Benchmark Prices for Solar PV Components and Systems for Nepal

जर्मन सहयोग
DEUTSCHE ZUSAMMENARBEIT

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

This document was produced with funding by Federal Ministry for Economic Cooperation and Development, Germany (BMZ) through Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Published by
Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices Bonn and Eschborn

Promotion of Solar Technologies for Economic Development (POSTED)
NTNC Complex, Khumaltar
Lalitpur, Nepal
P.O. Box 1457
T +977 1-553 8129
E posted@giz.de
I www.giz.de

Developed by
Integration Umwelt & Energie GmbH, Germany

Authors
Muhammad Imran, Germany
Òscar Monés Pederzini, Germany
Ramasubramanian V., India

Review
Kushal Gautam, Kathmandu
Dr. Bharat Poudel, Kathmandu
Felix Nitz, Kathmandu

Coordination
Dr. Bharat Poudel, Kathmandu
Felix Nitz, Kathmandu

Photo credit
Courtesy Pixabay
www.pexels.com/photo/blue-solar-panel-board-356036

Responsible
Felix Nitz, Kathmandu

Kathmandu, December 2022

CONTENTS

Acronyms

AC	Alternating current
BoQ	Bill of quantity
C&I	Commercial and industrial systems
CAPEX	Capital expenditure
DC	Direct current
Km	Kilometre
kW	Kilowatt
kWh	Kilowatt-hour
kWp	Kilowatt-peak
LV	Low voltage
Li-ion	Lithium-ion
NPR	Nepalese Rupees
O&M	Operation & maintenance
OPEX	Operational expenditure
POSTED	Promotion of Solar Technology for Economic Development, a development programme of GIZ
PV	Photovoltaic
RE	Renewable energy
SHS	Solar home systems
SIP	Solar irrigation pumps
SMG	Solar mini-grid
SRT	Solar rooftop (grid-tied)
SSLS	Solar street lighting systems
USD	United States Dollar
W	Watts
Wh	Watt-hour

1. Context

Nepal has been a pioneer in decentralized small, mini, and micro hydropower early on. Though the technology may be robust in electrical and civil engineering, quality issues in the implementation and chronically poor operation & maintenance (O&M) have socialized the cost of energy poverty in communities.

To improve access to electricity, contribute to a reduction of CO_2 emissions, enhance economic development, and improve supply reliability and local capacities, the “Promotion of Solar Technologies for Economic Development” programme (POSTED) supports processes, regulations, standards, and digital tools as well as to build up capacities on national and sub-national level underpinning the paradigm change effectively.

2. Objectives

The overarching objective of the assignment is to generate information regarding costs relevant to actors and development partners in the market for solar PV technologies. Specifically, the assignment seeks to produce current estimates for prices for selected solar PV systems based on their cost in the principal countries of origin while estimating the cost of transport and importation to provide reference points for benchmarking prices in Nepal.

3. Approach and Scope

The following flow chart illustrates the approach and methodology to be applied for this assignment.

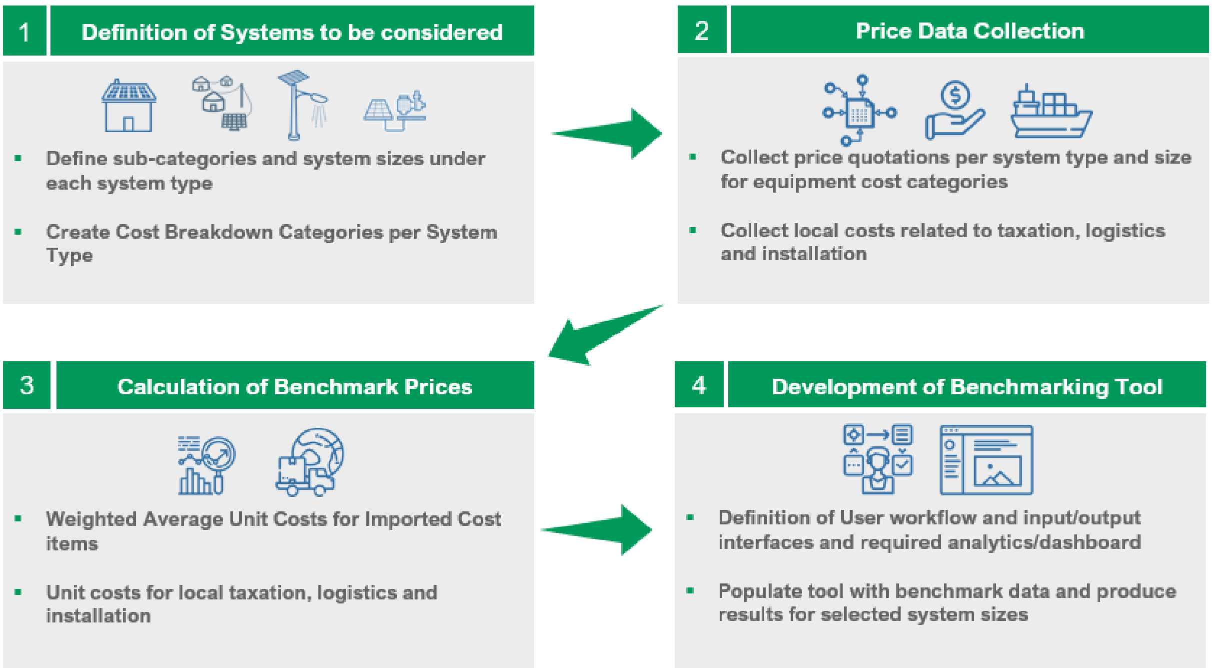


Figure 1: Methodology for cost benchmarking study

After analysing the local context and understanding the type of solar PV systems that are more prevalent in Nepal, the following system types and sub-categories were analysed. The table also illustrates the different components considered under each system configuration.

Table 1: System types and sub-categories

System Types (and sub-categories)	SPV Module	Mounting	CC/ MPPT	Solar Inverter	Battery Inverter	Battery	Fuel Generator	Energy meter	Others/ BOS
Solar Home Systems (SHS) - 0 W to 100 W									
PV DC Coupled	■	■	■			■			■
Residential Solar Rooftop Systems (SRT) - 100 W to 10 kW									
PV + grid *grid-tied PV system*	■	■	■	■					■
PV + grid + storage *grid-tied PV system with storage*	■	■	■	■	■	■		■	■
Commercial & Industrial Solar Systems (C&I) - 10 kW to 300 kW									
PV + grid + storage (10 kW to 100 kW)	■	■	■	■	■	■		■	■
PV + grid + storage (100 kW to 300 kW)	■	■	■	■	■	■		■	■
Solar Mini-Grids (SMG) - 30 kW to 300 kW									
40-60%RE Systems: PV + Storage + Diesel + Grid (optional) *where up to 60% electricity is supplied by PV source and remaining via diesel or grid*	■	■	■	■	■	■	■	■	■
60-80%RE Systems: PV + Storage + Diesel + Grid (optional) *where up to 80% electricity is supplied by PV source and remaining via diesel or grid*	■	■	■	■	■	■	■	■	■
80-100%RE Systems: PV + Storage + Diesel + Grid (optional) *where up to 100% electricity is supplied by PV source and remaining via diesel or grid*	■	■	■	■	■	■	■	■	■
Solar Irrigation Pumping Systems (SIPs) - 1 to 30 kW									
PV *off-grid isolated SIP*	■	■	■	■					■
PV + Storage *off-grid isoloated SIP with storage*	■	■	■	■	■	■			■
Solar Street Lighting Systems (SSLS)									
SSLS Type 2 (Illumination: 20 W)	■	■	■			■			■
SSLS Type 3 (Illumination:30 W)	■	■	■			■			■
SSLS Type 4 (Illumination: 40 W)	■	■	■			■			■

For each system, the required components are defined in the following sections, and the goal is to provide a benchmark cost estimation per component (when available) and for the whole system overall (NPR/kWp). For those systems where the range of sizes is big enough to observe significant economies of scale, several reference sizes are defined.

Based on the primary and secondary data collected, the price estimates are analysed and filtered for each system type. Where needed, outliers are removed to prevent the averages from being skewed disproportionally. Additional specific considerations concerning the benchmarking methodology include:

- **Regional preferences** assume that most of the system installations are likely to procure the equipment from India or China.
- **Extrapolations** for components where linear cost extrapolations are possible and suitable, regression formulas are used to calculate the price points for sizes where no direct data is available.
- **Scenarios to define variable parameters** for systems, especially those involving distribution networks, assumptions are made to create systems with some specific details (e.g., number of connections, kilometre (km) of low voltage (LV) network) to develop cost benchmarks for sample systems sizes.

A simple benchmarking tool is developed in Excel which enables easy usage of the information for cost estimation/benchmarking and allows future refinements of the costs when new data becomes available. The complete methodology along with further details on processing steps is available in Annexe IV. The following table summarizes the sample size for each system type.

Table 2: Sample size per system type

System type	Size of sample
Solar home systems (SHS)	33
Residential solar rooftop systems (SRT)	25
Commercial and industrial solar systems (C&I)	18
Solar mini-grids (SMG)	245
Solar irrigation pumping systems (SIPs)	38
Solar street lighting systems (SSLS)	19
Individual components	190

4. Results and Findings

4.1 Methods for pricing estimation and benchmarking

To perform this study, the first activity has been to collect the required data for the analysis. This data has been acquired through current developer quotations, developer quotations from past projects (one year old or less), academia reports, state-of-the-art handbooks and through live market websites.

Based on the collected data points for the different system types, an in-depth analysis was carried out in the statistical software R to filter the outliers and proceed with only suitable data points. R is an open-source language and environment for statistical computing and graphics. The logic can be downloaded for free here: (https://cran.rstudio.com/), while the interface of RStudio can be also downloaded for free here: (https://posit.co/products/open-source/rstudio/). Upon further inspection, it was observed that calculating simple average costs was not suitable due to the large variation in multiple factors (e.g., size of PV, battery capacity, etc.). Therefore, where relevant, sub-categories were developed for some of the technologies.

Estimation by average (median)

For technologies and/or sub-categories where uniform unit prices were observed, average (median) unit costs were calculated. The choice of using the median value (instead of the arithmetic mean value) was made since it is more suitable for data points with higher variability (which was the case in the study here). The following boxplot illustrates the suitability of using the median for estimating unit costs of SHS. The larger red dot represents the arithmetic mean value which in this case is placed at the 75th percentile because of a few outliers. Using the mean would in this case cause the benchmarking to be highly over-estimated and therefore the median value is a better choice for calculations.

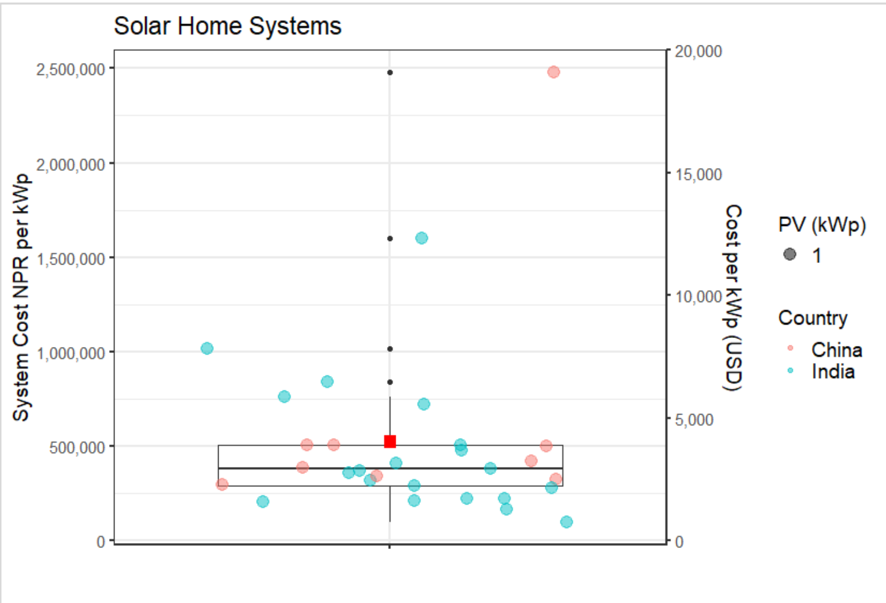


Figure 2: Mean vs. median for datasets with outliers

Estimation by line/curve of best fit

For technologies where uniform unit prices were not observed, a line/curve of best fit was used using regression methods. The first-level analysis of collected price points reveals that linear interpolation is not suitable as the prices of components and systems do not increase proportionally to system size (due to economies of scale effects). At the same time, the relationship is unidirectional, i.e., larger systems will have higher prices. To match this combination of trends, a logarithmic regression is applied to find the curve of best fit. The generic formula for such a regression is as follows:

$$Y = blog_{10}X + a$$

Where,

X = input value (e.g., size of the SIP)	b = gradient
Y = Output value (e.g., cost of SIP)	a = intercept
	ln = log with base 10

The following figure explains the use of this estimation method for the case of solar irrigation pumps (SIP). It can be seen that while linear regression tends to under and overestimate the prices, a logarithmic regression provides a very good tracing of the price points to enable a more accurate estimation of prices for other system sizes without overly simplifying the approximation. The resulting benchmark costs and pricing curves for the respective systems are in the following sections.

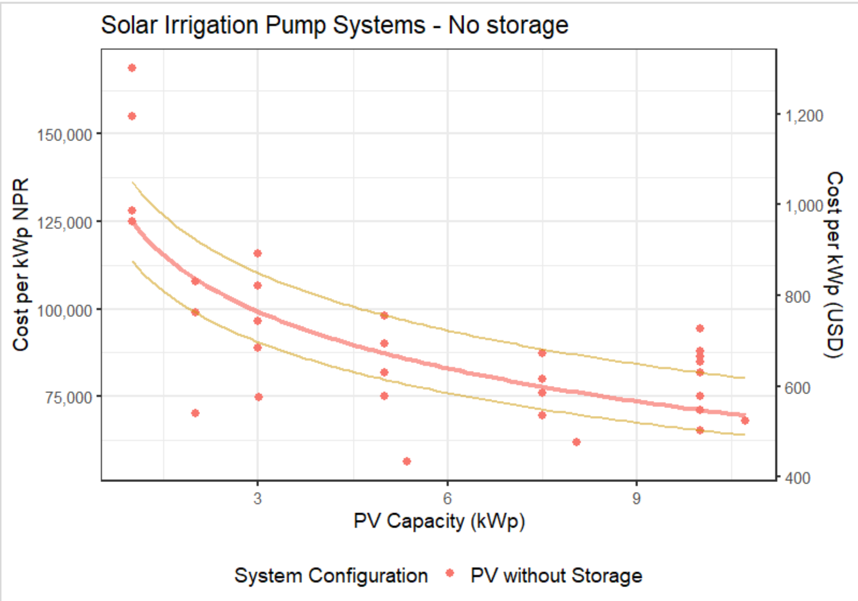


Figure 3: Logarithmic regression for estimating the unit cost of SIP systems

4.2 Component costs

The following table provides the average (median) cost of the major components of PV systems. Boxplots for some of them are presented in Annexe I.

Some relevant comments on the data points and their usage are listed below:

- Pre-paid smart meters: Due to the declining cost difference between traditional meters and new smart meters, only data for smart meters was considered for this study. The prices found in Chinese and Indian markets were often lower than in Africa due to lower shipping costs.
- Distribution network: The costs for an LV network in a mini-grid is highly dependent on the physical layout and density of the community. Large spread-out settlements (as can be expected in mountainous regions) would tend to require more meters of cabling per connection.

The benchmark value provided here provides a rough estimate based on actual planned and implemented mini-grids, but the value should still be taken with caution. It is advisable to consider the actual costs on a project-by-project basis by comparing the unit costs of items (e.g., cables, and poles) from the bill of quantity (BoQ).

Table 3: Component unit costs

Component	Cost in USD	Unit
Solar panel	330	USD/kWp
Solar mounting (ground)	62	USD/kWp
Solar inverter	180	USD/kW
Battery storage (Li-ion)	380	USD/kWh
Battery inverter	205	USD/kW
Back-up diesel generator	245	USD/kW
Pre-paid smart meter	50	USD/connection
LV distribution network	20,000	USD/km

4.2.1 Comparison to Nepal prices

The following figure shows how the information found for internationally procured component costs compares to retail prices in Nepal.

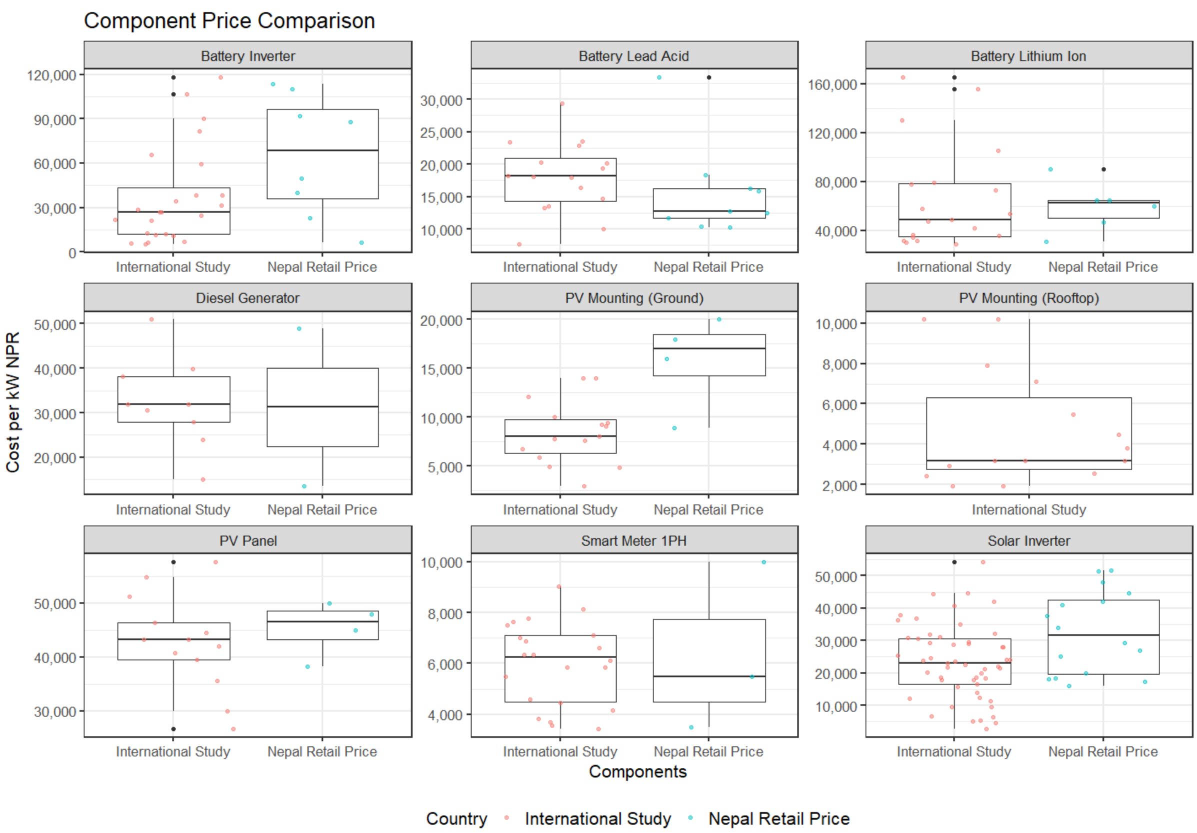


Figure 4: Component cost comparisons

The observations from the component cost comparisons are the following:

- Most components are slightly more expensive if procured in Nepal.
- In some cases, the variability is high. Battery inverters, lithium-ion batteries, PV mounting structures, PV panels and solar inverters cost considerably more in Nepal than the average cost considering international data.
- For diesel generators and smart meters, there does not seem to be an obvious difference in pricing. Finally, the quotations for lead acid batteries from Nepalese companies seem to be lower than the mean values obtained internationally.

The table below shows the mean values per unit cost for both internationally sourced components as well as for quotations for components purchased in Nepal.

Table 4: Mean values of per unit cost for both internationally sourced components and components purchased in Nepal

Component	International data	Nepal retail price	Unit	Nepali retail prices are higher by
Solar panel	330	350	USD/kWp	6%
Solar mounting (ground)	62	120	USD/kWp	94%
Solar inverter	180	250	USD/kW	39%
Battery storage (Li-ion)	380	460	USD/kWh	21%
Battery storage (Lead-acid)	126	98	USD/kWh	-22%
Battery inverter	205	420	USD/kW	105%
Back-up diesel generator	245	250	USD/kW	2%
Pre-paid smart meter	50	50	USD/connection	0%

The Nepali retail prices presented above are for indicative comparison only. The rest of the analysis presented in the report is based only on international price data. The conversion to NPR in the following sections is also for reference only. For components such as solar and battery inverters, a combination of high end and medium end products as been considered to keep the comparison consistent with the international data gathering approach.

Table 5: Typical sizes of components and cost comparison for internationally sourced data and Nepal retail prices

Component	Size	Unit	International price (NPR)	Nepal retail price (NPR)	Nepali retail price overcost	
Solar Panel 50 W	0.05	kWp	2,143	2,273	6%	*
Solar Panel 100W	0.10	kWp	4,287	4,547	6%	*
Solar Panel 130 W	0.13	kWp	5,573	5,910	6%	*
Solar Panel 300 W	0.30	kWp	12,860	13,640	6%	*
Solar Panel 350 W	0.35	kWp	15,003	15,913	6%	*
Solar Mounting (Ground)	1	kWp	8,054	15,588	94%	*
Solar Mounting (Ground)	5	kWp	40,269	77,940	94%	*
Solar Inverter 5 kW	5	kW	116,910	173,500	48%	
Solar Inverter 10 kW	10	kW	233,820	309,844	33%	
Storage Li Ion 1.2 kWh	1.2	kWh	59,234	71,705	21%	
Storage Li Ion 4.8 kWh	4.8	kWh	236,938	286,819	21%	
Storage 1.2 kWhFlooded	1.2	kWh	19,641	15,000	-24%	
Storage 2.4 kWh Flooded	2.4	kWh	39,282	25,070	-36%	
Storage 1.2 kWh Gel	1.2	kWh	19,641	16,500	-16%	
Storage 2.4 kWh Gel	2.4	kWh	39,282	33,000	-16%	
Battery Inverter 10 kW	10	kW	266,295	405,000	52%	
Battery Inverter 25 kW	25	kW	665,738	960,500	44%	
Back-up Diesel Gen 1 kW	1	kW	31,826	32,475	2%	*
Back-up Diesel Gen 10 kW	10	kW	318,255	324,750	2%	*
Prepaid Smart Meter	1	unit	6,500	6,500	0%	*

** Is for prices calculated using unit cost quotations.*

4.3 Other costs

In addition to the costs of the equipment (which were based on supplier quotations), the remaining cost of the systems are divided into the following three categories and are expressed as % of the total equipment costs. The values are derived from available quotations for actual systems as well as other industry benchmarks (in particular, the recently published World Bank handbook for mini-grids: *Energy Sector Management Assistance Program. 2022. Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers. Washington, DC: World Bank.*

The reason for this level of estimation is that such costs are often dependent on the size of the order, the delivery time allowed and prevailing market conditions for the logistics. It is suggested that the percentage points are adjusted as and when more accurate estimations are available for specific use cases.

Table 6: Other costs by system type

Other costs	SHS	SRT	C&I	SMG	SIP	SSLS
Logistics	5%	5%	5%	5%	5%	5%
Installation	5%	10%	10%	10%	10%	10%
Balance of System	-	-	2%	2%	2%	-

4.4 Solar home systems

System sizes	0 to 100 W (DC systems)
Estimation method	Average (median) price per W
Sub-categories	Not applicable: only DC systems considered

Sub-categories	NPR/kWp	USD/kWp
DC with battery	375,000	2,885

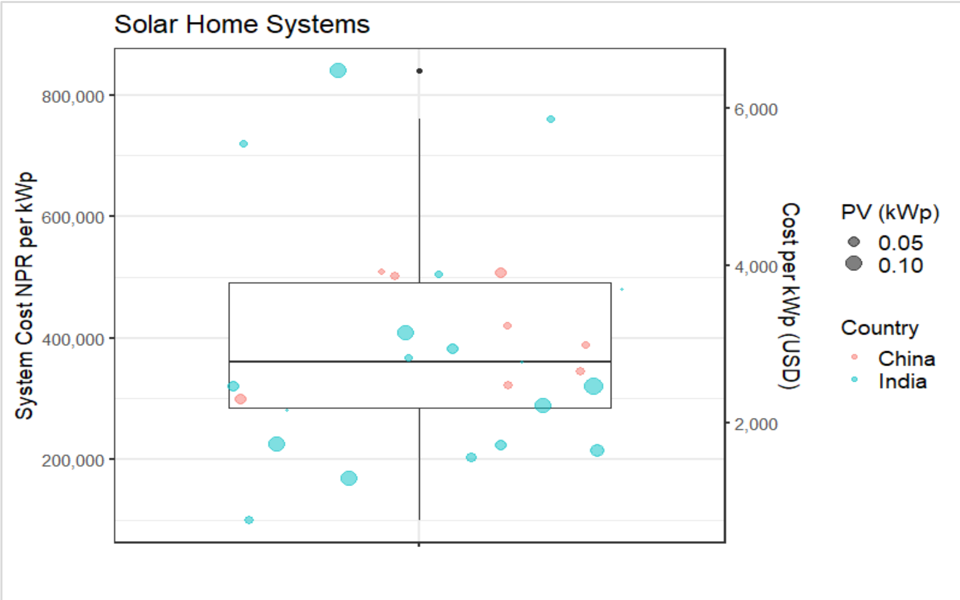


Figure 5: Boxplot of SHS equipment costs

Remarks:

- Due to a very established market for SHS, there was high variability in packages of SHS (number of light bulbs included, USB ports, fan, etc.).
- No significant difference was found between the Chinese and Indian markets.
- Due to the small range of sizes (10 Wp –100 Wp), no economy of scale was observed for this technology in terms of PV size.
- Economies of scale could be found in the size of the ordered lot, but for this assignment project-related lots were considered (100 – 500 units) and only one unit price is used to avoid artificially reducing prices for larger quantities.
- The recommendation would be to focus on 50 Wp or larger systems since the smaller ones are likely to become insufficient rapidly and pose a waste management risk.

Table 7 provides resulting benchmark prices for some sample system sizes.

Table 7: Solar home systems - Benchmark prices for sample system sizes

System specifications	Price (NPR)	Price (USD)	System specifications	Price (NPR)	Price (USD)
10 W	4,000	30	60 W	25,000	190
20 W	8,500	70	70 W	29,000	220
30 W	12,500	100	80 W	33,000	250
50 W	20,500	160	90 W	37,000	280
55 W	22,500	160	100 W	41,500	320

4.5 Solar rooftop systems

System sizes	100 W to 10 kW (AC systems)
Estimation method	Average (median) price per kWp
Sub-categories	(a) Without battery (b) With battery

Sub-categories	NPR/kWp	USD/kWp
Without Battery	73,000	560
With Battery	116,000	890

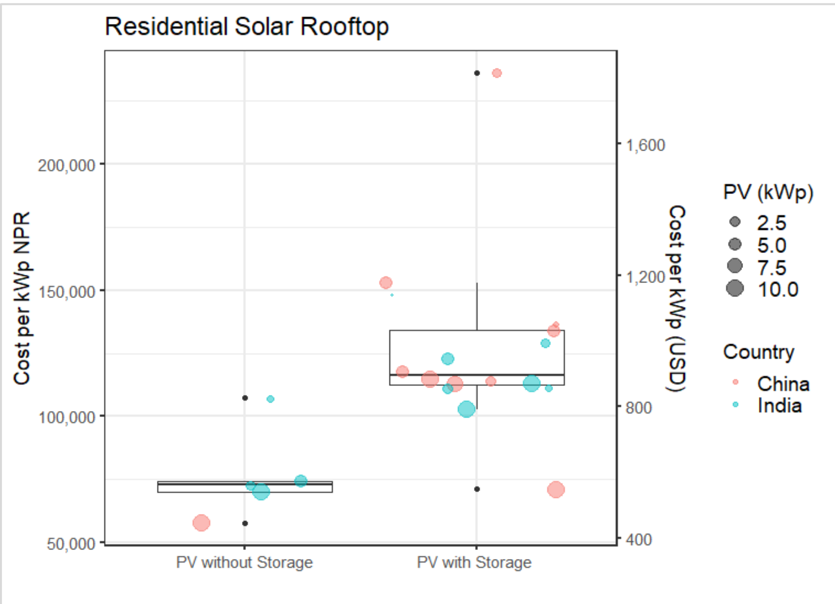


Figure 6: Boxplot of SRT categorized into systems with and without battery storage

Remarks:

- Within this range of technologies (100 Wp to 10 kW), no significant economies of scale are observed.
- The variability in systems in this case is already reduced compared to SHS.

- The most relevant difference in cost is the inclusion of battery storage.
- Provided the size and nature of these systems, many can be found in areas with good grid supply and used to mainly reduce electrical bills, so it is common to have them also without storage options.

Table 8 and Table 9 provides resulting benchmark prices for some sample system sizes.

Table 8: Solar rooftop systems without battery - benchmark prices for sample system sizes

System specifications	Price (NPR)	Price (USD)	System specifications	Price (NPR)	Price (USD)
1 kW PV	85,000	650	6 kW PV	512,000	3,950
2 kW PV	171,000	1,300	7 kW PV	598,000	4,600
3 kW PV	256,000	1,950	8 kW PV	683,000	5,250
4 kW PV	342,000	2,650	9 kW PV	769,000	5,900
5 kW PV	427,000	2,650	10 kW PV	854,000	6,550

Table 9: Solar rooftop systems with battery - benchmark prices for sample system sizes

System specifications	Price (NPR)	Price (USD)	System specifications	Price (NPR)	Price (USD)
1 kW PV + battery	136,000	1,050	6 kW PV + battery	814,000	6,250
2 kW PV + battery	271,000	2,100	7 kW PV + battery	950,000	7,300
3 kW PV + battery	407,000	3,150	8 kW PV + battery	1,086,000	8,350
4 kW PV + battery	543,000	4,200	9 kW PV + battery	1,221,000	9,400
5 kW PV + battery	679,000	4,200	10 kW PV + battery	1,357,000	10,450

4.6 Commercial and industrial systems (grid-tied)

System sizes	10 kW to 300 kW
Estimation method	Average (median) price per kWp
Sub-categories	(a) Systems below 100 kW (b) Systems above 100 kW

Sub-categories	NPR/kWp	USD/kWp
Small C&I (x < 100 kWp)	69,000	530
Large C&I (x > 100 kWp)	58,000	445

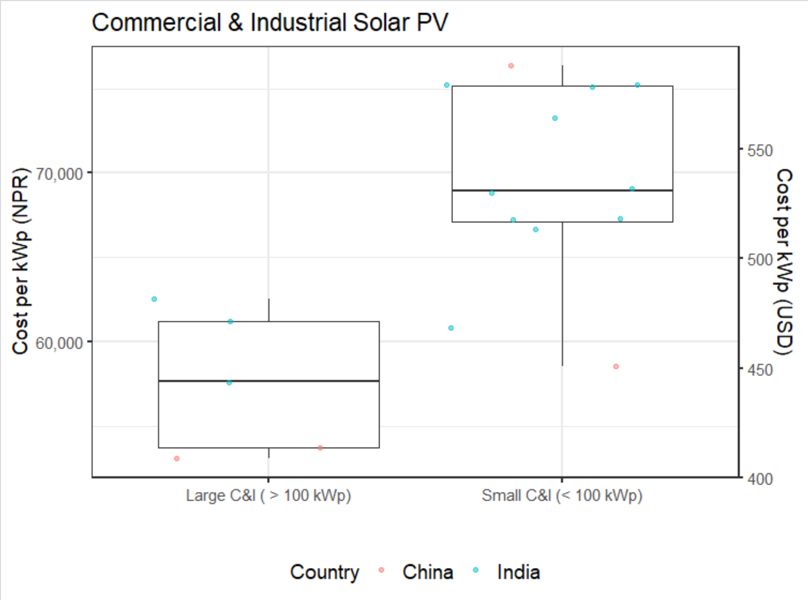


Figure 7: Boxplot of C&I grid-tied equipment costs categorized into small and large systems

Remarks:

- The main difference between commercial and industrial grid-tied solar systems is observed in the size of the installation since these systems are big enough to show economies of scale.
- Therefore, two sub-categories are proposed for cost benchmarking, 10-100 kW and 100-300 kW.
- The systems here provided include no storage since most installations of this size are often found in areas with grid supply and mostly with a backup generator.
- In areas with bad grid supply, storage can be included for C&I solutions as well, and to quantify how a significant storage bank would affect the price, the benchmarking costs found in the component section can be used as a proxy.

Table 10 provides resulting benchmark prices for some sample system sizes.

Table 10: Commercial and industrial grid-tied systems - benchmark prices for sample system sizes

System specifications	Price (NPR)	Price (USD)	System specifications	Price (NPR)	Price (USD)
10 kWp	807,000	6,200	**125 kWp**	8,483,000	65,250
20 kWp	1,615,000	12,400	**150 kWp**	10,179,000	78,300
30 kWp	2,422,000	18,650	**200 kWp**	13,572,000	104,400
60 kWp	4,844,000	37,250	**250 kWp**	16,965,000	130,500
100 kWp	6,786,000	51,800	**300 kWp**	20,358,000	156,600

4.7 Solar mini-grids

System sizes	30 kW to 300 kW
Estimation method	Average (median) price per kWp for generation system, meter cost per connection and distribution network cost per km of grid
Sub-categories	(a) High RE fraction 80-100% (b) Medium RE fraction 60-80% (c) Low RE fraction 40-60%

Generation system	NPR/kWp	USD/kWp
High RE (80-100%)	236,000	1,815
Medium RE (60-80%)	201,000	1,545
Low RE (40-60%)	185,000	1,425

Meters	NPR/connection	USD/connection
Pre-paid smart meter	6,500	50

Distribution network	NPR/km	USD/km
LV Network	2,600,000	20,000

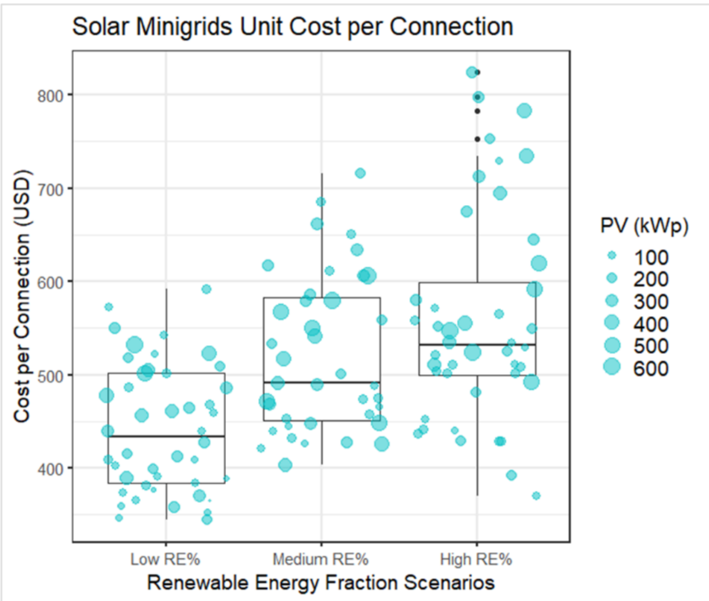


Figure 8: Boxplot of mini-grid costs categorized by RE faction

Remarks:

- Generally, mini-grid prices cannot be benchmarked on any single matrix (e.g., installed PV capacity). This is because various factors affect the component costs.
- For purposes of this assignment, generation system costs are benchmarked on installed PV capacity, meter costs on the number of connections and distribution network costs on a kilometre of the grid line.
- While only systems of 30 kW and 300 kW are presented below, further insights on general trends in system types and related costing for mini-grids are presented in Annexe II. They are useful for getting a deeper understanding of the cost dynamics for such complex systems.

Table 11 provides resulting benchmark prices for some sample system sizes.

Table 11: Solar mini-grids - benchmark prices for sample system sizes

System specifications	Price (NPR)	Price (USD)	System specifications	Price (NPR)	Price (USD)
30 kW, Low RE, 200 connections, 2.5 km grid	15,620,000	120,150	300 kW, Low RE, 1,000 connections, 2.5 km grid	102,960,000	792,000
30 kW, Mid RE, 200 connections, 2.5 km grid	16,181,000	124,450	300 kW, Mid RE, 1,000 connections, 2.5 km grid	108,576,000	835,200
30 kW, High RE, 200 connections, 2.5 km grid	17,410,000	318,600	300 kW, High RE, 1,000 connections, 2.5 km grid	120,861,000	929,700

Detailed breakdowns of the cost benchmarking for sample 30 kW and 300 kW systems are presented next. The systems are only exemplary and the final cost depends on the combination of installed PV capacity, the number of connections expected and the total length of the distribution network.

30 kW mini-grid (High RE, 200 connections, 2.5 km grid)

Table 12: Breakdowns of the cost benchmarking for sample 30 kW solar mini-grid

30 kWp Minigrid	Number of Connections		200		
100 % RE Scenario	km of Distribution line		2.5		
Categories	Benchmark Costs		Sizing	Unit	Cost
Solar Panel	330	USD/kWp	30	kWp	$9,900
Solar Mounting (Ground)	62	USD/kWp	30	kWp	$1,860
Solar Inverter	180	USD/kW	30	kWp	$5,400
Battery Storage (Li ion)	380	USD/kWh	60	kWh	$22,800
Battery Inverter	205	USD/kW	15	kW	$3,075
Back- Up Diesel Generator	245	USD/kW	10	kW	$2,450
Metering	50	USD/conn.	200	conn	$10,000
Distribution Network	20,000	USD/km	2.5	km	$50,000
Soft Costs					
Logistics	5%	of total Cost			$6,511
Installation	10%	of total Cost			$13,023
Land Acquisition	2.0%	of total Cost			$2,605
BOS	2.0%	of total Cost			$2,605
Total	130,228	USD			
Total Cost per Connection	723	USD / connection			
Total Cost per kWp	4,341	USD / kWp			

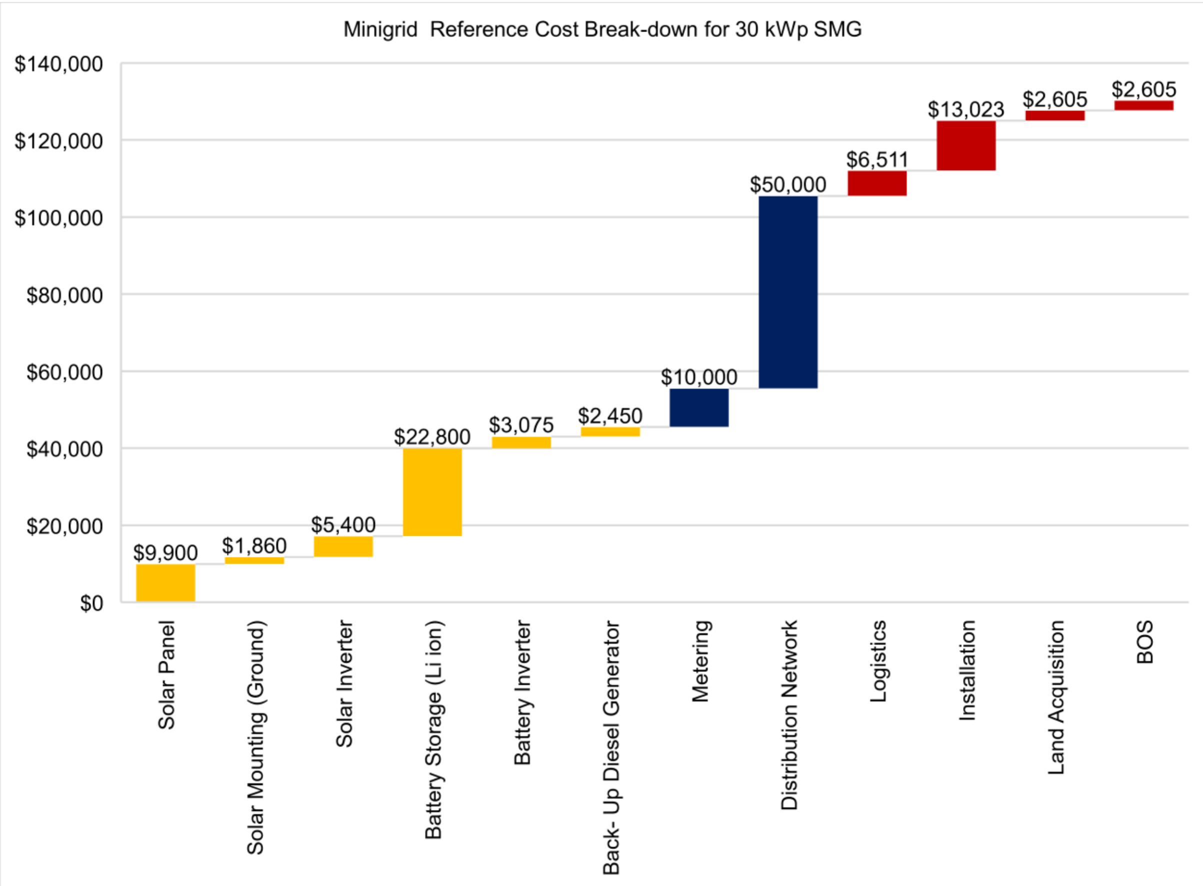


Figure 9: Cost breakdown of exemplary 30 kW mini-grid

300 kW mini-grid (High RE, 1,000 connections, 10 km grid)

Table 13: Breakdowns of the cost benchmarking for sample 300 kW solar mini-grid

300 kWp Minigrid	Number of Connections	1000			
100 % RE Scenario	km of Distribution line	10.0			
Categories	**Benchmark Costs**		**Sizing**	**Unit**	**Cost**
Solar Panel	330	USD/kWp	300	kWp	$99,000
Solar Mounting (Ground)	62	USD/kWp	300	kWp	$18,600
Solar Inverter	180	USD/kW	300	kWp	$54,000
Battery Storage (Li ion)	380	USD/kWh	600	kWh	$228,000
Battery Inverter	205	USD/kW	150	kW	$30,750
Back- Up Diesel Generator	245	USD/kW	100	kW	$24,500
Metering	50	USD/conn.	1000	conn	$50,000
Distribution Network	240	USD/km	10	km	$252,000
Soft Costs					
Logistics	5%	of total Cost			$47,303
Installation	10%	of total Cost			$94,606
Land Acquisition	2.0%	of total Cost			$18,921
BOS	3.0%	of total Cost			$28,382
Total	946,063	USD			
Total Cost per Connection	901	USD / connection			
Total Cost per kWp	3,154	USD / kWp			

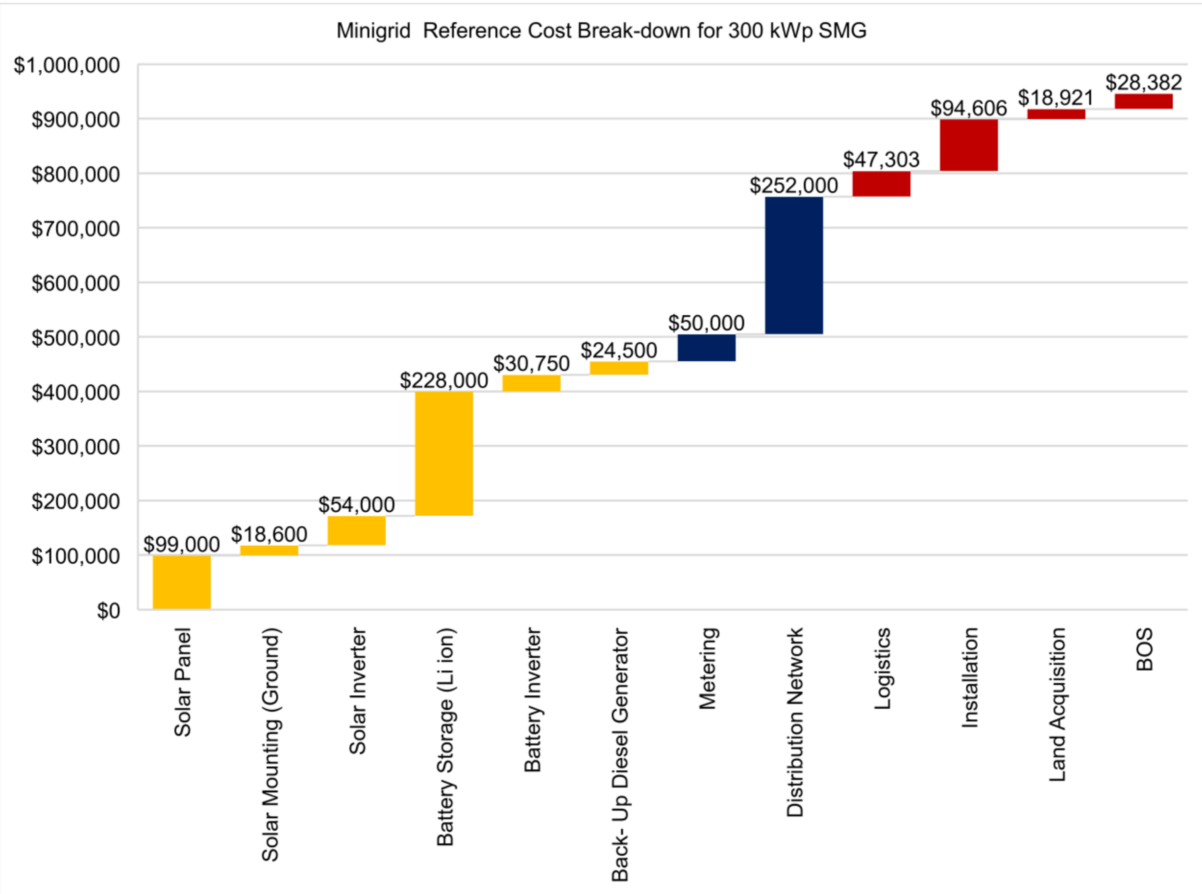


Figure 10: Cost breakdown of exemplary 300 kW mini-grid

4.8 Solar irrigation pumping systems

System sizes	1 to 30 kW (DC systems)
Estimation method	Logarithmic curve of best fit for cost per kWp
Sub-categories	(a) Without battery storage (b) Without battery storage

Sub-categories	Intercept (a)	Gradient (b)
Without battery	124,859	- 53,753
With battery	150,471	- 43,700

$$Y = b\,log_{10}\,X + a$$

Where,

X = input value (e.g., size of the SIP)

Y = Output value (e.g., cost of SIP)

b = gradient

a = intercept

ln = log with base 10

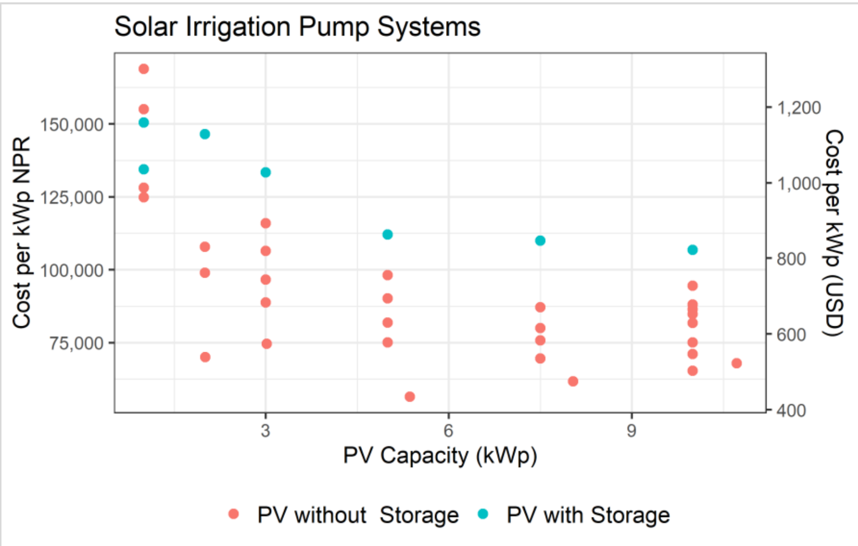


Figure 11: Spread of SIP unit costs categorized into systems with and without battery storage

Remarks:

- The initial screening showed two main findings: a clear difference in price for those systems with and without storage, and a non-linear descent in unit price as the system size increased.
- For this reason, the analysis is separated based on the system configuration, and a logarithmic regression is used to estimate the cost per kWp of the solar irrigation systems.
- The quotations collected were for small systems (1-10 kW) and caution should be exercised when estimating cost for larger systems.

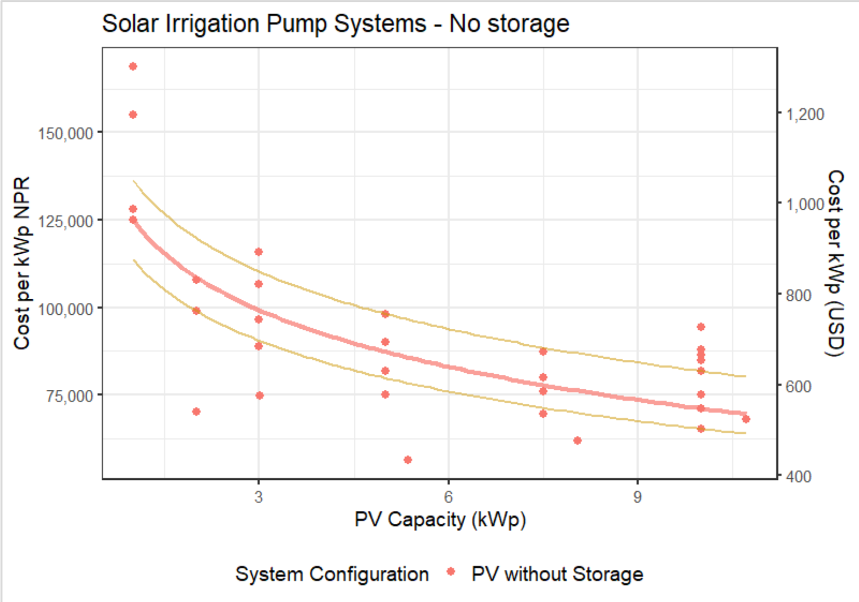


Figure 12: Curve of best fit for SIP systems without battery storage

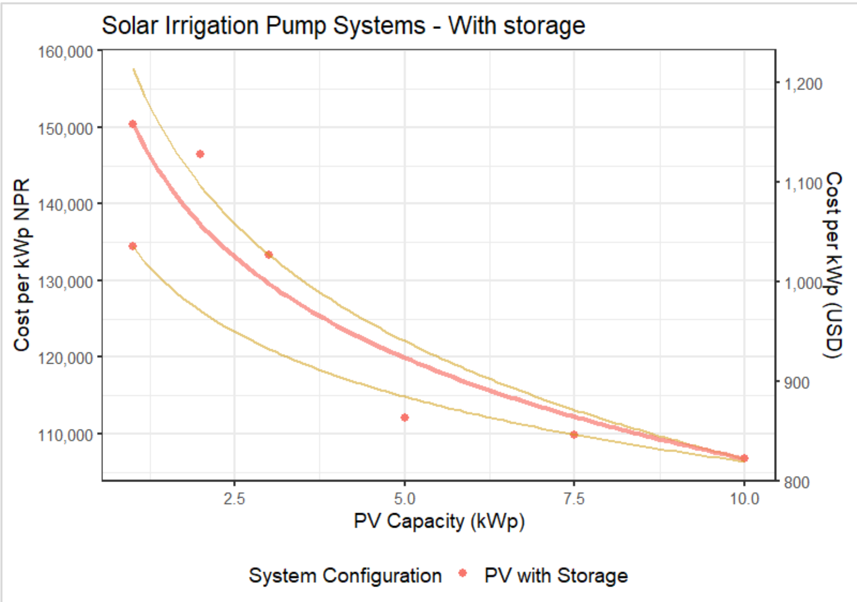


Figure 13: Curve of best fit for SIP systems with battery storage

Table 14 provides resulting benchmark prices for some sample system sizes.

Table 14: Solar irrigation pumps without battery - benchmark prices for sample system sizes

System specifications	Price (NPR)	Price (USD)	System specifications	Price (NPR)	Price (USD)
1 kW PV	146,000	1,100	10 kW PV	832,000	6,400
2 kW PV	254,000	1,950	15 kW PV	1,082,000	8,300
4 kW PV	433,000	3,350	20 kW PV	1,285,000	9,900
6 kW PV	583,000	4,500	25 kW PV	1,454,000	11,200
8 kW PV	714,000	4,500	30 kW PV	1,596,000	12,300

Table 15: Solar irrigation pumps with battery - benchmark prices for sample system sizes

System specifications	Price (NPR)	Price (USD)	System specifications	Price (NPR)	Price (USD)
1 kW PV + battery	264,000	2,050	10 kW PV + battery	1,874,000	14,400
4 kW PV + battery	482,000	3,700	15 kW PV + battery	2,608,000	20,050
8 kW PV + battery	872,000	6,700	20 kW PV + battery	3,286,000	25,300
6 kW PV + battery	1,226,000	9,450	25 kW PV + battery	3,922,000	30,150
8 kW PV + battery	1,559,000	9,450	30 kW PV + battery	4,524,000	34,800

The systems included above consider only electromechanical components. For standardisation purposes, components such as collection reservoirs, water pipes or distribution reservoirs are not included.

4.9 Solar street lighting

System sizes	20, 30 and 40 W Illumination systems
Estimation method	Average (median) price per W
Sub-categories	(a) Type 2 [20 W] (b) Type 3 [30 W] (c) Type 4 [40 W]

Sub-categories	NPR/kWp	USD/kWp
Type 2	15,000	115
Type 3	25,000	190
Type 4	30,000	230

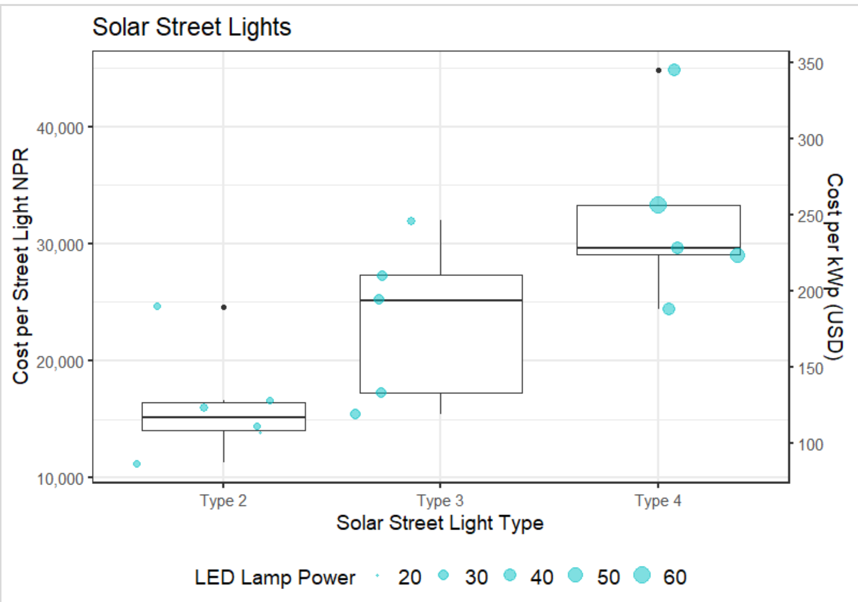


Figure 14: Box plot of SSLS costs categorized by system types

Remarks:

- Due to large variations in systems found in the market, the assessment considers the available systems via the illumination of the bulbs to provide a uniform basis for comparison instead of the PV panel size.
- No information was found on generic centralized systems. It is recommended to consider bundles or types 2, 3 and 4 for creating customized purchase orders for larger systems.
- Alternatively, if the lighting is to be powered via a mini-grid or from a central grid supply, the cost of the relevant equipment can be considered separately. For mini-grids, it is typical to consider street lighting as an item of public utility and its cost is considered as a CAPEX item without charging the consumers directly for it. Its expense is indirectly recovered via the tariff.

Table 16 provides resulting benchmark prices for some sample system sizes.

Table 16: Solar street lights - benchmark prices for sample system sizes

System specifications	Price (NPR)	Price (USD)	System specifications	Price (NPR)	Price (USD)
Type 2 – 100 pieces	1,725,000	13,250	**Type 2 – 500 pieces**	8,625,000	33,200
Type 3 – 100 pieces	2,875,000	22,100	**Type 3 – 500 pieces**	14,375,000	55,300
Type 4 – 100 pieces	3,450,000	26,550	**Type 4 – 500 pieces**	17,250,000	66,350

5. Use of the Price Estimation Tool

The different modules of the tool are presented below along with some basic instructions on proper usage and possible future improvements.

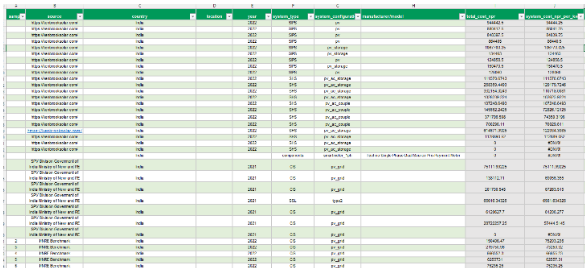
Data input module

Purpose

Entering price quotations for the different system types

Details

The sheet works as the main database which is used for analyzing the trends and creating sub-categories for each technology.



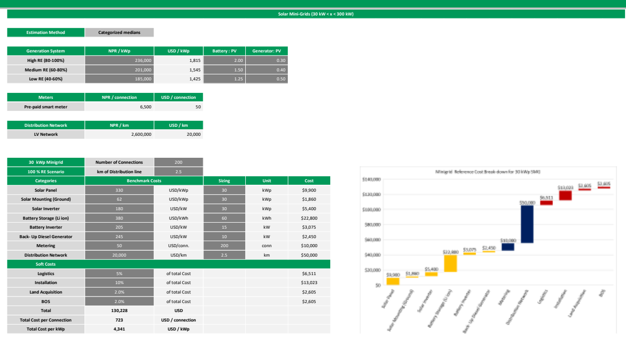
Calculation module

Purpose

Contains formulas for price benchmarking

Details

Based on the analysis of data carried out in the statistical software tool R, average (median) benchmark values and coefficients for curves of best fit are inserted in this sheet to function as the basis for calculating costs of desired system sizes.



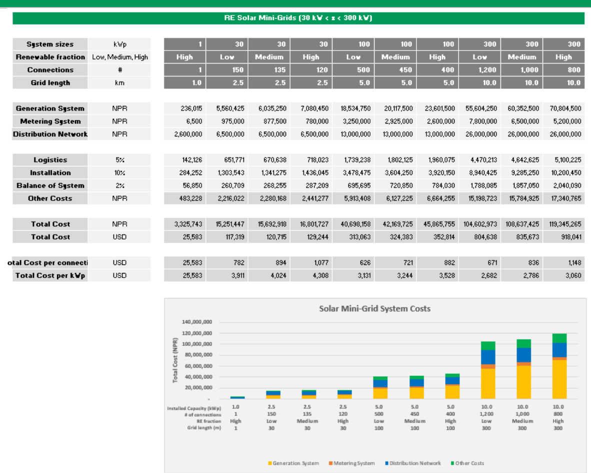
Results module

Purpose

Display results based on selected system and size

Details

Grey cells are input cells where the user can provide desired system types, sizes and further characteristics (e.g., number of connections). The tool then calculates the pricing for the systems and presents them in a tabular as well as graphical manner.



RE Solar Mini-Grids (30 kW < x < 300 kW)

System sizes	kWp	1	30	30	30	100	100	100	300	300	300
Renewable fraction	Low, Medium, High	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Connections	#	1	150	135	120	500	450	400	1,200	1,000	800
Grid length	km	1.0	2.5	2.5	2.5	5.0	5.0	5.0	10.0	10.0	10.0
Generation System	NPR	236,015	5,560,425	6,035,250	7,080,450	18,534,750	20,117,500	23,601,500	55,604,250	60,352,500	70,804,500
Metering System	NPR	6,500	975,000	877,500	780,000	3,250,000	2,925,000	2,600,000	7,800,000	6,500,000	5,200,000
Distribution Network	NPR	2,600,000	6,500,000	6,500,000	6,500,000	13,000,000	13,000,000	13,000,000	26,000,000	26,000,000	26,000,000
Logistics	5%	142,126	651,771	670,638	718,023	1,739,238	1,802,125	1,960,075	4,470,213	4,642,625	5,100,225
Installation	10%	284,252	1,303,543	1,341,275	1,436,045	3,478,475	3,604,250	3,920,150	8,940,425	9,285,250	10,200,450
Balance of System	2%	56,850	260,709	268,255	287,209	695,695	720,850	784,030	1,788,085	1,857,050	2,040,090
Other Costs	NPR	483,228	2,216,022	2,280,168	2,441,277	5,913,408	6,127,225	6,664,255	15,198,723	15,784,925	17,340,765
Total Cost	NPR	3,325,743	15,251,447	15,692,918	16,801,727	40,698,158	42,169,725	45,865,755	104,602,973	108,637,425	119,345,265
Total Cost	USD	25,583	117,319	120,715	129,244	313,063	324,383	352,814	804,638	835,673	918,041
otal Cost per connecti	USD	25,583	782	894	1,077	626	721	882	671	836	1,148
Total Cost per kWp	USD	25,583	3,911	4,024	4,308	3,131	3,244	3,528	2,682	2,786	3,060

Legend
Input Cells: The User needs to provide an input here or select from drop down list
Intermediate Cells: These cells are used for intermediate calculations and should not be changed by the user
Results: The cells with this color provide the final results of the calculation

6. Conclusions and Recommendations

The assignment looked at PV price data from India, China, and other countries to develop benchmark prices for various PV technologies relevant to Nepal. Some relevant observations are listed below:

- The study provides a good overview of prevailing technologies in the market and characterises the systems into logical sub-categories for price benchmarking. In particular, it acknowledges that for complex systems such as mini-grids, the price benchmarking must consider multiple system compositions (RE share) and network layouts.
- While the analysis provided under this assignment is considered relatively robust (since it is based on multiple sources for data collection and the sector experience of the experts), the analysis is only as good as the data collected. Therefore, future revisions can improve upon this by collecting more data points for the various technologies and sub-system categories.
- The assignment concentrated primarily on equipment prices obtained from suppliers. Further value chain costs (e.g., international shipping, inland transport, etc.) were estimated as a percentage of equipment prices to get a ballpark figure. However, it must be acknowledged that these costs are often variable and depend on multiple factors such as order size, prevailing market conditions of supply and demand parity and other logistical aspects (e.g., COVID-19, global or regional conflicts).
- One of the main findings is the difference in cost between several components internationally and their retail price when procured in Nepal. The general trend has been that components purchased in Nepal are more expensive or the same as internationally. If we divide these differences into sub-groups, we observe the following:
    - Solar mounting structures and electronic components such as batteries and solar inverters have a significant over cost ranging from 75% - 105 % when purchased in Nepal.
    - Based on the obtained quotations, lithium-ion storage batteries are approximately 20% more costly when purchased in Nepal.
    - There are a few components where no significant difference in cost is observed. These include solar panels, backup diesel generators and smart meters.
    - Finally, based on the data collected only one component seems to be less expensive when procured in Nepal. These are lead-acid batteries. The identified price for lead-acid batteries in Nepal is 20% cheaper compared to the international unit cost.

Based on the learning from this assignment and the developed database and tool, the following future improvements can be considered:

- Collection of quotations from Nepali vendors/retailors can help to make a better estimation of logistic and installation costs of the various systems
- The current data analysis is done in R for easier processing of collected data which came in various forms and levels of detail. The development of data collection forms to collect prices with uniform granularity will enable easier data processing directly in the Excel tool.
- The database should be updated after approximately 8-12 months since the impending international inflation is likely to cause a further escalation in prices and the current estimates might not provide a good overview of the market conditions at that time in future.

- Based on actual systems from Nepal, the sub-categories under each technology could be revised to better capture the more important market segments. In particular, site-specific characteristics of mini-grids should be considered to estimate distribution network and installation costs.
- For large-scale solar technologies, it has been observed the size of the purchased lot has a significant effect on the unit cost of the main components. This assignment has considered lot sizes in the order of a project, but further savings could be obtained if addressed as a programme and considering larger lots.

Annex I: Boxplots of Costs of Selected Components

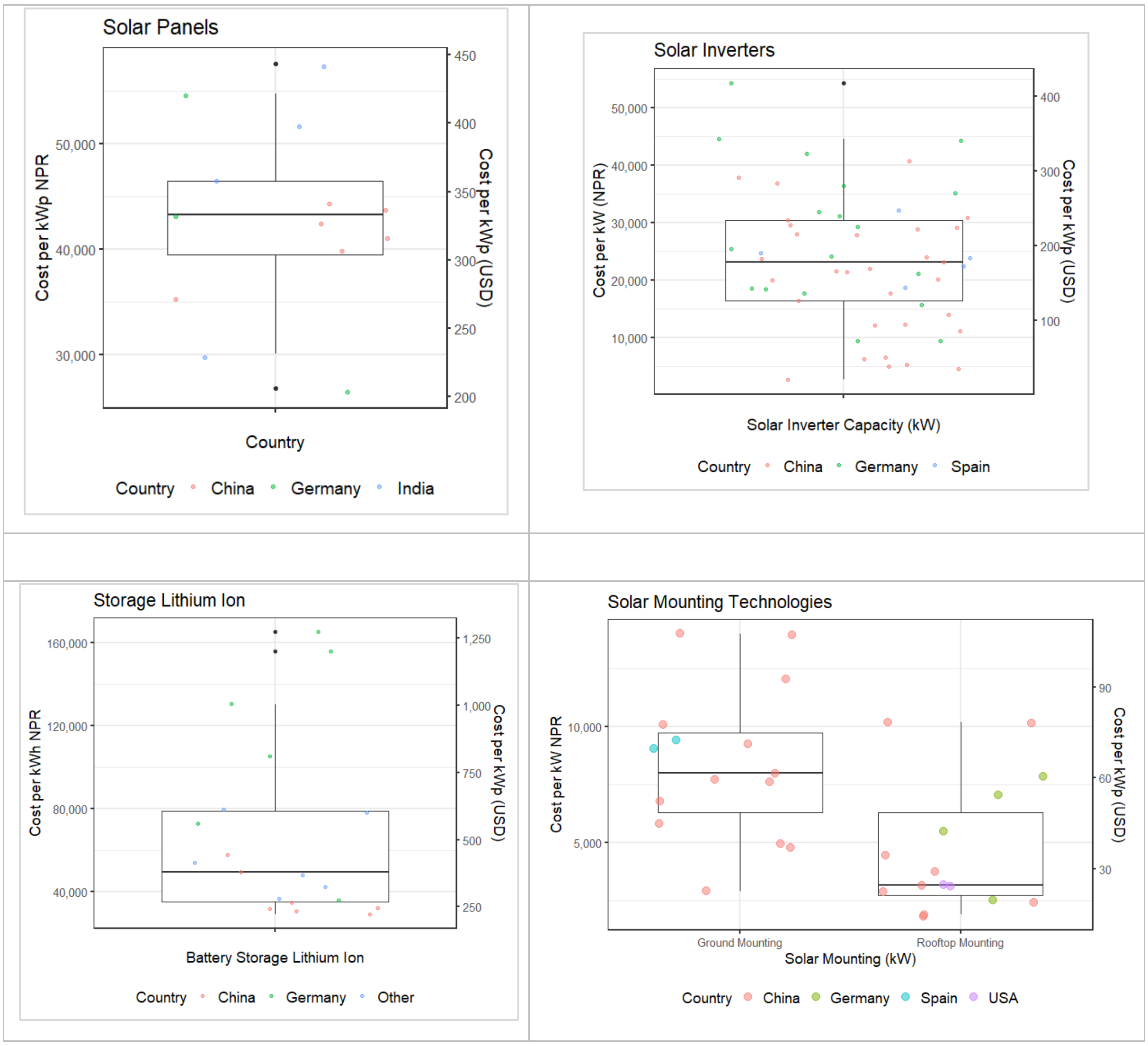


Figure 15: Boxplots for some component costs

Annex II: Further Insights into Mini-Grid Systems and Costs

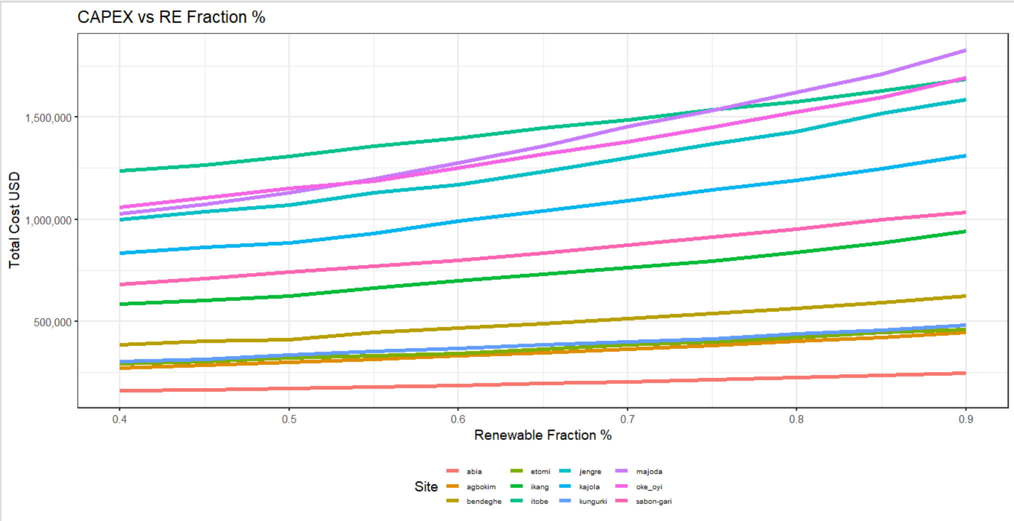


Figure 16: Same system at different RE% scenarios

In Figure 16, each line of colour represents the same system in different RE% scenarios. The fixed costs are the same and the generation asset costs increase as the RE% increases, contrary to OPEX costs in diesel.

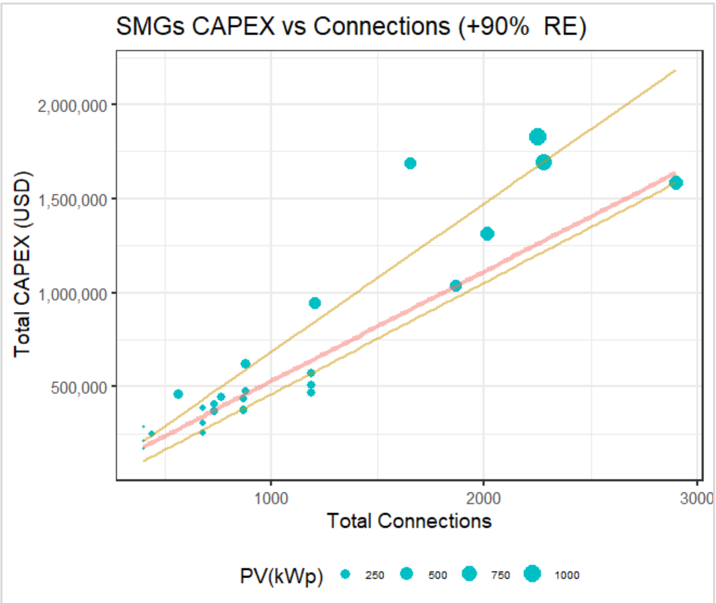


Figure 17: Relationship between total CAPEX and total connections

Mini-grids can have very diverse configurations or renewable energy fractions. Any selected approach has impacts on CAPEX and OPEX. For this reason, to be able to compare investment costs, similar systems should be looked at. In this case, we look at solar mini-grids with storage and a renewable energy fraction of 90% or more. It can be observed that there is a strong relationship between total CAPEX and total connections. However, this could also vary, depending on population density or average energy consumption per connection.

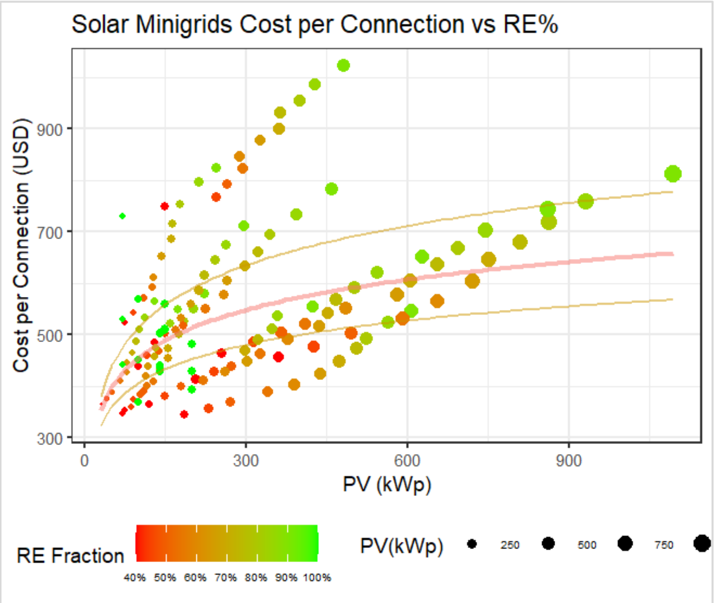


Figure 18: Cost per connection compared to the total installed capacity

Figure 18 shows the cost per connection compared to the total installed solar capacity in kWp. The colour shows the renewable energy fraction. For similar systems, it can be observed how a higher renewable energy fraction often leads to higher costs per connection, since they require more renewable energy assets to deliver the same amount of energy. What this graph fails to show is the impact these greener systems have on lowering the OPEX and the impact on the project's financial viability overall.

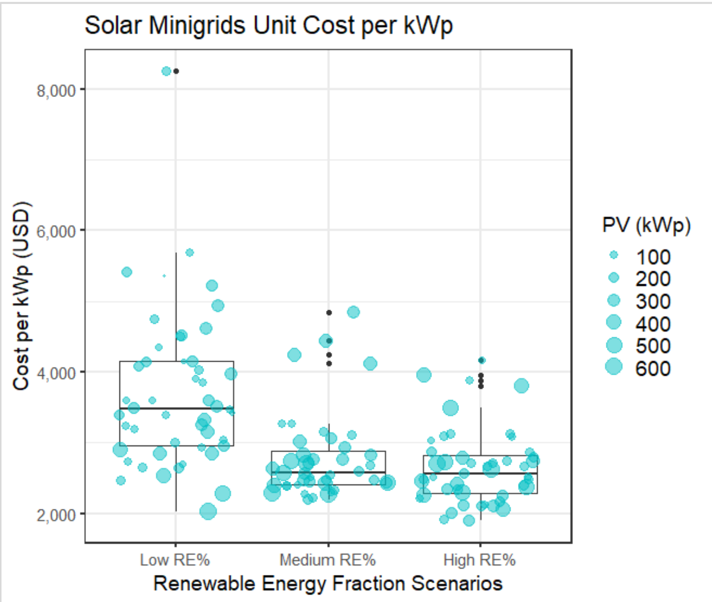


Figure 19: Cost per kWp of different RE fractions

Figure 19 shows three boxplots divided by RE fraction categories (Low: 40% - 60%, Medium: 60% - 80%, High: 80% - 100%). The costs per kWp decrease as the RE fraction increases. This is because the fixed costs remain the same (distribution network, metering, installation, etc.), but we are dividing by a larger PV capacity. Still, high renewable energy systems are more expensive overall if we look at total cost instead of cost per kWp.

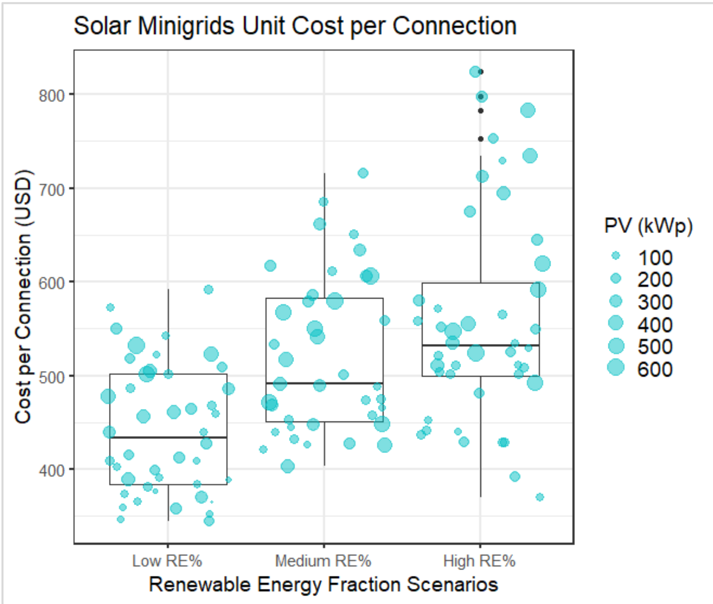


Figure 20: Cost per connection of different RE fractions

Figure 20 shows the same systems as above and divided by the same RE categories, but now showcasing the cost per connection. In this case, we observe how this cost per connection increases as the RE fraction does since the total cost of the system increases but the number we divide by as we increase the RE% remains the same. Higher RE% scenarios come at a higher cost but improve energy security, reduce GHG emissions, and lower fuel expenses and other operational costs. To find the exact optimum fraction though, project-specific simulations must be performed.

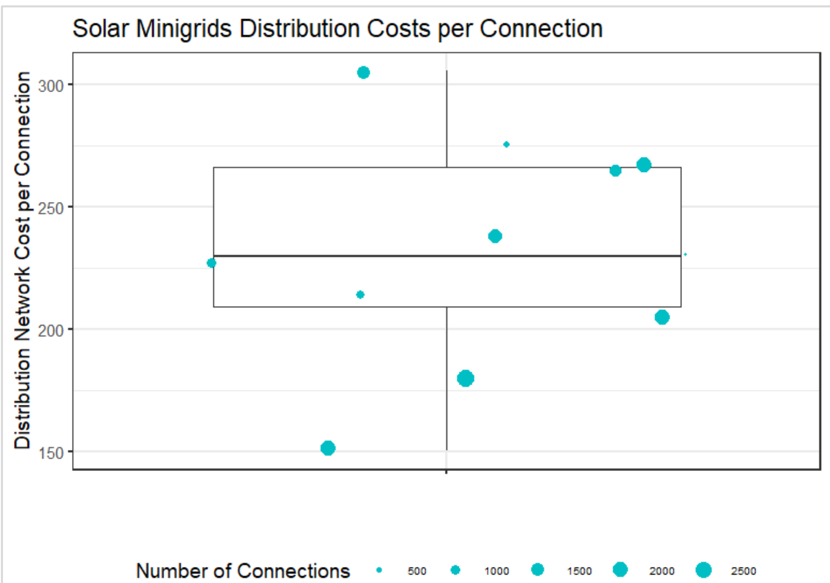


Figure 21: Distribution network costs per connection of solar mini-grids

The graph above shows the distribution network costs per connection, while the size conveys the total number of connections. The lowest values observed for distribution costs per connection are 150 USD per connection, while the highest ones remain at over 300 USD per connection. Variables that can be factored to include this variability are mostly population density, and how many kilometres of the network is required to cover similar numbers of connections. While connections increase the metering and service line costs, the length of the network increases the investment in poles and conductors, amongst other items.

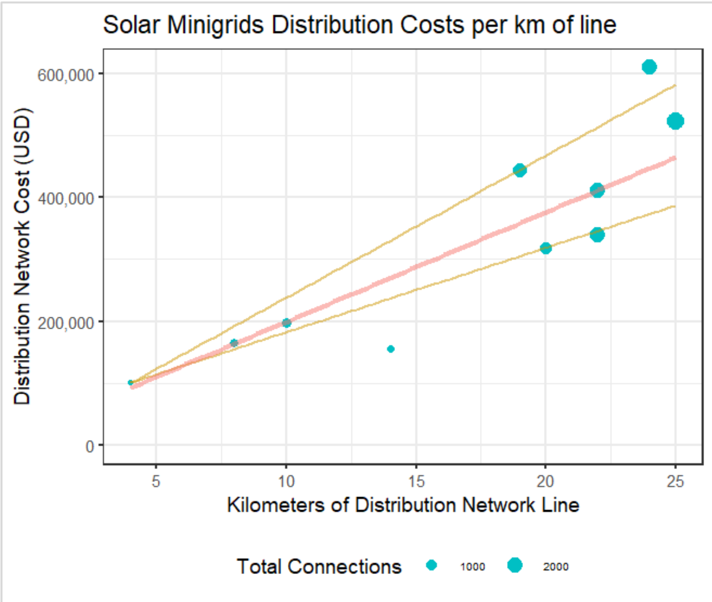


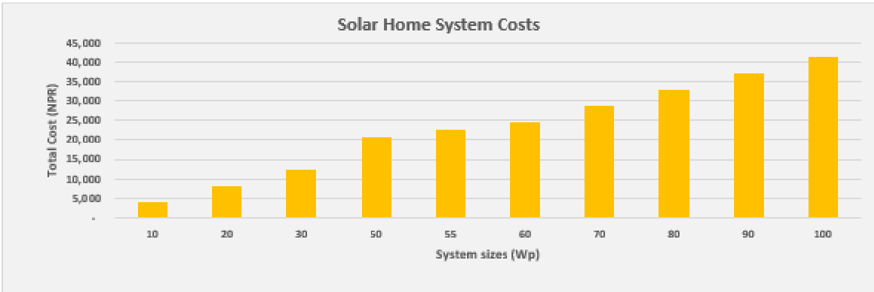
Figure 22: Total cost of distribution network vs. length of distribution network

Figure 22 shows the total costs in the distribution network for sampled SMGs vs. the length of the distribution network required in kilometres. In this case, a more linear progression can be observed, which allows for simpler and more accurate estimates. The only challenge in using this metric is that knowing the length of the distribution network required is less immediate than assessing the potential number of connections.

Annex III: Excel Tool Results Module

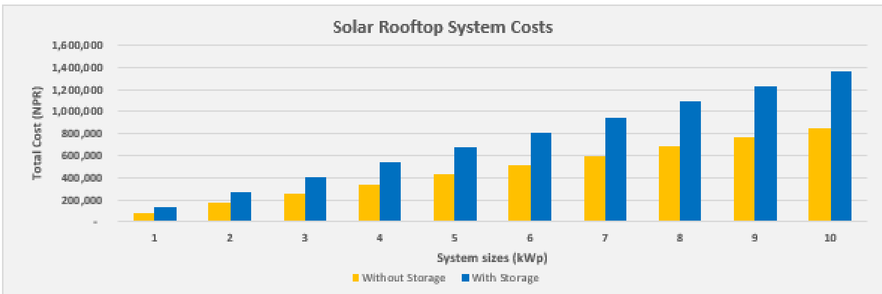
Solar Home Systems (0 W< x < 100 W)

System sizes	Wp	10	20	30	50	55	60	70	80	90	100
Equipment cost	NPR	3,746	7,492	11,237	18,729	20,602	22,475	26,220	29,966	33,712	37,458
Logistics	5%	187	375	562	936	1,030	1,124	1,311	1,498	1,686	1,873
Installation	5%	187	375	562	936	1,030	1,124	1,311	1,498	1,686	1,873
Balance of System	0%	-	-	-	-	-	-	-	-	-	-
Total Cost	NPR	4,120	8,241	12,361	20,602	22,662	24,722	28,842	32,963	37,083	41,203
Total Cost	USD	32	63	95	158	174	190	222	254	285	317



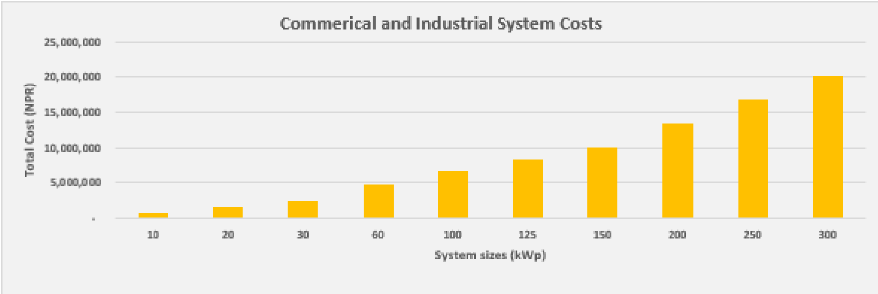
Solar Rooftop Systems (100 W < x < 10 kW)

System sizes	kWp	1	2	3	4	5	6	7	8	9	10
		Without Storage									
Equipment cost	NPR	72,826	145,652	218,478	291,304	364,130	436,956	509,782	582,608	655,434	728,260
Logistics	5%	3,641	7,283	10,924	14,565	18,207	21,848	25,489	29,130	32,772	36,413
Installation	10%	7,283	14,565	21,848	29,130	36,413	43,696	50,978	58,261	65,543	72,826
Balance of System	2%	1,457	2,913	4,370	5,826	7,283	8,739	10,196	11,652	13,109	14,565
Total Cost	NPR	85,206	170,413	255,619	340,826	426,032	511,239	596,445	681,651	766,858	852,064
Total Cost	USD	655	1,311	1,966	2,622	3,277	3,933	4,588	5,243	5,899	6,554
		With Storage									
Equipment cost	NPR	116,207	232,414	348,621	464,828	581,035	697,242	813,449	929,656	1,045,863	1,162,070
Logistics	5%	5,810	11,621	17,431	23,241	29,052	34,862	40,672	46,483	52,293	58,104
Installation	10%	11,621	23,241	34,862	46,483	58,104	69,724	81,345	92,966	104,586	116,207
Balance of System	2%	2,324	4,648	6,972	9,297	11,621	13,945	16,269	18,593	20,917	23,241
Total Cost	NPR	135,962	271,924	407,887	543,849	679,811	815,773	951,735	1,087,698	1,223,660	1,359,622
Total Cost	USD	1,046	2,092	3,138	4,183	5,229	6,275	7,321	8,367	9,413	10,459



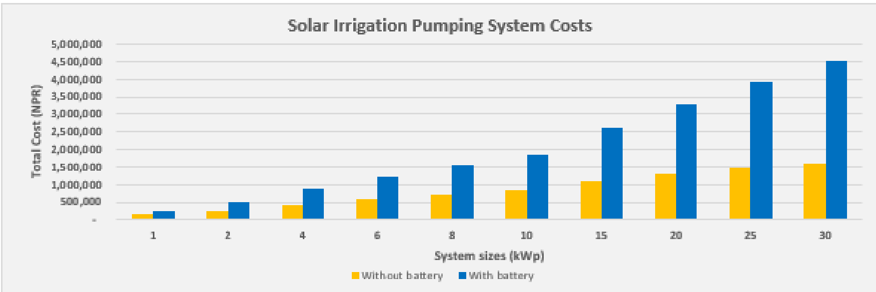
Commercial and Industrial PV Systems (30 kW < x < 300 kW)

System sizes	kWp	10	20	30	60	100	125	150	200	250	300
Equipment cost	NPR	689,440	1,378,880	2,068,320	4,136,640	5,753,600	7,192,000	8,630,400	11,507,200	14,384,000	17,260,800
Logistics	5%	34,472	68,944	103,416	206,832	287,680	359,600	431,520	575,360	719,200	863,040
Installation	10%	68,944	137,888	206,832	413,664	575,360	719,200	863,040	1,150,720	1,438,400	1,726,080
Balance of System	2%	13,789	27,578	41,366	82,733	115,072	143,840	172,608	230,144	287,680	345,216
Total Cost	NPR	806,645	1,613,290	2,419,934	4,839,869	6,731,712	8,414,640	10,097,568	13,463,424	16,829,280	20,195,136
Total Cost	USD	6,205	12,410	18,615	37,230	51,782	64,728	77,674	103,565	129,456	155,347

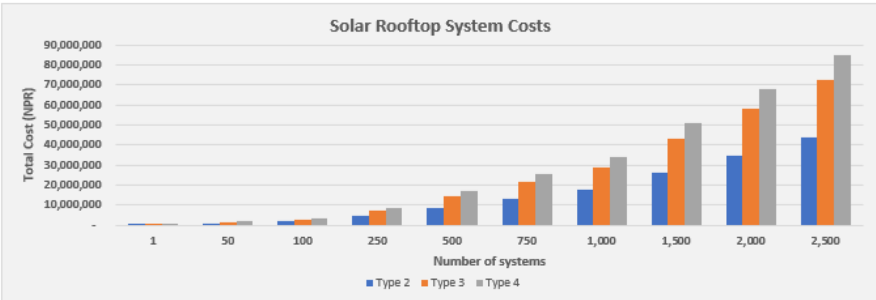


Solar Irrigation Pumping Systems (0 < x < 30 kW)

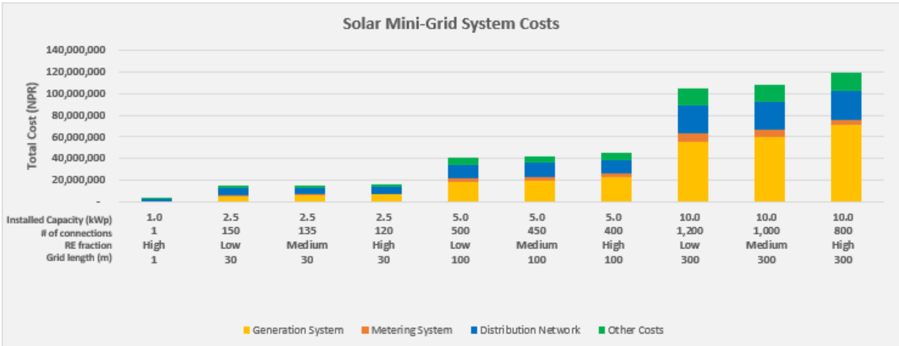
System sizes	kWp	1	2	4	6	8	10	15	20	25	30
		Without battery									
Equipment cost	NPR	124,859	217,354	369,983	498,182	610,516	711,053	924,598	1,098,480	1,242,869	1,363,756
Logistics	5%	6,243	10,868	18,499	24,909	30,526	35,553	46,230	54,924	62,143	68,188
Installation	10%	12,486	21,735	36,998	49,818	61,052	71,105	92,460	109,848	124,287	136,376
Balance of System	2%	2,497	4,347	7,400	9,964	12,210	14,221	18,492	21,970	24,857	27,275
Total Cost	NPR	146,084	254,305	432,881	582,873	714,304	831,932	1,081,779	1,285,222	1,454,157	1,595,595
Total Cost	USD	1,124	1,956	3,330	4,484	5,495	6,399	8,321	9,886	11,186	12,274
		With battery									
Equipment cost	NPR	225,706	411,946	744,961	1,048,184	1,332,061	1,601,550	2,229,182	2,808,446	3,351,745	3,866,382
Logistics	5%	11,285	20,597	37,248	52,409	66,603	80,078	111,459	140,422	167,587	193,319
Installation	10%	22,571	41,195	74,496	104,818	133,206	160,155	222,918	280,845	335,174	386,638
Balance of System	2%	4,514	8,239	14,899	20,964	26,641	32,031	44,584	56,169	67,035	77,328
Total Cost	NPR	264,076	481,977	871,605	1,226,376	1,558,511	1,873,814	2,608,143	3,285,882	3,921,542	4,523,667
Total Cost	USD	2,031	3,708	6,705	9,434	11,989	14,414	20,063	25,276	30,166	34,797



Solar Street Lights (Type 2, 3 and 4)											
No. of systems	**#**	**1**	**50**	**100**	**250**	**500**	**750**	**1,000**	**1,500**	**2,000**	**2,500**
		Type 2									
Equipment cost	NPR	15,203	760,150	1,520,300	3,800,750	7,601,500	11,402,250	15,203,000	22,804,500	30,406,000	38,007,500
Logistics	5%	760	38,008	76,015	190,038	380,075	570,113	760,150	1,140,225	1,520,300	1,900,375
Installation	10%	1,520	76,015	152,030	380,075	760,150	1,140,225	1,520,300	2,280,450	3,040,600	3,800,750
Balance of System	0%	-	-	-	-	-	-	-	-	-	-
Total Cost	NPR	17,483	874,173	1,748,345	4,370,863	8,741,725	13,112,588	17,483,450	26,225,175	34,966,900	43,708,625
Total Cost	USD	134	6,724	13,449	33,622	67,244	100,866	134,488	201,732	268,976	336,220
		Type 3									
Equipment cost	NPR	25,176	1,258,800	2,517,600	6,294,000	12,588,000	18,882,000	25,176,000	37,764,000	50,352,000	62,940,000
Logistics	5%	1,259	62,940	125,880	314,700	629,400	944,100	1,258,800	1,888,200	2,517,600	3,147,000
Installation	10%	2,518	125,880	251,760	629,400	1,258,800	1,888,200	2,517,600	3,776,400	5,035,200	6,294,000
Balance of System	0%	-	-	-	-	-	-	-	-	-	-
Total Cost	NPR	28,952	1,447,620	2,895,240	7,238,100	14,476,200	21,714,300	28,952,400	43,428,600	57,904,800	72,381,000
Total Cost	USD	223	11,136	22,271	55,678	111,355	167,033	222,711	334,066	445,422	556,777
		Type 4									
Equipment cost	NPR	29,613	1,480,650	2,961,300	7,403,250	14,806,500	22,209,750	29,613,000	44,419,500	59,226,000	74,032,500
Logistics	5%	1,481	74,033	148,065	370,163	740,325	1,110,488	1,480,650	2,220,975	2,961,300	3,701,625
Installation	10%	2,961	148,065	296,130	740,325	1,480,650	2,220,975	2,961,300	4,441,950	5,922,600	7,403,250
Balance of System	0%	-	-	-	-	-	-	-	-	-	-
Total Cost	NPR	34,055	1,702,748	3,405,495	8,513,738	17,027,475	25,541,213	34,054,950	51,082,425	68,109,900	85,137,375
Total Cost	USD	262	13,098	26,196	65,490	130,981	196,471	261,961	392,942	523,922	654,903



RE Solar Mini-Grids (30 kW < x < 300 kW)											
System sizes	kWp	1	30	30	30	100	100	100	300	300	300
Renewable fraction	Low, Medium, High	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Connections	#	1	150	135	120	500	450	400	1,200	1,000	800
Grid length	km	1.0	2.5	2.5	2.5	5.0	5.0	5.0	10.0	10.0	10.0
Generation System	NPR	236,015	5,560,425	6,035,250	7,080,450	18,534,750	20,117,500	23,601,500	55,604,250	60,352,500	70,804,500
Metering System	NPR	6,500	975,000	877,500	780,000	3,250,000	2,925,000	2,600,000	7,800,000	6,500,000	5,200,000
Distribution Network	NPR	2,600,000	6,500,000	6,500,000	6,500,000	13,000,000	13,000,000	13,000,000	26,000,000	26,000,000	26,000,000
Logistics	5%	142,126	651,771	670,638	718,023	1,739,238	1,802,125	1,960,075	4,470,213	4,642,625	5,100,225
Installation	10%	284,252	1,303,543	1,341,275	1,436,045	3,478,475	3,604,250	3,920,150	8,940,425	9,285,250	10,200,450
Balance of System	2%	56,850	260,709	268,255	287,209	695,695	720,850	784,030	1,788,085	1,857,050	2,040,090
Other Costs	NPR	483,228	2,216,022	2,280,168	2,441,277	5,913,408	6,127,225	6,664,255	15,198,723	15,784,925	17,340,765
Total Cost	NPR	3,325,743	15,251,447	15,692,918	16,801,727	40,698,158	42,169,725	45,865,755	104,602,973	108,637,425	119,345,265
Total Cost	USD	25,583	117,319	120,715	129,244	313,063	324,383	352,814	804,638	835,673	918,041
Total Cost per connection	USD	25,583	782	894	1,077	626	721	882	671	836	1,148
Total Cost per kWp	USD	25,583	3,911	4,024	4,308	3,131	3,244	3,528	2,682	2,786	3,060



Annex IV: Methodology

Introduction

For several decades solar PV systems have enjoyed subsidy support in Nepal. For large parts, subsidies have attained the objective of increasing affordability and adoption at scale. However, subsidies have also obstructed the play of market forces which, in free markets, should lead to progressive improvements of consumer value through private sector competition for features, quality and price.

Preliminary findings by GIZ POSTED suggest, among other things, that subsidized solar irrigation pumps deployed are often of inferior standard and that prices for several solar PV components are substantially higher than in neighbouring India.

Objectives of the assignment

The overarching objective of the assignment is to generate information regarding costs relevant to actors and development partners in the market for solar PV technologies. Specifically, the assignment seeks to produce current estimates for prices for selected solar PV systems based on their cost in the principal countries of origin while estimating the cost of transport and importation to provide reference points for benchmarking prices in Nepal.

Approach and scope of the assignment

The following flowchart illustrates the approach and methodology applied for this assignment.

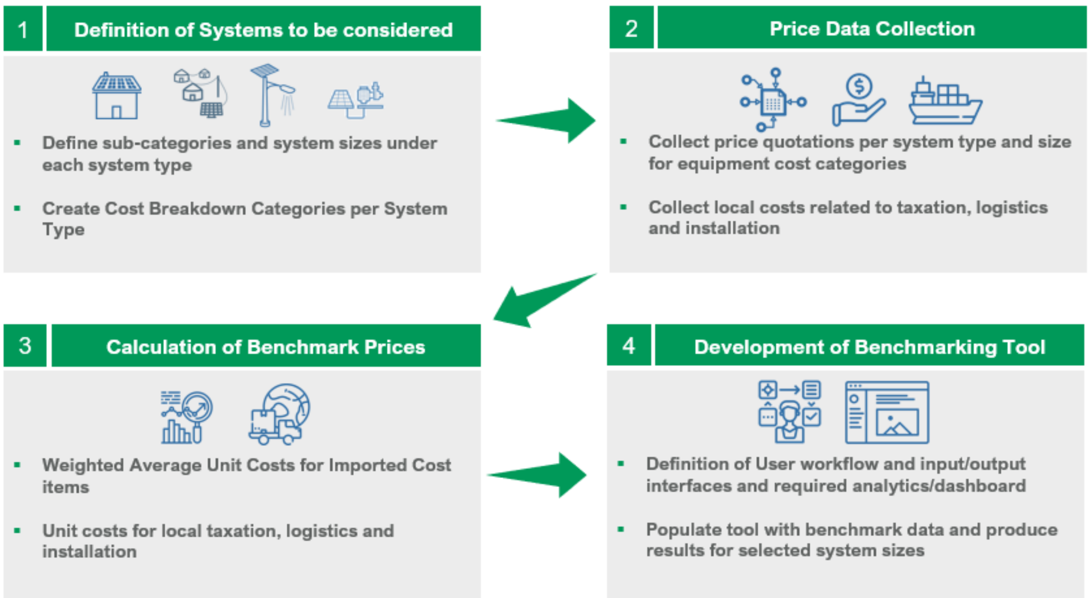


Figure 23: Methodology flowchart

After analyzing the local context and understanding the type of solar systems that are more prevalent in the region, the following systems are considered as shown in Table 17. For each system, the required components are defined in the following sections, and the goal is to provide a benchmark costing estimation per component in the system (when available) and for the whole system overall (NPR/kWp).

The goal of the study is to define suitable benchmark units per kWp, so it is applicable for most system sizes within the typically observed ranges. For those systems where the range of sizes is big enough to observe significant economies of scale, several reference sizes is defined.

Table 17: Solar PV system types

	System type	Configuration	Mounting
1.	Solar home systems (SHS)	10, 20, 50, 55, 60, 80, 100 W_P	
2.	Institutional, commercial solar systems (C&I)	a) PV + grid + no storage	Rooftop
			Ground-mounted
		b) PV + grid + storage	Rooftop
			Ground-mounted
3.	Residential solar rooftop system (SRT)	a) PV + grid + storage	Rooftop
		b) PV+ no grid + storage	Rooftop
4.	Solar mini-grids (SMG)	a) PV + grid + storage	Ground-mounted
		b) PV+ no grid + storage	Ground mounted
5.	Solar irrigation pumping systems (SIPs)	Multiple sizes	Ground-mounted
6.	Solar street lighting systems (SSLS)	Type 2, 3 and 4 (see Annex) and a centralised system	

Definition of system configurations

Table 18 lists the different components for each of the system types and respective subcategories. The component categories are created based on standard system designs that are normally deployed for such system types. Where relevant, additional components are lumped under the Balance of System (BoS) category to ensure a more consistent and homogenous breakdown of categories for cost estimating and benchmarking.

Prices will be collected with the same granularity as with the breakdown of system components presented in the table. In case a further detailed breakdown of costs is collected, they will be aggregated to ensure consistency in the methodology for comparison.

For situations where prices per component are not available, extrapolation from other similar components will be done with reasonable adjustments for economies of scale (e.g., a 10 kW inverter will not cost twice as much as a 5 kW inverter). In addition to the component breakdown presented in the table above, the following additional costs will be collected for each system:

- Transportation:
  - International travel from source to Kathmandu (India, China, any other market)
  - Domestic travel (cost of X km local transport)
- Taxation per item
- Retail margins on the system level (X% margin for SHS, Y% for mini-grids)

Table 18: Components per system type

System type	Coupling	SPV Module	Mounting	DC/AC Disconnect	CC/ MPPT	Solar Inverter	Battery Inverter	Battery	Fuel Generator	Metering	Others/ BOS
Commercial & Industrial solar systems (C&I)											
PV + grid + no storage (Rooftop PV)	AC	✓	Rooftop	✓	✓	✓				✓	✓
PV + grid+ no storage (Ground Mounted PV)	AC	✓	Ground Mounted	✓	✓	✓				✓	✓
PV + grid + storage	AC	✓	Rooftop	✓	✓	✓	✓	✓		✓	✓
PV + grid + diesel +storage	AC	✓	Ground Mounted	✓	✓	✓	✓	✓		✓	✓
Residential solar rooftop system (SRT & SHS)*											
PV (unmounted)	DC	✓			✓						✓
PV DC Coupled	DC	✓	Rooftop		✓						✓
PV AC Coupled	AC	✓	Rooftop		✓	✓					✓
PV+ inverter+storage	AC	✓	Rooftop		✓	✓	✓	✓			✓
PV + grid + storage	AC	✓	Rooftop		✓	✓	✓	✓		✓	✓
PV+ no grid + storage	AC	✓	Rooftop		✓	✓	✓	✓			✓
Solar mini-grids (SMG)											
PV + Diesel (DC)	DC	✓	Ground Mounted	✓	✓				✓	✓	✓
PV + Diesel (AC)	AC	✓	Ground Mounted	✓	✓	✓			✓	✓	✓
PV + Storage (DC)	DC	✓	Ground Mounted	✓	✓		✓	✓		✓	✓
PV + Storage + Diesel (DC)	DC	✓	Ground Mounted	✓	✓		✓	✓	✓	✓	✓
PV + Storage + Diesel (AC)	AC	✓	Ground Mounted	✓	✓	✓	✓	✓	✓	✓	✓
PV+Storage+Grid (AC)	AC	✓	Ground Mounted	✓	✓	✓	✓	✓		✓	✓
PV+ Storage +Diesel + Grid (AC)	AC	✓	Ground Mounted	✓	✓	✓	✓	✓	✓	✓	✓
Solar irrigation pumping systems (SIPs)											
PV 1kWp	AC	✓	Ground Mounted		✓	✓				✓	✓
PV + Storage 1kWp	AC	✓	Ground Mounted		✓	✓	✓	✓		✓	✓
PV 5 kWp	AC	✓	Ground Mounted		✓	✓				✓	✓
PV + Storage 5kWp	AC	✓	Ground Mounted		✓	✓	✓	✓		✓	✓
Solar street lighting systems (SSLS)											
SSLS Type 2	DC	✓	Pole Mounting		✓			✓			✓
SSLS Type 3	DC	✓	Pole Mounting		✓			✓			✓
SSLS Type 4	DC	✓	Pole Mounting		✓			✓			✓

* Unless specified, all PV systems include some sort of mounting

The image below shows an SMG in the configuration of AC-coupled PV, with storage and diesel generator backup for illustration purposes.

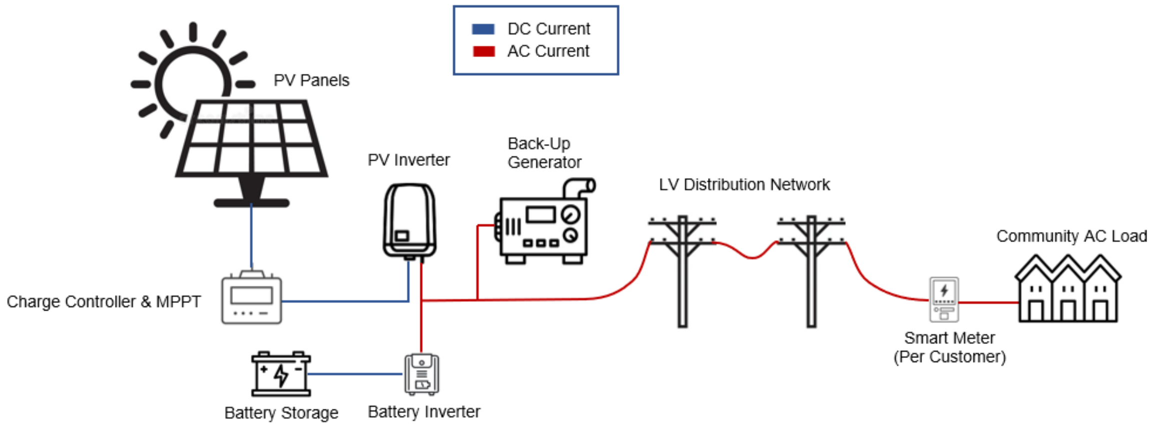


Figure 24: Illustration of AC-coupled SMG configuration with diesel generator backup

Data collection and processing

Keeping into account the fact that most of the installations in Nepal are expected to procure systems from regional sources, i.e., India followed by China, the study focuses on collecting more robust data from these markets. Specifically for India, physical market surveys are conducted, and quotations are collected from suppliers who are active in the Nepali market as well.

Furthermore, data points from other countries in the region (e.g., Bangladesh) are also collected. Finally, price estimates from established suppliers in Europe and USA are incorporated in the assessment (but with less weightage so as not to skew the prices due to these outliers for the Nepali market).

In addition to sourcing equipment from external markets, some components and services (especially for civil works) are primarily procured from the local market and therefore these costs will be collected from the Nepali market exclusively.

Other cost assumptions and simplifications

The supply chain of PV systems is often complex due to international procurement, shipping and taxation regimes. They are accompanied by additional (and often) unexpected costs which can have a big influence on the final total costs of the systems.

Table 19 below summarizes the logistical flow of equipment from the source supplier to the final installation site and identifies additional cost considerations that have to be at each step. Reasonable estimates for these costs will be included in the assessment to reflect the true final costs of the systems. However, where needed, externalities, such as exchange rate fluctuations are identified to provide an estimation of the error range associated with the cost estimations.

It is understood that all imported goods are delivered to the border to be picked up at customs, and after some research with local experts, the table below which goods can be procured locally, and which need to be imported. It has also been flagged that almost all imported goods enter through India, regardless of if they are manufactured in India, China or other regions.

Table 19: Logistical flow of equipment

Component	Imported (Via India)	Procured Locally
Battery Inverter	■	
Fuel Generator		■
Battery	■	
CC/MPPT	■	
Distribution Cables		■
Distribution Poles		■
Indoor Installation		■
Mounting	■	
Others/BOS	■	■
Protection Systems	■	
Smart Metering	■	
Solar Inverter	■	
SPV Module	■	
Water Pump		■

Table 20 provides an overview of the other variable costs for which reasonable estimates will be assumed during the assignment. For Nepal-specific items (e.g., inland transport, civil works, etc.) costs estimates are collected only from the local market. Where relevant, possible sub-categories are created to provide an estimation of costs depending on local factors (e.g., civil costs vary significantly depending on the geography of the project location).

Table 20: Variable costs

Cost category	Possible options	Costs to consider
Equipment purchase	Primarily sourcing: India followed by China. Some imports from other markets	Cost at source/supplier facility
Transport from source to Nepal	Air or sea transport to Calcutta in India, Land transport within India to Nepal border customs (location of customs depends on the final destination within Nepal)	Transport costs Value added tax Custom duties Cost of clearing agents
Local storage and warehousing	Most local companies organize warehousing in the region of the final installation	Local storage costs
Transport in the country (up to site)	Road transport	Inland transport to the site (varies depending on the remoteness of the site and geographical zones)
Civil works	Mostly local construction companies are engaged to undertake civil works. Material is mostly procured locally as well (limits the quality of material that can realistically be procured near the site)	Raw material for civil works Labour costs Construction of powerhouse Construction of distribution network (poles, cables, etc.) Site supervision costs

Methods for cost benchmarking

Based on the primary and secondary data collected, the price estimates are analyzed and filtered for each system type. Where needed, outliers are removed to prevent the averages from being skewed unnecessarily. Furthermore, depending on the quality and time horizon of the collected price points, the benchmarking methodology aims to present the price point development for the past 2-3 years to indicate the market trajectory.

Additional specific considerations concerning the benchmarking methodology are presented below.

Regional preferences

Considering the scope of the assignment and the Nepali market, the majority of the system installations are likely to procure the equipment from India or China. Therefore, while the data are collected from other suppliers (Europe, USA, etc.), we propose to use a weighted average for calculating benchmark pricing to give more prominence to the costs collected from the Indian and Chinese markets.

Table 21: Weightage in final benchmarked price

	Price points from India	Price points from China	Other price points
Weightage in the final benchmarked price	200%	100%	50%

Extrapolations

For components where linear cost extrapolations are possible and suitable, linear regression formulas are set up to calculate the price points for sizes where no direct data is available. This is applied to the following equipment categories:

- PV costs per kW peak
- LV cable costs per km
- Battery storage per Wh
- Other similar items

Scenarios to define variable parameters

For some systems, especially those involving distribution networks, assumptions are made to create systems with some specific details (e.g., number of connections, km of LV network) to develop cost benchmarks for sample systems sizes. In cases where such assumptions are made, the results are split between standard costs and costs that are variable and depend on individual project sites.

Price benchmarking tool

A simple benchmarking tool is developed in excel which allows for easy usage of the information, provides the basis for cost estimation/benchmarking and allows future refinements of the costs when new data becomes available.

The tool has the following main modules. Each module is developed on a separate sheet in excel too.

- **Data input module:** this sheet allows entering price quotations for the different system types. The prices will need to be provided for one of the system sizes available and with the granularity compatible with the cost breakdown structure presented in the earlier sections of the methodology.
- **Calculation module:** this sheet contains all the formulas used for calculating the benchmark pricing. In addition, default average values are defined for components for which sufficient data might not be available.
- **Results module:** this sheet provides the price estimations for each of the system types and sizes. In addition, the sheet also includes some analytics to present the information graphically to show trajectories and allow first-level extrapolations for other system sizes.
- **Instruction module:** this sheet provides an introduction to the tool, how to use the different modules and answers to some basic usage questions.

Annex V: Reference Price Benchmarking Tool → Separate Excel file

Annex VI: R Scripts Used in the Analysis → Separate PDF file

Annex VII: GIZ Comparison of Reference Pricing → Separate Excel file

Deutsche Gesellschaft für
Internationale Zusammenarbeit (GIZ) GmbH

Registered offices Bonn and Eschborn

Friedrich-Ebert-Allee 36 + 40
53113 Bonn, Germany
T +49 228 44 60-0
F +49 228 44 60-17 66

Dag-Hammarskjöld-Weg 1 - 5
65760 Eschborn, Germany
T +49619679-0
F +49619679-1115

E info@giz.de
I www.giz.de