379,000	65,000	518,156	74,156	79	10.4%	4	943	979,056	1,038	119,000	141,000	518,000	258,000	273	GRID
8	8	Samtse	0502	Majuwa (Namgyeltchholing)	230	212	931,000	4,048	4,384	105,000	17,000	87,945	-34,055	-160	5.4%	16	212	258,040	1,215	30,000	29,390	87,945	28,555	134	GRID
9	9	Samtse	0503	Chingu (Bara upper)	70	76	260,000	3,714	3,428	33,000	6,000	31,260	-7,740	-102	7.3%	10	112	116,169	1,035	19,000	13,000	46,000	14,000	125	GRID
10	10	Samtse	0504	Denchhukha	1,140	997	4,385,000	3,846	4,400	490,000	77,000	526,333	-40,667	-41	8.3%	8	997	1,388,390	1,393	174,000	156,000	526,000	196,000	197	GRID
11	11	Gasa	0901	Lunana (all)	270	191	1,587,000	5,878	8,317	178,000	25,000	117,844	-85,156	-446	3.5%	18	205	992,493	4,835	118,000	80,000	124,000	-74,000	-360	GRID
12		Gasa	0902	Lunana [Alt-1] (Wache)	20	14	156,000	7,800	10,791	20,000	3,000	5,835	-17,165	-1,187	-5.7%		205	992,493	4,835	118,000	80,000	124,000	-74,000	-360	GRID
13		Gasa	0903	Lunana [Alt-2] (Thega)	20	14	151,000	7,550	10,446	19,000	2,000	5,835	-15,165	-1,049	-3.1%		205	992,493	4,835	118,000	80,000	124,000	-74,000	-360	GRID
14	12	Gasa	0904	Laya (Oneme Tsa)	350	259	976,000	2,789	3,772	118,000	21,000	170,069	31,069	120	12.0%	1	259	584,088	2,257	80,000	58,000	170,000	32,000	124	GRID
15		Gasa	0905	Laya [Alt-1] (Oneme Tsa)	250	191	672,000	2,688	3,522	82,000	14,000	127,845	31,845	167	13.2%		259	584,088	2,257	80,000	58,000	170,000	32,000	124	MHP
16		Gasa	0906	Laya [Alt-2] (Geza)	22	16	146,000	6,636	9,182	18,000	2,000	6,669	-13,331	-838	-1.9%		259	584,088	2,257	80,000	58,000	170,000	32,000	124	GRID
17		Gasa	0907	Laya [Alt-3] (Lung-go)	60	40	283,000	4,717	6,992	35,000	4,000	27,522	-11,478	-284	5.6%		259	584,088	2,257	80,000	58,000	170,000	32,000	124	GRID
18		Gasa	0908	Laya [Alt-4] (Samchuchengi Chu)	100	68	387,000	3,870	5,696	47,000	8,000	42,223	-12,777	-188	6.3%		259	584,088	2,257	80,000	58,000	170,000	32,000	124	GRID
19	13	Gasa	0909	Uesuna (Isuna)	12	7	192,000	16,000	26,564	23,000	4,000	2,918	-24,082	-3,332	Error	X	213	1,249,052	5,878	147,000	100,000	127,000	-120,000	-565	GRID
20	14	Wangduephodrang	1001	Phari Chu	120	77	891,000	7,425	11,599	99,000	14,000	36,474	-76,526	-996	-1.7%	22	77	358,894	4,672	41,000	31,000	36,000	-36,000	-469	GRID
21	15	Wangduephodrang	1002	Tara	290	152	1,227,000	4,231	8,057	137,000	16,000	141,929	-11,071	-73	7.2%	11	152	357,942	2,350	41,000	42,000	142,000	59,000	387	GRID
22	16	Zhemgang	1301	Zhemgang Shingkhar	510	330	1,694,000	3,322	5,131	189,000	27,000	286,570	70,570	214	11.2%	2	674	1,440,436	2,136	170,000	159,000	548,000	219,000	325	GRID
23	17	Zhemgang	1302	Khomshar	370	255	1,588,000	4,292	6,237	178,000	22,000	179,904	-20,096	-79	7.4%	9	393	980,951	2,495	114,000	94,000	285,000	77,000	196	GRID
24	18	Zhemgang	1303	Nimshong (Nimjong)	150	85	467,000	3,113	5,472	58,000	10,000	75,051	7,051	83	11.2%	3	214	622,176	2,907	71,000	60,000	173,000	42,000	196	GRID
25	19	Zhemgang	1304	Phulabi	75	39	282,000	3,760	7,199	36,000	6,000	21,053	-20,947	-535	2.3%	19	243	745,717	3,063	85,000	70,000	194,000	39,000	160	GRID
26	20	Zhemgang	1305	Nyakhar	190	98	698,000	3,674	7,127	86,000	14,000	73,279	-26,721	-273	6.1%	13	227	521,275	2,300	59,000	54,000	171,000	58,000	256	GRID
27	21	Mongar	1601	Sengor	90	68	474,000	5,267	6,986	53,000	6,000	63,112	4,112	61	8.7%	7	68	522,397	7,699	58,000	42,000	63,000	-37,000	-545	MHP UNDP/GEF Pjt.
28	22	Samdrup Jongkhar	1801	Shingkhar-Lauri (All)	910	729	4,408,000	4,844	6,048	488,000	55,000	425,120	-117,880	-162	6.9%	12	729	1,155,047	1,585	217,000	117,000	425,000	91,000	125	GRID
29		Samdrup Jongkhar	1802	Shingkhar - Lauri [Alt-1]	540	421	2,325,000	4,306	5,518	258,000	31,000	221,373	-67,627	-161	7.1%		421	652,990	1,550	152,000	61,000	221,000	8,000	19	GRID
30		Samdrup Jongkhar	1803	Lauri [Alt-2]	720	569	3,052,000	4,239	5,365	339,000	39,000	348,420	-29,580	-52	8.6%		569	833,911	1,466	180,000	91,000	348,000	77,000	135	GRID
31		Samdrup Jongkhar	1804	Zangthi [Alt-3]	360	283	2,221,000	6,169	7,846	246,000	23,000	193,327	-75,673	-267	5.5%		295	534,121	1,809	145,000	53,000	198,000	0	0	GRID
32	23	Samdrup Jongkhar	1805	Leishing Ri U/S	42	24	294,000	7,000	12,059	38,000	4,000	12,819	-29,181	-1,197	-1.6%	21	47	156,263	3,296	18,000	11,000	22,000	-7,000	-148	GRID
33		Samdrup Jongkhar	1806	Leishing Ri [Alt-1]	16	11	168,000	10,500	15,505	22,000	3,000	4,585	-20,415	-1,884	-9.3%		34	100,449	2,967	11,000	7,000	14,000	-4,000	-118	GRID
34	24	Samdrup Jongkhar	1807	Chhukarpo Ri D/S (Daldalay)	16	12	137,000	8,563	11,239	18,000	2,000	5,002	-14,998	-1,230	-4.3%	25	60	187,315	3,143	21,000	13,000	27,000	-7,000	-117	GRID
35	25	Samdrup Jongkhar	1808	Chhukarpo Ri U/S (Augotar)	28	14	177,000	6,321	13,068	22,000	3,000	8,234	-16,766	-1,238	-2.5%	24	47	156,263	3,296	18,000	11,000	22,000	-7,000	-148	GRID
36	26	Samdrup Jongkhar	1809	Leishing Ri Tributary	18	14	155,000	8,611	11,444	19,000	3,000	5,418	-16,582	-1,224	-7.0%	26	23	71,823	3,119	8,000	5,000	9,000	-4,000	-174	GRID
37	27	Trashigang	1901	Sakten	500	363	2,469,000	4,938	6,806	274,000	27,000	308,736	7,736	21	8.9%	6	363	451,085	1,243	71,000	73,000	309,000	165,000	455	GRID
38		Trashigang	1902	Sakten - Merak [Alt.-1]	890	669	4,616,000	5,187	6,896	510,000	54,000	581,503	17,503	26	8.7%		669	1,099,183	1,642	144,000	148,000	582,000	290,000	433	GRID
39	28	Trashigang	1903	Khelphu	32	18	247,000	7,719	13,811	30,000	3,000	9,901	-23,099	-1,292	-2.4%	23	18	271,937	15,206	31,000	16,000	10,000	-37,000	-2,069	MHP
							Average =	6,436	9,430						2.1%			Average =	3,694						
							Average (w/o negative EIRR project)=	4,993	6,495						7.8%			Average (w/o negative EIRR project)=	2,428						

Source: JICA Study Team

Note: "Error" in EIRR is large negative value of EIRR.

14.3 Economic Evaluation of Rural Electrification Programs

14.3.1 Quantity and Cost of On-grid Distribution Facilities

The quantity and cost of on-grid distribution facilities was estimated using GIS data and summarized by the economic evaluation program. **Table-14.3.1** below shows a summary list of the quantity of distribution facilities in the master plan. Detailed quantity tables by Dzongkhag are shown in **Appendix C-III-2**.

Table-14.3.1 Construction Quantity of Distribution Facility

(1)	New medium voltage distribution line	Unit	Quantity
	33kV	km	1,527
	11kV	km	795
	6.6kV	km	0
	Total	km	2,322
(2)	**Pole mounted transformer**		
	33/0.4-0.23kV	Nos.	2,020
		kVA	51,687
	11/0.4-0.23kV	Nos.	896
		kVA	22,386
	6.6/0.4-0.23kV	Nos.	0
		kVA	0
	Total	Nos.	2,916
		kVA	74,073
(3)	**Transformer for voltage compensation**		
	33/6.6kV	Nos.	0
		kVA	0
	11/11kV	Nos.	5
		kVA	10,000
(4)	**Sectionalizing Switch**		
	For 33kV	Nos.	62
	For 11kV	Nos.	18
(5)	**Low voltage line**		
	3 Phase 4 wires 0.4-0.23V	km	724
	Single phase 2 wires 0.23V	km	3,209
(6)	**Right of way**		
	33kV	m^2	7,726,621
	11kV	m^2	15,948,261
TOTAL		**km**	**2,322**

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Among all medium voltage lines, 1,527 km is 33 kV lines, 795 km is 11 kV lines. The length of covered conductors required for environmentally protected areas is 286 km, which represents 12.3% of the total line length. The number of distribution substations is 2,916.

The estimated Dzongkhag-wise distribution line cost and equipment cost sis shown in **Table-14.3.2**.

The costs shown in **Table-14.3.2** above include equipment, transportation, installation, and 3% of the total amount for administration fees. These cost data were estimated by using GIS, the results of economic calculations, and using BPC’s unit cost tables.

Table-14.3.2 Cost Estimation of Distribution Facilities

(a)	**New medium distribution line**	**Investment (1,000 Nu.)**
	33kV	1,028,248
	11kV	504,741
	6.6kV	0
(b)	Pole mounted transformer	
	33/0.4-0.23kV	543,957
	11/0.4-0.23kV	151,355
	6.6/0.4-0.23kV	0
(c)	Transformer for voltage compensation	
	33/6.6kV	0
	11/11kV	20,914
(d)	Sectionalizing Switch	
	For 33kV	30,733
	For 11kV	8,977
(e)	Low voltage line	
	3 Phase 4 wires 0.4-0.23V	734,251
	Single phase 2 wires 0.23V	175,100
(f)	Right of way	
	33kV	9,323
	11kV	3,411
TOTAL		3,211,010

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In addition, cost breakdown of material, transportation, labor, administration, and contingency for distribution line construction is shown in **Table-14.3.3** below. Of the total cost, about 64% is for material, about 16% is for transportation, about 8% is for labor, about 3% is for administration, and about 9% is for contingency.

Table-14.3.3 Cost Breakdown of Distribution Line Construction

(unit: x 1,000 Nu.)

Dzongkhag	Material	Transportation	Labour	Administration	Contingency	Total Investment
Bumthang	38,176	13,400	5,850	1,723	5,915	65,064
Chukha	114,608	6,705	15,292	4,098	14,070	154,773
Dagana	153,855	48,003	19,382	6,637	22,788	250,664
Gasa	19,948	4,279	2,657	807	2,769	30,459
Haa	17,937	3,148	2,437	706	2,423	26,651
Lhuntse	76,040	43,001	10,335	3,881	13,326	146,582
Mongar	125,636	63,698	16,343	6,170	21,185	233,032
Paro	9,782	1,335	1,485	378	1,298	14,278
Pemagatshel	86,181	31,930	10,972	3,872	13,295	146,250
Punakha	16,716	3,260	2,298	668	2,294	25,236
Samdrup Jongkhar	239,916	46,784	31,085	9,534	32,732	360,051
Samtse	264,889	10,331	37,361	9,377	32,196	354,154
Sarpang	186,405	18,175	24,720	6,879	23,618	259,797
Thimphu	1,120	153	152	43	147	1,615
Trashigang	115,557	49,574	15,491	5,419	18,604	204,645
TrashiYangtse	79,730	37,314	9,528	3,797	13,037	143,406
Tsirang	85,409	24,982	10,277	3,620	12,429	136,718
Wangduephodrang	156,249	36,562	19,191	6,360	21,836	240,198
Trongsa	138,350	26,978	18,245	5,507	18,908	207,988
Zhemgang	133,837	33,928	17,098	5,546	19,041	209,450
Total	**2,060,341**	**503,537**	**270,200**	**85,022**	**291,910**	**3,211,010**

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14.3.2 Off-grid Equipment Cost

The off-grid cost by Dzongkhag is shown in **Table-14.3.4** below. Off-grid installation is developed household-wise, and the cost was simply estimated based on US$495.3 per household, as described previously in Section 11.3. The total investment for off-grid solar home systems was US$2.54 million. The transport, administrative and marketing cost are all summed together as annual administrative cost, which is estimated to be 500 Nu./set.

Table-14.3.4 Investment for Off-grid Solar Home Systems

Dzongkhag	Nos. of Village	Nos. of Household	Investment (1000 Nu.)	
			If connected to the Grid	By Solar
Bumthang	5	28	6,245	624
Chukha	30	387	46,799	8,626
Dagana*	18	280	47,218	6,241
Gasa	14	233	62,971	5,193
Haa	5	100	11,272	2,229
Lhuntse	30	368	81,160	8,202
Mongar	57	642	124,957	14,309
Paro	11	92	23,940	2,051
Pemagatshel	7	48	12,859	1,070
Punakha	18	112	28,097	2,496
Samdrup Jongkhar	49	507	79,001	11,300
Samtse	21	348	37,056	7,756
Sarpang	39	555	61,957	12,370
Thimphu	15	141	40,329	3,143
Trashigang	23	192	37,388	4,279
TrashiYangtse	5	46	9,571	1,025
Trongsa	5	49	8,410	1,092
Tsirang	16	198	29,186	4,413
Wangduephodrang	53	461	88,723	10,275
Zhemgang	28	346	63,914	7,712
Total nos.	449	5,133	901,052	114,407
in 1000 US$			$20,023	$2,542

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14.3.3 On Off Grid Threshold Cost

As explained in the section of on/off grid criteria, Section 13.4, the on/off grid determination is undertaken by the comparison of the net economic benefits. Algebraically, the following conditions holds for on grid determination;

$$GB - GC = SB - SC$$

Whereas GB: Grid Economic Benefit:

GC: Grid Economic Cost

SB: Solar Economic Benefit

SC: Solar Economic Cost.

Rearranging the equation, it can get the determination of the threshold cost for grid extension as flows;

$$GC = GB - SB + SC$$

From the equation above, we can calculate the threshold on-grid cost.

First, the study team derived the annual threshold cost for grid extension. Grid benefit should be evaluated at the year 2020 which is the terminal target year of the master plan. Since the benefit is converted into a unit value per kWh, the demand growth needs to be taken into account. The unit power demand growth from the year is 18% from 120 kWh/HH to 141 kWh/HH. Here "HH" stands for household. Given these assumptions, the following tabulations;

GB = 1326 Nu./HH/Month(Year 2004) x 12 month x 1.18 = 18,772 Nu./year.,

SB= 410 Nu./HH/Month x 12 month = 4,922 Nu./year, and

SC = 2,988 Nu./year.

Therefore GC = 1) - 2) + 3)＝16,838 Nu./year.

The grid cost includes three components of annualized investment cost, annualized LV cost, and annual O&M cost, all measured in economic cost terms. Decomposition into the three elements depends on the configuration of distribution system. For a small village located far from the trunk line has a high proportion of MV and high O&M cost. Conversely, a larger village in a near distance will have smaller portion of O&M cost.

Here we will derive an average investment threshold cost as an indicative measure. On the average, the ratio of annualized investment cost to O&M cost is 79.7:20.3. The conversion factor for investment is on the average 0.97 and that for O&M is 1.11. Therefore the weighed average conversion factor is 0.97 x 0.797 + 1.11 x 0.0.203 = 1.00.

The conversion of annual cost into one-time investment cost is 9.02 with a discount rate of 12% over 30 years. The average threshold investment cost per household is derived by 16,838 x 9.02 x 0.797 = 121,047 Nu. or US$2,690.

So roughly speaking the threshold investment cost is somewhere near US$2,700/HH. The on-off grid determination is conducted on a village-basis. In estimating the power demand for villages, the demands from administration, school, and industries are also taken into account. These will add in favor for grid extension by adding more demand to justify the investment costs to the village in question.

14.3.4 Overall Electrification Project Cost

Total project cost was estimated by summarizing distribution line cost, off-grid solar home system cost, and information and communication equipment as a sub-total. The total estimated cost includes the cost of 7% of sub-total as foreign consultant and 2% of sub-total as training and capacity. As for information and communication, 3% of equipment, transportation, and installation cost is included as administration cost as well as distribution facility. The detailed estimation of information and communication is described in Section 18.3.

The total project cost was estimated to be US$86.5 million as is shown in **Table-14.3.4**.

Table-14.3.4 Total Project Cost Estimation

Items	Amount (1,000 Nu.)	Amount (US$)
Distribution facility	3,211,010	71,355,785
Information and communication facility	242,762	5,394,720
Off-grid facility	114,407	2,542,375
Sub-total	*3,568,180*	*79,292,879*
Consultancy service	255,000	5,666,667
Training and capacity building	71,364	1,585,858
TOTAL	**3,894,543**	**86,545,404**

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14.4 Effect on Poverty Reduction

14.4.1 Distribution Analysis

The main objective of distribution analysis is to check who bears the costs and receives the benefits arising from the project in question. Since improving the well-being of the poor is one of chief goals in development and particularly so in Bhutanese national policy context. The distribution analysis undertaken here follows a standard procedure adopted by the ADB. The first step in this analysis is to identify the key players for the rural electrification. The second step is to allocate the financial net costs and economic net benefits and costs to the identified players. The final step is to estimate the shares of the poor in terms of costs and benefits and then derive a ratio called “Poverty Reduction Impact Ratio”, in order to estimate the net impact of the project to the poor.

14.4.2 Distribution of Financial and Economic Net Benefits

There are four key players in rural electrification. The Bhutan Power Corporation is a semi-government company which is solely responsible for engineering and operation of rural power supply at present. The government is not only a policy maker but also the main source of financing the implementation. Labor is an important sector in which the poor comprises a large segment as the provider of inputs in construction and operation. The consumer is the main beneficiary of the power supply. Private contractors and vendors are also important providers of inputs but for the sake of convenience, they are bundled into the government/economy sector in this analysis.

The main beneficiaries in rural electrification are the consumer who receives power priced below the average cost of the supply. Labor who gets jobs is a minor beneficiary. The BPC may have to absorb the largest portion of the net economic loss without subsidies.

The net economic benefits here is defined as the difference between estimated economic benefits and costs minus the financial revenues and costs. For instance labor sector receives wages of 254 million Nu. as the payment for construction but due to underemployment, the real economic costs are estimated worth only 191 million Nu. The difference of 48 million Nu. is considered as net economic benefit to labor sector.

The net losses that the government bears in terms of difference between economic costs and financial costs are the losses of social welfare that arises from the distortion of foreign exchange market due to imposition of import taxes for the import of equipment and materials. This loss is equivalent to 217 million Nu.

Table-14.4.1 shows the estimated distributions of net economic benefits and costs more in detail.

Table-14.4.1 Distribution of Financial and Economic Benefits and Costs by Sector

Million Nu.

Overall Project Cost Benefits (Present Value Basis)

					Distribution			
Project Components	Financial Present Values	Conversion Factors	Economic Present Values	Difference Between Economic and Financials	BPC	Government/ Economy	Labor	Consumers
Benefits								
Consumer Surplus			10,420	10,420				10,420
Cost Saving								
Revenue	893	1	893	0	0			
Total Benefits								
Capital Costs	-2,777		-2,850	-73				
Equipment	-1,961	1.1	-2,157	-196		-196		
Transportation	-481	0.9	-433	48		48		
Labor	-254	0.75	-191	63			63	
Administration	-81	0.85	-69	12	12			
Operation and Maintenance	-776	89.4%	-693	82				
Equipment/Material	-194	1.1	-213	-19		-19		
Skilled	-175	1	-175	0				
Unskilled Labor	-407	0.75	-305	102			102	
Opportunity Costs			-2,256	-2,256				
Transmission Loss			-379	-379	-379			
Loss of Export Sales			-1,877	-1,877	-1,877			
Total Costs	-3,553		-5,799	-2,245.95				
Net Benefits	-2,659		5,515	8,174	-2,243	-167	165	10,420

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14.4.3 Poverty Reduction Impact

Since the chief objective of rural electrification in Bhutan is to reduce poverty in rural areas, it is important to assess quantitative impacts of the projects to be implemented on the poor population. A preliminary estimate of the population below poverty line (income poverty line) is approximately 40% as discussed in the Section 13.9. Although the latest living standard survey may curtail this figure to some extent, isolated locations of the target rural areas under the master plan are likely to lead to a larger incidence of poverty. For the purpose of a preliminary estimation, the rough estimates of 40% for rural area and 25% for the nation would suffice. The proportion of the poor among the labor class is estimated to be 50% of the total.

In addition to net economic benefits and costs detailed in **Table-14.4.1**, the total economic analysis needs to add the financial net return (which is negative in this case). It is a well-known fact that rural electrification is a financially non-viable project. Thus it is a question who should bear the deficit. Here, the matrix is so designed that the BPC absorbs the entire deficit of 2,659 million Nu. for the purpose of analysis as shown in Financial Return for BPC in **Table-14.4.2**. The net economic benefits for each sector is equivalent to the total net benefits calculated in **Table-14.4.1**.

After applying the estimated proportion of the poor within each sector, the share of the poor in net economic costs and benefits are estimated as shown in the last row of **Table-14.4.2**. The poverty impact ratio is derived by dividing the total net benefits accruing to the poor by the total economic benefits generated by the entire project. The estimated poverty impact ratio is 54%. It implies that the poor is to receive 54% of the net benefits created by the project.

Table 14.4.2 Poverty Reduction Impact Ratio Estimation

	Sectors				
	BPC	Government / Economy	Labor	Consumers	Total
Net Economic Benefits	-2,243	-167	165	10,420	8,174
Financials Return	-2,659				-2,659
Proportion of Poor	0.25	0.25	0.5	0.4	
Benefits to Poor	-1,226	-42	82	4,168	2,983

Poverty Imapct Ratio = (Total Benefits to Poor / Total	54%

Prepared by JICA Study Team

THE INTEGRATED MASTER PLAN STUDY
FOR DZONGKHAG-WISE ELECTRIFICATION
IN BHUTAN

FINAL REPORT

PART-C

MASTER PLAN AND IMPLEMENTATION STRATEGY

CHAPTER 15 ON-GRID RURAL ELECTRIFICATION MASTER PLAN BASED ON ECONOMIC EVALUATION

15.1 Phase Development Master Plan

15.1.1 On-grid Electrification Plan by Phase

In Bhutan, a Five Year Plan (FYP) is used for national development planning. The rural electrification project will be implemented in three (3) phases within the following FYPs:

- Phase-1: 10th FYP (2007-2012)
- Phase-2: 11th FYP (2012-2017)
- Phase-3: 12th FYP (2017-2020, until the target year for achieving 100% electrification)

The implementation phase in which feeders for a particular distribution line extension will be constructed needs to be determined. The immediate priority is to determine the funding plan for implementation in 10th FYP (2007-2012). Therefore, the location and cost of the feeders that are to be constructed during 10th FYP need to be determined. This can be done on the basis of economic analysis.

This Chapter describes on-grid electrification planning by phase, based on the genuine economic evaluations, and shows the detailed process that was used to reach the final plan. The optimized final electrification plan by phase will be described in Chapter 16. The final plan is prepared based on the analysis of results presented in this Chapter.

15.1.2 Definition of Feeder Configuration

Since the coverage of the master plan is quite extensive, the evaluation is carried out by a specially designed computer program as described in Chapter 13. To do so, the system of the distribution networks are arranged in a simple structure that comprises of nodes and lines. Nodes are placed on GIS maps for each Dzongkhag to determine the route and length of the distribution lines. The nodes may be places to represent not only the geographical features but also the planning factors such as the disjuncture of environmentally protected areas, the deployment of equipment, tap-offs, and location of villages.

All the distribution lines are classified into two types, i.e. “***trunk***”, and “***branch***” For conventional purposes for this study. A group of lines starting from the trunk to all the connected branches is called a “***feeder***”. The trunk is defined as a root line that constitutes the first off-shoot from the existing or already planned line. The branch is defined as a line that comes off from the trunk line defined for this study. In other words, trunk line comprises the first level of the distribution hierarchy while branch lines comprise the secondary, tertiary or further lower levels of the distribution network hierarchy. The concept is shown in the **Figure-15.1.1.**

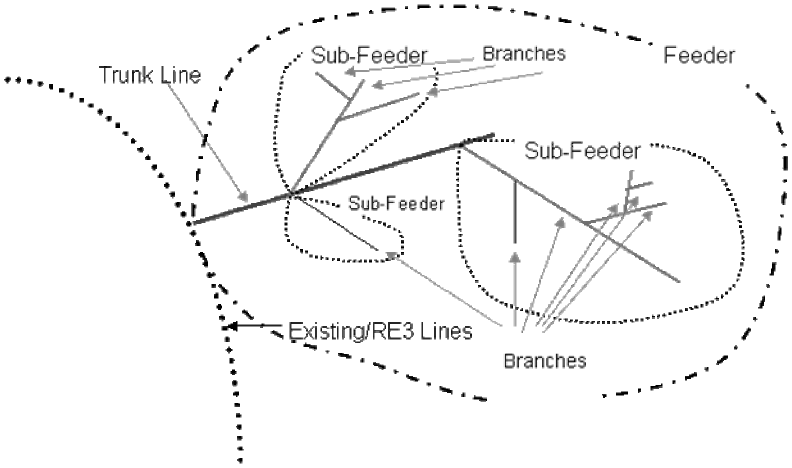

Figure-15.1.1 Definition of a Feeder, Sub-feeder, and Branch

The on/off grid evaluation in this study adopts an approach that starts from the very end of the network and then go up the ladder of the hierarchy branch by branch and finally to a feeder. On the other hand, the economic evaluation is a feeder-wise approach to determine the allocation of feeders into the implementation phase.

15.1.3 Method of Phase Development Plan based on Economic Evaluation

The GIS design described in earlier chapters was prepared for a total of 209 feeders that have to be constructed by the end of 12th FYP (2020). In order to determine which of those 209 feeders can be constructed in 10th, 11th, and 12th FYP, an economic analysis was undertaken. The construction cost, economic internal rate of return (EIRR), benefit/cost ratio (B/C), number of electrified households, and line distance for every feeder were calculated, based on the projected demand for the years 2007, 2012, and 2017.

There are a number of methods that can be used to determine which feeder will be implemented in each phase. These methods can be summarized as follows:

a) Budget Allocation: Determine the budget for each five year plan, sort the feeders by EIRR (highest EIRR is at the top of the list), remove feeders that have an EIRR of less than 12%, and then progressively work down the list to allocate feeders until the budget limit is reached.

b) EIRR Cutoff Limit: Select all the feeders for which the EIRR exceeds 12% for implementation in each FYP

c) Household Numbers: Based on government policy, determine the target number of households to be electrified in each FYP.

Here, the EIRR stands for EIRR (Economic Internal Rate of Return).

As a result of discussions held with the Department of Energy (DOE), Method (c) was selected. For phase planning, the target number of households for on-grid electrification in

10th FYP was determined to be 20,000[1]. This number represents the forecast number of households for 2007, which is the start year of 10th FYP.

Figure-15.1.2 below illustrates the flow of the process of Phase-1 feeder selection process.

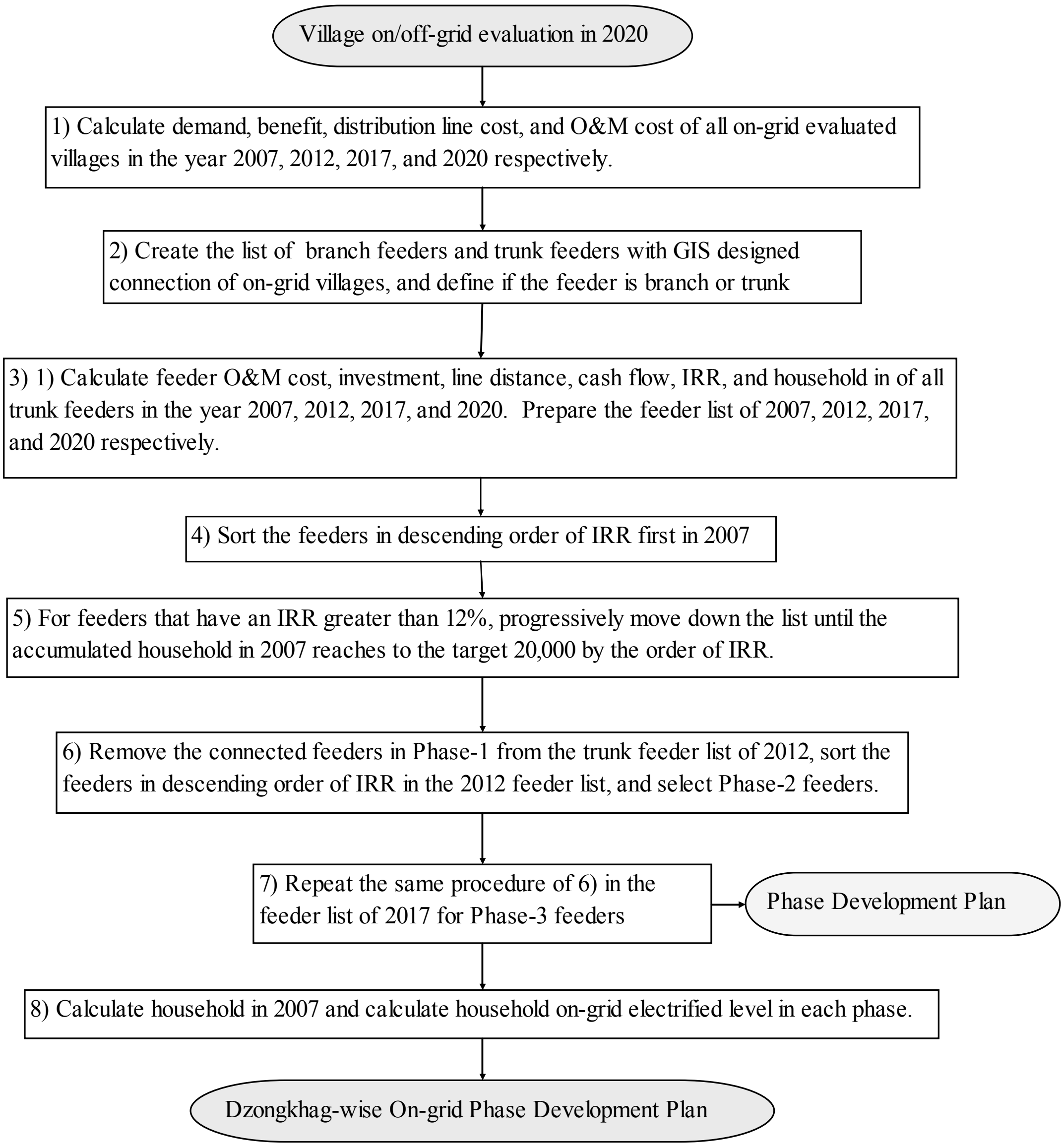

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Figure-15.1.2 Conceptual Flow of the Phase Development Electrification Plan based on Economic Evaluation

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[1] Here, the household numbers are the numbers forecast for 2007, which is the starting year of 10th FYP. The number of households is predicted to increase year by year, so the number of households connected to a particular feeder would be expected to be greater in 2012 than in 2007. The corresponding number of feeders required to connect the 20,000 household electrification target with the 2007 forecasted households will be smaller than the number forecast for 2012. Consequently, from an economic point of view, it would be preferable to prepare the electrification plan with the household numbers forecast for 2012, which is the end of 10th FYP. This is because the overall cost will be lower with a smaller number of feeders. However, if the actual household increase is lower than forecasted, the government can not achieve the household electrification target of 20,000. Therefore, in order to achieve the 20,000 household target, the number of households forecast for 2007 was applied. Therefore, certainty of achieving government target was given a higher priority than economic efficiency.

The procedure that was used to determine the feeders that would be developed in particular FYP's is described below.

1) Village locations were determined and these were mapped using GIS, as described earlier in Chapter 7.

2) An Excel worksheet was prepared for each village. Initially, data such as the village name, location (XYZ coordinates), number of households (as forecast for 2020), etc. were entered into these worksheets, as described in Chapter 8.

3) A Visual Basic program was in Excel used to undertake route analysis to determine which villages would be connected to a main feeder, and which villages would be connected via a branch feeder, according to GIS design.

4) Economic data related to village electrification, such as predicted electricity demand (kWh), investment cost, benefit, etc. were calculated for each village using the 2020 forecasts. These data formed the 2020 economic analysis baseline that was described in earlier chapters (Chapter 14). Analysis of these economic data allowed villages to be categorized into on-grid or off-grid.

5) The village-based demand, benefit, and economic cost for the investment and operation and maintenance (O&M) cost was calculated in Excel for all on-grid villages for the years 2007, 2012 and 2017 respectively. These data augmented the 2020 data that were calculated previously.

6) For each trunk feeder (i.e. a local medium-voltage distribution line network comprising a main feeder and various branch feeders), aggregated economic data such as feeder demand, economic cost and O&M cost, line length, cash flow, EIRR, and number of households for 2007, 2012, 2017, and 2020 were calculated. It is noted that the EIRR of each feeder is different in each year, because of the projected demand increase. Generally, the EIRR in 2012 is higher than EIRR in 2007.

7) Prepare a list of all feeders for 2007, 2012, 2017, and 2020 respectively.

8) Using the list of candidate feeders, extract the connections to the on-grid villages that could be made in each FYP. This was done as follows:

   Sort the feeders in descending order of EIRR (highest EIRR is at the top of the list) for 2007 (10th FYP).

   a) For feeders that have an EIRR greater than 12%, progressively move down the list until the accumulated number of households in 2007 reached the target number of 20,000 for Phase-1.

   b) Remove the feeders that would be connected in Phase-1 from the trunk feeder list for 2012, sort the feeders in descending order of EIRR in the 2012 feeder list, and select the Phase-2 feeders in the same way as the 2007 selection process.

c) Repeat the same procedure for the 2017 feeder list for Phase-3 feeders. The phase development plan is prepared with this list.

d) Calculate the number of on-grid households in 2007 including existing and ADB/RE-3 lines, and calculate household on-grid electrification percentage in each phase.

e) Based on the result of this temporary on-grid electrified level by this procedure, Dzongkhag-wise phase development plan can be prepared.

In addition, alternative phase plans were examined for (a) budget limit of US$30 million and, (b) budget limit of US$40 million, and (c) a simple EIRR cutoff limit. The results are shown in **Appendix C-III-3**. These alternative plans correspond to the budget allocation and EIRR cutoff limit method respectively, as described above. If the condition, such as budget limitation of FYP, is changed, those alternative plan would be referred.

15.2 On-grid Electrification Plan of Phase-1 (2007-2012)

10th FYP is defined as the Phase-1 trunk feeder construction period. There are 209 trunk feeders in total, of which 125 trunk feeders were allocated for Phase-1 construction, using the methodology described above. The trunk feeders allocated for Phase-1 are listed in **Table-15.2.1**.

Table-15.2.1 Phase-1 (10th FYP) Feeder List by Economic Evaluation

Feeder Name	HH in 2007	Investment (1000 Nu.)	Distance (m)	IRR	B/C
(A) Bumthang					
MPA11F1-3	7	967	818	17.6%	1.58
MPA11F1-4	147	17,604	13,945	13.4%	1.23
MPA11F1-1	126	17,081	12,659	12.8%	1.18
MPA11F3-1	27	2,286	2,616	11.8%	1.11
(B) Chukha					
MPB11F1-1	42	2,290	609	41.2%	4.38
MPB11F5-2	10	461	145	31.3%	3.12
MPB11F5-1	7	379	128	30.8%	3.05
MPB33F4-1	18	1,781	1,159	28.4%	2.68
MPB11F3-3	13	544	117	23.2%	2.24
MPB11F4-1	14	860	470	24.2%	2.26
MPB33F4-19	9	677	418	20.1%	1.84
MPB11F4-2	15	1,018	457	16.1%	1.48
MPB11F2-1	64	6,974	9,572	18.4%	1.60
MPB11F5-3	28	2,489	2,404	17.0%	1.52
MPB11F1-2	201	14,548	12,665	15.6%	1.41
MPB33F4-6	750	65,710	44,819	14.7%	1.34
MPB11F3-1	68	4,444	2,865	14.0%	1.29
MPB33F4-3	1,797	169,798	134,880	13.7%	1.25
MPB33F2-1	38	3,060	1,595	11.4%	1.07
(C) Dagana					
MPC33F6-1	6	652	277	17.6%	1.63
MPC33F6-2	3	631	361	13.1%	1.21
(E) Haa					
MPE11F2-1	12	753	73	23.5%	2.30
(F) Lhuntse					
MPF11F1-7	3	646	505	57.7%	6.05
MPF33F6-4	17	1,271	46	19.0%	1.82
MPF11F4-1	36	3,514	2,187	17.8%	1.62
MPF11F4-2	17	1,574	618	14.5%	1.34
MPF11F1-5	64	6,680	3,824	16.5%	1.50
MPF33F6-3	8	587	28	14.7%	1.38
MPF11F3-4	43	3,951	2,053	13.5%	1.24
MPF33F6-8	189	23,283	10,824	13.8%	1.27
MPF33F6-7	132	17,708	7,703	13.1%	1.21
MPF11F5-2	312	36,829	25,587	12.3%	1.15
(G) Mongar					
MPG11F12-3	4	392	81	24.8%	2.41
MPG33F5-1	85	10,263	4,144	21.2%	1.98
MPG11F2-1	8	479	46	17.7%	1.67
MPG33F3-1	228	20,938	6,548	16.5%	1.53
MPG11F12-2	15	923	403	16.2%	1.49
MPG11F12-1	9	569	167	16.2%	1.50
MPG33F7-1	31	3,416	965	16.2%	1.50
MPG33F14-1	289	35,578	17,756	15.8%	1.45
MPG11F1-1	84	10,674	8,792	15.0%	1.36
MPG11F12-5	6	427	39	15.1%	1.41
MPG33F10-1	134	13,652	4,123	13.6%	1.26
MPG33F14-3	11	872	191	13.1%	1.22
(H) Paro					
MPH11F2-2	16	980	126	16.7%	1.57
MPH11F4-1	2	374	440	17.8%	1.57
MPH33F3-2	17	2,428	3,073	13.4%	1.22
MPH33F3-1	13	929	731	12.4%	1.15
MPH11F1-3	9	914	1,208	13.0%	1.19
(I) Pemagatshel					
MPI33F2-3	96	7,641	4,007	24.3%	2.27
MPI33F2-2	7	763	539	15.6%	1.42
MPI33F3-2	520	61,289	46,576	14.8%	1.35
(K) Samdrup Jongkhar					
MPK33F3-1	20	1,713	808	31.5%	3.07
MPK11F7-2	274	20,073	16,375	20.7%	1.86
MPK33F7-7	66	6,028	2,588	20.6%	1.91
MPK33F1-1	950	82,024	54,389	17.9%	1.62
MPK33F3-2	103	7,362	2,937	17.1%	1.58
MPK33F6-1	11	685	174	16.1%	1.50
MPK33F3-4	438	50,263	35,827	14.4%	1.31
MPK33F3-3	20	1,387	740	13.7%	1.26
MPK11F7-9	174	15,957	16,626	13.7%	1.25
MPK33F7-1	115	14,899	12,188	13.6%	1.25
MPK33F3-6	41	3,099	1,533	12.5%	1.16
MPK11F2-3	8	570	343	13.1%	1.21
MPK11F2-4	929	143,273	79,483	12.2%	1.14

Feeder Name	HH in 2007	Investment (1000 Nu.)	Distance (m)	IRR	B/C
(L) Samtse					
MPL11F1-1	366	24,072	17,088	19.5%	1.77
MPL33F2-6	9	487	101	18.3%	1.72
MPL11F1-4	50	2,972	1,775	17.5%	1.59
MPL11F5-14	28	1,562	832	16.9%	1.55
MPL11F5-5	519	34,548	28,176	16.9%	1.52
MPL33F2-5	13	731	316	17.0%	1.57
MPL33F2-10	32	2,227	1,081	13.5%	1.25
MPL33F2-11	23	1,862	1,258	14.0%	1.28
MPL11F6-4	40	2,865	2,382	12.1%	1.13
MPL11F5-1	159	12,181	12,202	13.0%	1.20
EXL15	1,144	80,725	84,877	12.4%	1.15
MPL11F1-2	189	13,953	12,360	11.5%	1.08
(M) Sarpang					
MPM33F3-1	35	5,400	6,675	41.0%	3.77
MPM11F2-3	260	16,217	6,474	29.5%	2.87
MPM11F2-1	12	1,126	1,154	30.0%	2.71
MPM11F4-6	35	2,199	985	24.1%	2.27
MPM11F1-2	41	1,764	477	22.6%	2.16
MPM11F2-2	17	975	13	18.0%	1.72
MPM11F4-7	10	527	175	18.6%	1.73
MPM11F4-5	35	2,057	635	16.8%	1.56
MPM33F2-21	23	1,797	785	15.7%	1.45
MPM11F1-1	45	2,949	1,483	15.2%	1.40
MPM33F1-1	34	2,265	443	15.1%	1.41
MPM33F2-4	64	4,442	1,185	14.3%	1.33
MPM11F4-1	195	17,088	17,604	11.9%	1.11
(O) Trashigang					
MPO11F9-14	83	8,998	5,013	26.6%	2.50
MPO11F3-1	17	932	37	24.8%	2.47
MPO11F9-2	317	33,372	16,629	20.9%	1.93
MPO11F1-8	244	27,338	15,981	20.3%	1.85
MPO11F1-3	400	43,595	28,396	18.7%	1.69
MPO11F9-1	18	2,301	2,911	18.4%	1.61
MPO11F9-15	23	1,888	966	14.8%	1.36
MPO33F8-1	75	8,055	3,797	15.8%	1.45
MPO11F9-13	23	1,598	442	14.7%	1.36
MPO11F9-17	145	13,492	8,860	15.1%	1.38
MPO11F7-2	8	868	519	15.2%	1.39
MPO11F7-5	5	351	69	14.9%	1.38
MPO11F9-7	282	25,498	15,446	14.3%	1.31
MPO11F1-1	121	12,235	11,077	14.2%	1.29
MPO11F3-2	5	1,366	2,034	15.1%	1.34
MPO11F2-1	84	8,004	6,545	13.5%	1.23
(P) TrashiYangtse					
MPP33F1-13_2	35	4,485	1,858	19.2%	1.77
MPP33F1-13_1	15	941	123	16.8%	1.57
MPP33F1-14	63	7,491	3,747	15.4%	1.41
MPP33F1-8	359	36,573	13,636	15.6%	1.44
MPP33F1-18	336	35,425	15,950	15.6%	1.43
MPP33F1-9_1	66	5,856	1,379	13.7%	1.27
MPP33F1-1	346	51,063	28,448	12.3%	1.15
(Q) Trongsa					
MPQ33F1-13	384	56,878	37,905	15.2%	1.38
MPQ33F1-10	86	9,904	4,317	14.4%	1.33
MPQ33F1-8	229	32,522	26,229	13.9%	1.27
MPQ33F1-7	7	595	198	11.6%	1.09
(R) Tsirang					
MPR11F2-1	42	2,743	1,153	15.0%	1.38
MPR33F2-5	46	3,334	436	15.0%	1.40
MPR33F2-1	553	48,549	19,669	15.4%	1.42
MPR33F3-1	1,691	190,781	107,719	14.9%	1.36
MPR11F1-1	30	2,224	1,482	12.4%	1.15
MPR33F1-1	1,251	124,835	70,144	12.5%	1.16
(S) Wangduephodrang					
MPS11F1-1	203	40,136	53,043	14.9%	1.33
(T) Zhemgang					
MPT33F2-6	708	101,269	94,297	12.4%	1.15

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The feeders passing through more than two Dzongkhag are included in the Dzongkhag from which the source of the feeders start.

Based on economic evaluation, the total investment required for the Phase-1 trunk feeders is US$47.3 million. The total line distance is 1,431 km. The number of on-grid electrified households is 20,654. The highest EIRR among the Phase-1 trunk feeders shown in **Table-15.2.1** is 58%, which is for MPF11F1-7, in Lhuntse Dzongkhag. The lowest EIRR is 12%, which is for MPT33F2-6, in Zhemgang Dzongkhag . All the Phase-1 trunk feeders have an EIRR of greater than 12%.

Trunk feeder names that begin with "EX" (e.g. "EXL15") represent existing power lines that require replacement. These lines need to be replaced because they do not have sufficient capacity to support additional power lines required by the master plan. The amount of investment required for Phase-1 includes the cost of upgrading these lines.

15.3 On-grid Electrification Plan for Phase-2 (2012-2017)

Phase-2 is for the 11th FYP, which extends from 2012 to 2017. The remaining 84 trunk feeders (out of a total of 209 feeders) are planned to be constructed in Phase-2. Therefore, on-grid electrification will be accomplished by the end of Phase-2. **Table-15.3.1** below shows the Phase-2 project list, sorted by descending order of EIRR.

In Phase-2, the total required investment will be US$24.0 million, the line length is 891 km, and the number of on-grid electrified households is 8,687 as of the year 2007.

The EIRR's for the Phase-2 trunk feeders are comparatively lower than in Phase-1 because the higher EIRR feeders are already allocated to Phase-1. The highest Phase-2 EIRR is 21%, which is for MPB33F2-7 in Chukha Dzongkhag. The lowest EIRR is 7%, for MPL33F2-12 in Samtse Dzongkhag. In Phase-2, there are 32 feeders that have EIRR's lower than 12%. The EIRR's calculated for Phase-2 apply the demand forecast for 2012, which is the start of 11th FYP.

The combined total number of households that will be electrified (Phase-1 plus Phase-2) is 29,341 households, as of 2007. The total cost for the distribution lines will be US$71.4 million and the total line distance will be 2,313 km. **Table-15.3.2** summarizes the number of households and villages, cost, and line distance for each phase in each Dzongkhag, based on economic evaluation.

Figure-15.3.1 shows the national on-grid electrification phase development plan of 10th and 11th FYP, based on genuine economic evaluation. The plan has a target of 20,000 on-grid electrified households in 10th FYP and all remaining on-grid households for 11th FYP.

Table-15.3.1 Phase-2 (11th FYP) Feeder List by Economic Evaluation

Feeder Name	HH in 2007	Investment (1,000 Nu.)	Distance (m)	IRR	B/C
(A) Bumthang					
MPA11F2-1	168	27,033	34,415	13.9%	1.26
(B) Chukha					
MPB33F2-7	111	10,144	6,929	21.4%	1.95
MPB33F2-5	20	1,494	1,014	14.1%	1.29
MPB33F3-1	4	389	41	13.8%	1.28
MPB33F5-3	18	2,825	3,523	11.8%	1.10
MPB33F2-4	4	435	139	11.6%	1.09
MPB11F3-4	5	534	619	8.6%	0.89
MPB33F2-2	24	2,573	2,663	8.1%	0.85
(C) Dagana					
MPC33F3-1	431	60,659	54,719	10.8%	1.03
MPC33F1-2	73	8,093	3,284	10.1%	0.96
MPC33F2-1	865	90,597	77,723	9.7%	0.94
MPC33F6-3	18	2,108	1,293	8.6%	0.86
(D) Gasa					
MPD33F1-1	184	30,255	32,039	9.6%	0.95
(E) Haa					
MPE11F1-1	16	1,963	2,029	10.2%	0.99
MPE11F1-2	10	1,276	1,436	12.0%	1.12
(F) Lhuntse					
MPF11F3-3	86	10,342	6,650	13.5%	1.24
MPF33F6-6	14	1,808	798	11.8%	1.10
MPF11F3-2	6	1,029	1,112	10.7%	1.03
MPF33F6-5	37	4,636	2,170	11.3%	1.06
MPF11F3-7	25	2,897	2,103	10.6%	1.02
MPF11F1-1	96	13,931	11,569	9.4%	0.93
MPF11F5-1	26	3,253	2,592	9.3%	0.92
MPF33F6-1	72	11,554	7,383	8.2%	0.84
(G) Mongar					
MPG11F2-3	177	25,622	24,269	14.6%	1.32
MPG33F11-1	18	1,966	642	10.6%	1.00
MPG11F12-4	16	1,593	1,233	10.4%	1.00
(H) Paro					
MPH33F1-5	4	694	768	13.7%	1.24
MPH33F2-3	2	566	612	11.8%	1.10
MPH33F2-2	12	1,558	1,747	9.8%	0.96
MPH33F2-1	11	1,664	1,571	8.7%	0.88
MPH11F2-3	17	4,118	6,719	7.8%	0.86
MPH11F1-4	1	540	881	8.6%	0.91
(I) Pemagatshel					
MPI33F1-1	1,154	150,092	101,859	13.0%	1.20
MPI33F3-5	4	407	38	10.8%	1.02
MPI33F3-1	66	9,785	6,875	10.4%	0.99
(J) Punakha					
MPJ33F1-5	45	5,152	4,031	12.6%	1.16
MPJ33F1-9	84	13,168	14,975	13.3%	1.21
MPJ11F1-2	15	3,211	5,426	12.6%	1.16
MPJ33F1-2	26	2,414	1,990	10.3%	0.99
MPJ33F1-6	12	1,079	1,143	8.9%	0.91
(K) Samdrup Jongkhar					
MPK11F5-4	56	4,563	3,933	13.6%	1.25
MPK33F7-4	148	14,085	9,435	13.2%	1.22
MPK33F3-18	10	820	699	12.3%	1.14
MPK11F5-3	43	5,810	7,547	10.5%	1.01
MPK33F3-8	39	4,874	4,234	9.9%	0.97
MPK33F3-10	5	977	1,281	9.2%	0.93
(L) Samtse					
MPL11F4-1	93	7,094	7,174	14.1%	1.28
MPL33F2-7	223	17,853	12,388	14.1%	1.29
MPL11F3-1	42	3,164	3,418	13.0%	1.19
MPL11F6-1	51	4,039	4,409	12.2%	1.13
MPL33F2-3	4	399	160	12.5%	1.16
MPL11F2-1	13	1,077	1,517	11.0%	1.05
MPL33F2-4	6	550	447	9.3%	0.92
MPL33F2-1	17	1,702	1,682	9.1%	0.91
MPL33F2-12	7	750	722	6.8%	0.76
(M) Sarpang					
MPM33F2-5	763	84,891	67,112	12.7%	1.18
MPM33F1-2	590	65,764	55,323	12.5%	1.16
MPM11F3-5	24	2,120	1,997	11.7%	1.10
MPM33F2-1	78	7,365	4,878	11.4%	1.08
MPM33F2-22	14	1,242	1,169	11.3%	1.07
(N) Thimphu					
MPN33F2-1	14	1,604	1,482	10.7%	1.03
(O) Trashigang					
MPO11F7-1	5	393	175	15.9%	1.46
MPO11F2-4	30	2,798	1,627	13.9%	1.28
MPO11F6-1	39	3,816	2,921	13.5%	1.24
MPO11F7-7	62	5,800	4,139	13.2%	1.21
MPO11F7-3	11	822	711	12.5%	1.16
MPO11F10-1	4	435	237	11.4%	1.07
MPO11F3-3	15	1,737	1,723	11.1%	1.05
MPO11F7-4	3	341	146	8.5%	0.84
MPO11F9-11	14	2,065	2,014	8.1%	0.85
(P) TrashiYangtse					
MPP33F1-7	7	611	124	12.5%	1.16
(Q) Trongsa					
MPQ33F1-3	223	36,591	26,991	13.0%	1.20
(R) Tsirang					
MPR11F1-2	30	3,182	3,623	8.6%	0.89
(S) Wangduephodrang					
MPS33F3-24	4	378	98	13.9%	1.29
MPS33F3-1	1,093	141,540	117,770	13.2%	1.22
MPS33F3-23	52	4,910	2,636	12.8%	1.19
MPS33F3-37	13	1,486	1,111	12.5%	1.16
MPS33F3-31	18	3,802	3,538	11.6%	1.09
MPS33F3-33	59	9,700	10,490	11.1%	1.05
MPS11F2-1	4	1,298	2,009	9.2%	0.94
MPS33F3-34	17	4,454	5,280	8.0%	0.85
(T) Zhemgang					
MPT33F3-1	628	87,217	68,784	13.8%	1.26
MPT33F2-2	116	15,625	11,475	13.8%	1.27
MPT33F1-3	40	3,584	1,938	12.1%	1.13

* Includes 396 households connected to existing line that will be replaced.

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As for the feeders that pass through more than two Dzongkhags, those are included in Dzongkhag from which the source of the feeders start.

Table-15.3.2 Overview of Phase Plan based on Economic Evaluation by Dzongkhag

Dzongkhag	On-grid Household in 2007			On-grid Village			Line Distance (m)			Investment (x US$1,000)		
	Phase-1	Phase-2	TOTAL	Phase-1	Phase-2	TOTAL	Phase-1	Phase-2	TOTAL	Phase-1	Phase-2	TOTAL
Bumthang	307	168	475	23	7	30	30,039	34,415	64,454	838	597	1,436
Chukha	1,422	279	1,701	63	15	78	94,186	31,376	125,562	2,717	699	3,416
Dagana	855	1,305	2,160	27	38	65	53,373	121,337	174,711	2,213	3,320	5,533
Gasa	0	184	184	0	7	7	0	32,039	32,039	0	672	672
Haa	182	26	208	8	2	10	20,925	3,465	24,389	517	72	588
Lhuntse	821	362	1,183	46	27	73	53,376	34,379	87,755	2,136	1,100	3,236
Mongar	1,057	1,310	2,367	44	82	126	62,856	111,164	174,019	2,714	3,780	6,494
Paro	57	47	104	5	6	11	5,577	12,297	17,874	120	195	315
Pemagatshel	470	125	595	16	10	26	31,521	23,752	55,273	1,074	511	1,585
Punakha	0	182	182	0	17	17	0	27,565	27,565	0	556	556
Samdrup Jongkhar	3,135	301	3,436	113	15	128	223,214	27,144	250,219	7,637	744	8,382
Samtse	4,071	439	4,510	138	22	160	269,334	31,154	291,631	7,021	791	7,813
Sarpang	1,150	1,458	2,608	50	73	123	68,727	129,716	198,443	2,173	3,561	5,735
Thimphu	0	14	14	0	1	1	0	1,482	1,482	0	36	36
Trashigang	1,867	183	2,050	70	12	82	119,504	13,693	133,197	4,457	424	4,881
TrashiYangtse	1,220	7	1,227	50	1	51	65,141	124	65,265	3,152	14	3,165
Trongsa	706	223	929	33	11	44	68,650	26,991	95,641	2,209	809	3,018
Tsirang	2,423	30	2,453	69	1	70	117,228	3,623	120,851	5,220	71	5,291
Wangduephodrang	203	1,260	1,463	13	89	102	53,043	142,932	195,975	887	3,703	4,590
Zhemgang	708	784	1,492	34	30	64	94,297	82,196	176,493	2,249	2,364	4,613
TOTAL	**20,654**	**8,687**	**29,341**	**802**	**466**	**1,268**	**1,430,992**	**890,844**	**2,312,840**	**47,336**	**24,020**	**71,356**

Dagana in Phase-2 includes 396 households for the replacement of exsisting lines.

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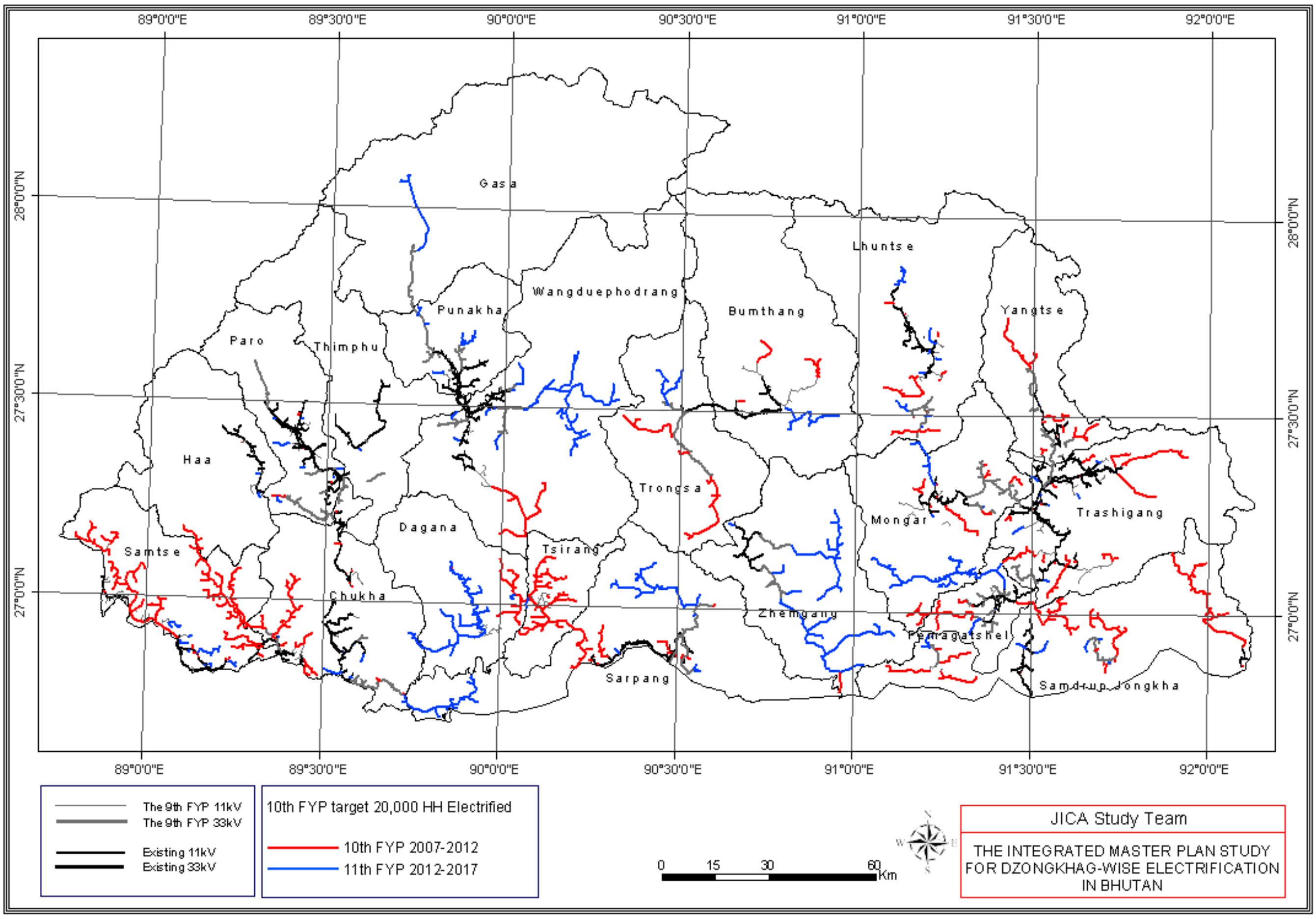

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Figure-15.3.1 National Phase Development Plan for On-grid Electrification based on Economic Evaluation

15.4 Phase Development Plan by Economic Evaluation

The on-grid electrification percentage was calculated in each phase, based on the phase development plan. The converted number for the year 2007 was applied in each stage. The percentage of electrified households is defined by the following formula:

$$E.L._{Pn} = \sum_{n} \frac{HH_{p2007} + HH_{Pn}}{HH_{p2007} + HH_{P1} + HH_{P2} + HH_{P3} + HH_{OFF}}$$

Where,
$E.L._{Pn}$: Electrified percentage at Phase-"n" (n=1,2,3)
HH_{p2007} : Projected household in 2007 by existing and ADB/RE-3
HH_{Pn}: Household number electrified by phase-n in 2007
HH_{OFF}: Off-grid household number in 2007

The national on-grid household electrification percentage is 56.1% at the beginning of 10th FYP, i.e. at the end of ADB/RE-3. Paro has the highest percentage (96.0%,) followed by Thimphu (93.9%). Zhemgang has the lowest percentage (24.3%) and the second lowest is Samdrup Jongkhar (31.2%). This deviation in the electrification percentage is an issue in terms of Dzongkhag equity.

Meanwhile, the national on-grid electrification level will be 83.4% at the end of 10th FYP. The highest percentage is 98.6% in Yangtse and the lowest is 36.4% in Gasa. The deviation of electrification percentages is still not small. At the end of 11th FYP, the highest electrification level will be 99.1% in Bumthang and the lowest will be 68.7% in Gasa, while the nation average will be 94.7%. The countermeasures to mitigate the observed deviations will be discussed in the next chapter.

Talbe-15.4.2 On-grid Electrification Percentage by Dzongkhag for each Phase

Dzongkhag	Target nos. of Electrifi-cation	At the end of 9th FYP		At the End of 10th FYP			At the End of 11th FYP		
		On Grid Electrified Households	% On-grid Electrified	On Grid Electrified Households	off + non-electrified Households	% On-grid Electrified	On Grid Household	off + non-electrified	% On-grid Electrified
Bumthang	2,012	1,518	75.4%	1,825	187	**90.7%**	1,993	19	99.1%
Chukha	4,550	2,565	56.4%	3,987	563	**87.6%**	4,266	284	93.8%
Dagana	3,379	1,019	34.2%	1,874	1,109	**62.8%**	3,179	200	94.1%
Gasa	569	207	36.4%	207	362	**36.4%**	391	178	68.7%
Haa	1,203	926	77.0%	1,108	95	**92.1%**	1,134	69	94.3%
Lhuntse	2,643	1,166	44.1%	1,987	656	**75.2%**	2,349	294	88.9%
Mongar	5,851	2,986	51.0%	4,043	1,808	**69.1%**	5,353	498	91.5%
Paro	4,387	4,213	96.0%	4,270	117	**97.3%**	4,317	70	98.4%
Pemagatshel	2,772	2,129	76.8%	2,599	173	**93.8%**	2,724	48	98.3%
Punakha	2,414	2,139	88.6%	2,139	275	**88.6%**	2,321	93	96.1%
Samdrup Jongkhar	5,574	1,737	31.2%	4,872	702	**87.4%**	5,173	401	92.8%
Samtse	7,879	3,114	39.5%	7,185	694	**91.2%**	7,624	255	96.8%
Sarpang	5,093	2,100	41.2%	3,250	1,843	**63.8%**	4,708	385	92.4%
Thimphu	1,933	1,798	93.0%	1,798	135	**93.0%**	1,812	121	93.7%
Trashigang	8,752	6,546	74.8%	8,413	339	**96.1%**	8,596	156	98.2%
Trashi Yangtse	3,102	1,840	37.8%	3,060	42	**98.6%**	3,067	35	98.9%
Trongsa	1,729	768	45.8%	1,474	255	**85.3%**	1,697	32	98.1%
Tsirang	3,406	812	47.9%	3,235	171	**95.0%**	3,265	141	95.9%
Wangdue phodrang	4,225	2,388	50.0%	2,591	1,634	**61.3%**	3,851	374	91.1%
Zhemgang	2,322	565	24.3%	1,273	1,049	**54.8%**	2,057	265	88.6%
TOTAL	73,795	40,536	56.1%	61,190	12,209	**83.4%**	69,481	3,918	94.7%

All households were forecast number of the year 2007 to calculate electrified percentage, since existing electrified household in 9th fYP was only available in 2007.
Dagana includes 396 households for the replacement of exsisting lines.

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