Costs of Future Energy Supply, Armenia 2050

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Introduction

Armenia can choose different energy paths: a renewable path, where energy consumption is gradually changed to renewable energy over the next 30-40 year, a business as usual (BAU) path, where a large part of the energy consumption remains fossil fuel, and a nuclear path, where the existing nuclear power plant is replaced with a new nuclear power plant. In this note is compared the expected economy of the renewable path in 2050 with the economy of the BAU path in 2050. The nuclear path is not included because the development of a new nuclear power plant will be a costly and risky investment that will increase the Armenian energy costs considerably and it is therefore not a viable solution, if an optimal economic path for Armenia is the objective.

Economic forecasts until 2050 are obviously very uncertain, and even though the analysis is based on internationally recognised and well-documented sources, the analysis must be seen as best estimate with current knowledge and under the given assumptions. If costs of renewable energy and/or energy efficiency is reduced faster than expected, as have happened for some technologies in the past, the renewable path can be cheaper, but maybe with a different combination of solutions. If the fossil fuel prices are falling compared with the forecast and there is no extra costs of emitting CO2, the BAU scenario will be cheaper.

General assumptions

For the analysis is used the energy balances for 2050 for the renewable energy scenario and the BAU scenario developed by INFORSE in 2017, while for costs of technologies and fuel prices is used 2030 costs as the year furthest into the future, where internationally recognised forecasts are available for all fuels and technologies.

For the fuels are used cost forecasts from International Energy Agency (IEA) New Policy Scenario, supplemented with other data, when necessary. Table 1 shows the fuel cost data used.

Fuel costs, €/MWh, 2030	Production/ import price, €/MWh	Price at plants	Price at households	Sources
Coal	9.1	10.2		DEA 2017/IEA, New Policy Scenario, import by sea, + cost of delivery
Diesel oil	60.1		64.1	Source: DEA 2017/IEA, New Policy Scenario
Natural gas	31.7	32.7	33.1	Source: DEA 2017/IEA, New Policy Scenario
Wood chips	19.2	21.4	23.2	DEA 2017, reduced to Armenian wage level
Straw	14.4	22.3		DEA 2017
Biofuel, liquid			83.2	Estimate based on DEA 2017

Table 1: *Fuel cost estimates for 2030. Recalculated to €/MWh from DKK/GJ. DEA 2017 = Danish Energy Agency, www.ens.dk, "Brændselspriser 2017". Coal delivery costs from Danish sources only. Costs of wood chips: DEA 2017 reduced with 11% because of lower wages in Armenia compared with Danish wages.*

For the calculations is used an interest rate of 5%, which is the interest rate that Armenia should be able to use for financing strategic investments in the future. The current interest rate of the Central Bank of Armenia is 6%.

Technology costs

For the costs and technology parameters for energy supply technologies is in general used data from Danish Energy Agency, Technology Catalogue for Electricity and Heat Supply, supplemented with other sources, when needed. https://ens.dk/service/fremskrivninger-analyser-modeller/teknologikataloger. The main technologies and parameters are given in table 2.

Technology	Investment (€/kW out)	Lifetime (years)	Fixed O&M (€/y/kW)	Variable O&M (€/MWh)	Electric efficiency	Heat efficiency	Sources
Solar heating, large	374.5	30	0.57	0			DEA1
Wind, land	1320	25	0	13	35%	Cap. factor	DEA1
Hydro power old	0	50	50	0			IEA1*
Hydro power new	2125	50	50	0			IEA1
PV, medium	760	30	8				Own 1
PV, large	475	30	5				Own 1
Decentral CHP, woodchips	3000	30	29	3.8667	29%	77%	DEA1
Decentral CHP, straw	4000	25	40	6.4	29%	72%	DEA1
Decentral CHP, biogas	5900	20	0	35.067	43%	48%	DEA1
CHP, gas, GTCC	860	25	28.6	4.3	57%	32%	DEA1
Central CHP, woodchips or coal	2010	40	61.6	2.2	43%	47%	DEA1
Central PP, gas, GTCC	860	25	28.6	4.3	61%		DEA1
Nuclear power plant	7144	40	0	27			Own 2
Large boiler, gas, condensing	60	25	1.95	1.1	0%	104%	DEA1
Large boilers, wood chip, condensing	800	20	0	5.4	0%	108%	DEA1
Biogas production	2213	20	127				DEA1
Biogas-upgrade	318	15	0	4			DEA1
Large heat pump	603	20	4	0	COP =	3.00	DEA1
Large heat storage	486	20	0.63	0.6		88%	DEA1
Elektrolysis-H2, AEC	1000	20	28.75	0	60%	15%	DEA1
Elektrolysis-H2, SOEC	590	28.75	20	0	98%	-15%	DEA1

H2 Storage	11000	30	69	0			Own 3
Geothermal heating	1600	25	209	0			DEA1
Geothermal CHP	1585	35	40	0	50%	50%	Arm1
End-use heat pumps	1375	20	14	0	COP =	3.63	DEA2
End-user boilers, gas	250	22	4	7.2	100%		DEA2
End-user boilers, wood pellets	1150	20	7	0	89%		DEA2
End-user solar heating	1000	20	20	0			IRENA
Fuel cells	400	5		10	55%		DEA1

Table 2:Costs of investment and operating & maintenance as well as lifetimes and electricity and heat efficiencies. Investments are given in €/kW of electricity, or heat for heat-only plants, except for solar, where it is per MWh of annual output, biogas, where it is per si storages where it is per MWh of stored energy. Efficiencies are given compared with lower heating value of fuels, thus efficiencies above 100% is possible for condensing boilers. For windpower is given capacity factor instead of efficiency. For heat pumps is given coefficient of performance (COP) instead of efficiency. For geothermal CHP is given efficiency in percentage of used energy, losses are not included.

Sources for table 2:

DEA1: Danish Energy Agency, Technology Catalogue for Electricity and Heat Supply, supplemented with other sources, when needed. https://ens.dk/service/fremskrivninger-analyser-modeller/teknologikataloger

DEA2: Energinet Denmark and Danish Energy Agency: "Individual Heating Plants and Energy Transport", May 2012, gaskedel

IEA1: Hydropower essentials, IEA, Average for Medium-sized hydro, see https://www.iea.org/publications/freepublications/publication/hydropower_essentials.pdf

IEA1*; As above but without investment costs because it is existing plants.

Own1: Costs of solar power are based on information from solar power company Better Energy, Denmark. This is based on realised costs in 2016-2017 and a conservative estimate of the development (price reductions) until 2030.

Own2: Estimation of costs based on data from Flamanville and Oikuluoto nuclear power plants under construction, including estimates for operating, maintenance and decommissioning costs for the plants. Investment including decommissioning and interest during 5year construction period. O&M including fuel and waste handling costs

Own3: Own estimate of investment costs and operating & maintenance costs from various sources, included DEA1 and estimates of costs of large-scale production of tanks for hydrogen cars

Arm1: Cost from project Jermaghbyur geothermal of 1564 USD/kW, price increased with price index increase from 198 Jan.2006 to 236 in Jan. 2016, lifetime and O&M from IEA Technology Roadmap Geothermal Heat and Power, Efficiency: is fraction of useful energy for CHP operating with source temperature 250'C, assuming 8000 operating hours/year

IRENA: Calculated from IRENA, Solar Heating and Cooling for Residential Applications, Technology brief 2015, with the assumption that end-use systems are three times as expensive than central systems

For the costs of energy efficiency (reduction of heart demand) is used an estimate for Eastern Europe of 1000 € to save 1 MWh of heat, and a lifetime of investments of 30 years. This is an average of many actions, from simple drought proofing with much lower costs, window renovations, insulation of roofs and floors, and some wall insulation, which itself is more expensive.

For costs of district heating is used data from DEA2, and the assumption that 80% of the district heating is installed in cities with dense heat demand in average 120 TJ/ha, 10% in low residential areas, and 10% in new build, energy efficiency buildings. The average investment costs is 20.9 €/MWh of annual heat supply, and the annual O&M costs are 0.85% of investment costs. Lifetime is 40 years.

Energy production (full load hours)

To calculate total energy costs based on technology costs and energy demands, it is necessary to use estimates of how much is produced from each technology. For renewable energy this factor depends mainly on the input, while for fossil fuel, the question is mainly how it is used: as peak, medium or base load plant. The use can be expressed in full load hours: number of equivalent hours per year, where the installation runs 100% capacity. In practice most installation run on lower capacity much of the time, but with this method the hours with part-load are recalculated to fewer hours with full load.

For this study is used the following full load hours, given in table 3:

Solar heating, central	Factor is not used, instead is used, annual production per of 650 kWh/ m2 for Armenia	
Solar heating, end-users	Factor is not used, instead is used, annual production per of 650 kWh/ m2 for Armenia	
Wind, land	2050	Equal to 35% capacity factor, used for Armenia
Hydro, old	1538	Calculated from Armenian hydropower statistics,
Hydro, new	1538	As above
Solar electric medium	1777	Estimate from solar irradiation of 1750 kWh/m2 horizontal surface in Armenia, new plants, see below
Solar electric large	1777	Same as for solar electric medium
CHP, coal	5500	For plants/sectors supplying main part of heating a typical value is 5500 hours, for base-load plants with other plants for medium load value can be up 7000 hours, value can also be calculated from statistics, but then have to be corrected for need of standby-load
CHP, gas	5500	Same as CHP for coal
CHP, biomass	7000	Same as CHP for coal
PP coal	5000	For plants/sectors supplying large part of power, typical values are 5000 hours over lifetime, for base-load plants/sectors with other medium load, it can be up to 7000 hours, for medium load plants, value is lower
PP gas	1384	As for PP for coal, but these plants are often sued as

		peak load plants, with much lower full load hours, 1000 - 2000 hours depending on system and gas costs
PP biomass	1384	As for PP using gas
PP nuclear	7000	Typical value for base load plants are 7000 hours, as nuclear power are mostly in base loads because of high costs
Large boilers, gas	1000	Typically used as peak load with only 1000 hours, but can be larger
Large boilers, biomass	5500	Typically covering most of heat load in specific systems, with typically capacity factors of 5500 hours
Biogas, CHP	8000	Typically running constantly except for maintenance periods, leading to 8000 hours/year
Biogas, gas upgrade	8000	Typically running constantly except for maintenance periods, leading to 8000 hours/year
Large heat pumps	2500	Typically only running when power production is higher than power demand, which depends on system, but should be over 2000-2500 hours to justify investment
Large heat storage	Factor is not used, instead is used how many times/year the storage is used, in this case 26 time/year (every second week)	
Elektrolysis-H2, AEC	5000	Depends on system and of periods with high production of renewable energy, but because of high costs, typical practical values should be within 3000 - 7000 hours
Elektrolysis-H2, SOEC	5000	As for AEC fuel cells
H2 Storage	Factor is not used, instead is used how many times/year the storage is used, in this case weekly storage, 52 times/year	
Geothermal	8000	Typically running constantly except for maintenance periods, leading to 8000 hours/year, for heating-only plants, value can be lower, linked to heat demand, typically 5000 - 7000 hours
Indiv. heat pumps	2580	For domestic heating from one source only (no peak or base load), the capacity factor is typically 30%, equal to 2580 full load hours for Northern, Central and Eastern Europe, can be higher in Atlantic climate and is lower in Southern Europe
Indiv. gas boiler	2580	As for individual heat pumps
Indiv. bio boiler	2580	As for individual heat pumps

Table 3 Use of technologies expressed in full load hours, except for solar heating and storages.

The full load hours for solar PV can be estimated from solar irradiation on horizontal surfaces with reasonable accuracy. The table 4 below gives an estimate of this:

Correlation based on:	https://emp.lbl.gov/publications/maximizing-mwh-statistical-analysis			
Formula	Capacity factor = solar irradiation*0.0423/365			
Solar irradiation	1000	1500	1750	2000
Capacity Factor	11.6%	17.4%	20.3%	23.2%
Full load hours	1015	1523	1777	2030

Table 4: Correlation between solar irradiation and full load hours of new PV installations. Comment: The values are for recent, optimised plants (2013 and later) in USA, for older plants the value is typically 10-20% lower.

Cost estimates

Based on above data and assumptions, and of the expected energy balance of Armenia, can be calculated the costs of the energy system, including pay-back of investments, interests, O&M and fuels. This is done for 2050 for the scenario with 100% renewable energy in table 5.

	Invest mill. €	LFCC, M€	Fixed O&M, M€	Var. O&M, M€	Fuel costs, M€	Total, M€
Solar heating, central	835	54	1.3	0	0	56
Solar heating, end-users	2361	189	47		0	237
Wind, land	1473	105		30	0	134
Wind, off-shore	0	0		0	0	0
Hydro, old	0	0	65		0	65
Hydro, new	1529	84	36		0	120
Solar electric medium	0	0	0.0		0	0
Solar electric large	570	37	6		0	43
CHP, coal	0	0	0	0	0.0	0
CHP, gas	2	0		0.1	1	1
CHP, biomass	88	6	1	1	10.1	17
PP coal	0	0	0.0	0.0	0	0
PP gas	4	0	0.1	0.0	0	0
PP biomass	1824	106	0.0	33.9	25	166
PP nuclear	0	0	0.0	0.0	0	0
Large boilers, gas	0	0	0.0	0.0	0	0
Large boilers, biomass	0	0	0.0	0.0	0	0
Biogas, CHP	35	3	0	1	0	4
Biogas, gas upgrade	35	3	2	0.4	0	5
Large heat pumps	169	14	1	0.0	0	15
Large heat storage	42	3	0.1	1.4	0	5
Elektrolysis-H2, AEC	274	22	8		0	30
Elektrolysis-H2, SOEC	0	0	0		0	0
H2 Storage	290	19	2		0	21
Geothermal	119	7	3		0	10
Indiv. heat pumps	645	52	6	0.0	0	58
Indiv. gas boiler	7	1	0	0	0	1
Indiv. bio boiler	1329	107	9	0.0	87.5	203
Biofuel use					35	35
Oil use					1	1
Power import/export					0	0
TOTAL SUPPLY		**811**	**187**	**68**	**159**	**1226**

District heating, 80% high rise	73.0	4	0.6			5
Heat efficiency	Extra savings					
Heat efficiency	5329	347				347
		1162	**188**	**68**	**159**	**1573**

Table 5. Estimate of costs of energy system in Armenia in 2050 with 100% renewable energy, including costs for new district heating system and for heat savings. Investment costs are converted to equal annual payments during lifetime including interest rates (levelized fixed cost charges). For heat savings is estimated that 35% of the heat savings will be realised with BAU development, where house renovations and new windows will reduce heat demand without specific energy efficiency investments.

Costs of the BAU Scenario is similarly found in table 6

	Consumption, GWh	Size, MW/m2	Invest mill. €	LFCC, M€	Fixed O&M, M€	Var. O&M, M€	Fuel costs, M€	Total, M€
Solar heating, central	0	0	0	0	0.0	0	0	0
Solar heating, end-users	1069	1645299	1069	86	21		0	107
Wind, land	2288	1116	1473	105		30	0	134
Wind,. off-shore	0	0	0	0		0	0	0
Hydro, old	1989	1293	0	0	65		0	65
Hydro, new	222	145	307	17	7		0	24
Solar electric medium		0	0	0	0.0		0	0
Solar electric large	918	600	285	19	3		0	22
CHP, coal	0	0	0	0	0	0	0.0	0
CHP, gas	1	0	0	0		0.0	0	0
CHP, biomass	0	0	0	0	0	0	0.0	0
PP coal	0	0	0	0	0.0	0.0	0	0
PP gas	2182	959	825	59	27.4	5.7	69	161
PP biomass		0	0	0	0.0	0.0	0	0
PP nuclear	0	0	0	0	0.0	0.0	0	0
Large boilers, gas	2	2	0	0	0.0	0.0	0	0
Large boilers, biomass	0	0	0	0	0.0	0.0	0	0
Biogas, CHP	0	0	0	0	0	0	0	0
Biogas, gas upgrade	67	8	21	2	1	0.2	0	3
Large heat pumps	0	0	0	0	0	0.0	0	0
Large heat storage	0	0	0	0	0.0	0.0	0	0
Elektrolysis-H2, AEC		0	0	0	0		0	0
Elektrolysis-H2, SOEC		0	0	0	0		0	0
H2 Storage		0	0	0	0		0	0
Geothermal		0	0	0	0		0	0
Indiv. heat pumps	2318	898	1235	99	12	0.0	0	111
Indiv. gas boiler	15709	6089	1522	116	24	113	520	773
Indiv. bio boiler	447	154	158	13	1	0.0	10.4	24

Biofuel use	0						0	0
Oil use	4019						258	258
Power import/export	0						0	0
TOTAL SUPPLY				**513**	**162**	**149**	**857**	**1682**

Table 6 . Estimate of costs of energy system in Armenia in 2050 with BAU Scenario, no district heating and only BAU heat savings.

To the BAU costs should be added costs of CO2 emissions of 4.66 million ton of CO2/year.

Comparison of scenarios

The two scenarios can be compared, see table 7 and figure 1

Comparison of scenario costs, million €/year in 2050	Capital Expenses	Operating & maintenance	Fuel costs	CO2-cost	Total ex CO2	TOTAL
Armenia, action scenario 2050, 100% renewable	1162	256	159	0	1577	1577
Armenia, BAU scenario 2050	513	311	857	116.5	1682	1798

Table 7, comparison of economic estimates for 2050 of scenarios.

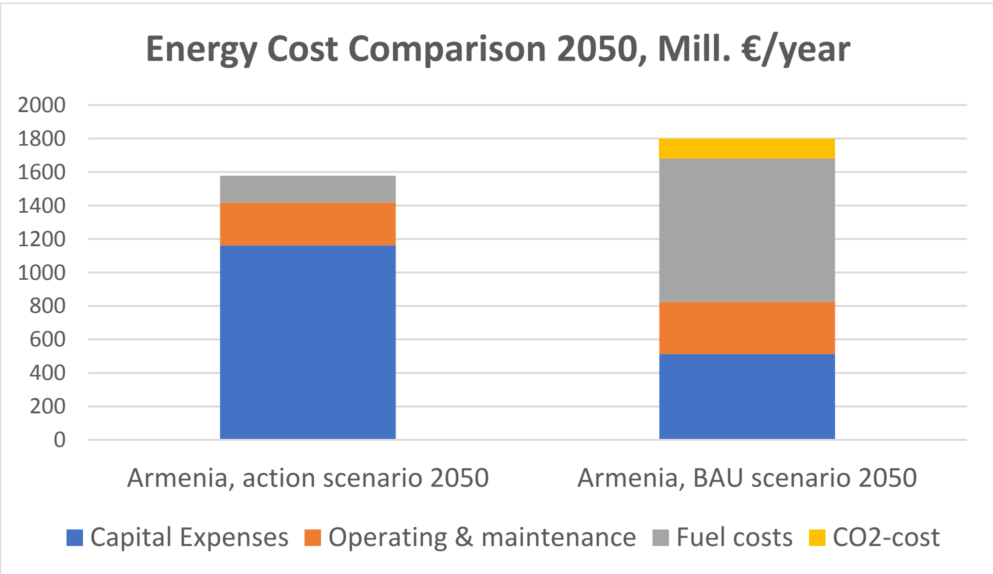

Figure 1; , comparison of economic estimates for 2050 of scenarios.

From figure 1 and table 7 it is seen that with the assumptions used, the action scenario have lower costs in 2050 than the BAU scenario. The difference without CO2 costs is 7%, increasing to 14%, if CO2 costs are included.

While this shows the economic potential of following the action scenario, the uncertainties are so high, that an economic benefit of 7% is below the uncertainties. Instead the analysis can be used to conclude that each of the options included in the action scenario should be analysed in details and those that are economic beneficial at present should be realised as soon as possible,.