RENEWABLE ENERGY IN ARMENIA

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Yerevan, November 25, 2017

Energy Sector Overview

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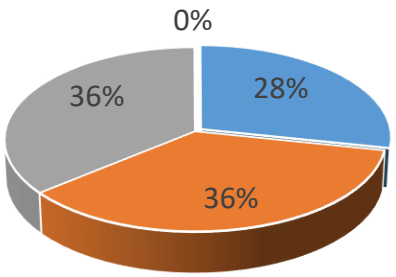
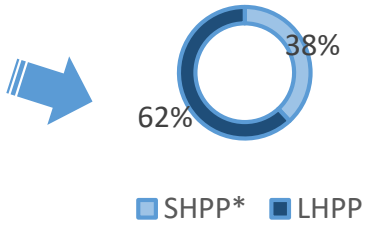
Electricity Production in 2015

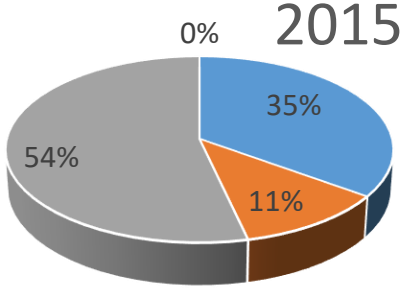


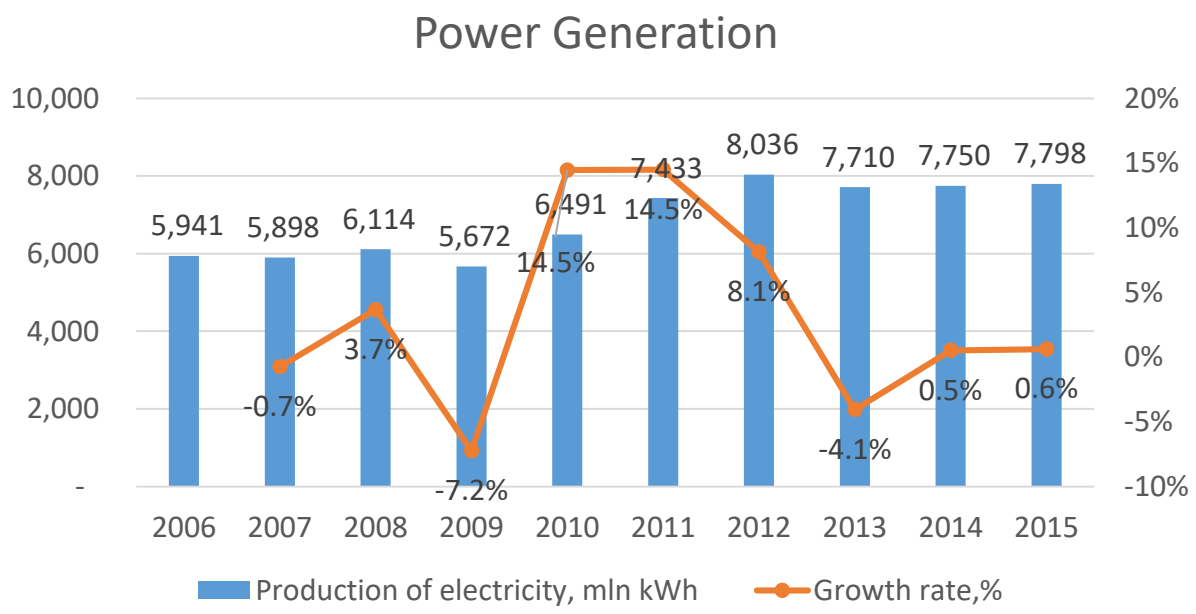


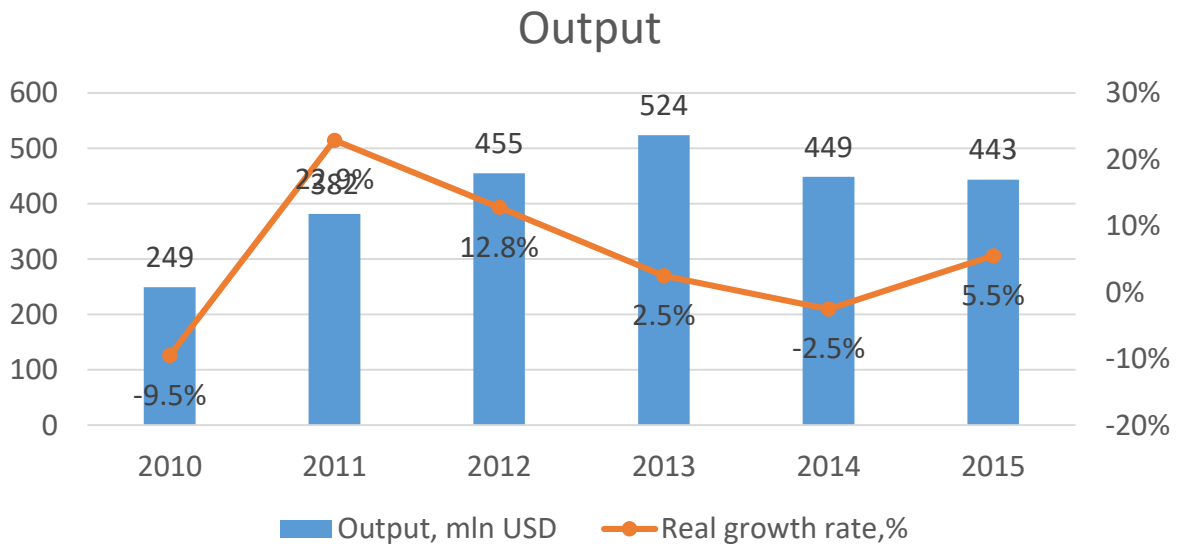
7798 mln kWh

Installed capacities as of 2015

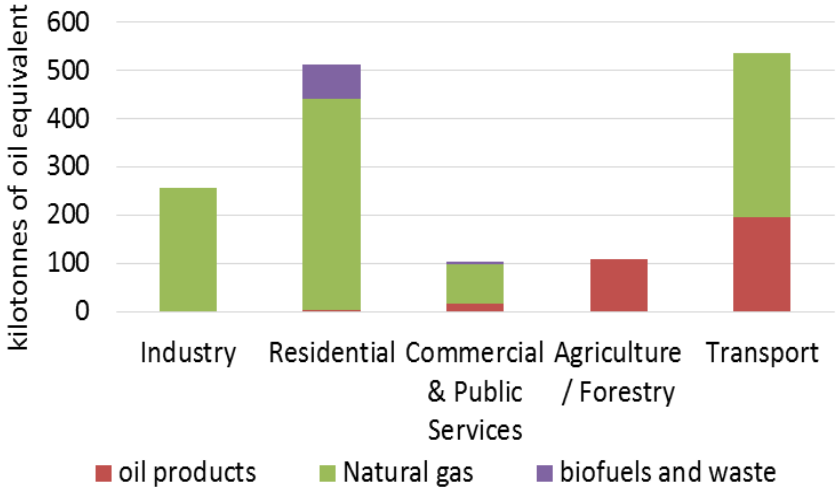
3565 MW




Power Generation
10,000
8,000
6,000
4,000
2,000
-
20%
15%
10%
5%
0%
-5%
-10%
5,941
5,898
6,114
5,672
6,491
7,433
8,036
7,710
7,750
7,798
-0.7%
3.7%
-7.2%
14.5%
14.5%
8.1%
-4.1%
0.5%
0.6%
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Production of electricity, mln kWh
Growth rate,%

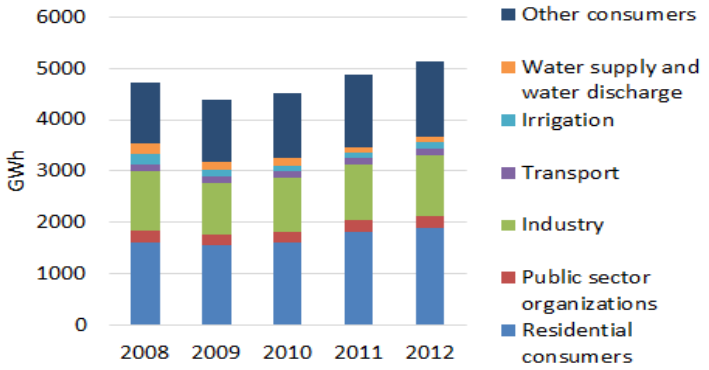

Output
600
500
400
300
200
100
0
30%
20%
10%
0%
-10%
-20%
249
382
455
524
449
443
-9.5%
12.8%
2.5%
-2.5%
5.5%
2010
2011
2012
2013
2014
2015
Output, mln USD
Real growth rate,%

Primary Fuel Consumption by Customer



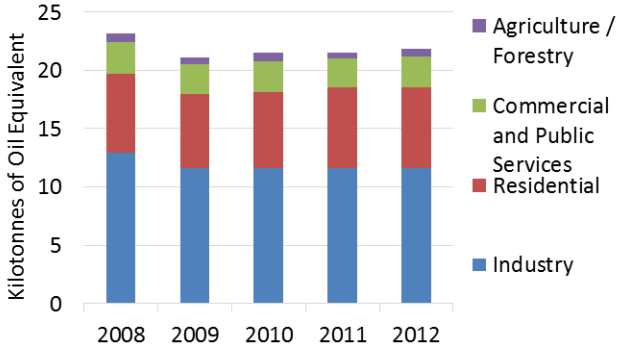
Source: Energy Institute of Armenia

Electricity Consumption by Customer



Source: PSRC, "Main Characteristics," 2008-2012

Heat Consumption by Customer, 2008-2012

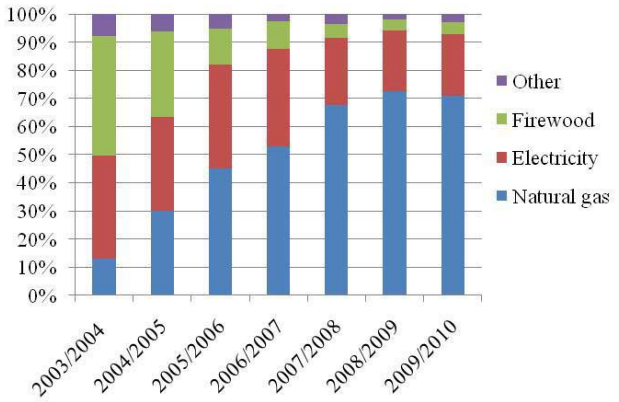


Source: Energy Institute of Armenia

Gas & Heating Sector Structure

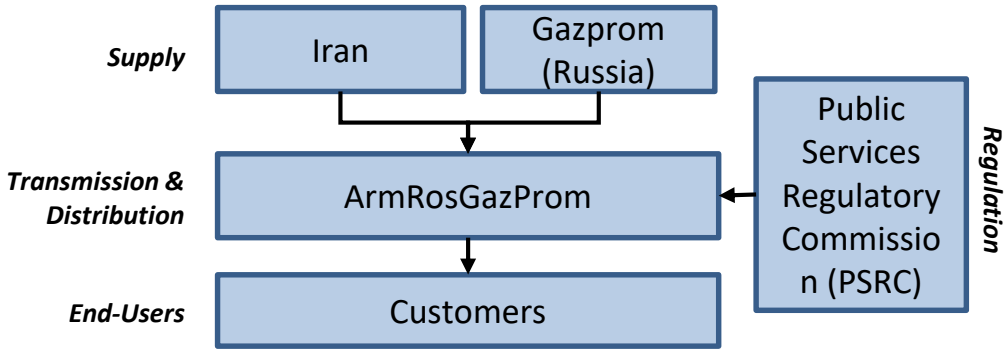
- Residential customers use natural gas mainly for heating
- The share of the population using natural gas for heating has increased steadily since 2003
- Gas is imported from Russia and Iran
- The PSRC regulates the transmission and distribution of gas in Armenia

Heating Fuel Mix in Armenia, 2003-2010

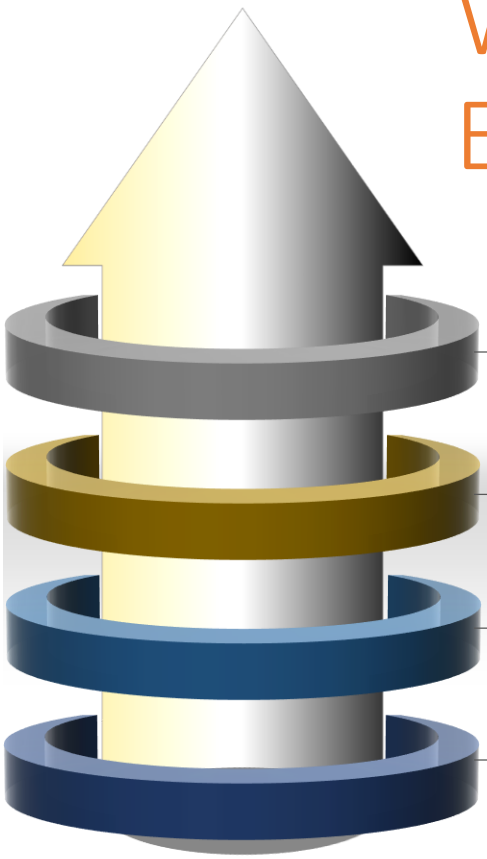


Source: R2E2 & EDRC, "Assessment of Heat Supply and Heating Options in Multi-Apartment Blocks in Armenia," May 2011

Structure of the Natural Gas Sector in Armenia



Why Renewable Energy



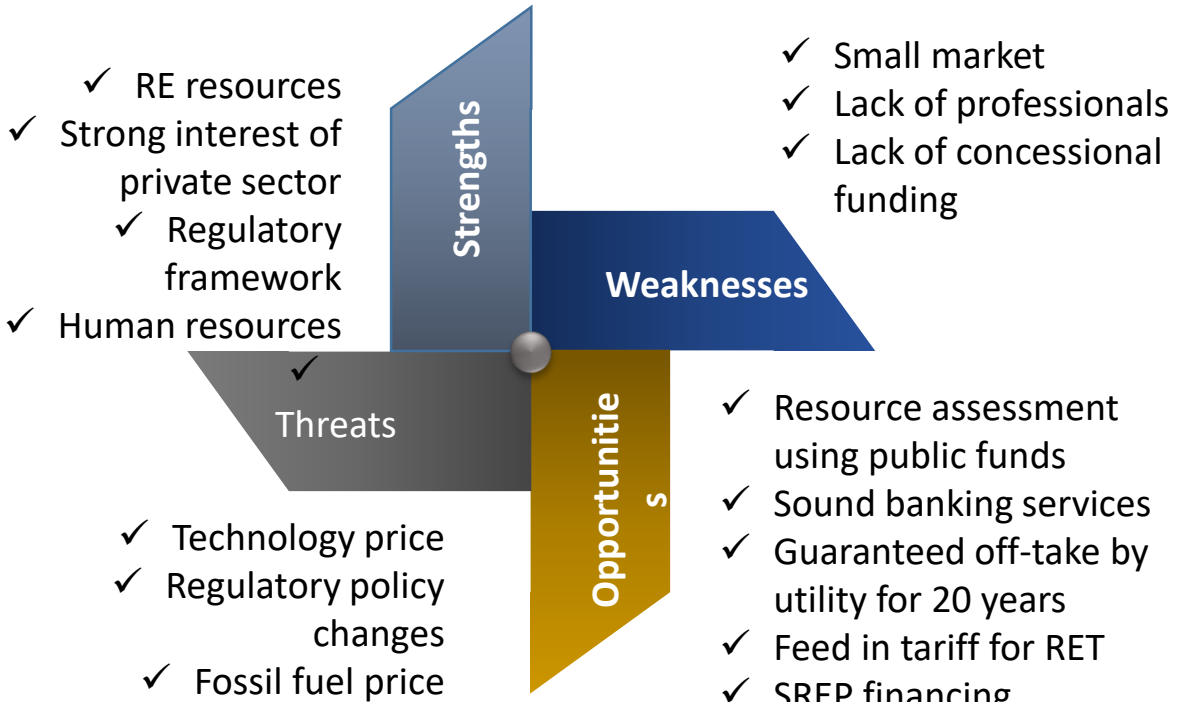
Transformation of overall economy

Regulatory and institutional framework

No fossil fuel resources, existence of RE resources

High dependence of imported primary energy sources

SWOT for RE Development in Armenia



Regulatory framework for RE is being continuously improved

- Tariffs at cost-recovery levels with sound tariff setting methodology
- Feed-in tariffs for small hydro, wind, biomass and biogas
- No license for RET <150 kW capacity, net metering operation
- Off-take guarantee of 20 years for RE
- Escrow account arrangement ensuring that all generators get paid in full and without delay
- 3-year VAT payment deferral for importers of plant and equipment with total value of more than $0.5 million, no custom fee

Government Prioritization of Renewable Energy

- The Law on Energy (2001, amended 2016)
- The Law on Energy Saving and Renewable Energy (2004, amended 2016)
- Energy Sector Development Strategy (2005)
- Action Plan of the Ministry of Energy and Natural Resources (2007)
- National Program on Energy Saving and Renewable Energy (2007)
- Hydropower Development Strategy (2011)
- National Energy Security Concept (2013)

Summary of Renewable Energy Potential

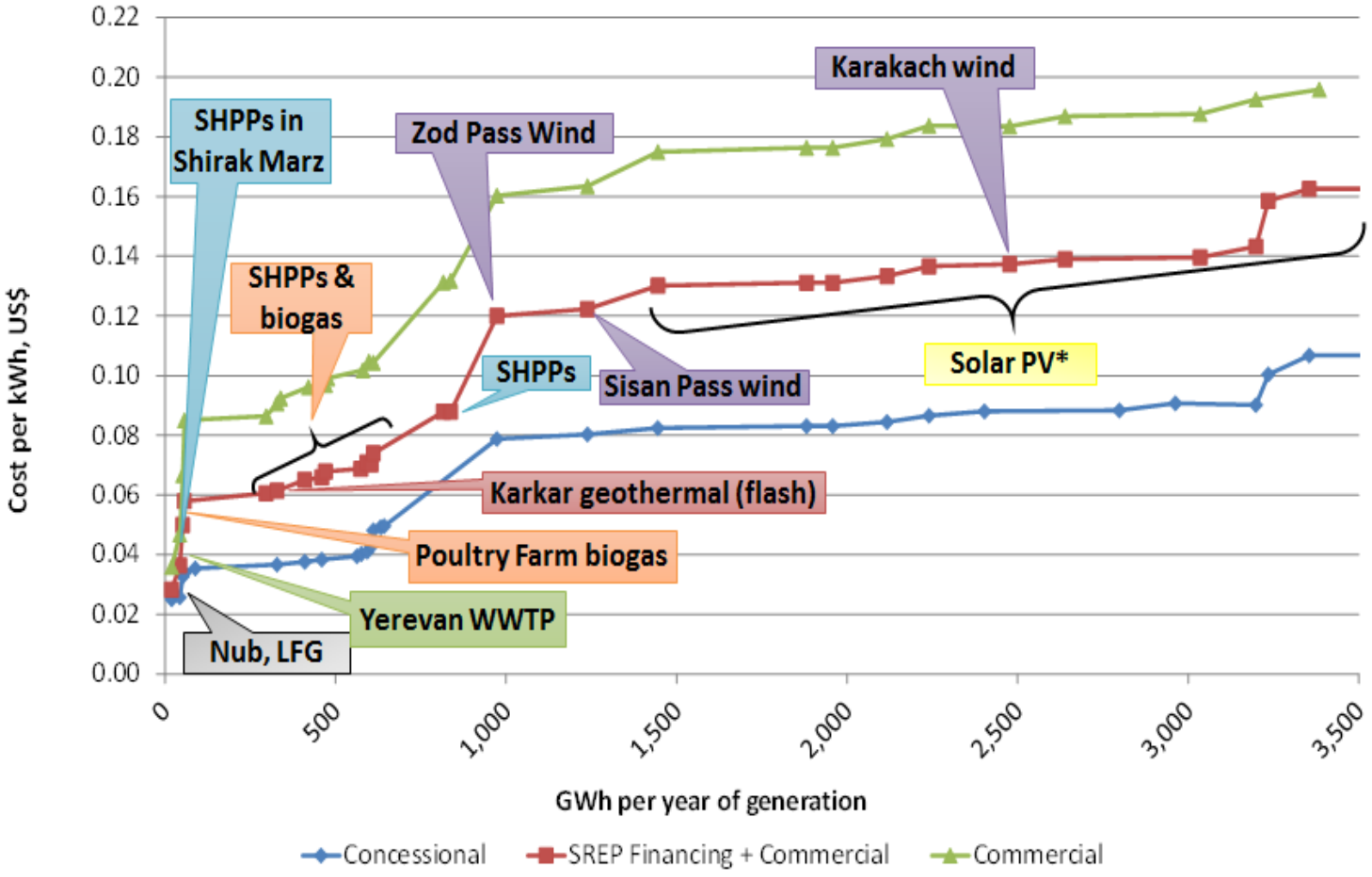
Technology	Capacity (MW)	Generation (GWh/yr or GWh_t/yr)
Wind	795	1,640
Solar PV	835 – 1,169[a]	1,735 – 2,118[a]
Concentrating solar power	1,169	2,358
Distributed solar PV	93	128
Geothermal power	31 – 54	244 – 436
Landfill gas	2.5	19
Small hydropower	91	334
Pumped storage hydropower	150	1,161 - 1,362[b]
Biogas	3.3	26
Biomass	29	228
Total (electricity)[c]	1,876 – 2,208	4,358 – 4,921
Solar thermal hot water	n/a	254
Geothermal heat pumps	n/a	4,423
Total (heat)		4,677

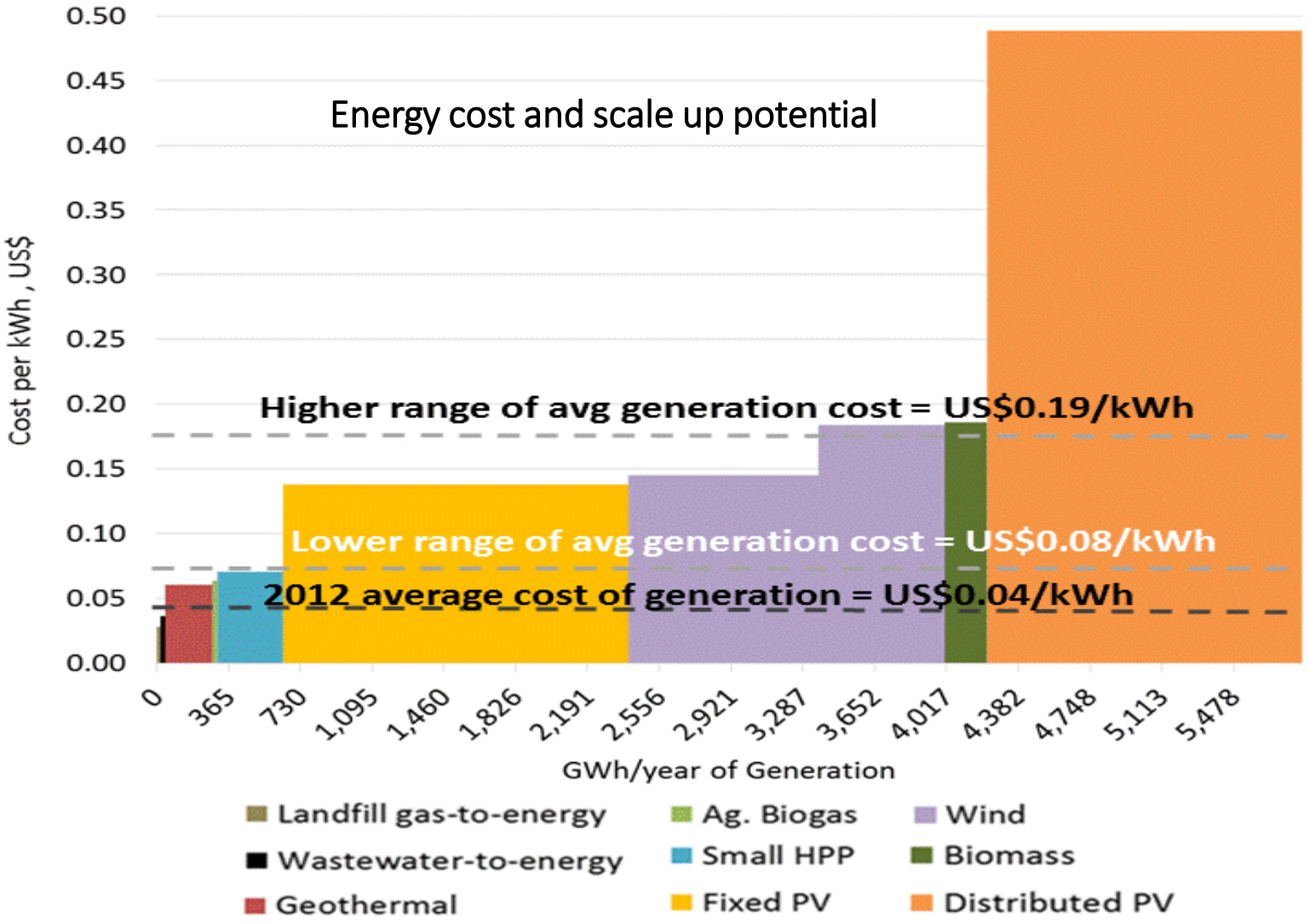
[a] Depends on which solar PV technology is assumed to be deployed: fixed-tilt polycrystalline PV, single-axis tracking polycrystalline PV, dual-axis tracking monocrystalline concentrating PV

[b] Pumped storage projects do not "generate" new renewable energy, but store energy that has been generated elsewhere. So, the pumped storage number is excluded from the total

[c] Solar PV or CSP can be built in the solar "zones." Therefore, the total includes only the generating potential for one of these technologies, so as not to double count

RE Supply Curve




Energy cost and scale up potential
Cost per kWh , US$
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Higher range of avg generation cost = US$0.19/kWh
Lower range of avg generation cost = US$0.08/kWh
2012 average cost of generation = US$0.04/kWh
0
365
730
1,095
1,460
1,826
2,191
2,556
2,921
3,287
3,652
4,017
4,382
4,748
5,113
5,478
GWh/year of Generation
Landfill gas-to-energy
Ag. Biogas
Wind
Wastewater-to-energy
Small HPP
Biomass
Geothermal
Fixed PV
Distributed PV

Wind

Area name	Capacity (MW)	Capacity Factor	Generation (GWh/yr)
North Karakhach	80	22.8%	160
Karakhach Pass	100	28.0%	245
Eastern Karakhach	40	21.4%	75
Pushkin Pass	25	22.6%	50
Sotk Pass	50	30.9%	125
Fontan	75	21.3%	140
Sisian Pass	100	30.3%	265
Total	**470**		**1,060**

Source: USAID, "Wind Energy in Armenia: Overview of Potential and Development Perspectives," 2010

Small Hydropower

Marz	Number	Capacity Factor	Capacity (MW)	Generation (GWh/yr)
Ararat	5	41.0%	5.0	18.0
Aratsotn	4	40.8%	3.5	12.5
Gegharkunik	10	47.2%	7.7	31.8
Kotaik	3	32.1%	3.6	10.1
Lori	24	44.5%	12.9	50.4
Shirak	3	50.9%	1.1	4.8
Syunik	21	41.9%	28.1	103.2
Tavush	17	44.6%	20.8	81.4
Vayots Dzor	3	31.8%	7.9	22.0
Total/Average	**90**	**43.2%**	**90.7**	**334.2**

Sources: R2E2, "Update of the Existing Scheme for Small Hydro Power Stations of the Republic of Armenia," 2008; R2E2, "Armenian MENR_SHPP pre-feasibility studies_01.04.13", 2013

Distributed Solar

- Estimated rooftop area available in Armenia and assumed half of the total area was developable
- Assumed 20,200 sq. m of rooftop area is needed per MW of solar, assuming fixed-tilt, polycrystalline panels
- Less optimal positioning on rooftops causes a lower CF compared with utility-scale solar
- Capacity factors are rough estimates to show how systems in different Marzes will perform relative to each other
- Actual capacity factors for distributed systems will vary significantly from system to system as they can not be easily optimized as utility-scale ground-mounted systems

Marz	Total Estimated Roof Area (sq. m)	Potential (MWac)	CF (AC)	Generation (GWh/yr)
Yerevan	7,716,937	191	16%	268
Aragatsotn	4,039,218	100	16%	140
Ararat	6,075,163	150	16%	211
Armavir	5,523,874	137	16%	192
Gegharquniq	5,246,894	130	17%	193
Lori	6,319,836	156	13%	178
Kotayq	3,837,887	95	16%	133
Shirak	5,475,094	136	17%	202
Syniq	2,512,322	62	16%	87
Vayots Dzor	1,354,618	34	17%	50
Tavush	3,599,381	89	16%	125
Total/Average	**51,719,336**	**1,280**	**16%**	**1,779**

Pumped Storage Hydropower

- Three potential pumped storage hydropower plants have been identified in Armenia
- Note that pumped storage does not generate new energy, but stores and releases energy from other generation sources, losing some of the original energy in the process
- As a result, energy from pumped storage is only as "renewable" as the energy that it stores, and it does not generate new renewable energy

Site Name	Generating Capacity (MW)	Estimated Energy Storage Capacity (MWh)
Aghbyurak	150	1,161
Tolors	150	1,254
Shamb	150	1,362

Sources: R2E2, "Assessment of Hydro Potential of Peak Capacities Generation for Armenian and Regional Markets," 2007 and Armenian Scientific Energy Research Institute of Energy analysis

WWTP Biogas-to-Power

- Assumed that the existing Aeratsia WWTP in Yerevan would be upgraded and anaerobic digesters would be installed at the facility
- Assumed that the wastewater flow at the facility would increase to 125 million gallons per day by 2025
- Based on this expected flow, a 3 MW cogeneration power plant could be installed at the site

Sources: SWECO, "Yerevan WWTP, Armenia," 2005; OECD, "Financing Strategy for Urban Wastewater Collection and Treatment Infrastructure in Armenia: Final Report," 2004; and Black & Veatch analysis.

Agricultural Biogas-to-Power

- Six small-scale anaerobic digester biogas-to-power projects were identified on farms in Armenia in a 2010 study by the GEF/UNDP
- It was determined that three of the six projects were determined to be good candidates for biogas-to-power projects: Araks, Arzni and Armavir
- These three projects are assessed and considered to be the "achievable" agricultural biomass potential in Armenia

Site Name	Capacity (MW)	Capacity Factor*	Generation (GWh/yr)
Araks Trchnafabrika CJSC	**1.4**	**90.0%**	**11**
Arzni Pedigree PBS OJSC	**0.8**	**90.0%**	**6**
Armavir Poultry Farm	**1.1**	**90.0%**	**9**
Getamech Poultry Plant Ltd.	2.2	90.0%	18
Yerevan Poultry Farm	0.8	90.0%	6
Ashtarak Dzu LLC	0.7	90.0%	5
Total	**7.0**		**55**

= Projects considered achievable for this analysis

Source: GEF/UNDP, "Final Report on Assessment of GHG Emissions Mitigation Potential in Animal Farming Sector of the Republic of Armenia, July 2010.

Landfill Gas-to-Power

Potential for LFG-to-Power in Armenia

- The City of Yerevan is currently studying the potential for upgrading the Nubarashen landfill to receive waste from other municipalities. This might make a landfill gas-to-power project technically feasible a the Nubarashen site.
- For this study, it was assumed that future Nubarashen landfill section B expansion could support a 2.5 MW LFG plant.

History of LFG-to-Power in Armenia

- A single, 1.5 MW landfill gas-to-power (LFG) project was proposed at the Nubarashen landfill by the Shimuzu corporation
- The portion of the landfill studied for the project produced much less gas than initially expected, and the project was deemed technically infeasible. A methane flare plant was installed instead.

Figure 1: Site overview

Figure 2: Flare plant

Sources: CDM Executive Board, "3rd Monitoring Report: Nubarashen Landfill Gas Capture and Power Generation Project in Yerevan," June 2012; Personal communication with Head of Investment and Development Projects Department of Yerevan Municipality on June 6, 2013; Personal communication with Artem Kharazyan on June 26, 2013

Biomass

- Biomass power generation potential assessed for both woody biomass and agricultural residues
- **Woody biomass** potential estimated based on the estimated amount of forestry residues available from fallen wood and sanitary cuttings
  - Forestry residues assumed to be sufficient to support a 4 MW biomass plant
- **Agricultural biomass** potential estimated based on the estimated amount of grain residues available
  - Grain residues assumed to be sufficient to support a 25 MW biomass plant

Sources: Forest Law Enforcement and Governance Report, 2011; Agricultural data from the Food and Agriculture Organization of the United Nations, 2000;

Geothermal Power

- Three potential geothermal power sites have been identified, but level of knowledge about potential of these sites is different
- Karkar site has been comprehensively assessed through surface studies. Drilling pending to confirm the resource.
- The existence of geothermal resources at the other two sites is highly uncertain without further exploration

Site Name	Capacity (MW)	Capacity Factor	Generation (GWh/yr)
Karkar	6 – 29	84 – 96	47 - 239
Potential site on Armenian-Georgian border	25	90	197
Total	**31 – 54**		**244 – 436**

Sources: GEF/World Bank, "Jermaghbyur Geothermal Project Feasibility Study Final Report," 2006; Hankinson, Denzel, "Economic and Financial Appraisal of the Potential Geothermal Power Plant at Karkar Final Report," November 2012; Personal communication with Dr. Arkadi Karakhanyan on June 6, 2013

Renewable Heat

- Total hot water and space heating load of residential and commercial buildings in Armenia was estimated
- The potential for solar thermal hot water systems and geothermal heat pumps to meet this heat load was assesed

	Space Heating (GWht/yr)	Water Heating (GWht/yr)	Total (GWht/yr)
Apartments	2,309	209	**2,518**
Houses	1,691	214	**1,905**
TOTAL	**4,000**	**423**	**4,423**

Geothermal Exploratory Drilling Project

Geothermal developments in the Period of 2009 – 2012 with support of the WB Group

Main surveys were done in 2 selected geothermal sites - Karkar and Gridzor

The studies were implemented in two phases, and the realization if the second phase depended on the findings of the first one.

Phase Ia – field geological surveys and 2D magnetotelluric (MT) sounding;

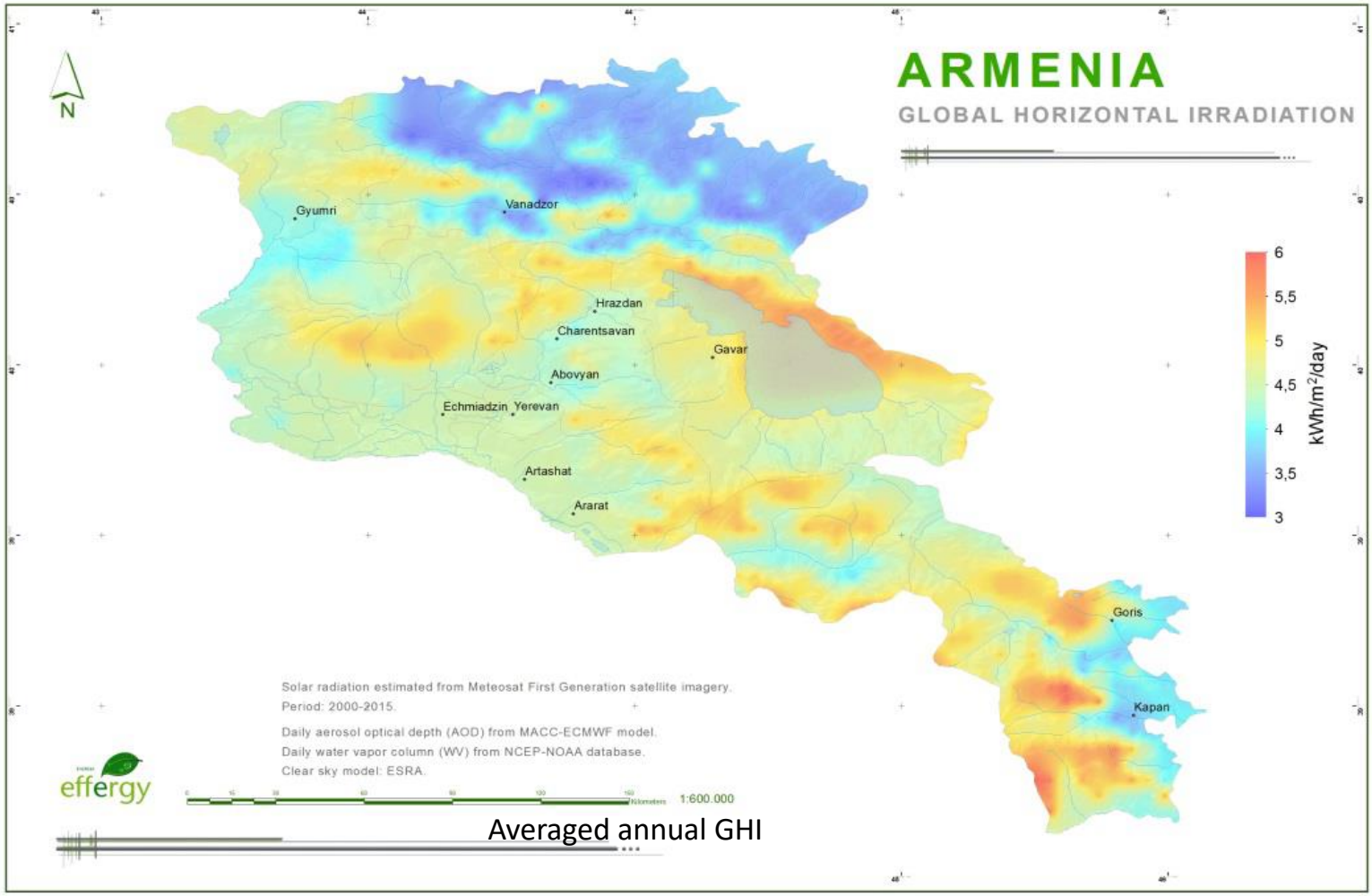
Phase Ib - interpretation of the data from Phase *Ia and* choice of one site for the 3D magnetotelluric (MT) sounding;

Phase IIa - three-dimensional (3D) magnetotelluric (MT) sounding;

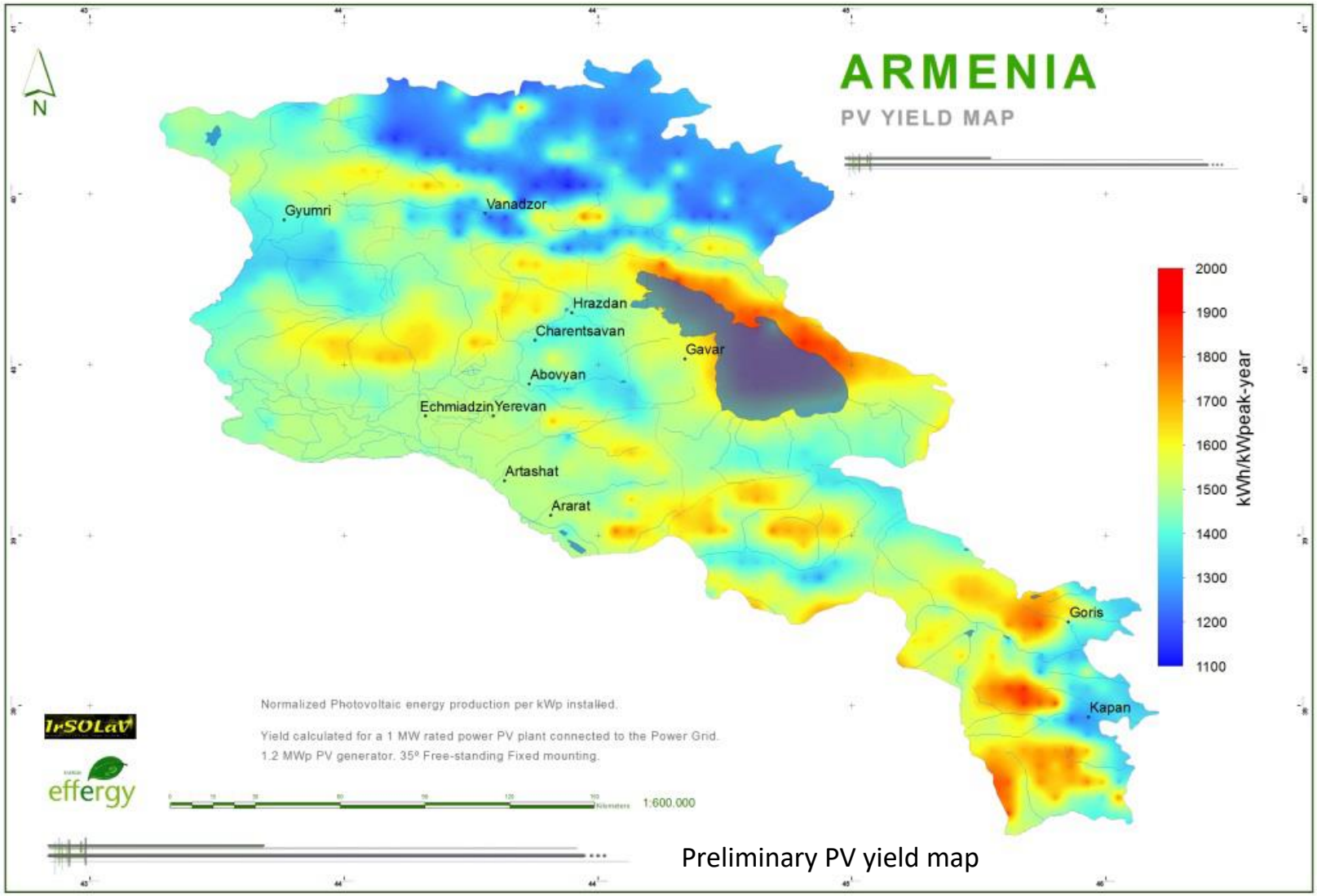
Phase IIb – interpretation of the data from Phase IIa to enable "drill/not drill" decision.

Karkar July 2016

Solar Power



Averaged annual GHI



Preliminary PV yield map

www.globalsolaratlas.info

Trainings at Merdzavan station

3. First Round Projects (1/2) – Masrik-1 (47 MW)

•The envisaged technology is **Mono or Poly crystalline** PV modules in **fixed structures** with connection to **central PV inverters** to achieve a total capacity of **47MW**.

•The plant will be connected to the **110 kV grid** through an output double transformer step-up substation. A **double 10 km electrical line** will be installed to connect the plant to the grid.

•A meteorological station has been installed in the area to collect ground data. Current satellite estimations result in a GHI of **1.770 kWh/m^2 per year**.

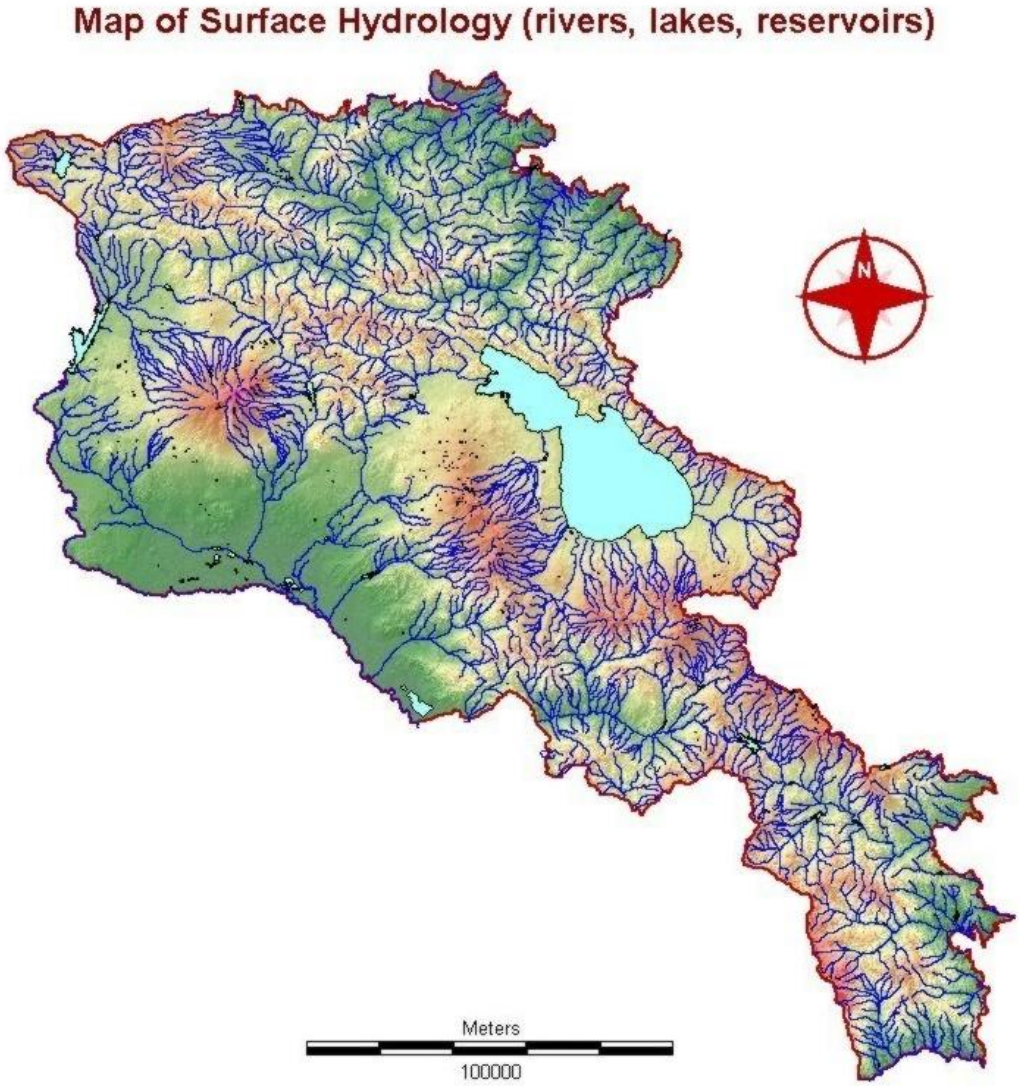
The Government can successfully scale up development of sustainable energy because…

- Necessary legal, regulatory and institutional framework is ready
- Private sector is interested to invest in renewable energy sector (more than 170 private power generation plants)
- Financial market is interested and capable in lending for RE investments
- The scientific community and academia remain committed and interested in geothermal and solar technologies
- Strong ecological society requires the scale up of sustainable energy
- The Government has successfully implemented several donor-funded projects in the renewable energy sector, including the WB, EBRD, KfW.

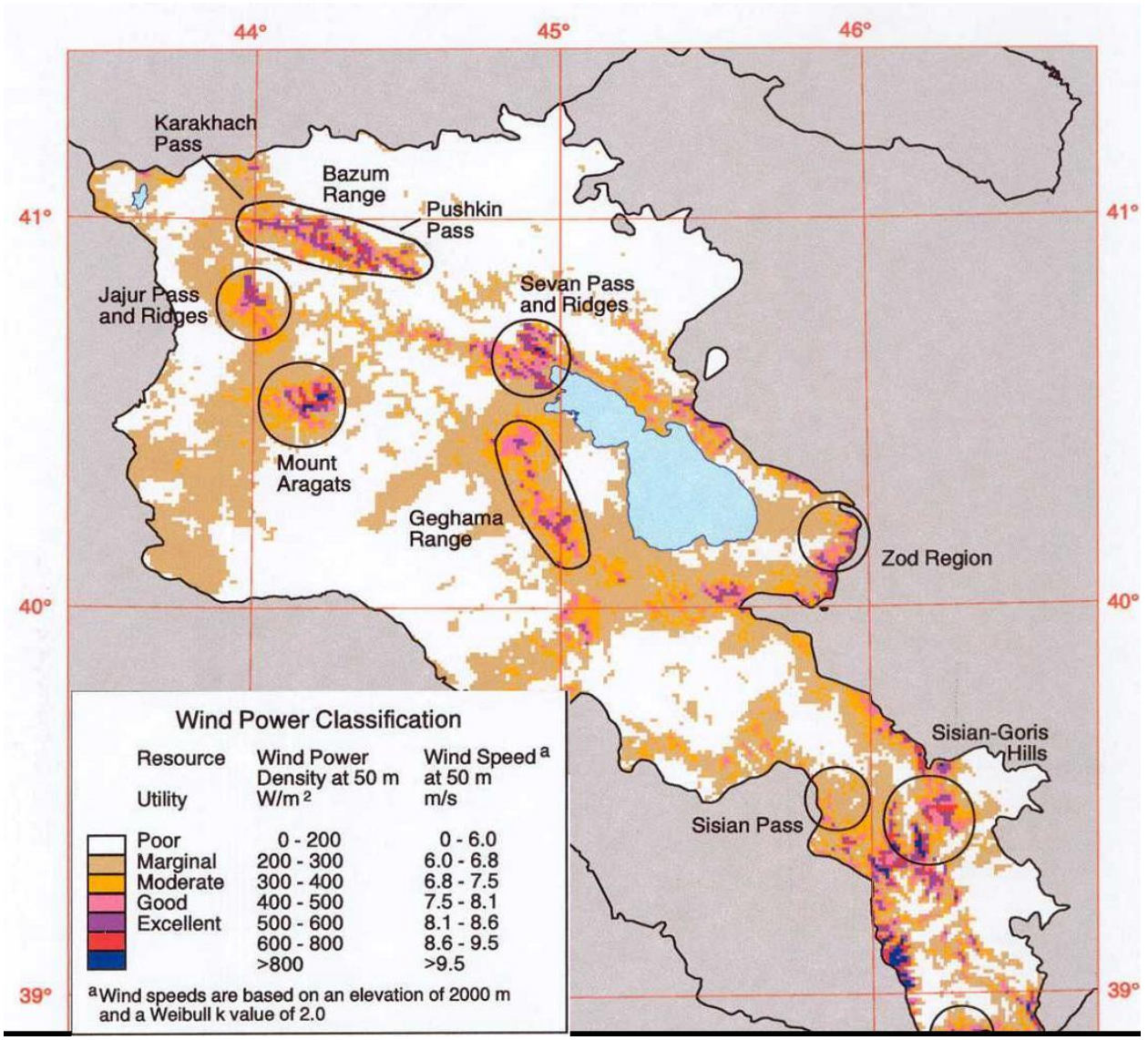
The SREP support will help us to have a success story for scaling up identified RE technologies and making Armenia more energy secure

Feasible Potential of Renewable Resources in Armenia

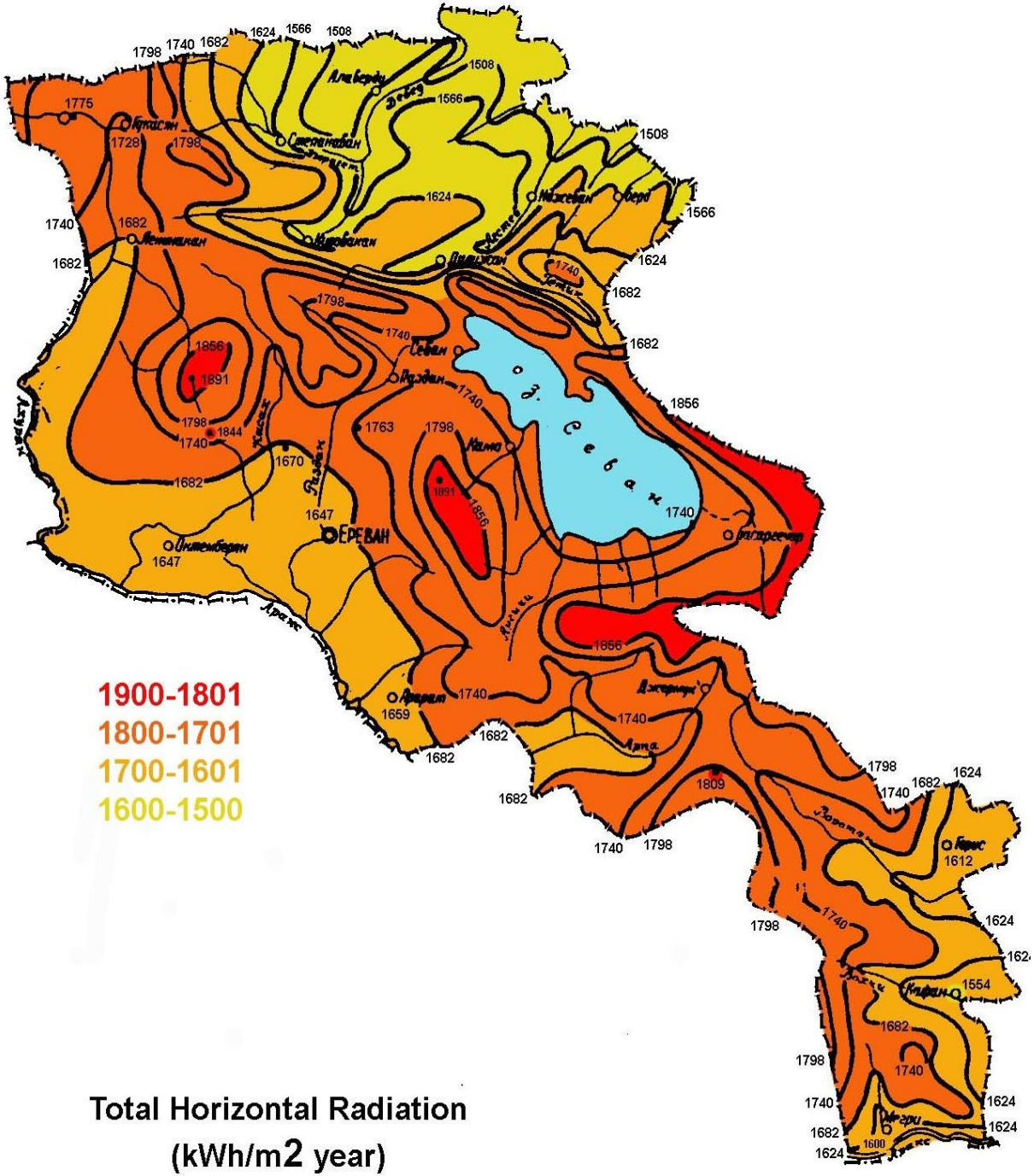
Hydro Resources 250-300MW



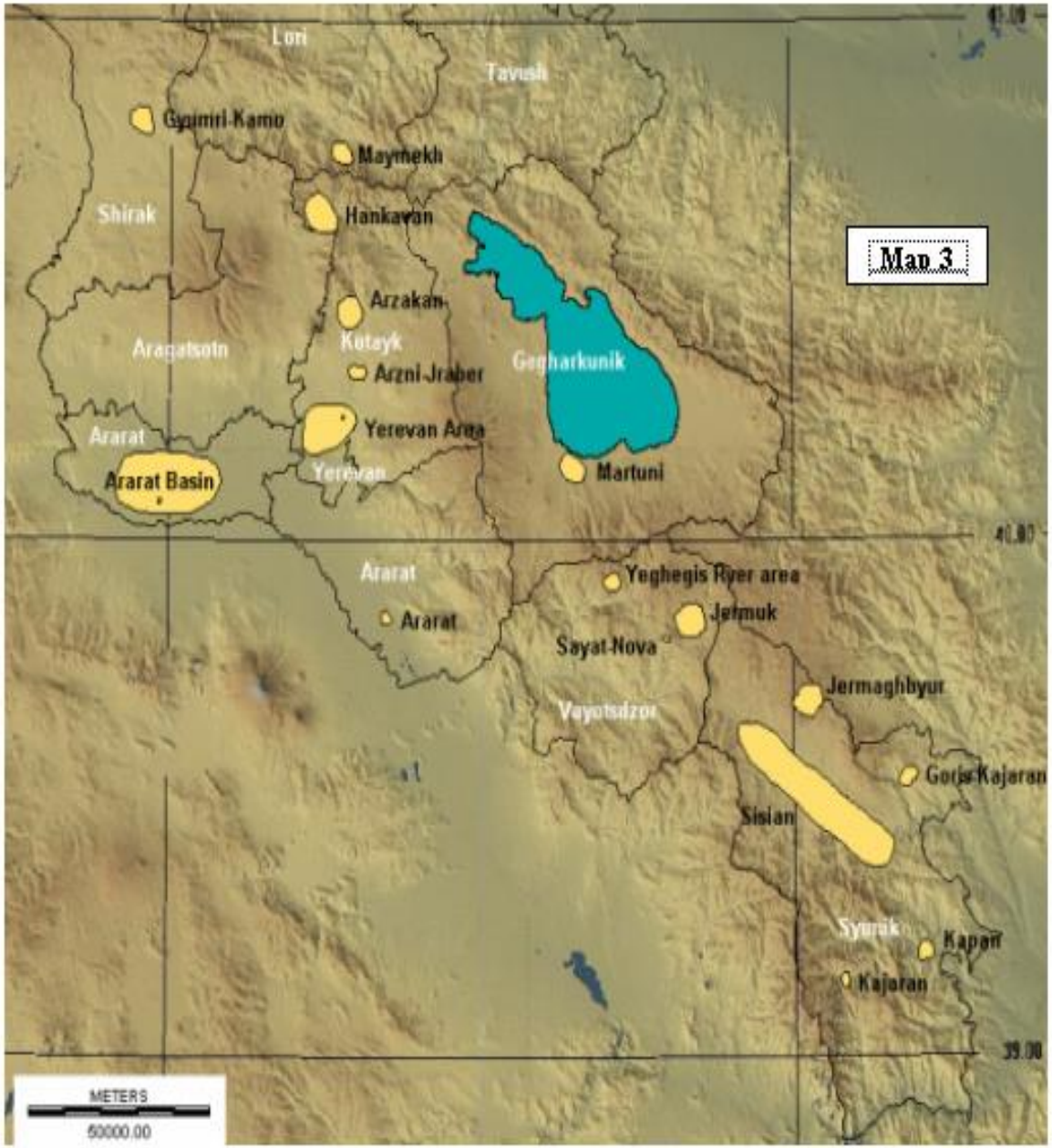
Wind resources 300-500MW



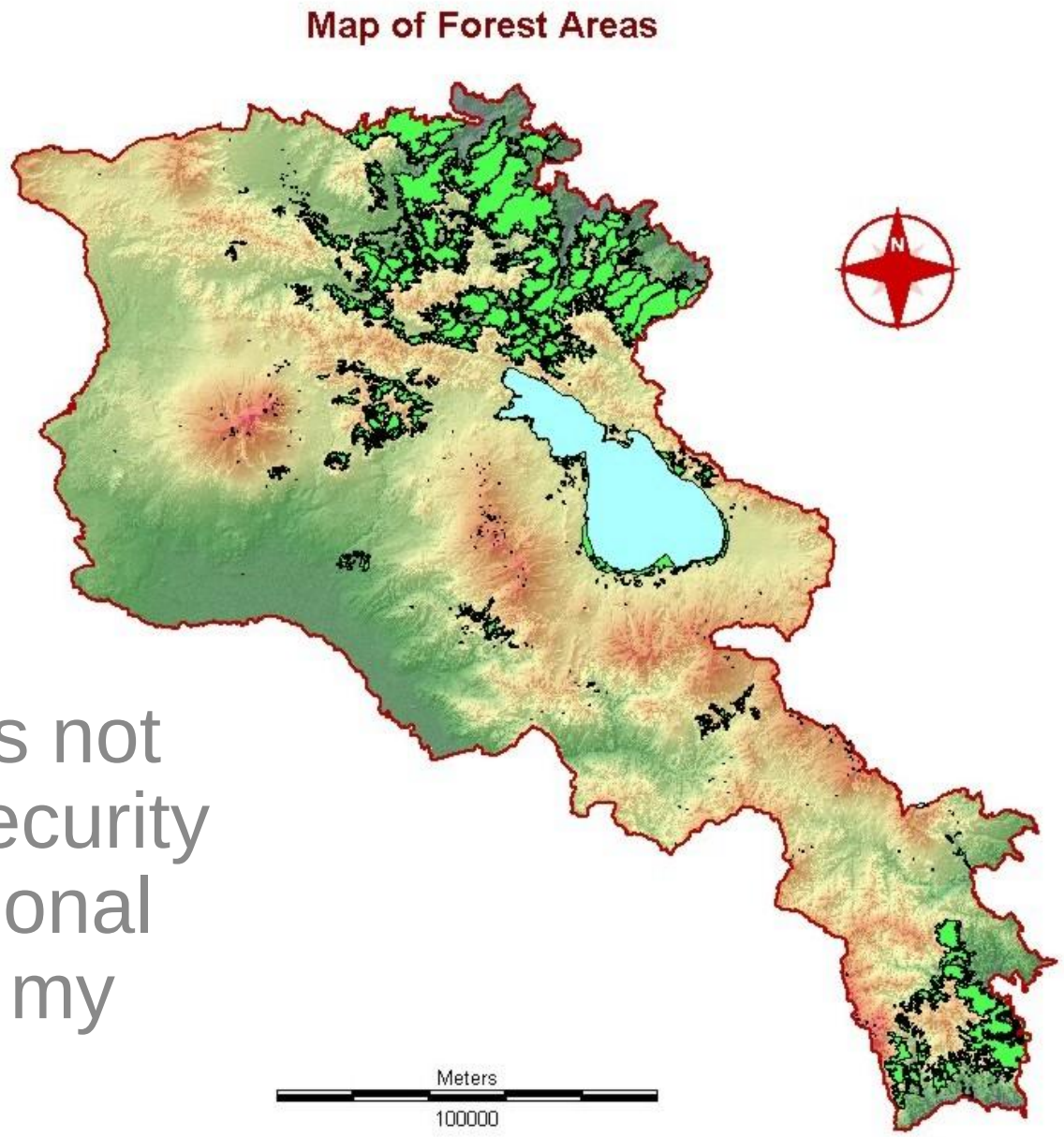
Solar resource >1000MW



- Geothermal resources
  - 25-50 MW



Forests-10%
Gas-0%
Oil-0%
Coal-0%



- Renewable is not only energy security but also National security for my country

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