KTH Department of Energy Technology

Division of Energy
Systems Analysis

WORLD BANK GROUP
Energy & Extractives

A GIS approach to electrification planning in Afghanistan

New Delhi
1st of February 2017

Background and scope

Universal access to affordable and reliable electricity is part and parcel to the success of any economic growth strategy in the country

Yet, 70% of Afghan population does not have access to affordable and reliable electricity services. Access to grid electricity reaches:

- 89% in urban centers (Kabul, Herat, Mazar-e-Sharif, Kandahar)
- But roughly 11% in rural areas (Ghor, Langman)

This study aims to develop an electrification model based on the ONSSET methodology that will:

- Capture the dynamics in the power sector of Afghanistan.
- Provide a sense of the **investment** and **capacity** requirements for full electrification of Afghanistan under certain targets.

ONSSET – The **O**pe**N** **S**ource **S**patial **E**lectrification **T**ool

- ✓ GIS datasets developed for Afghanistan
- ✓ Customized inputs according to study specifications
  - Social indicators (population growth, urbanization level, different demand patterns etc.)
  - Energy Access Goals
  - Technical factors (T&D losses for national grid, alternative technologies available etc.)
  - Cost elements (Investment cost – O&M – Fuel etc.)
- ✓ Quantification of Capacity – Investment requirements for electrification
- ✓ Visualization of key outputs in graphs & maps of high spatial resolution (1 sq.km)
- ✓ Support electrification efforts on a national and subnational level

Preparation of the model - Infrastructure

A GIS environment (e.g. ArcGIS, QGIS) is required

Dynamic datasets

(Current – projected/planned)

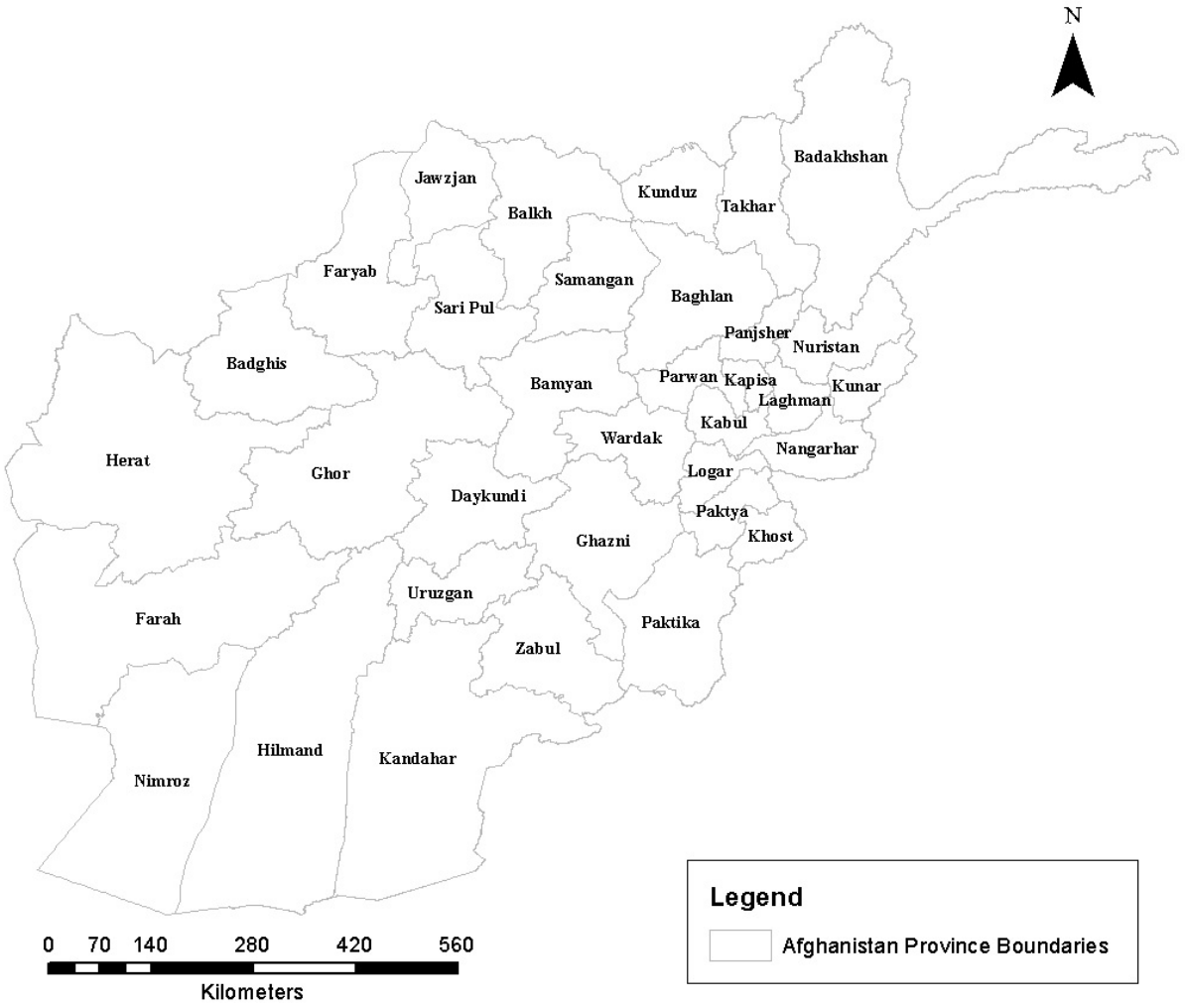
1. Administrative boundaries
2. **Population distribution & density**
3. Power plants (existing and planned)
4. **Transmission network** (existing and planned)
5. Sub-stations (existing and planned)
6. Road network (existing and planned)
7. Quarries and Mines

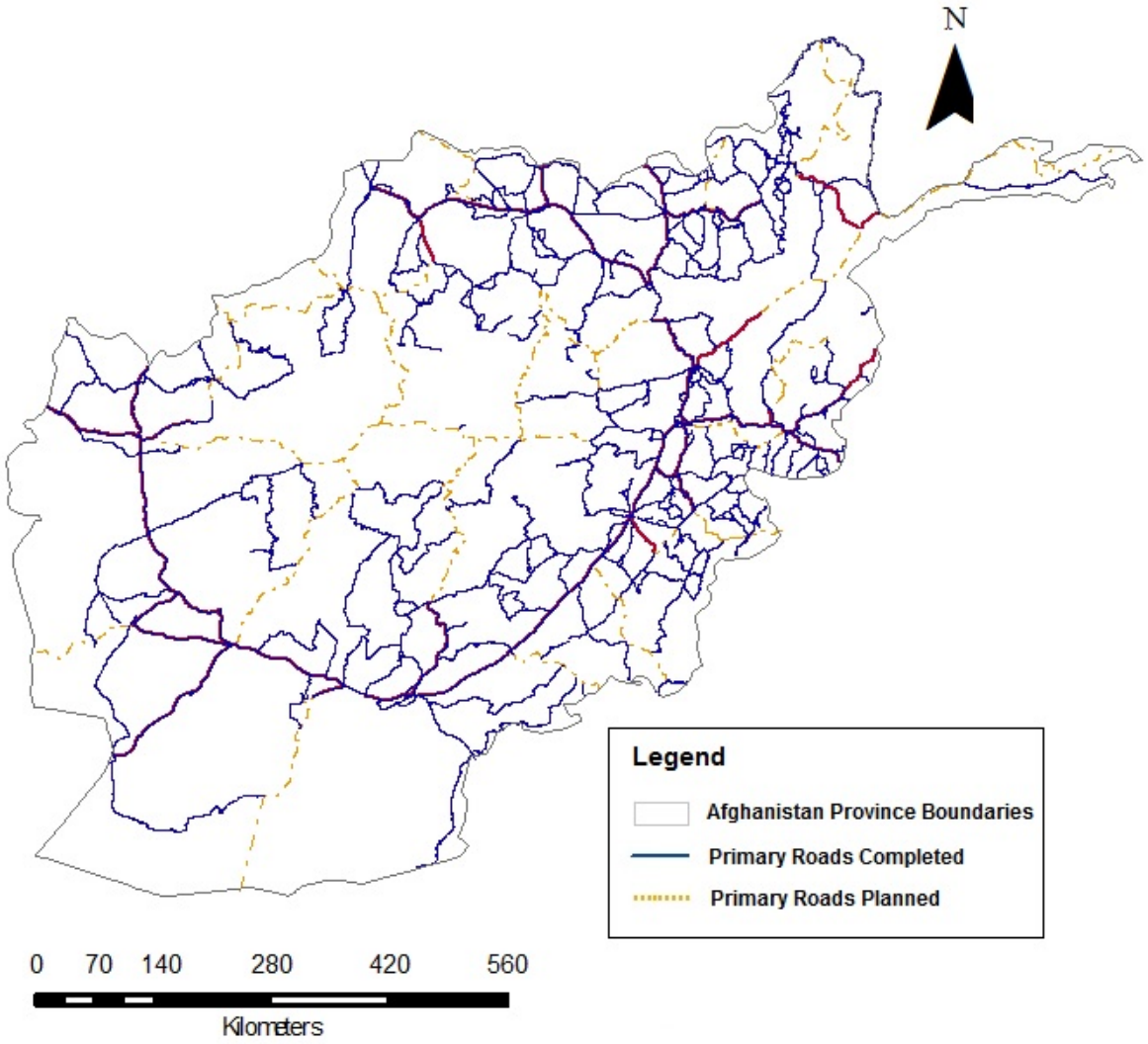
Static datasets

(Resources Potential)

8. Nighttime light maps
9. Land Cover
10. DEM (Digital Elevation Map)
11. Travel time to nearest town
12. Solar irradiation (with restrictions)
13. Wind velocity
14. Mini/Small hydropower potential

Preparation of the model - Infrastructure





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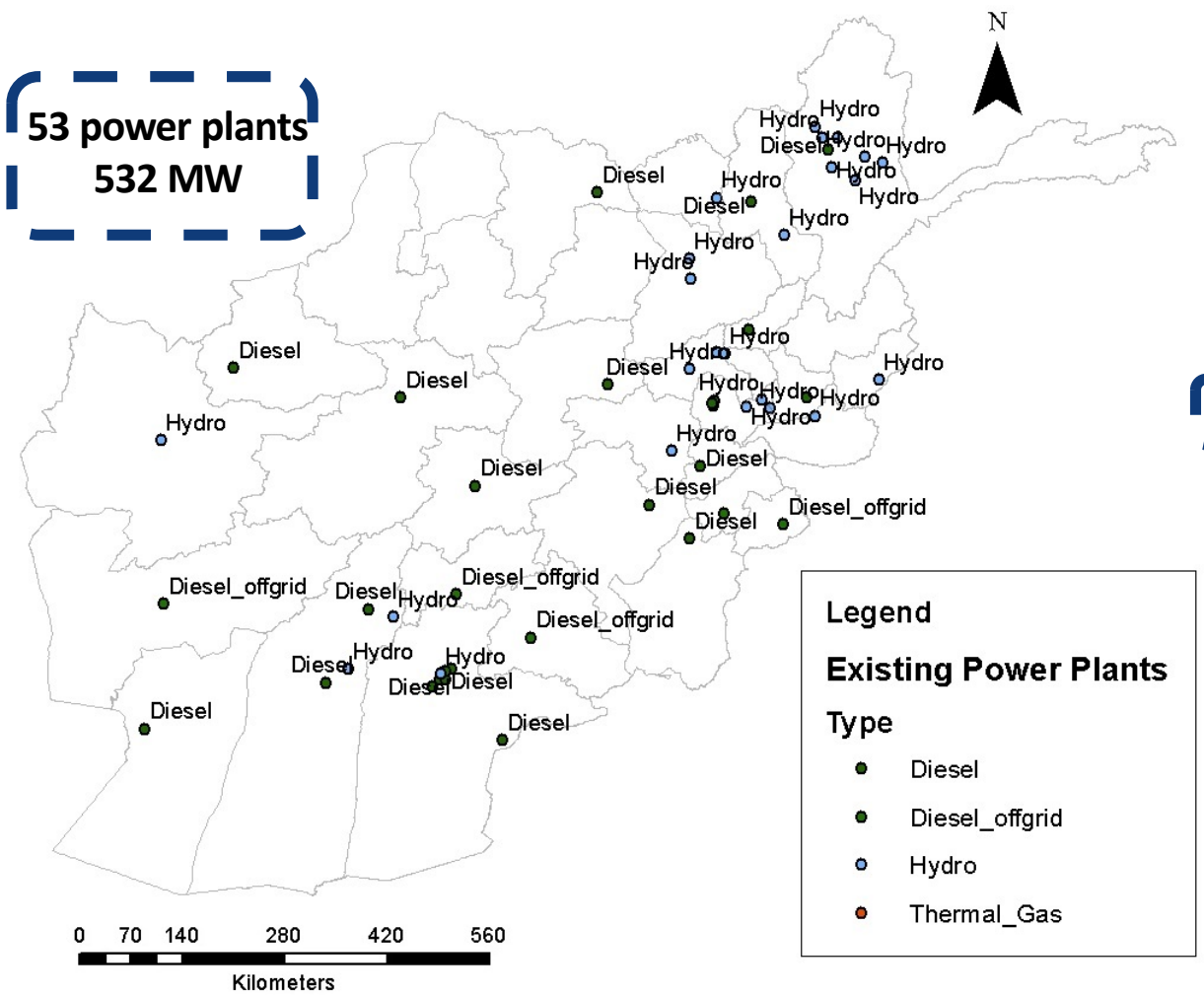

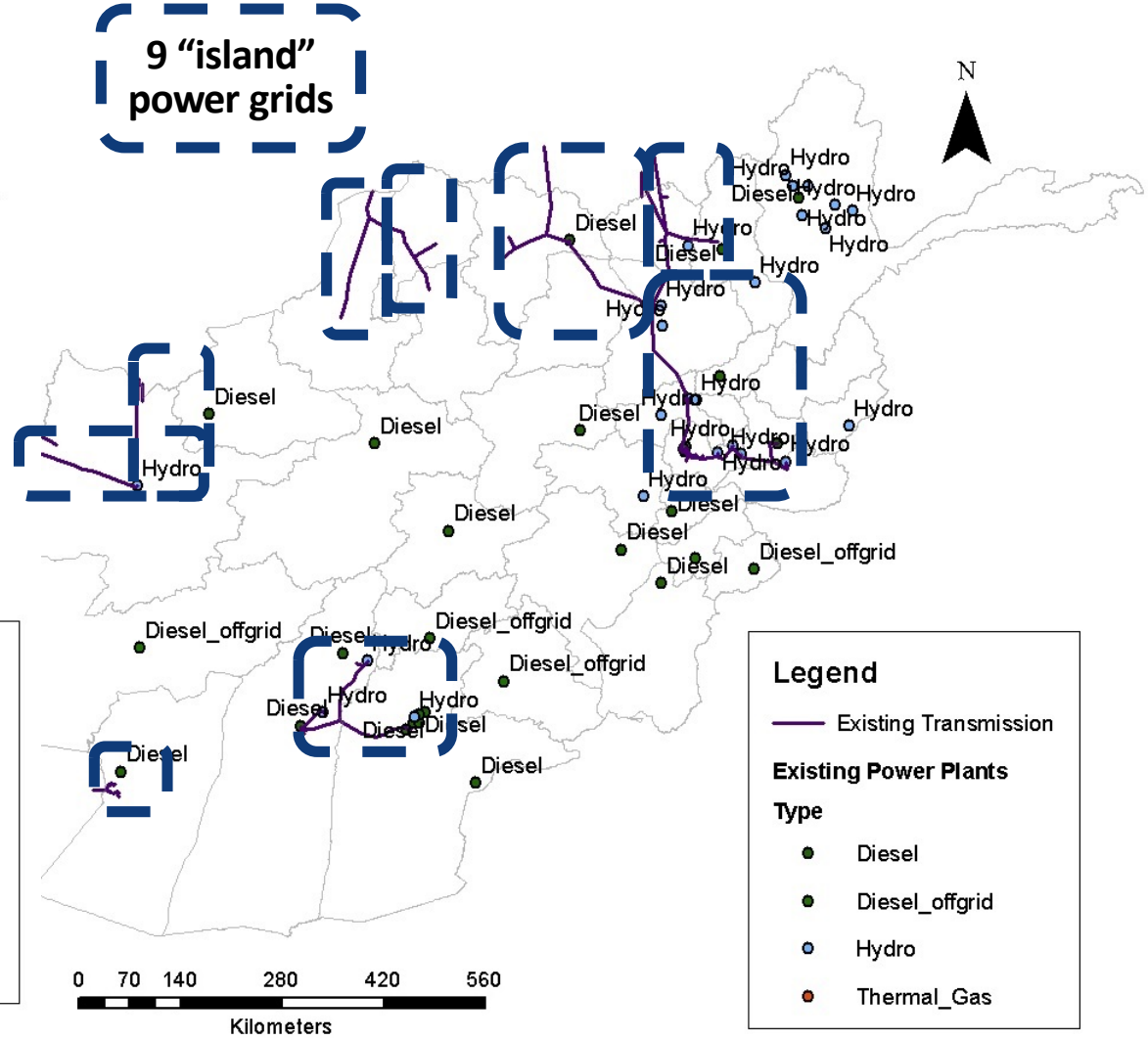

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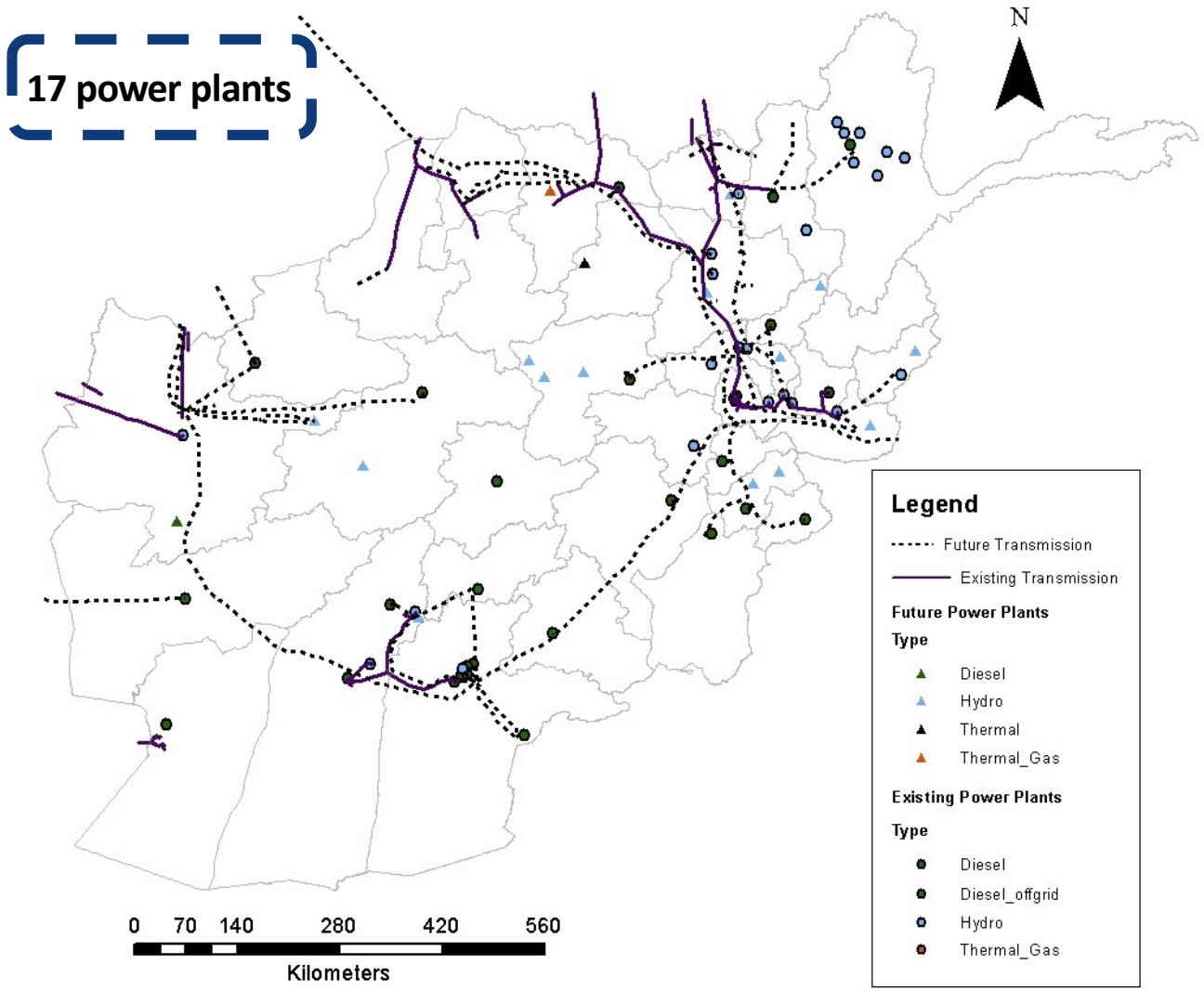

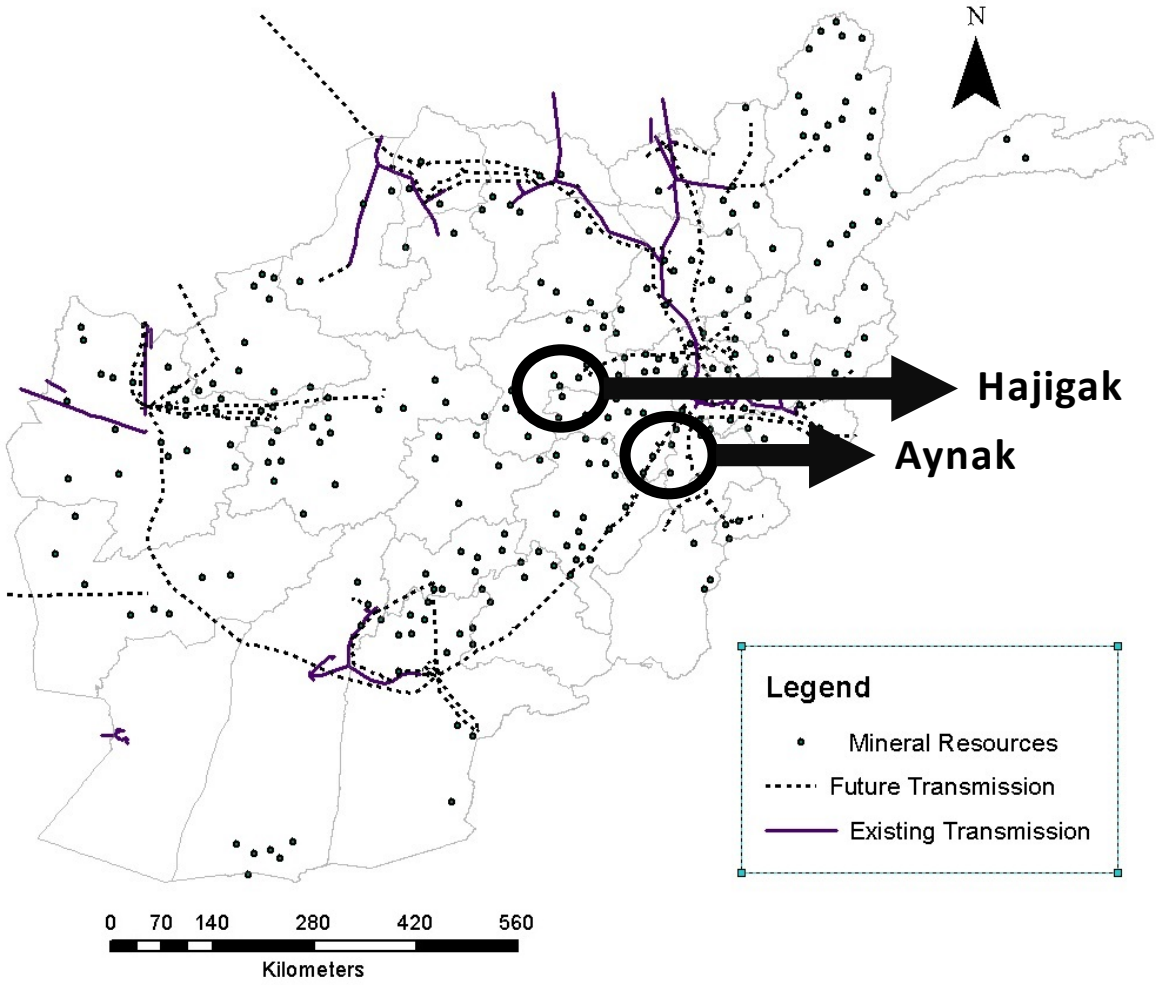

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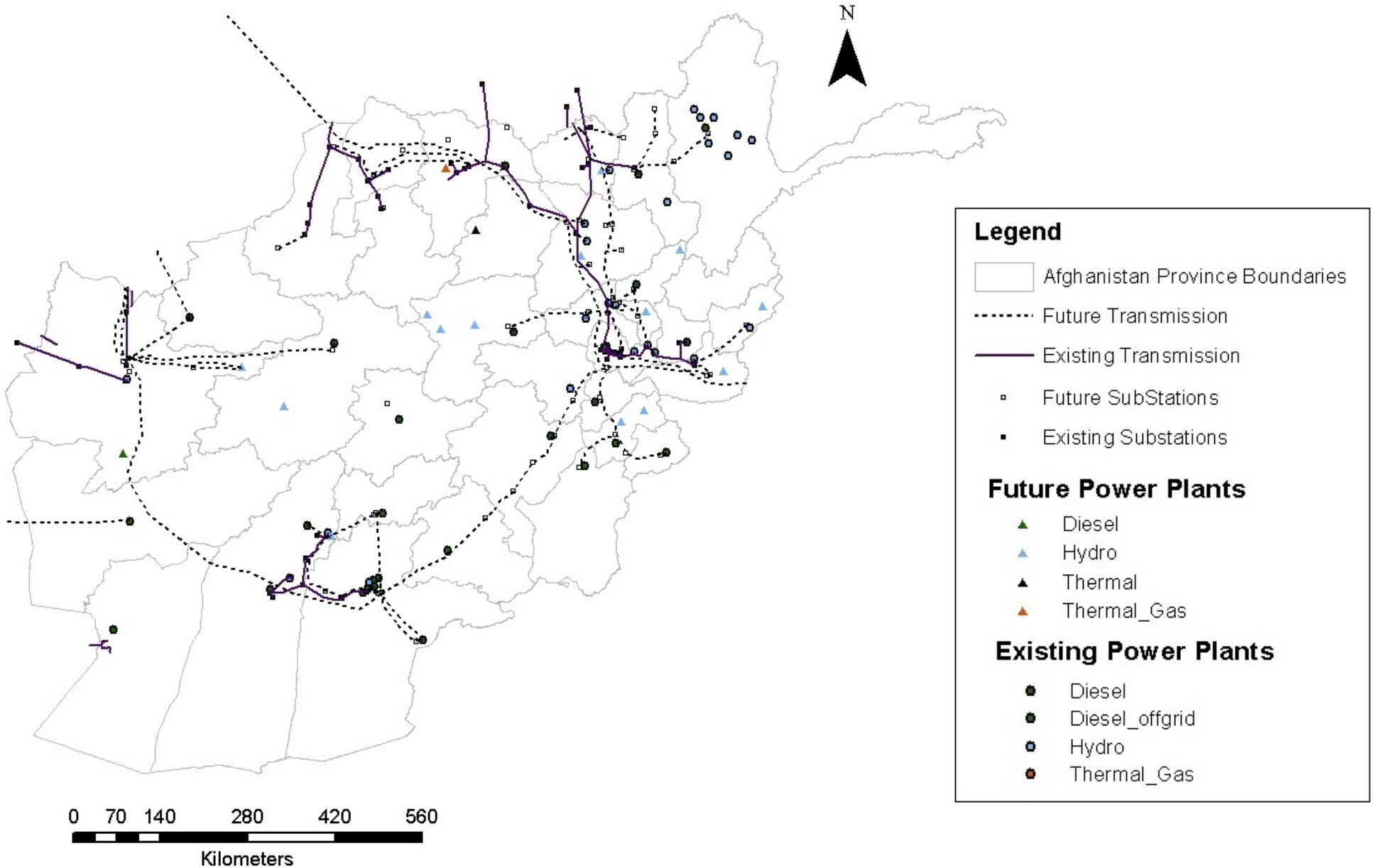
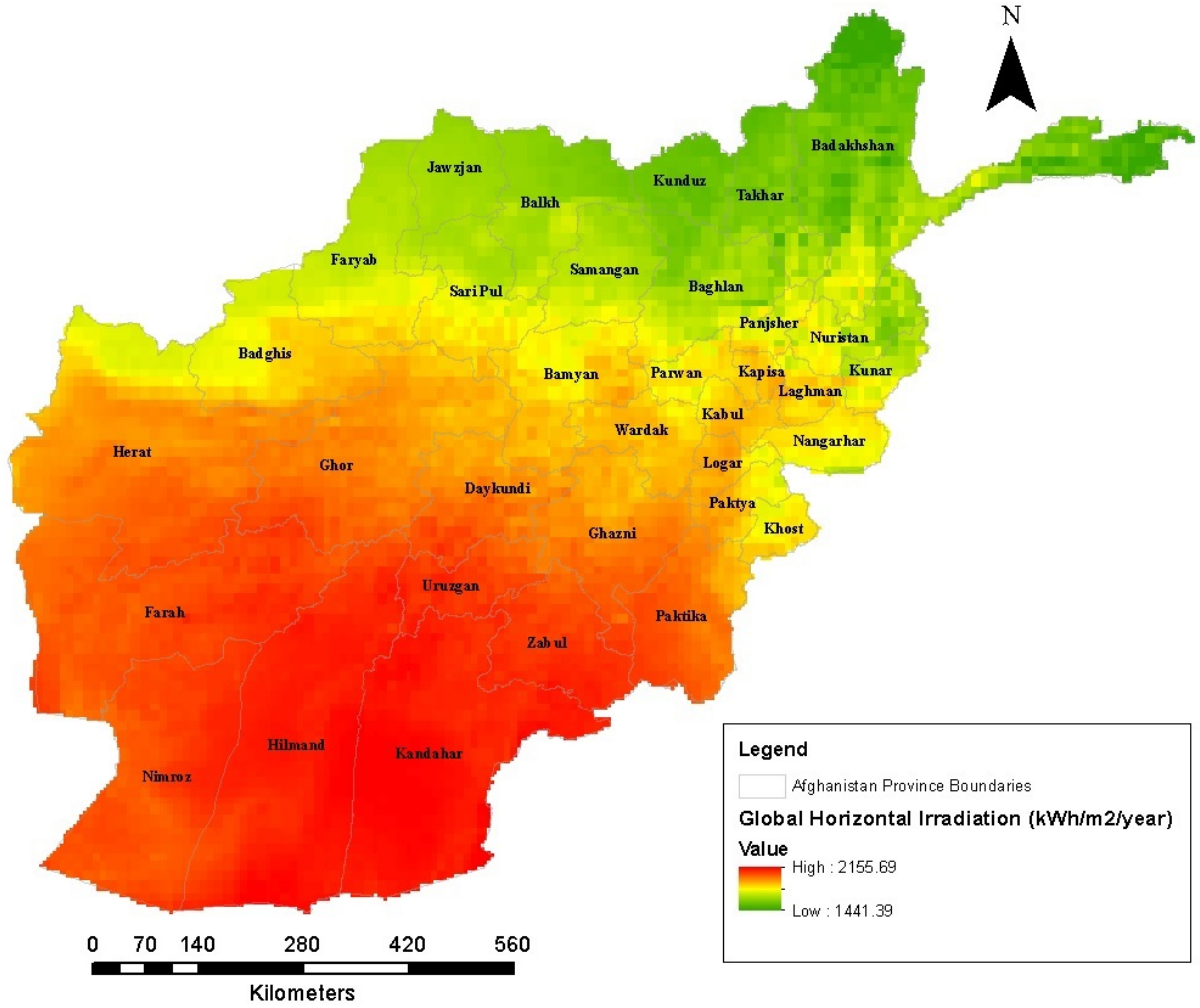


Preparation of the model – Resources & Energy Potential

Solar Potential – Photovoltaic Systems

List of restrictions zones used for the solar PV assessment in Afghanistan.

Layer	Type	Source
Protected areas	Strict Nature Reserves, Wilderness areas, National Parks, Natural Monument, Habitat/Species Management, Protected Landscape, Managed Resource protected areas	(1)
Croplands	Cultivated areas	(2)
Slope gradient	Exclude areas with more than 45 degrees terrain slope	(3)
Inland water	Lakes, Wetlands, Stagnant waters	(2) (4)
Permanent snow	High elevated, remote areas	(2)



1. **IUCN and UNEP-WCMC.** The World Database on Protected Areas (WDPA). [Online] UNEP-WCMC, 2014, www.protectedplanet.net.

2. **NASA MODIS.** Land Cover Type Yearly L3 Global 0.05Deg CMG. [Online] USGS Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota, https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mcd12c1.

3. **Jarvis, A., H.I. Reuter, A. Nelson, E. Guevara.** Hole-filled SRTM for the globe Version 4. [Online] CGIAR-CSI SRTM 90m Database, 2008, http://srtm.csi.cgiar.org.

4. *New global hydrography derived from spaceborne elevation data.* **Lehner, B., Verdin, K., Jarvis, A.** 10, 2008, Eos, Transactions, AGU, Vol. 89, pp. 93-94.

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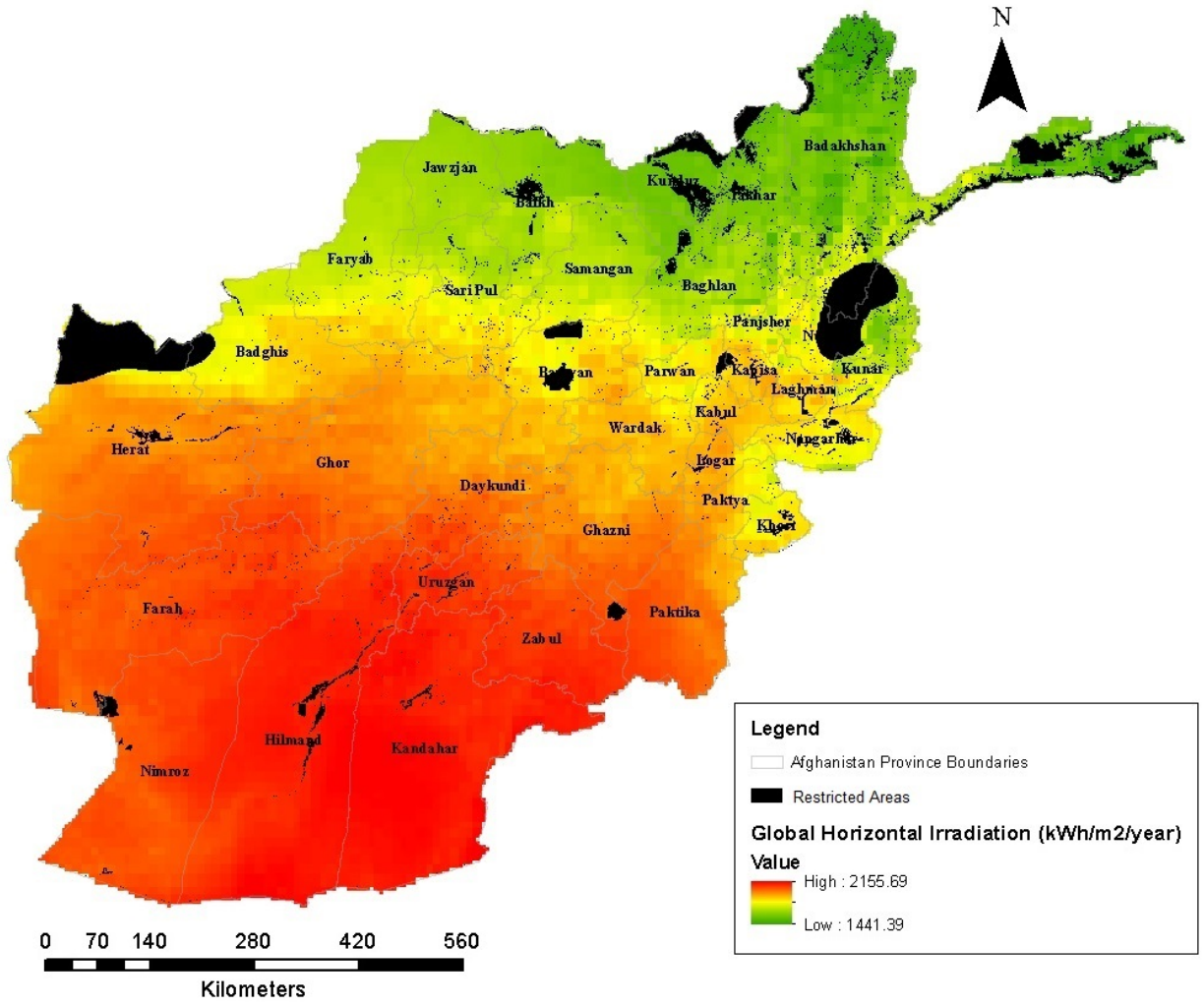

1. **IUCN and UNEP-WCMC.** The World Database on Protected Areas (WDPA). [Online] UNEP-WCMC, 2014, www.protectedplanet.net.

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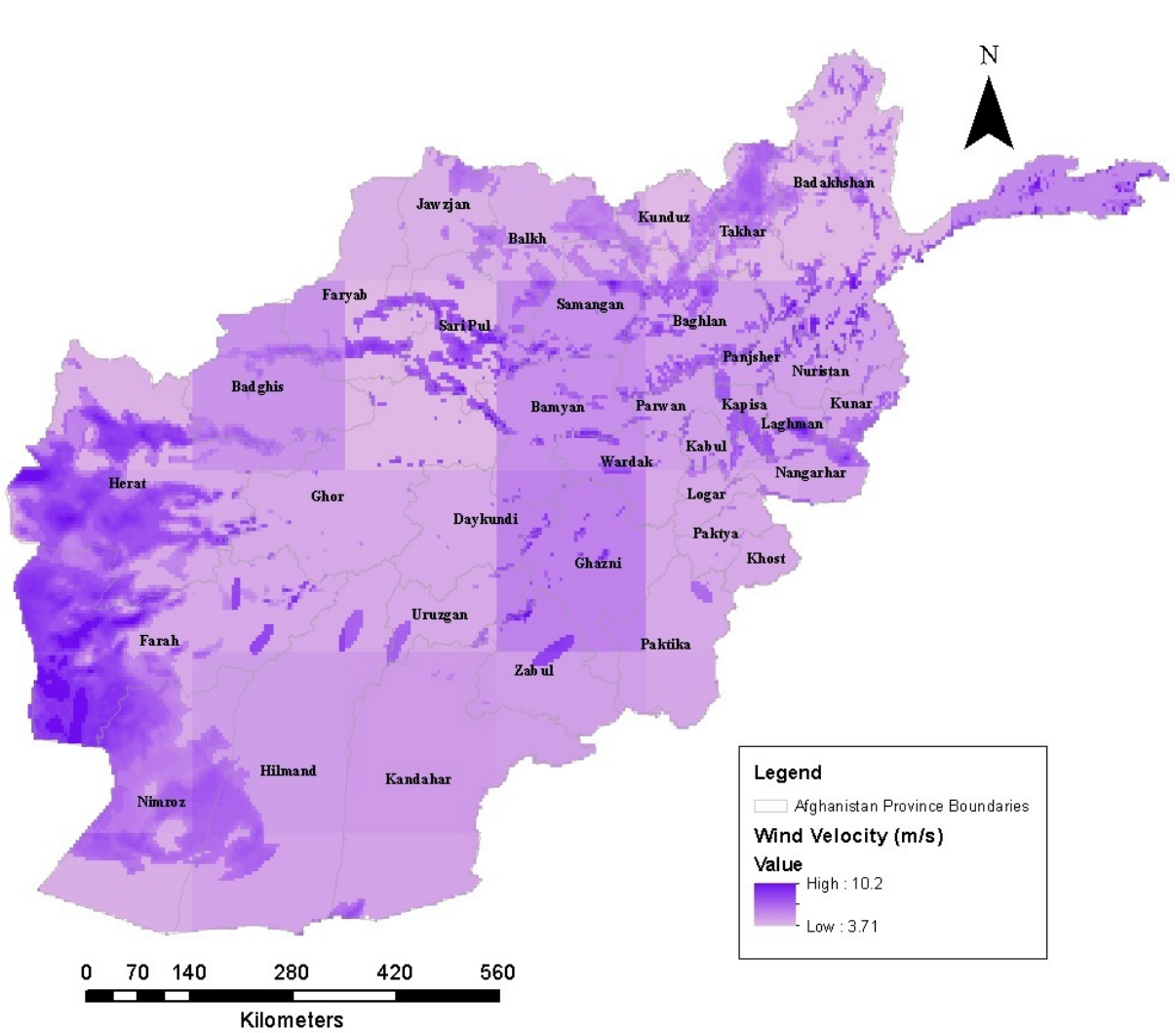
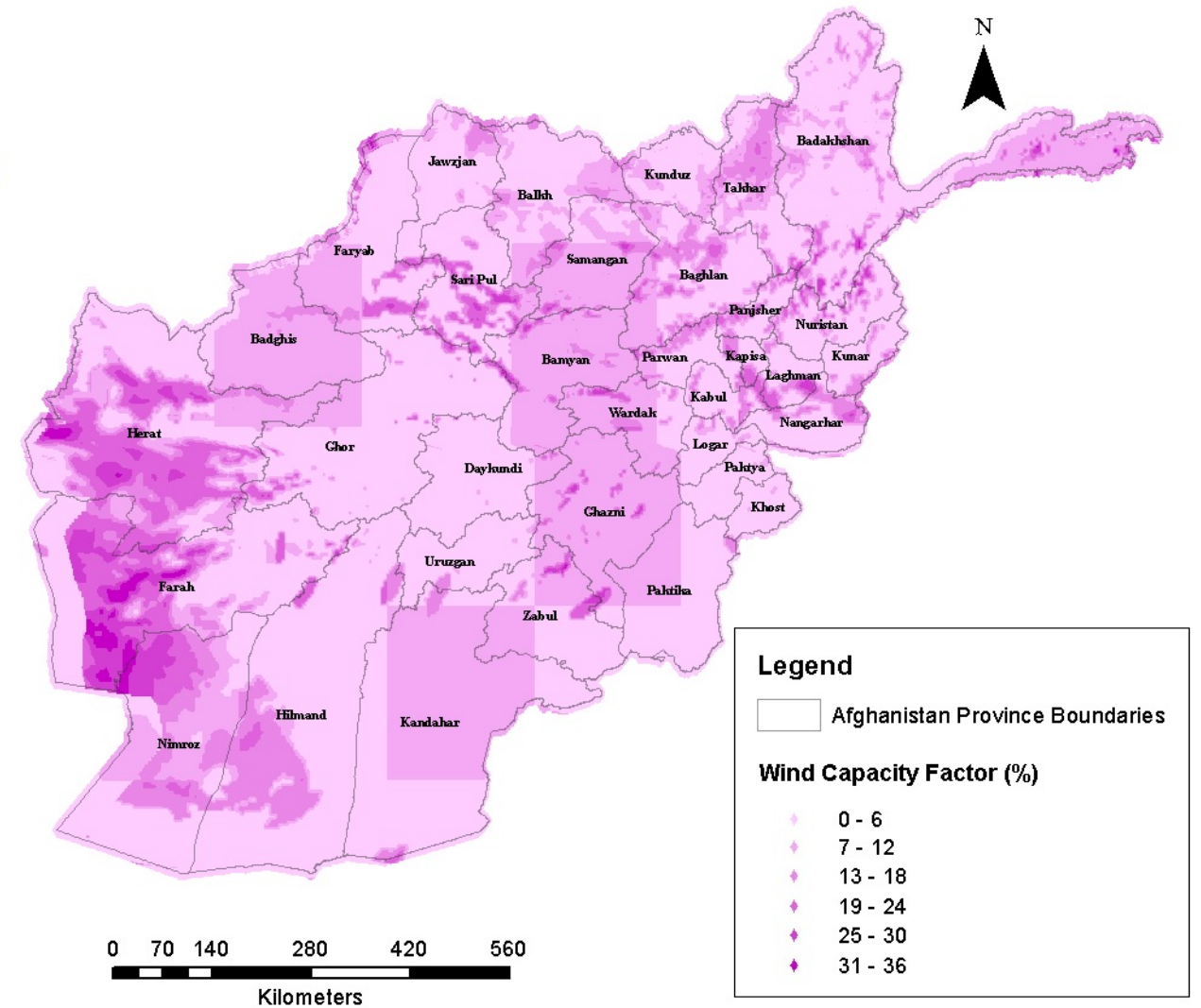
4. *New global hydrography derived from spaceborne elevation data.* **Lehner, B., Verdin, K., Jarvis, A.** 10, 2008, Eos, Transactions, AGU, Vol. 89, pp. 93-94.

Preparation of the model – Resources & Energy Potential

Wind Potential





Preparation of the model – Resources & Energy Potential

Hydropower Potential – 0.1 to 10 MW

List of restrictions zones used for the hydropower assessment in Afghanistan.

Layer	Type	Buffer	Source
Protected areas	Strict Nature Reserves, Wilderness areas, National Parks, Natural Monument, Habitat/Species Management, Protected Landscape, Managed Resource protected areas	500 m	(1)
Croplands	Cultivated areas	200 m	(2)
Barren land	Desert and inhabitable areas	-	(2)
Inland water	Lakes, Wetlands, Stagnant waters	-	(5)
Built Up	Residential areas	100 m	(6)
Perennial Rivers & Stream order	Permanent flow & confluence of more than 3 rivers	-	(7)

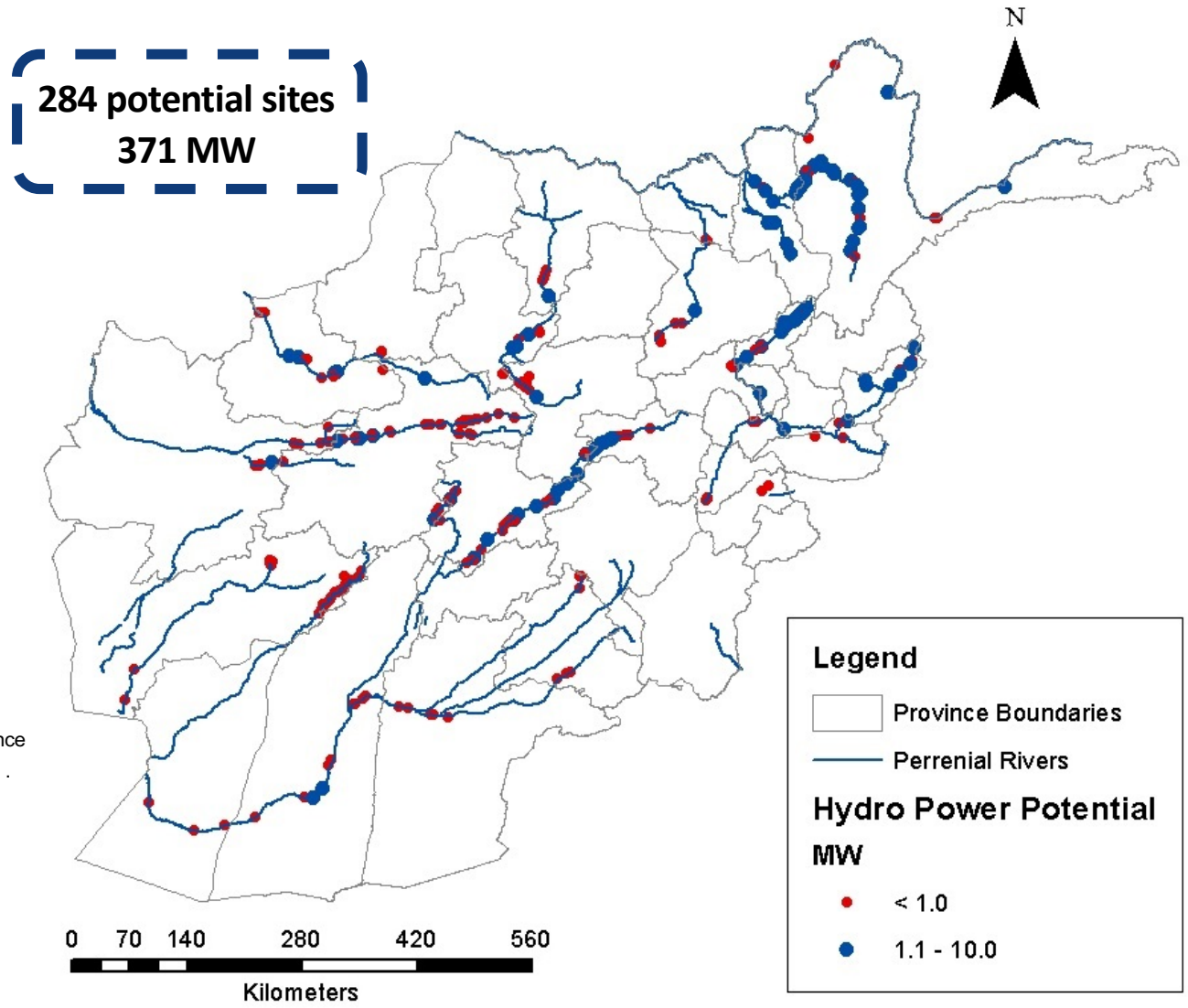
1. IUCN and **UNEP-WCMC**. The World Database on Protected Areas (WDPA). [Online] UNEP-WCMC, 2014, www.protectedplanet.net.

2. NASA MODIS. Land Cover Type Yearly L3 Global 0.05Deg CMG. [Online] USGS Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota,

5. **NASA Socioeconomic Data and Applications Center** (SEDAC). Millennium Ecosystem Assessment. [Online], http://dx.doi.org/10.7927/H4KW5CZ6.

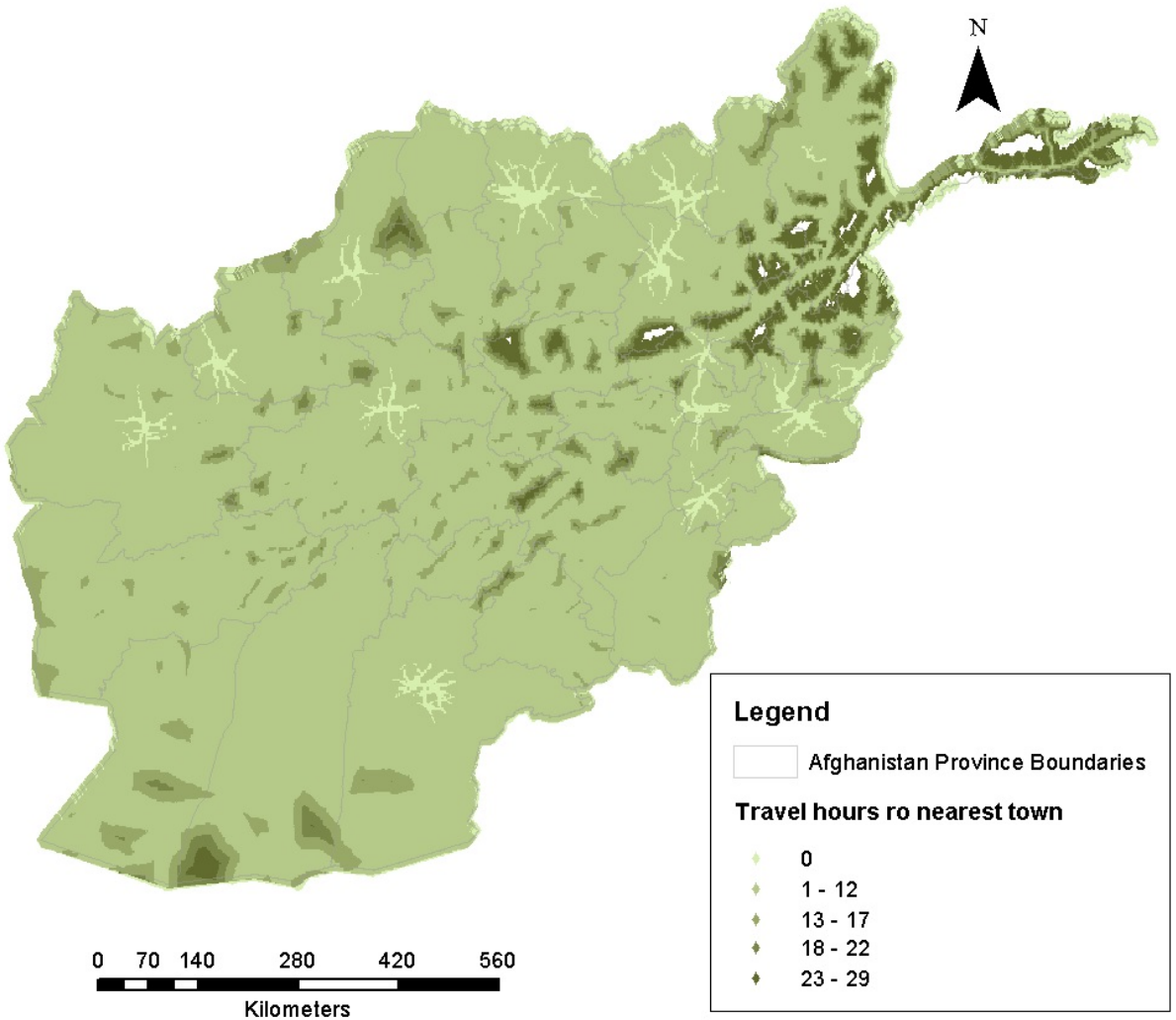
6. GIS-Lab. VMap0 data in ESRI shape format. [Online], http://gis-lab.info/qa/vmap0-eng.html.

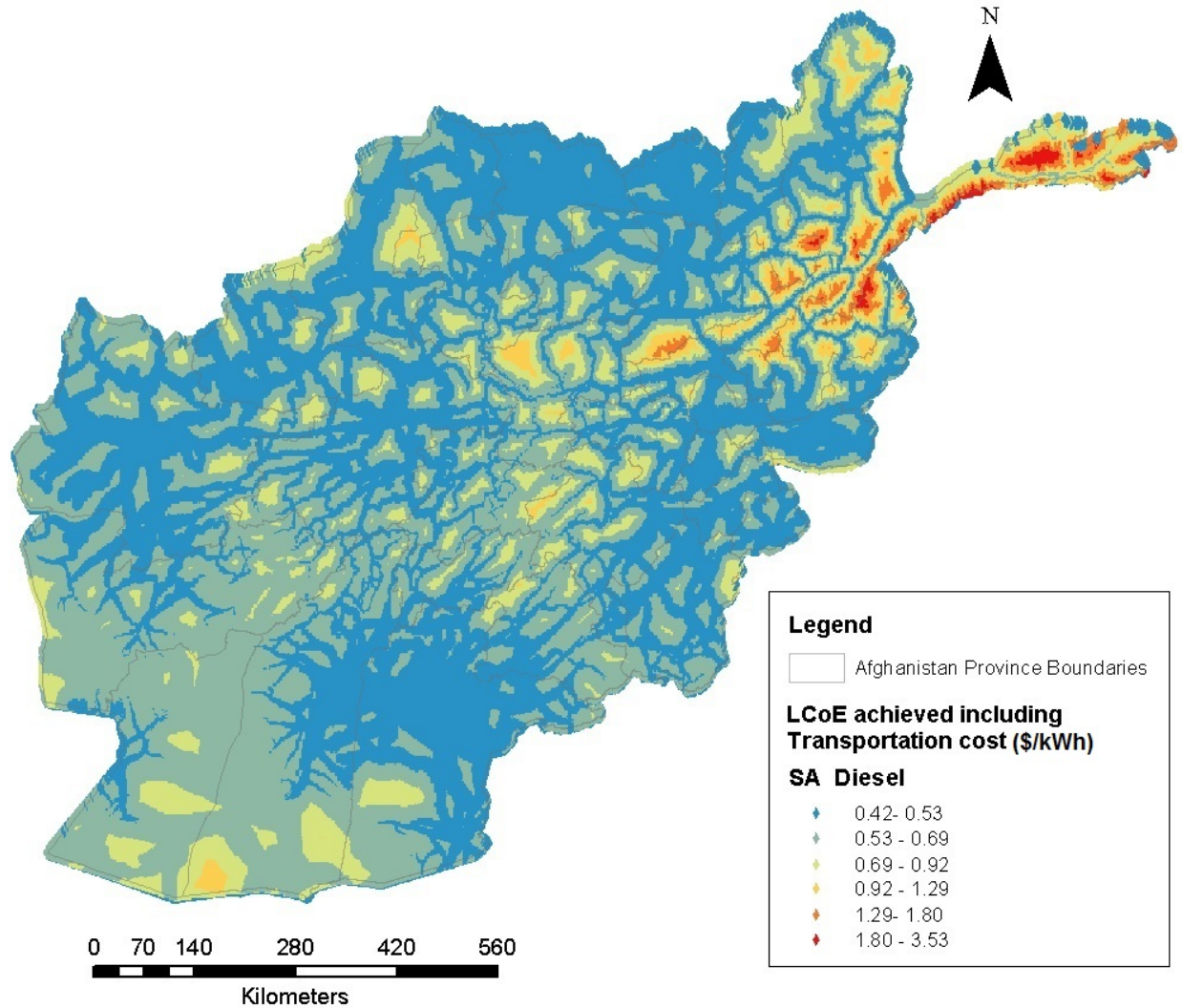
7. Provided by the World Bank for purposes of this project.



Preparation of the model – Resources & Energy Potential

Assessment of off-grid diesel generators





Preparation of the model – Social Indicators

Calibration and projection of key input datasets

Parameter	Metric	Value 2015	Value 2030
Population, total	Million Persons	32.527 [8]	44.310 (estimated based on growth rates below)
Urban population	Percent of total population	26.3 % [9]	35.8% (estimated based on growth rates below)
Rural population	Percent of total population	73.7% [9]	64.2% (estimated based on growth rates below)
Urban growth	Percent growth per year	3.96% [9]	3.49% (average value used in the model as 3.65% per year)[9]
Rural growth	Percent growth per year	1.85% [9]	1.12% (average value used in the model as 1.35% per year)[2]
Electricity access	Percent of total population	30% [10,11] (access to the national grid)	100%
Electricity access, urban	Percent of urban population	89% [11] (access to the national grid)	100%
Electricity access, rural	Percent of rural population	11% [11] (access to the national grid)	100%
People per household, urban	People per household	7.4 [11,12]	7 (assuming 5% decrease over the 15 year period) [13]
People per household, rural	People per household	8.5 [11,12]	8.1 (assuming 5% decrease over the 15 year period) [13]

8. The World Bank Open Data, 2015 (http://data.worldbank.org/indicator/SP.POP.TOTL?locations=AF)

9. United Nations, Department of Economic and Social Affairs, Population Division, 2015 https://esa.un.org/unpd/wpp/Download/Probabilistic/Population/ https://esa.un.org/unpd/wup/CD-ROM/

10. National Energy Supply Program (NESP – 2012)

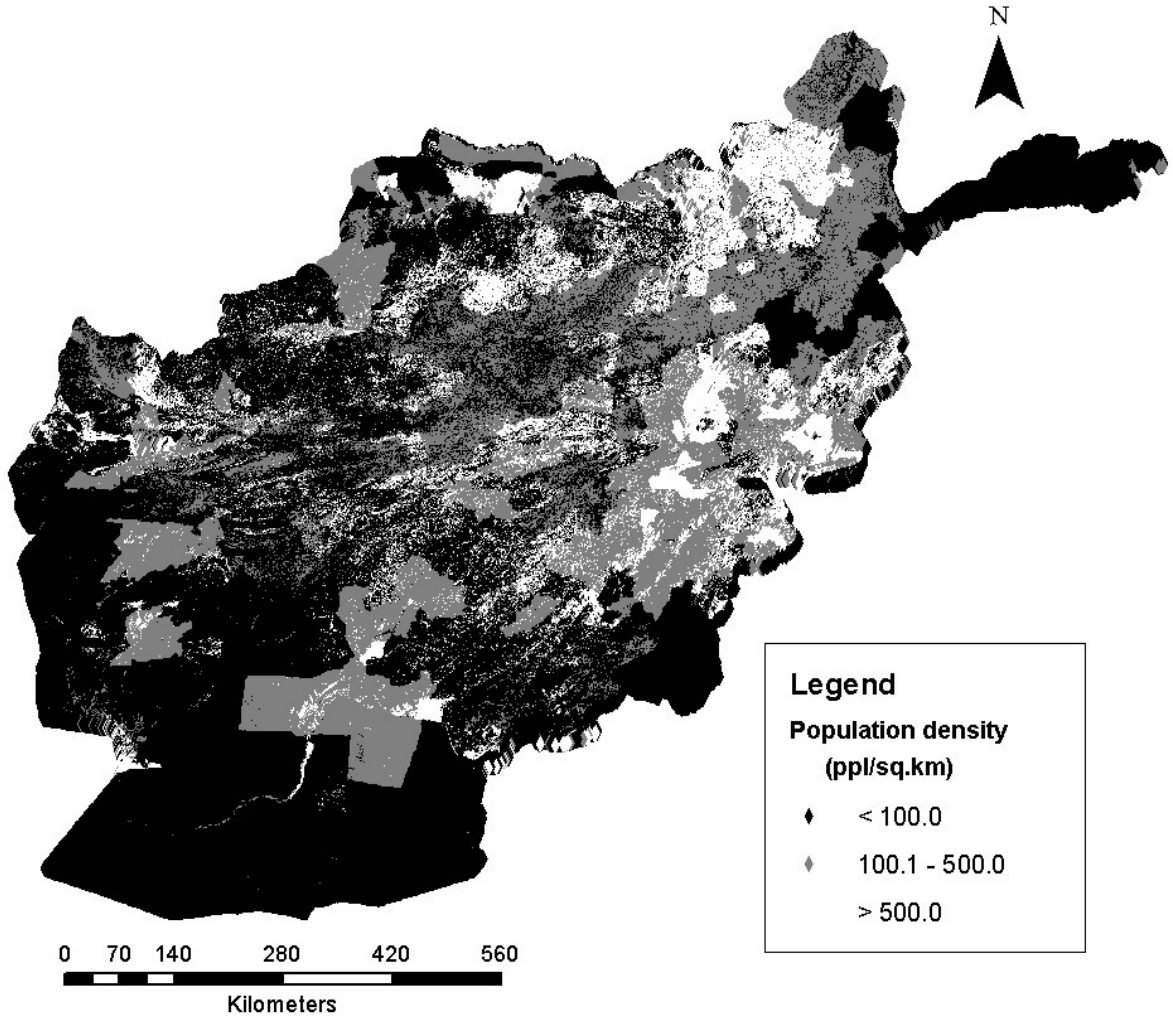
11. Afghanistan Living Condition Survey 2013 – 2014: National Risk and Vulnerability Assessment (http://www.af.undp.org/content/dam/afghanistan/docs/MDGs/NRVA%20REPORT-rev-5%202013.pdf)

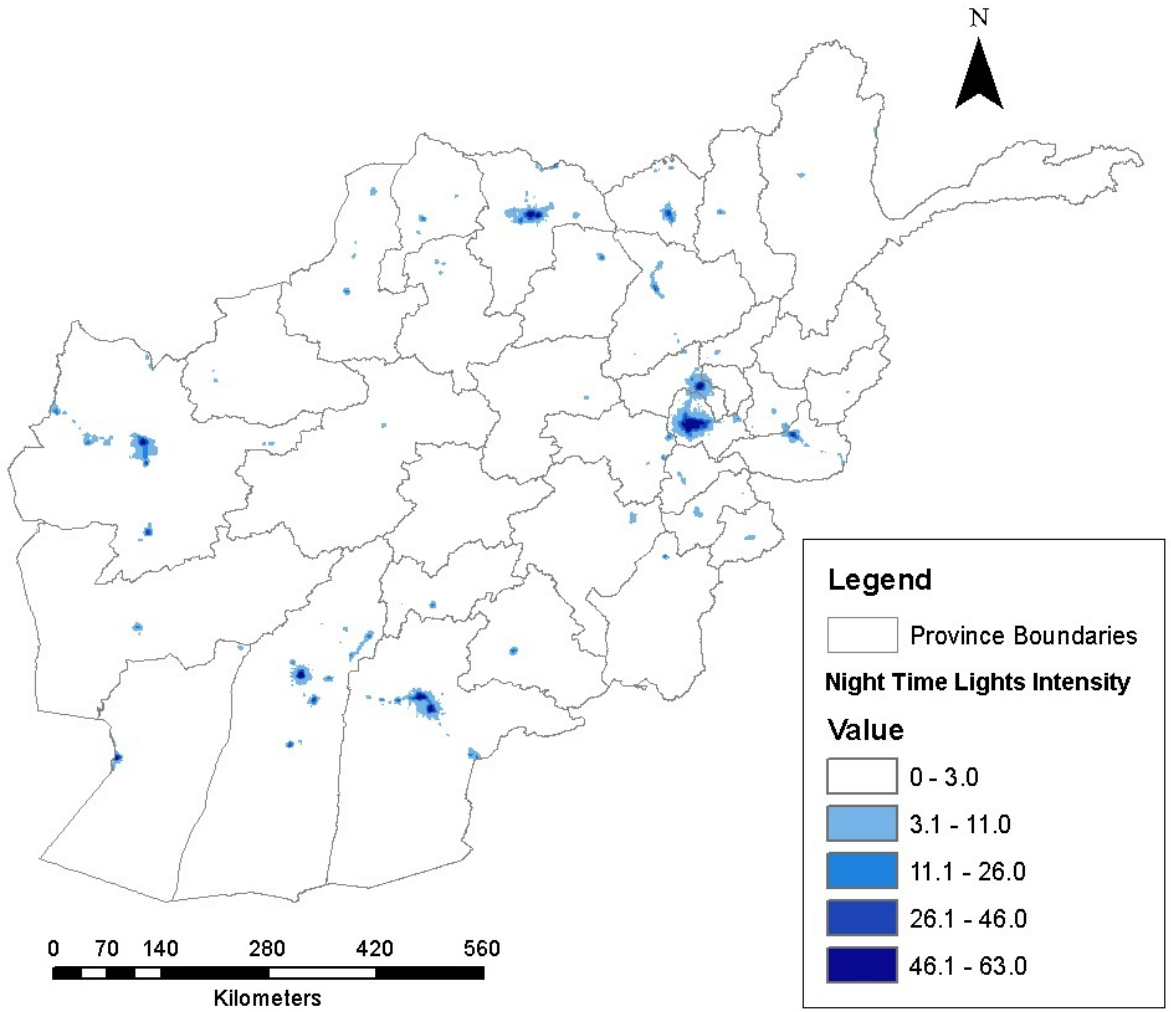
12. A survey of Afghan People, The Asian Foundation (2015).

13. Leveraging urbanization in south Asia. Managing spatial transformation for prosperity and livability (2015). https://openknowledge.worldbank.org/bitstream/handle/10986/22549/9781464806629.pdf?sequence=17&isAllowed=y

Preparation of the model – Social Indicators

Calibration and projection of key input datasets





Preparation of the model – Social Indicators

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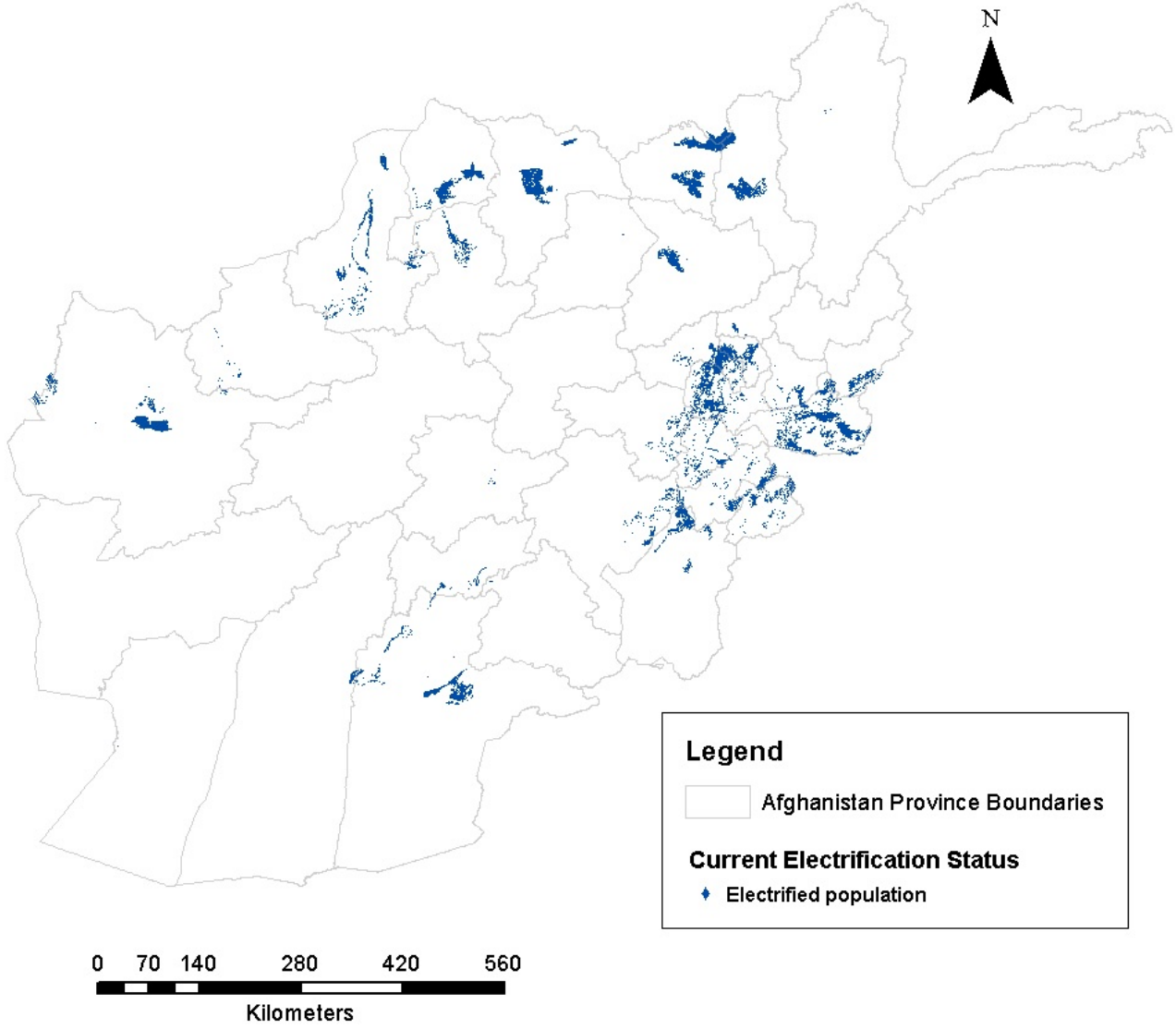


Identify current Electrification status:

- Night Lights index: >5
- Population: >500 people
- Distance from roads: <10 km
- Distance from grid: <10 km

The electrification rate under these assumptions is 30%

Preparation of the model – Technology Inputs

Technical and Economic parameters of the technologies used

Plant type	Plant capacity (kW)	Investment cost ($/kW)	O&M costs (% of investment cost/year)	Fuel cost $/liter (future)	Efficiency	Capacity factor	Life (years)
Diesel Genset Mini Grid	100	1,200 [14]	10%	**0.69 (1.00)**	37%	0.7	15
Small Hydro Mini Grid	1000	2,500 [15]	2%	-	-	0.5	30
Solar PV Mini Grid	100	2,600 [14], [15]	1.8%	-	-	Obtained for each grid point depending on solar availability	20
Wind Turbines Mini Grid	100	2,300 [14], [15]	3.5%	-	-	Obtained for each grid point depending on wind availability	20
Diesel Genset Stand Alone	1	2,000 [14]	10%	**0.69 (1.00)**	28%	0.5	10
Solar PV Stand Alone	0.4	5,500 [4] Including BoS	1.8%	-	-	Obtained for each grid point depending on solar availability	15

Parameter	Cost unit
HV lines (>110kV)	120,000 $/km [14]
MV lines (20 kV)	9,000 $/km [14]
LV lines (220 V)	5,000 $/km [14]
MV/LV transformer	3,500 $ per unit (50 kVA) [14]
Transmission loses	18.3% [14]
Connection cost per HH	$122 [14]
Cost of producing electricity	??

14. Islamic Republic of Afghanistan Ministry of Energy and Water, "Power Sector Master Plan," Asian Development Bank - Fichtner, 2013.

15. IRENA, "Renewable Power Generation Costs in 2014," IRENA, January 2015.

16. International Energy Agency, "World Energy Outlook 2015," IEA, Paris, 2015.

Running the model – Scenario Development

Important parameters and sensitivity

- **Energy Access Target**

  How many kWh will each household consume each year?

- **Diesel Price**

  How is diesel price expected to fluctuate over the next years?

- **Grid cost of electricity**

  What will be the production cost of electricity for the national grid over the next years?

Running the model – Scenario Development

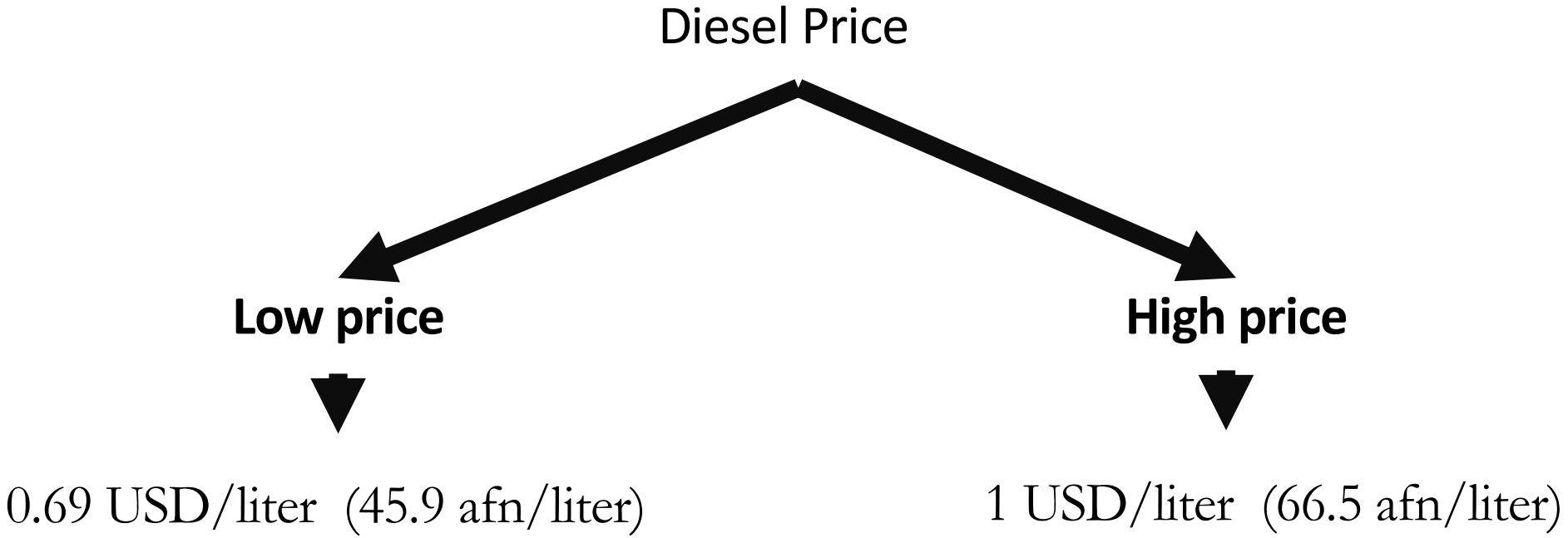
Energy Access Target

Access Level	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Indicative appliances powered	Task lighting + phone charging or radio	General lighting + fan + television	Tier 2 + medium power appliances (i.e. general food processing, refrigeration)	Tier 3 + Medium or continuous appliances (i.e. water heating, ironing, water pumping, rice cooking, micro wave)	Tier 4 + High power and continuous appliances (i.e. air conditioning)
Consumption per capita & year (kWh)	7.7	43.8	160.6	423.4	598.6
Consumption per urban household & year in Afghanistan (based on average household size: 7)	54	307	1,124	2,964	4,190
Consumption per rural household & year in Afghanistan (based on average household size: 8.1)	62	355	1,301	3,430	4,849

Adapted from Global Tracking Framework, 2015

What should be the **electricity consumption level** per household?

Running the model – Scenario Development



Based on exchange rate equal to 1 USD = 66.5 AFN

Running the model – Scenario Development

Grid Cost – Current situation

Power System in Afghanistan	Base year 2015				
	MW	GWh	(%)	USD/kWh	Investment (USD/kW)
Imports		3500	76.2%	0.049	-
Turkmenistan	up to 90	595.0	17.0%	0.028	-
Uzbekistan	up to 300	1995.0	57.0%	0.060	-
Tajikistan	up to 300	140.0	4.0%	0.035	-
Iran	up to 150	770.0	22.0%	0.040	-
Indigenous Generation		**1093**	**23.8%**	**0.104**	
Hydro	254.0	711.9	65.1%	0.091	2200
Oil	199.6	131.1	12.0%	0.300	500
Gas	67.0	249.4	22.8%	0.037	1000
Coal	0.0	0.0	0.0%	0.055	1500
Solar	0.1	0.3	0.0%	0.060	1953
Wind	0.0	0.0	0.0%	0.065	1750
Total	**520.7**	**4592.8**	**100.0%**	**0.062**	**1722.01**

What is the cost of electricity production at the moment?

↓

0.062 USD/kWh

What is the estimated investment cost per kW

↓

1722 USD/kW

Running the model – Scenario Development

Grid cost – Reference scenario according to government's plans

Power System in Afghanistan	End year 2030 – Reference scenario				
	MW	GWh	(%)	USD/kWh	Investment (USD/kW)
Imports		3500	24.3%	0.066	-
Turkmenistan	up to 90	595.0	17.0%	0.038	-
Uzbekistan	up to 300	1995.0	57.0%	0.081	-
Tajikistan	up to 300	140.0	4.0%	0.047	-
Iran	up to 150	770.0	22.0%	0.054	-
Indigenous Generation		**10898**	**75.7%**	**0.080**	
Hydro	2767.5	7757.8	71.2%	0.091	2230
Oil	66.0	43.4	0.4%	0.300	500
Gas	267.0	994.0	9.1%	0.037	1000
Coal	400.0	2102.4	19.3%	0.055	1500
Solar	0.1	0.3	0.0%	0.060	1130
Wind	0.0	0.0	0.0%	0.065	1600
Total	**3500.6**	**14397.8**	**100.0%**	**0.077**	**1970.07**

What is the cost of electricity production at the moment?

↓

0.077 USD/kWh

What is the estimated investment cost per kW

↓

1970 USD/kW

Running the model – Scenario Development

Grid cost – Higher renewable energy penetration scenario

Power System in Afghanistan	End year 2030 - Renewables scenario				
	MW	GWh	(%)	USD/kWh	Investment (USD/kW)
Imports		3500	24.1%	0.066	-
Turkmenistan	up to 90	595.0	17.0%	0.038	-
Uzbekistan	up to 300	1995.0	57.0%	0.081	-
Tajikistan	up to 300	140.0	4.0%	0.047	-
Iran	up to 150	770.0	22.0%	0.054	-
Indigenous Generation		**11028**	**75.9%**	**0.078**	
Hydro	2767.5	7757.8	71.2%	0.091	2230
Oil	0.0	0.0	0.0%	0.300	500
Gas	267.0	994.0	9.1%	0.037	1000
Coal	400.0	2102.4	19.3%	0.055	1500
Solar	40.0	105.1	1.0%	0.060	1130
Wind	26.0	68.3	0.6%	0.065	1600
Total	3500.6	**14527.7**	**100.0%**	**0.075**	**1988.98**

What is the cost of electricity production at the moment?

↓

0.075 USD/kWh

What is the estimated investment cost per kW

↓

1989 USD/kW

Running the model – Scenario Development

Grid cost – Higher imports scenario

Power System in Afghanistan	End year 2030 - Import scenario				
	MW	GWh	(%)	USD/kWh	Investment (USD/kW)
Imports		5680	39.1%	0.063	-
Turkmenistan	up to 90	738.4	13.0%	0.038	-
Uzbekistan	up to 300	2556.0	45.0%	0.081	-
Tajikistan	up to 300	1136.0	20.0%	0.047	-
Iran	up to 150	1249.6	22.0%	0.054	-
Indigenous Generation		**8848**	**60.9%**	**0.083**	
Hydro	2254.0	6318.3	58.0%	0.091	2230
Oil	199.6	131.1	1.2%	0.300	500
Gas	150.0	558.5	5.1%	0.037	1000
Coal	350.0	1839.6	16.9%	0.055	1500
Solar	0.1	0.3	0.0%	0.060	1130
Wind	0.0	0.0	0.0%	0.065	1600
Total	**2953.67**	**14527.8**	**100.0%**	**0.075**	**1603.40**

What is the cost of electricity production at the moment?

↓

0.075 USD/kWh

What is the estimated investment cost per kW

↓

1603 USD/kW

Running the model – Scenario Development

Important parameters and sensitivity

Electricity consumption level per household

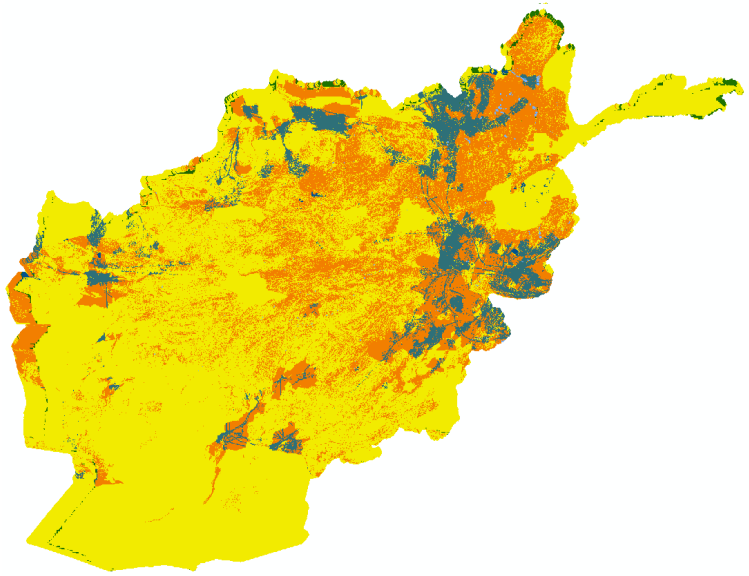
Diesel price

Scenarios	U5 - R3 (2657 kWh/hh/year)	U4 - R4 (2964 kWh/hh/year)	U4 - R2 (1635 kWh/hh/year)	U3 - R3 (1124 kWh/hh/year)
LD - 0.69 $/L	0.062	0.062	0.062	0.062
LD - 0.69 $/L	0.077	0.077	0.077	0.077
LD - 0.69 $/L	0.075 RE	0.075 RE	0.075 RE	0.075 RE
LD - 0.69 $/L	0.075 IM	0.075 IM	0.075 IM	0.075 IM
HD - 1.00 $/L	0.062	0.062	0.062	0.062
HD - 1.00 $/L	0.077	0.077	0.077	0.077
HD - 1.00 $/L	0.075 RE	0.075 RE	0.075 RE	0.075 RE
HD - 1.00 $/L	0.075 IM	0.075 IM	0.075 IM	0.075 IM

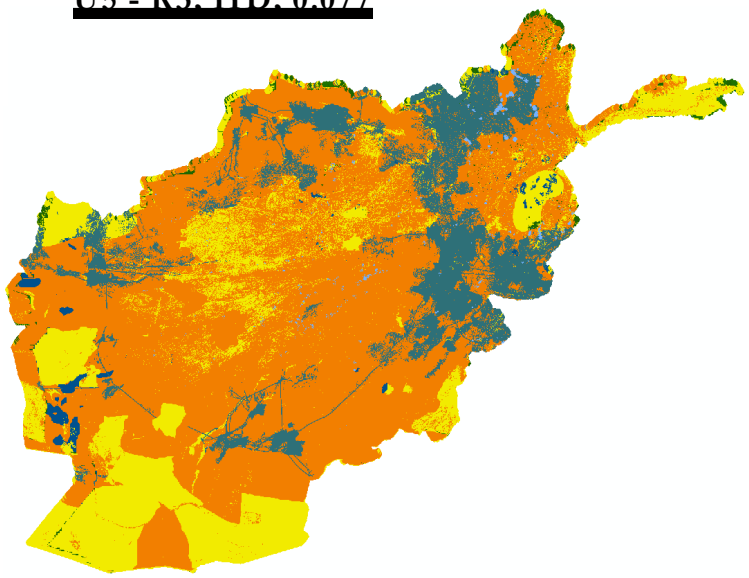
RE: Refers to the scenario with increased penetration of renewable based technologies (solar – wind)

IM: Refers to the scenario with increased imports from neighboring countries

Electrification analysis – Results



U5 - R3, HD, 0.077



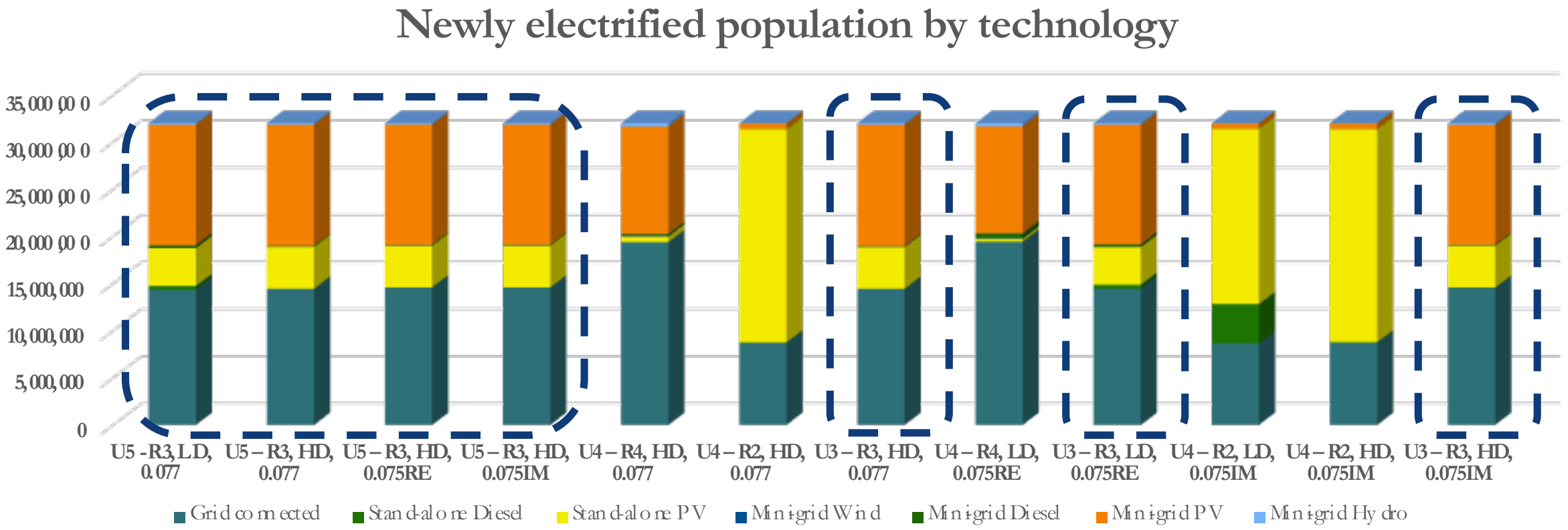
U4 – R4, HD, 0.077

- Grid
- Diesel Mini grid
- Hydro Mini grid
- PV Mini grid
- Wind Mini grid
- Diesel Stand alone
- PV Stand alone

Compare scenario results under different:

3. Demand levels

Electrification analysis – Summaries

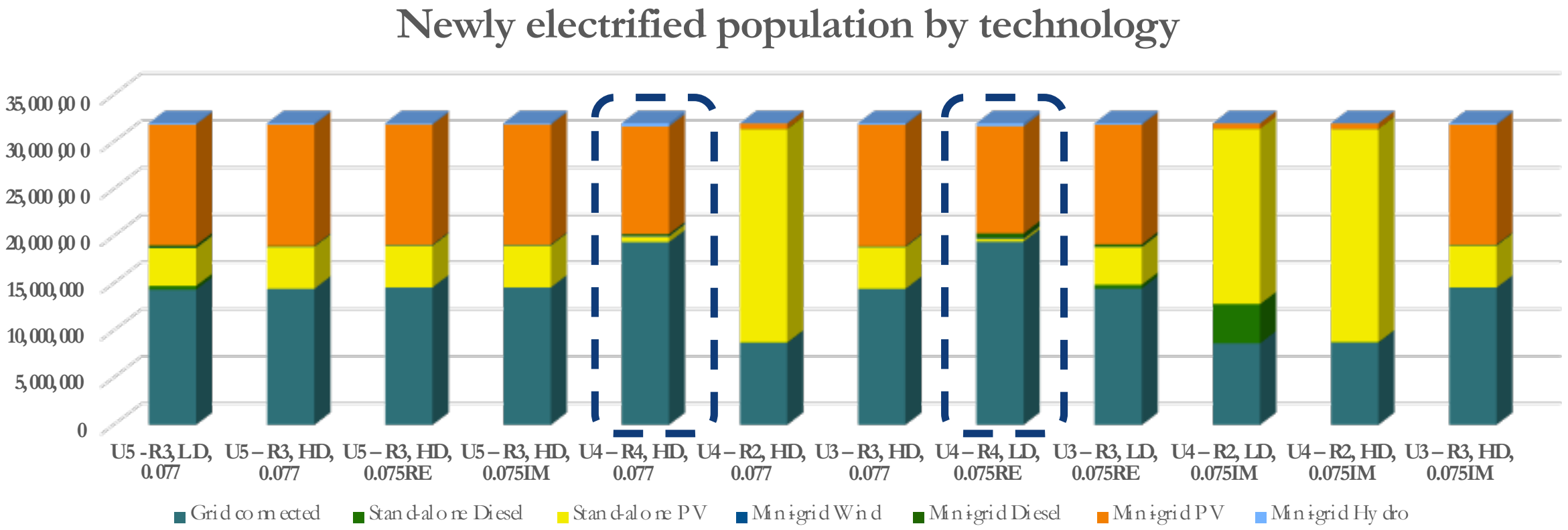


Grid ~ 45%

Mini-grid ~ 41%

Stand-alone ~ 14%

Electrification analysis – Summaries

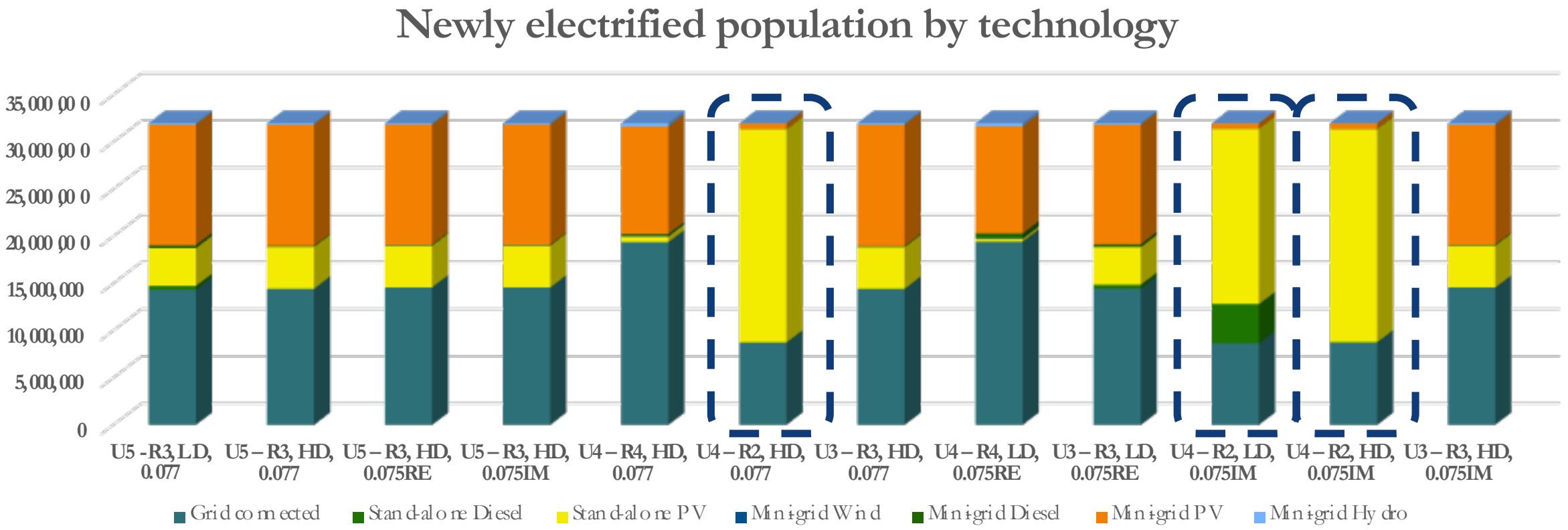


Grid ~ 60%

Mini-grid ~ 38%

Stand-alone ~ 2%

Electrification analysis – Summaries

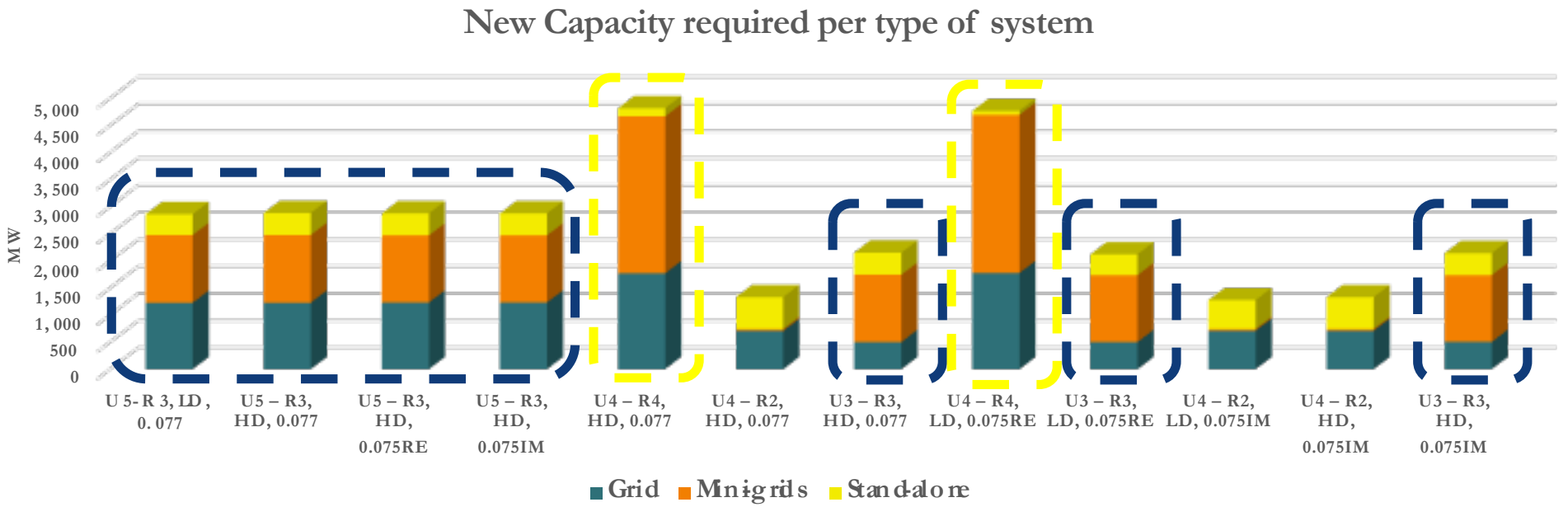


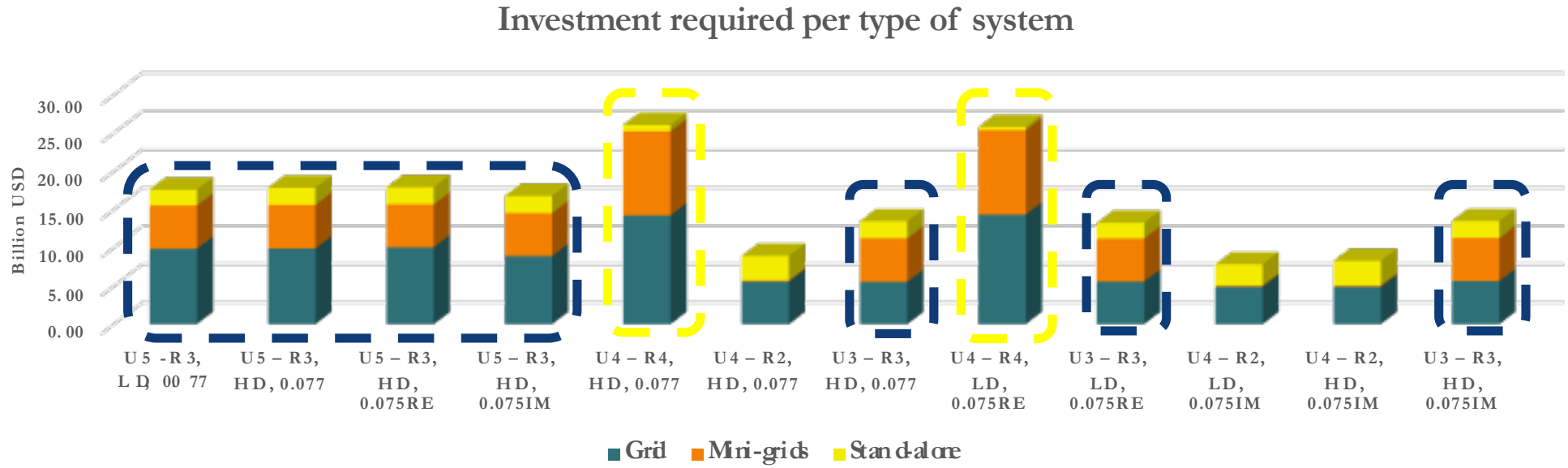
Grid ~ 27%

Mini-grid ~ 2%

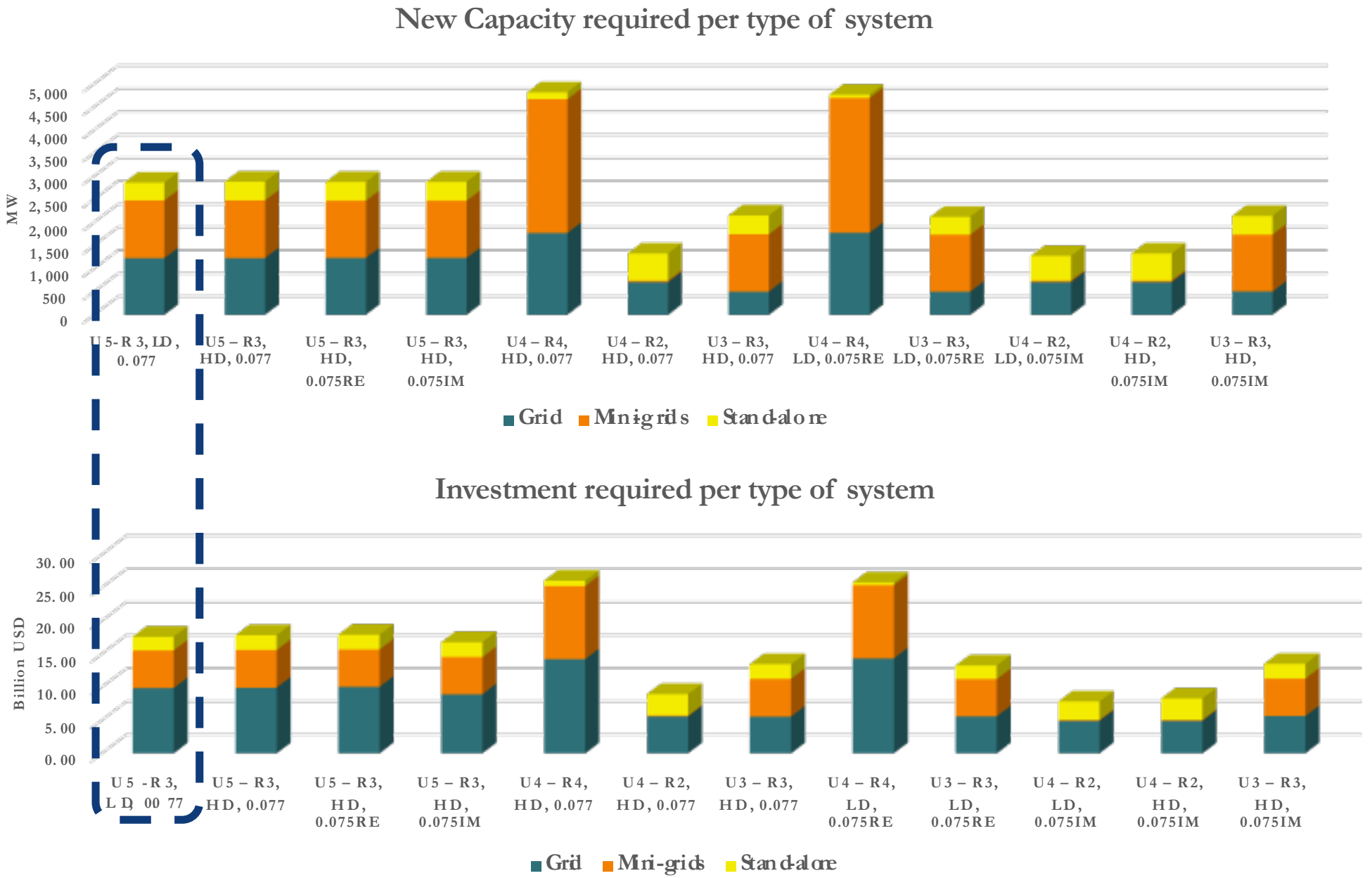
Stand-alone ~ 71%

Electrification analysis – Summaries





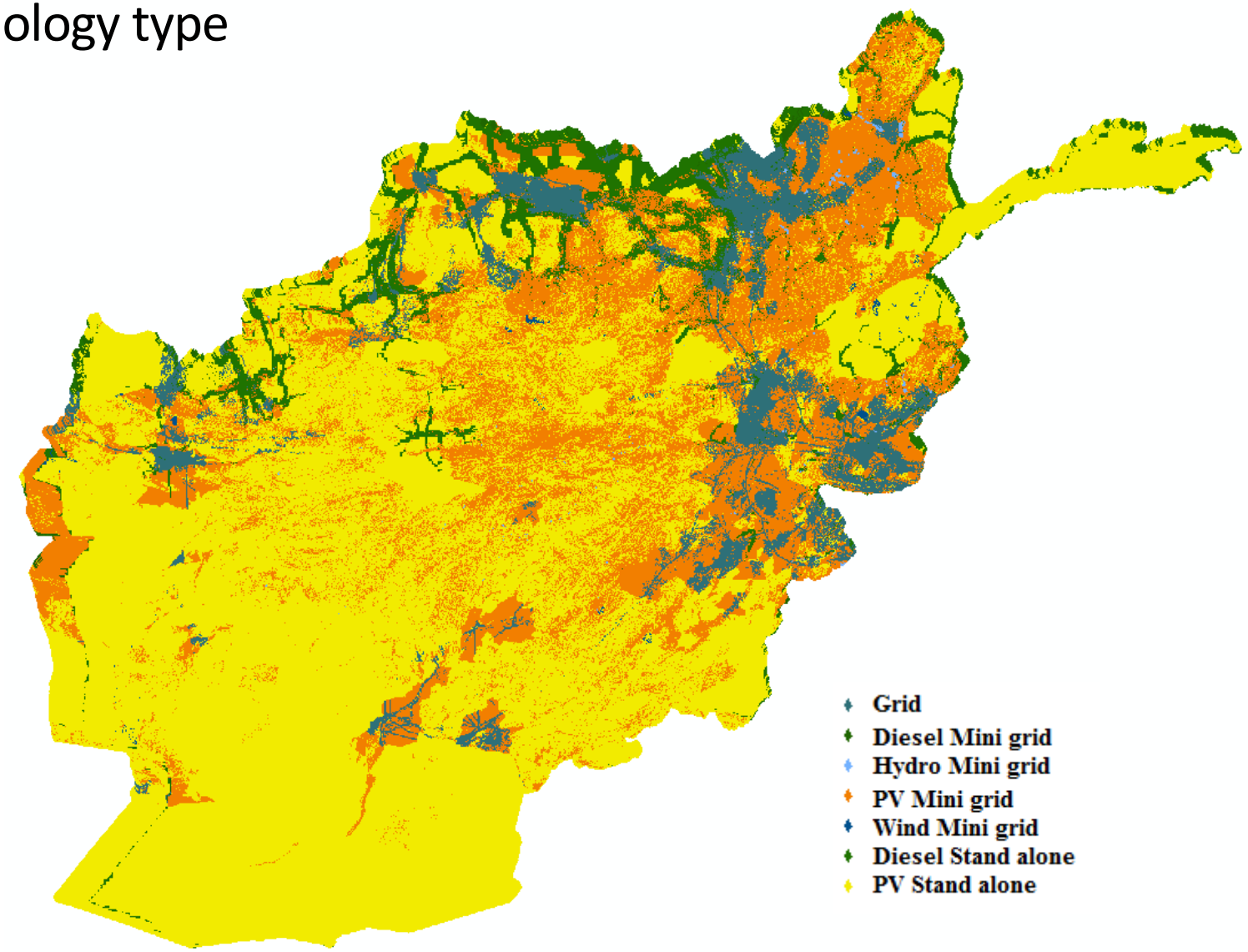
Electrification analysis – Summaries



Electrification analysis – U5 R3 LD 0.077

Results per technology type

People to receive electricity by 2030:		31,999,487	
Technology split out	**Share (%)**	**Capacity (MW)**	**Investment (billion USD)**
Grid extension	**44.9**	**1,225**	**9.84**
Mini grids	**41.4**	**1,252**	**5.7**
Diesel genset	0.8	12.8	**0.052**
PV system	40.0	1,228	**5.6**
Wind turbines	0.1	4.8	**0.021**
Mini – Small Hydro	0.5	6.6	**0.055**
Stand alone	**13.7**	**383**	**2.1**
Diesel genset	1.2	**20.6**	**0.06**
PV systems	12.5	**362.3**	**2.0**
Total	**100**	**2,860**	**17.58**



Electrification analysis – U5 R3 LD 0.077

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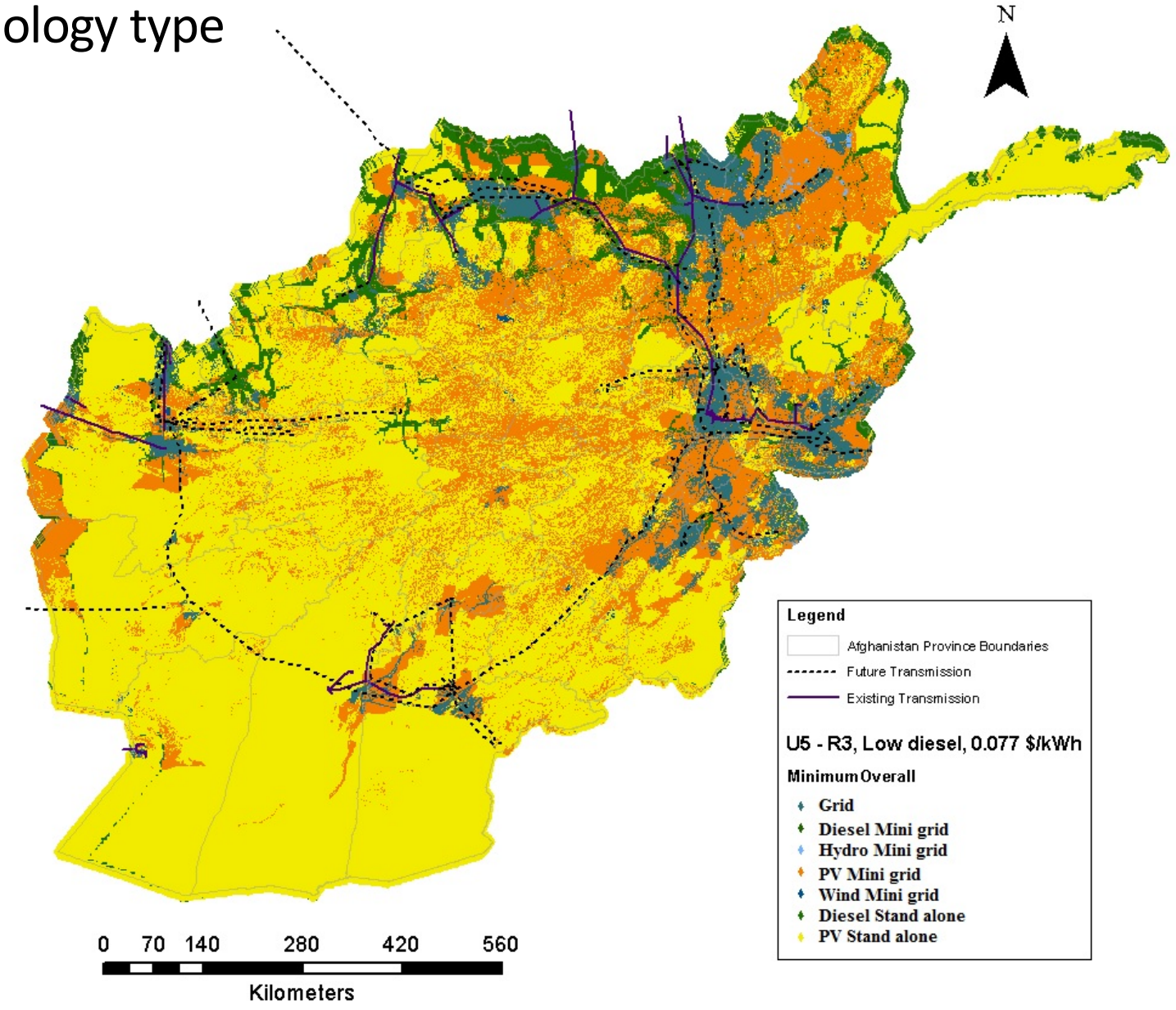

Electrification analysis – U5 R3 LD 0.077

Lowest LCoE achieved per location

People to receive electricity by 2030:	31,999,487		
Technology split out	**Share (%)**	**Capacity (MW)**	**Investment (billion USD)**
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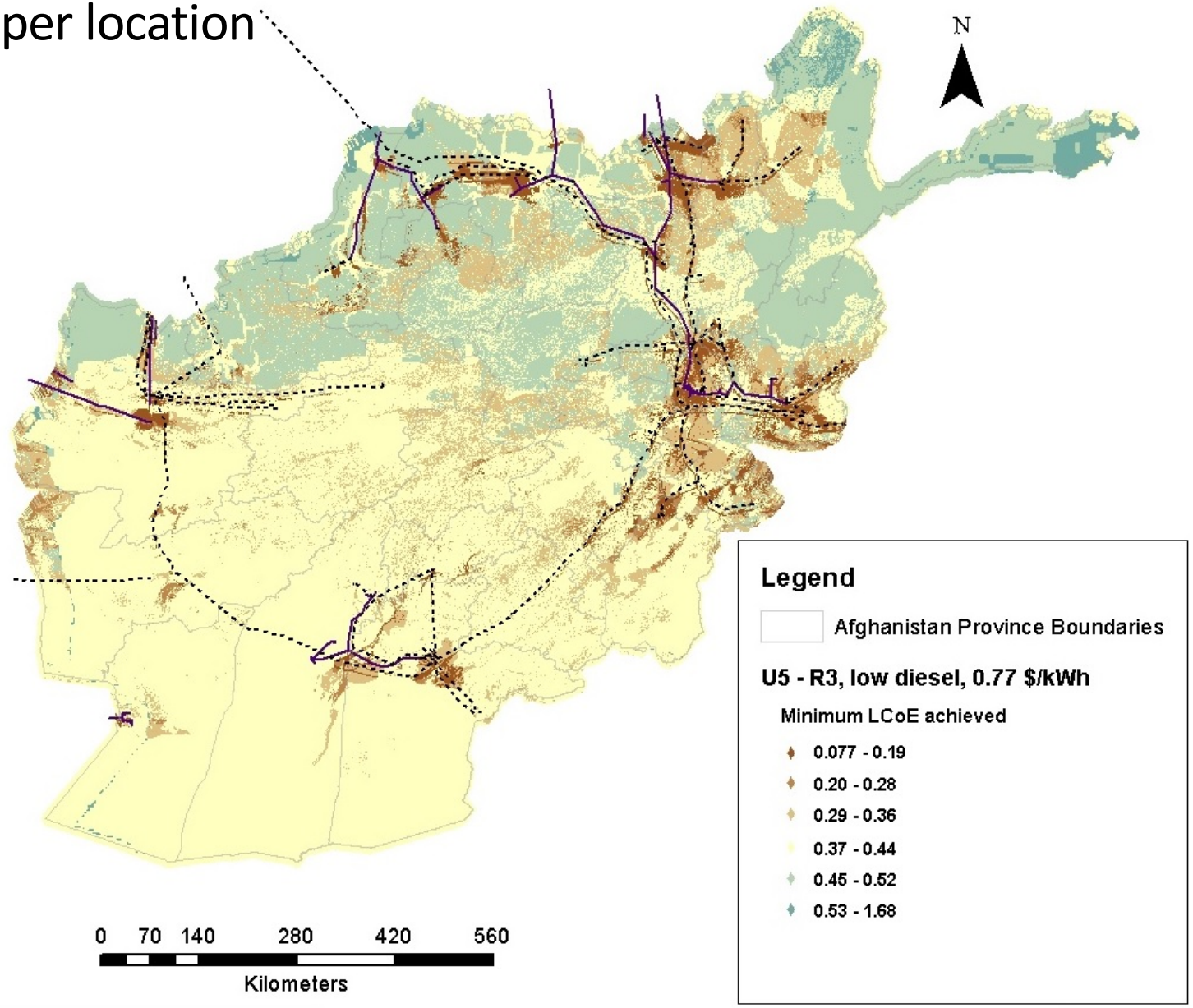
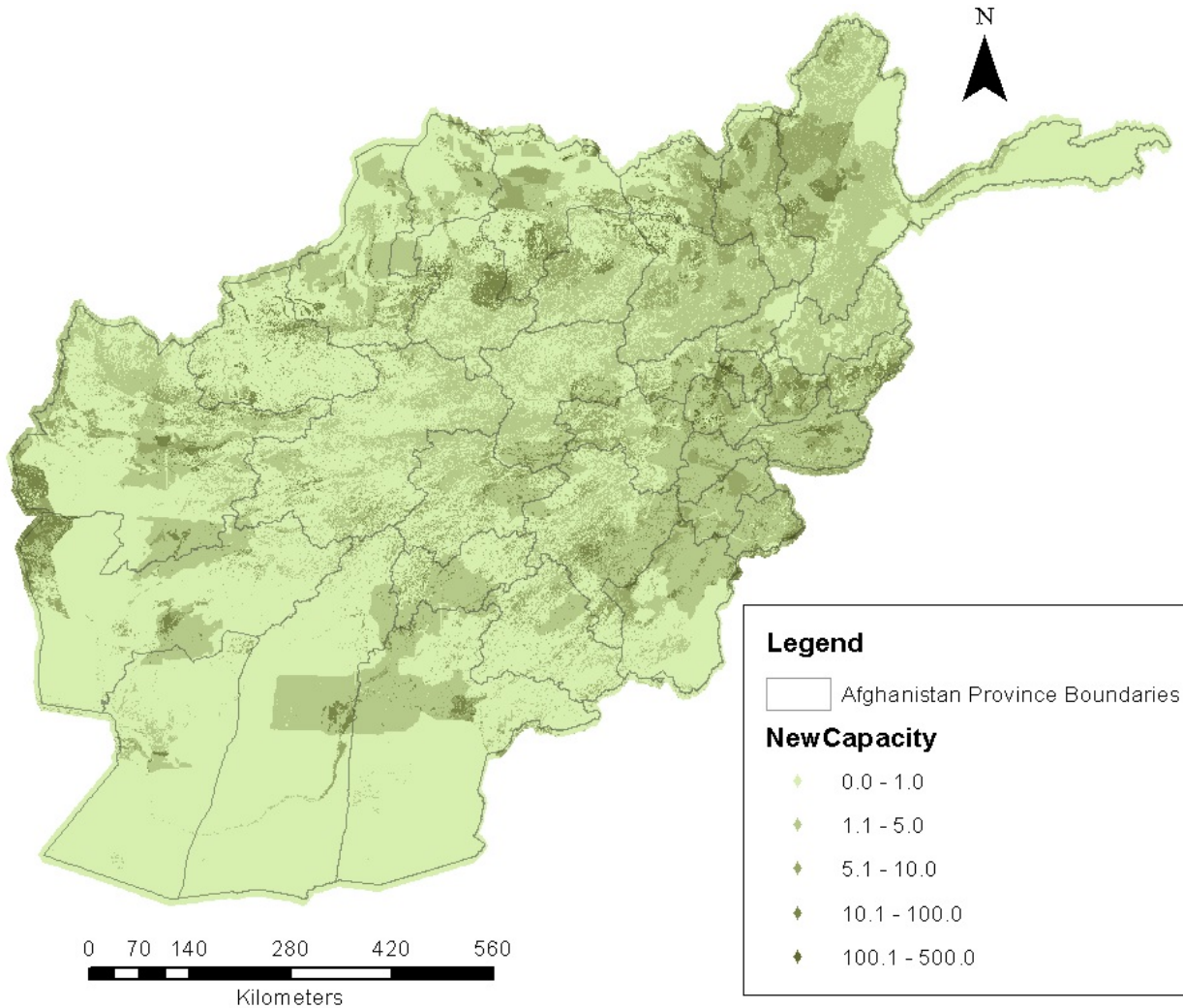
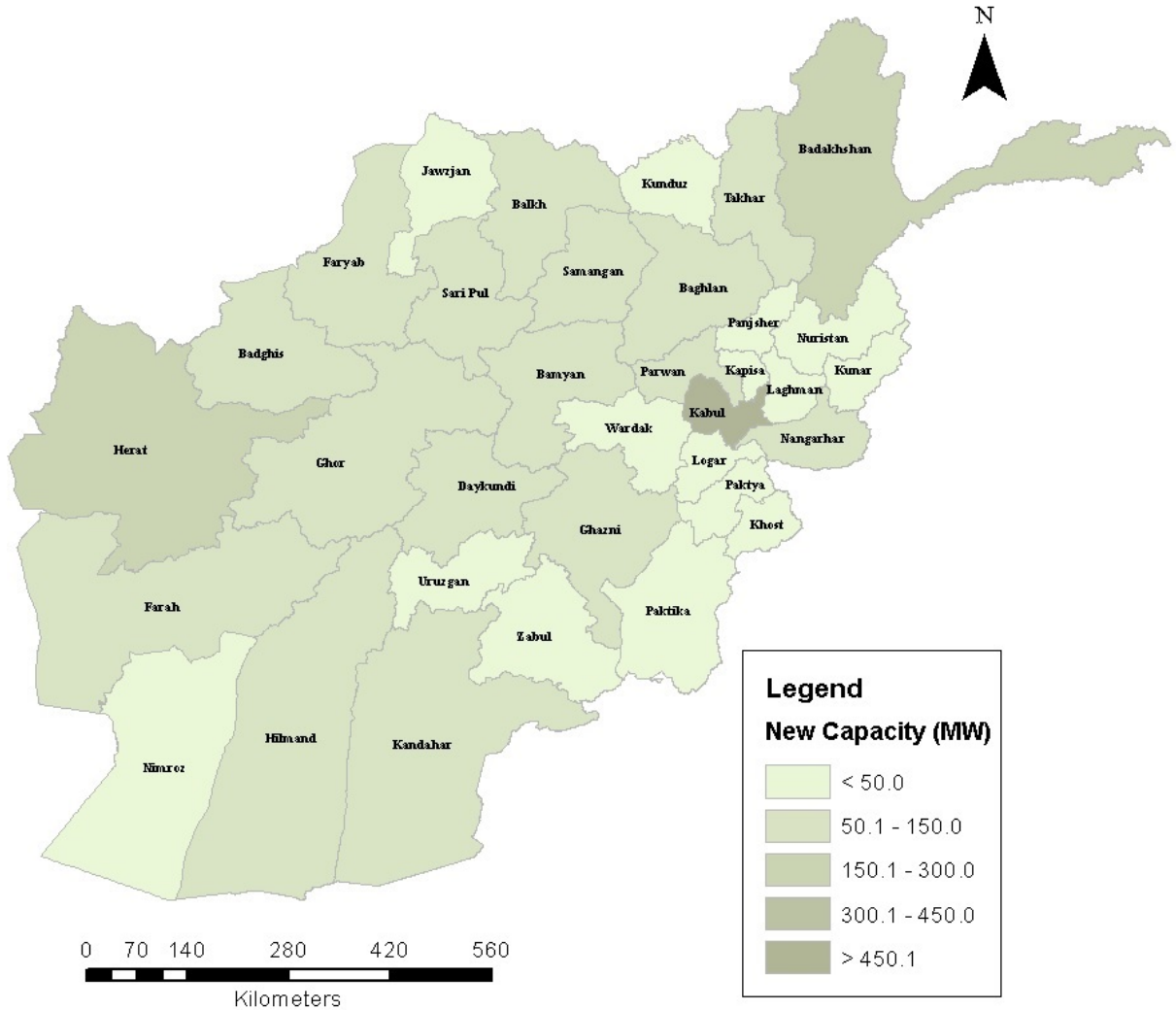


Electrification analysis – U5 R3 LD 0.077

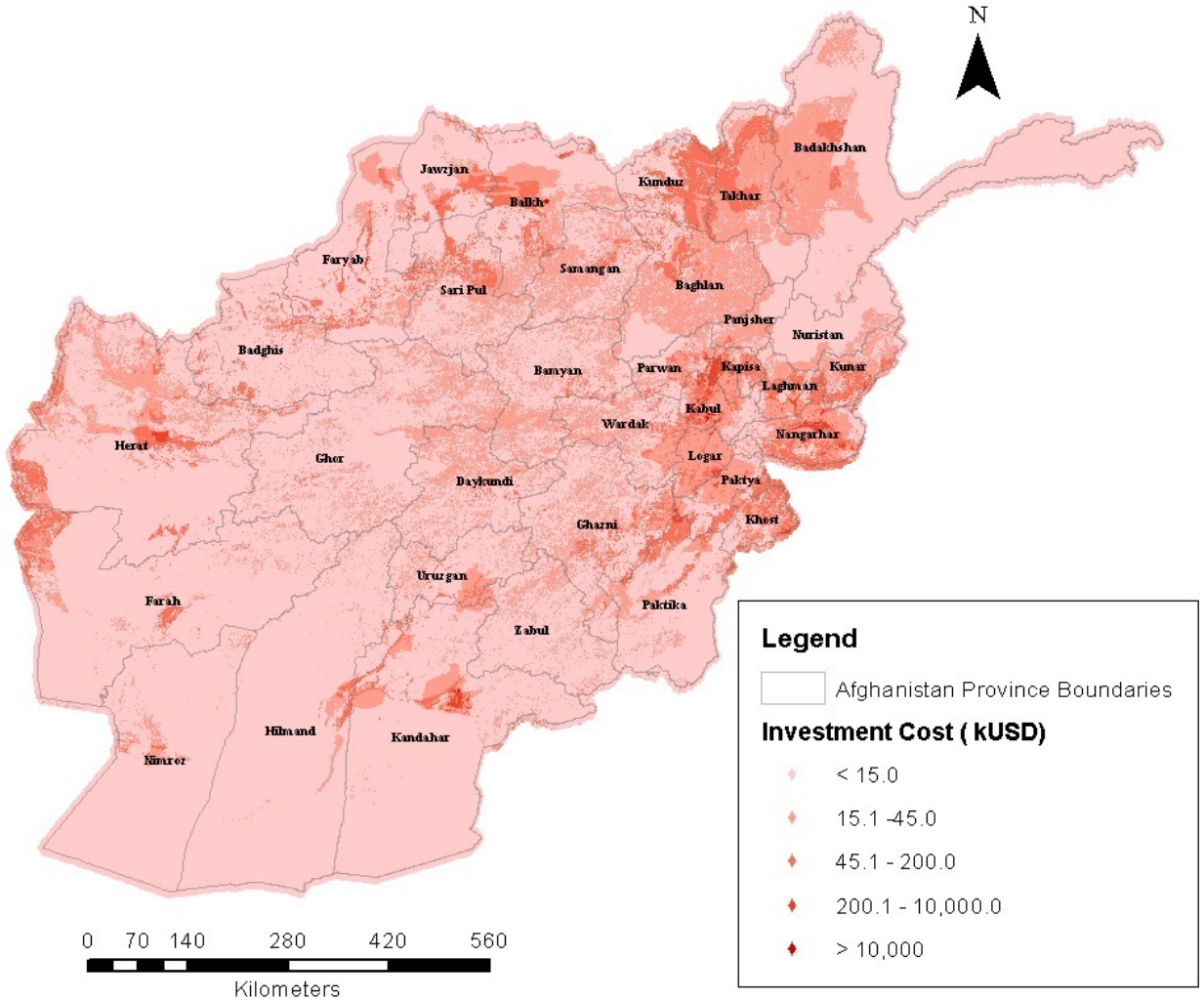
New capacity per location

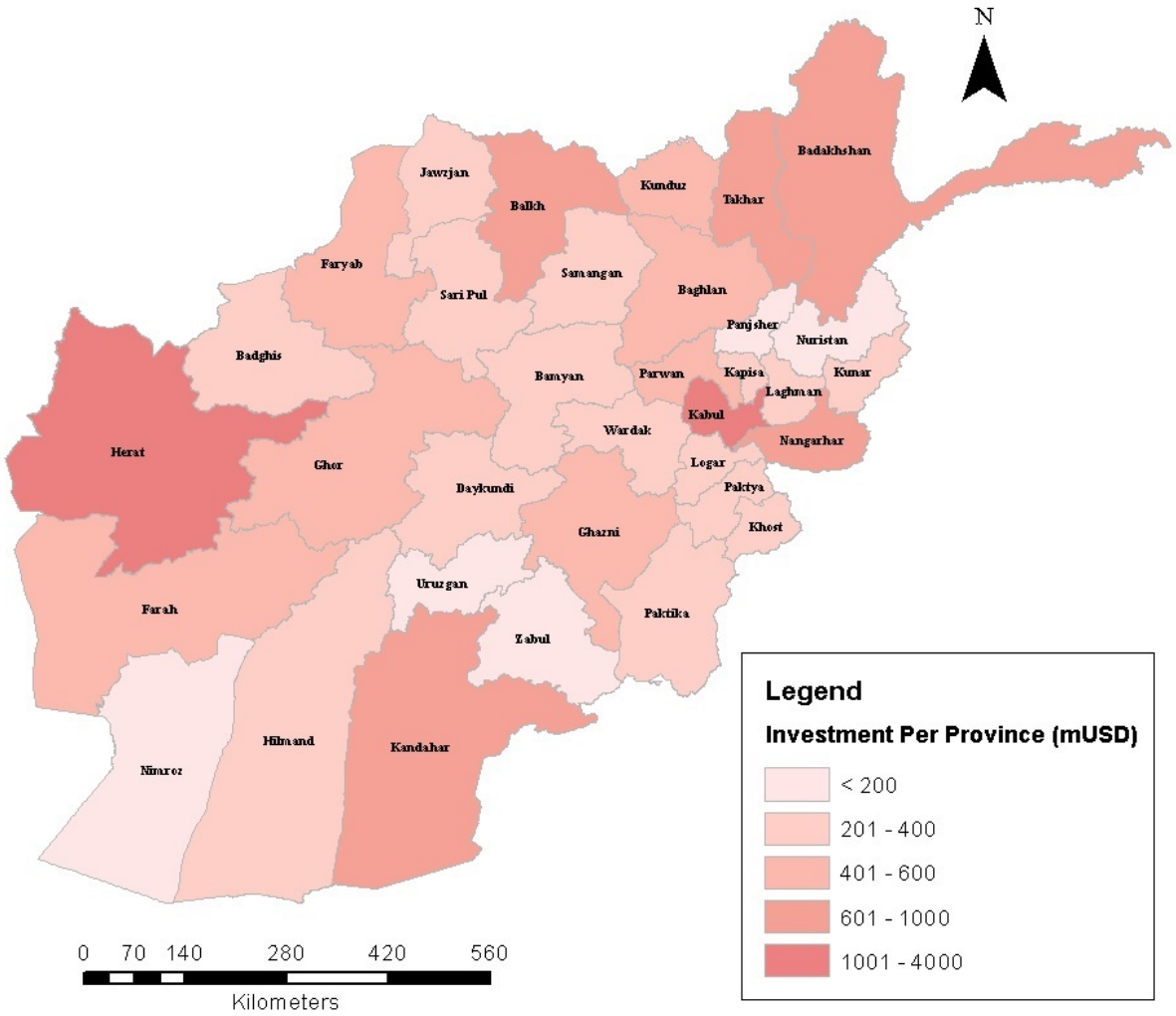




Electrification analysis – U5 R3 LD 0.077

Investment requirements per location





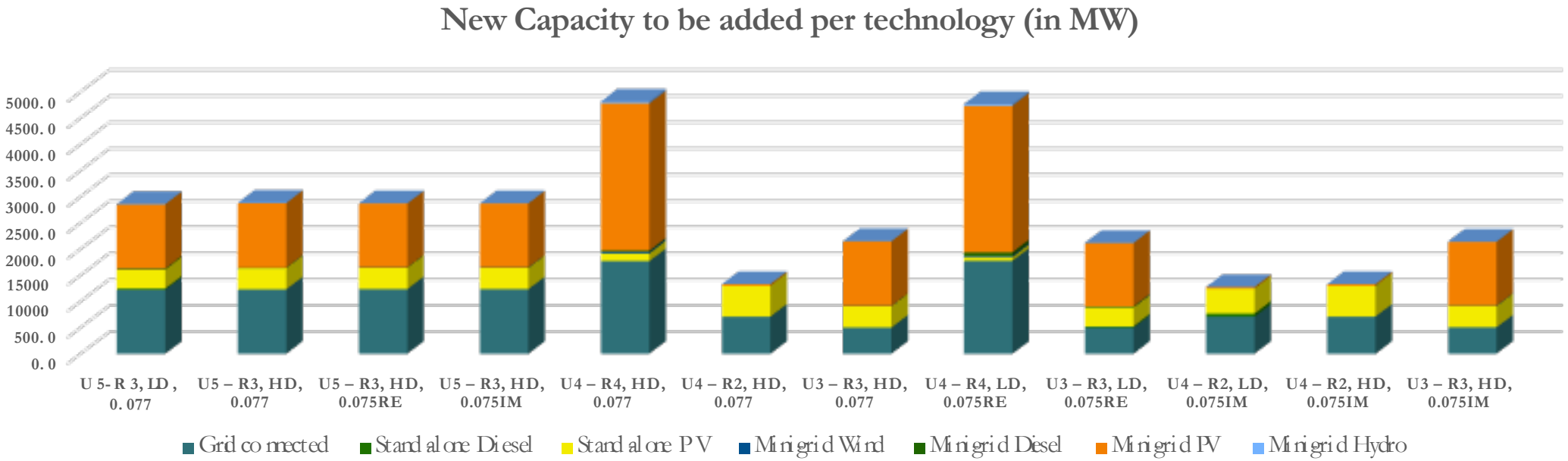
Electrification Pathways for Afghanistan

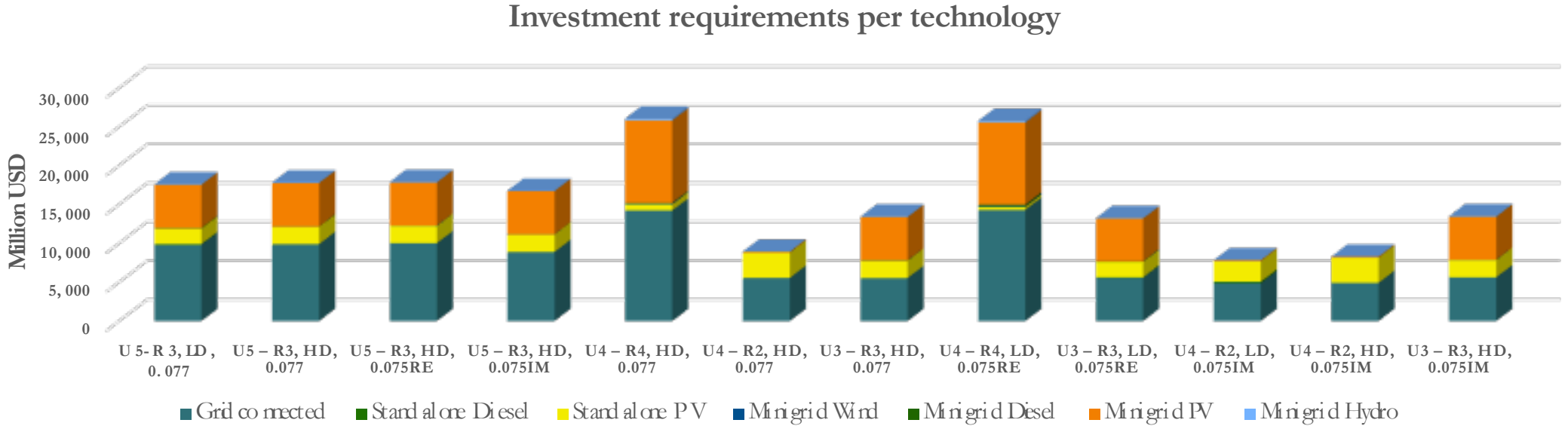
By 2030…

- **~ 32 million Afghans** will be getting access to modern, reliable and affordable electricity services.
- **Grid extension** is the least cost solution in densely populated areas which are close to the grid network
- **Low diesel** prices allows a small penetration (1-2%) of diesel gensets in the electrification mix. Increased diesel prices on the other hand, give a competitive advantage to **solar PV** systems.
- Other renewables (**Wind**, **Hydro**) penetrate in areas where these resources are available and signify decent potential.
- Higher electricity demand levels move the favorable electrification option from stand-alone systems to mini-grids to the grid.
- The investment requirements for full electrification can vary between **7.82 – 26.04 billion USD** depending on target capital and O&M costs per technology, actualization of future plans etc.
- The share of renewable energy sources in total electricity generation can reach more than 60% by 2030.

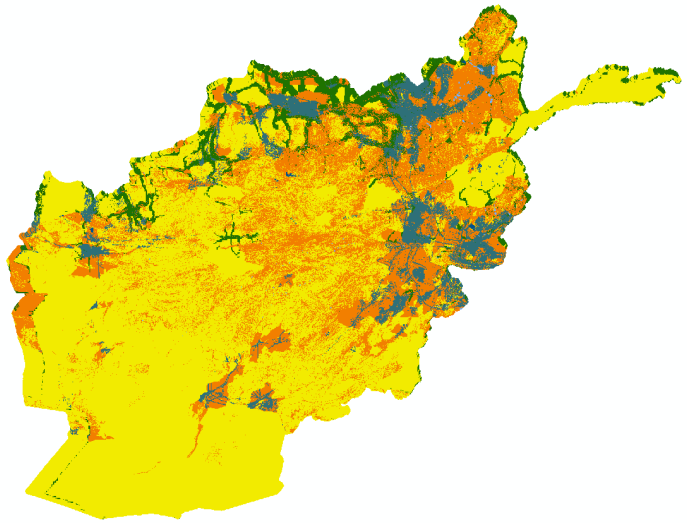
Additional Slides

Electrification analysis – Summaries

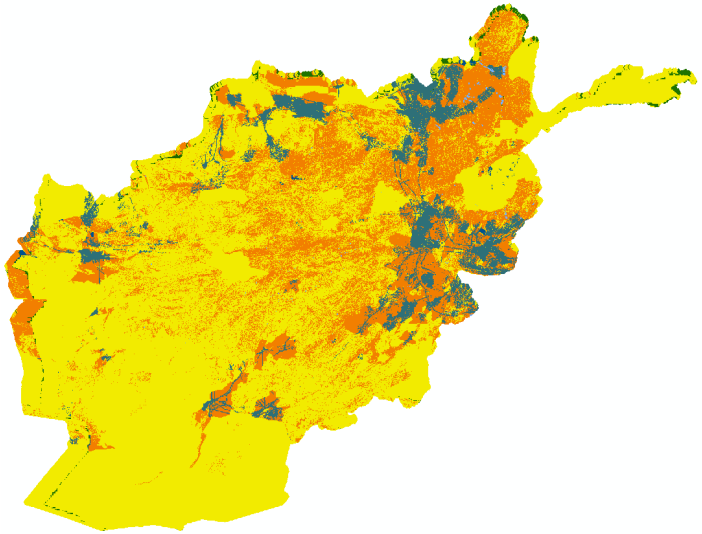




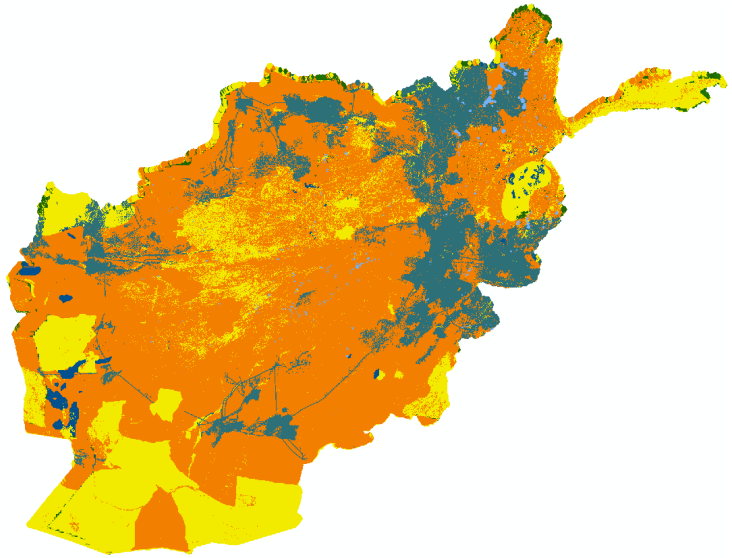
Electrification analysis – Results



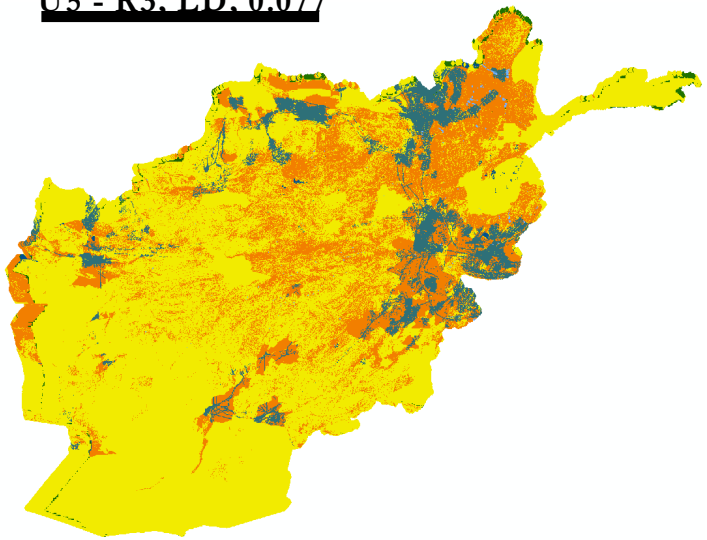
U5 - R3, LD, 0.077



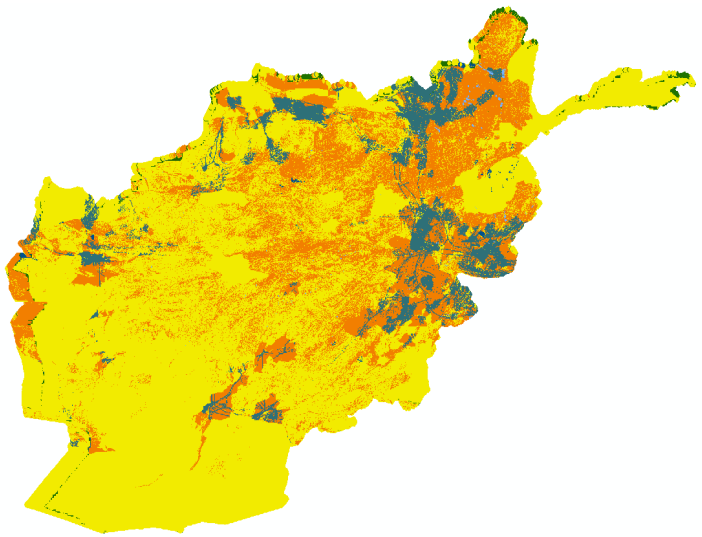
U5 - R3, HD, 0.077



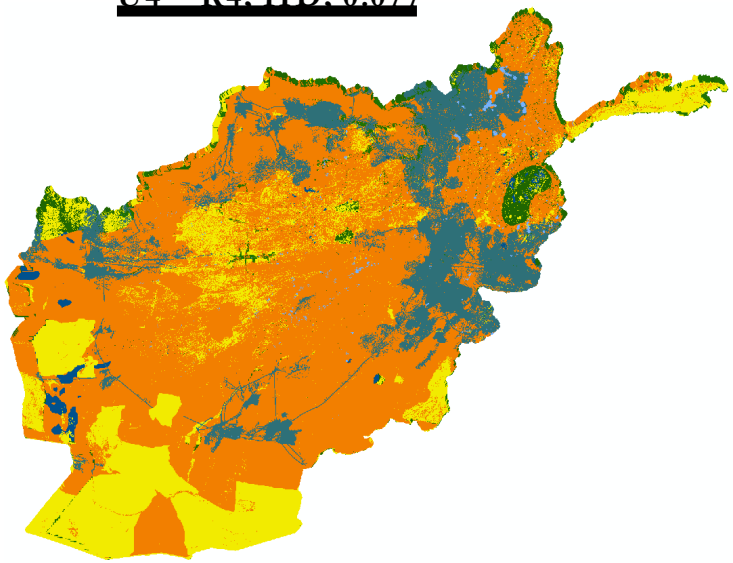
U4 – R4, HD, 0.077



U5 - R3, HD, 0.075RE

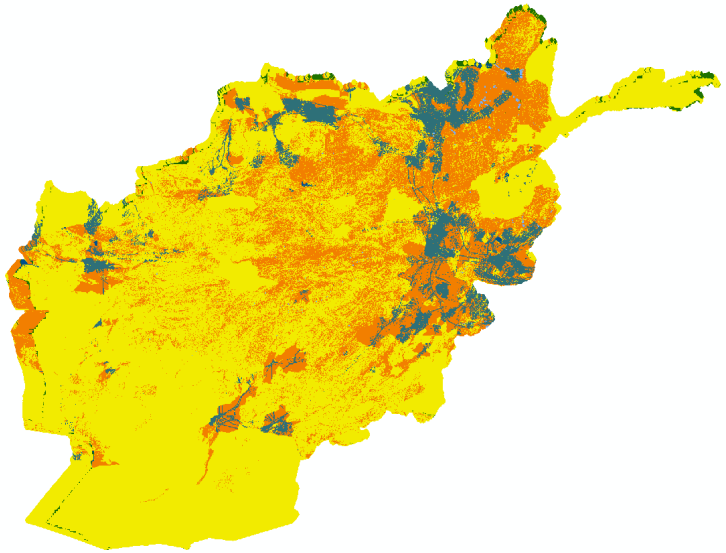


U5 - R3, HD, 0.075IM

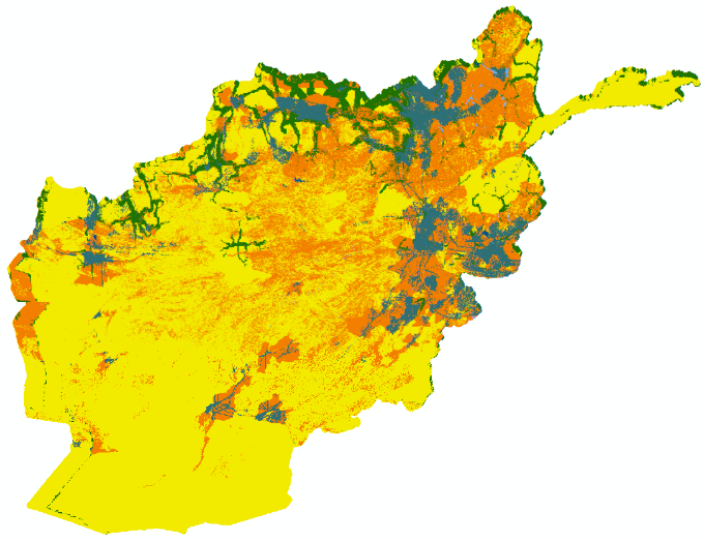


U4 – R4, LD, 0.075RE

Electrification analysis – Results



U3 – R3, HD, 0.077



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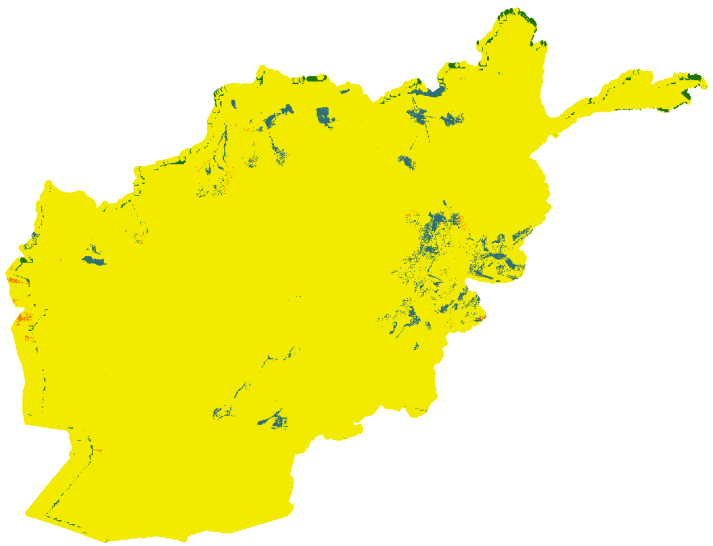

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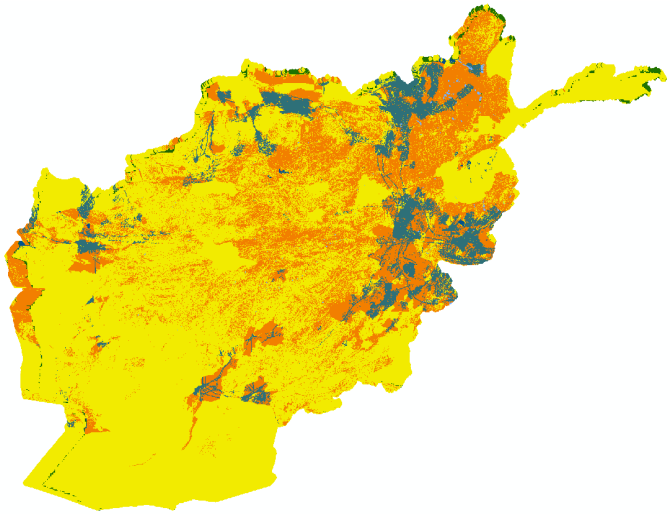
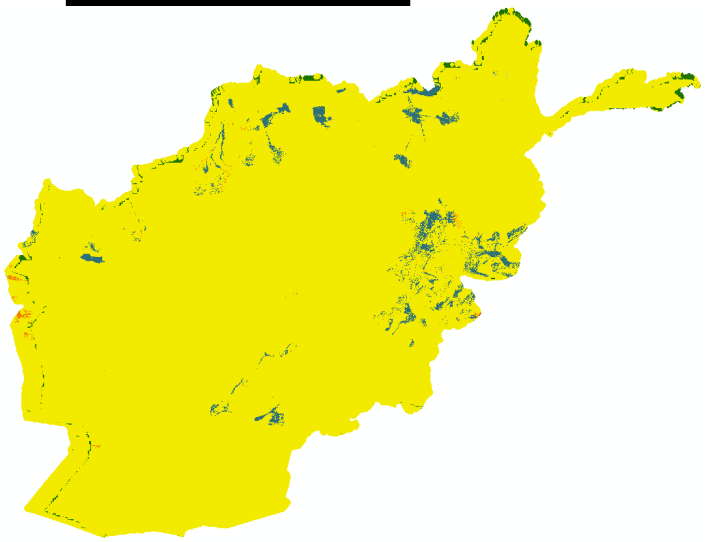
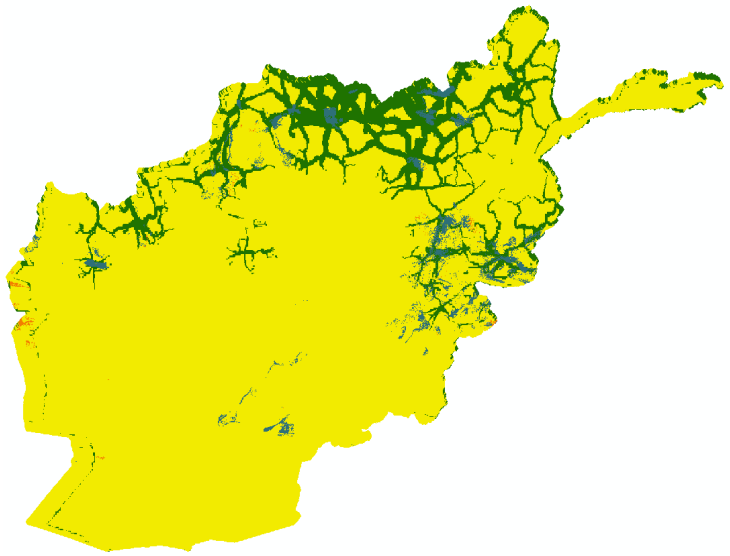


U4 – R2, HD, 0.077



U4 – R2, HD, 0.075IM



U4 – R2, LD, 0.075IM

Electrification analysis – Summaries