MINISTRY OF TERRITORIAL ADMINISTRATION AND INFRASTRUCTURE OF RA

MINISTRY OF ECONOMY OF RA

REPUBLIC OF ARMENIA MINISTRY OF ENVIRONMENT

Գերմանական համագործակցություն
DEUTSCHE ZUSAMMENARBEIT

Implemented by:
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Feasibility study and cost-benefit analysis on the approaches to reduce the use of fuelwood/dung for heating in rural Armenia

Report
Garik Arabyan
July 2020

Executive summary

Armenia is a mountainous landlocked country with no direct access to the sea and it does not have any significant fossil fuel resources. The country relies on nuclear, hydro and gas-fired thermal power plants and from recent years on rapidly growing solar power generation. Although Armenia doesn't produce any fossil fuel, the country manages to cover 28.4% (Energy balance of Armenia 2018) of its energy demand with domestic energy production (0.9 mln toe). According to Statistical Committee of the Republic of Armenia the households (HH) are the main and largest final consumers of energy (33.1 %) including natural gas.

Different surveys and statistics from recent years show that fuelwood has been largely used as a heating fuel especially in rural areas (approx. 70%). Often this is complemented by animal dung, which means that the latter is no longer available as valuable organic fertilizer. Many people burn plastic, rubber and other waste, producing toxic substances which are harmful for human health. Especially women and children are affected, as they spend more time at home close to the stoves. According to various assessments (2014-2018) the annual demand for fuelwood in Armenia varies from 0.5 to 2 mln m^3. This significantly exceeded the reported fuelwood supply and forest renewal capacity in Armenia resulting in forest degradation and deforestation.

The opportunities to produce renewable energy (RE) for HHs needs from sources such as solar and biomass are challenging. The communities and HHs can benefit from them. However, there are various limiting technical, financial and behavioral factors. In addition, homes in rural areas are typically less energy efficient and more dependent on fuelwood, dung and potentially more expensive heating fuels. Application of energy efficient (EE) technologies and utilization of available RE resources can increasingly help communities overcome barriers to harnessing local sources and to benefit from the energy which is cheaper, more efficient, secure and reliable. The use of RE and EE approaches can bring clear environmental, economic, technological and social benefits.

This feasibility study was conducted in the frames of the programme "Management of natural resources and safeguarding of ecosystem services for sustainable rural development in the South Caucasus" (ECOserve). The main aim was: 1. to identify marketable and replicable approaches/products for more efficient use or substitution of fuelwood or dung as a source of heating energy in rural HHs that addresses the specific benefits of women; and 2. to design respective targeted interventions for further piloting.

The study covered the main RE and EE measures applicable for rural HHs in Armenia. Cost-benefit analysis (CBA) was done to define the financial/economic feasibility and sustainability of the approaches/products and their potential for scaling up. The outcomes of CBA were then used in multi-criteria analysis (MCA) to assess the whole range of environmental, financial, technical and social criteria and determine the most preferential options.

The results of CBA showed that for forest adjacent areas (case 1) the replacement of existing inefficient heating devices (stoves and boilers) with efficient devices are economically most feasible measures which ensures the highest monetary savings. The results of the CBA for forest distant areas (case 2) show that the replacement of existing inefficient heating devices (stoves and boilers) with efficient devices in conjunction with shift from fuelwood to straw briquettes as alternative fuel are the most feasible measures which ensures the highest fuelwood and monetary savings.

The results of MCA showed that as in case of CBA the replacement of existing inefficient heating devices (stoves and boilers) with efficient devices and shift from fuelwood to straw briquettes are the most feasible measures.

The proposed feasible pilot interventions include the promotion of EE devices (stoves, boilers) and alternative biofuel (straw briquettes).

The experience from HH energy projects and interventions shows the following important aspects should be considered for their design and implementation of pilot interventions. The interventions should be based on the specific needs of the region/population. It is necessary to have a comprehensive approach to HH energy issues. The market-based approaches with state/public support are key components for ensuring the sustainability of EE and RE approaches. The financing options for low and middle income families can gradually increase the use of more efficient technologies and facilitate HH energy transition. Public awareness raising campaigns are prerequisites for successful interventions. It is important to ensure the sustainability of pilot interventions with consideration of financial, institutional, social, environmental and technological aspects of sustainability.

Table of Content

Executive summary ... iii

List of Abbreviations ... vii

1. Introduction ... 1

2. Energy in rural Armenia ... 3

   Energy demand, supply and efficiency ... 3

   Rural housing ... 4

   Energy balance of Armenia 2018 ... 5

   Use of EE and RE technologies in rural HHs ... 5

3. EE and RE technologies and alternative energy sources ... 7

   HH energy end-uses ... 7

   RE Solutions ... 7

      Non-pressurized solar water heater ... 7

      Pressurized solar water heater ... 8

      PV systems ... 8

      Geothermal and heat pumps ... 9

   EE Solutions ... 10

      Thermal insulation ... 10

      Centralized heating systems with biomass boilers ... 10

      High efficient heating stoves ... 11

      Heat exchangers ... 13

   Alternative biofuel ... 13

      Biogas ... 13

      Straw briquettes ... 13

4. Cost-benefit analysis of EE and RE measures ... 15

   Thermal insulation of HH (walls and roof) ... 17

   Replacement of windows and outside doors ... 18

   Replacement of heating devices ... 19

      Replacement of stoves ... 19

      Replacement of boilers ... 20

      Shift from traditional stoves to boilers with centralized heating system ... 22

   Shift from conventional types of fuel to alterative biomass fuel ... 23

   Installation of solar water heaters and solar PV stations ... 26

      Installation of solar water heaters ... 26

      Installation of solar PV stations ... 26

Installation of heat pumps 27
CBA conclusions 27
5. Multi-criteria assessment analysis 29
Multi-criteria assessment methodology 29
Selection of criteria 29
Evaluation of EE and RE measures 30
Weighting of criteria 33
Ranking of the proposed EE and RE measures 33
6. Feasible pilot interventions 35
Lessons learned from HH energy projects 35
Findings from field visits and meetings 36
Initial design of feasible pilot interventions 37
Sustainability of EE and RE models through pilot interventions 38
7. Conclusions 41
8. References 42
9. Annexes 43
Annex 1. CBA data and technical details for EE and RE measures 43
Thermal insulation of HH (walls and roof) 43
Replacement of windows and outside doors 44
Replacement of heating devices 45
Replacement of stoves 45
Replacement of boilers 48
Shift from traditional stoves to boilers with centralized heating system 50
Installation of solar water heaters 51
Installation of solar PV stations 52
Installation of heat pumps 52
Annex 2. Economic feasibility of producing straw briquettes in existing briquetting facilities.. 54
Annex 3. Companies providing EE and RE technologies and services in RA 56

List of Abbreviations

CAPEX	Capital expenditure
CBA	Cost-benefit analysis
EE	Energy efficiency
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GoA	Government of Armenia
HH	Household
IRR	Internal rate of return
kWh	Kilowatt*hour
MoTAI	Ministry of Territorial Administration and Infrastructures
NGO	Non-governmental organization
NPV	Net-present value
PV	Photovoltaic
RA	Republic of Armenia
RE	Renewable energy
TFC	Total final energy consumption
Toe	Tons of oil equivalent
UNDP	United Nations Development Program
VAT	Value added tax

1. Introduction

The programme “Management of natural resources and safeguarding of ecosystem services for sustainable rural development in the South Caucasus” (ECOserve) is part of the wider German support in the priority area “Environmental policy, conservation and sustainable use of natural resources in the South Caucasus”.

The objective of ECOserve is to improve the conditions for the sustainable and biodiversity-friendly use of natural resources in the prevailing land-use systems in the South Caucasus, with a special focus on energy security for the rural population.

The main aim of this assignment was to identify marketable and replicable approaches/products for more efficient use or substitution of fuelwood or dung as a source of heating energy in rural HHs that addresses the specific benefits of women. For identified approaches/products the initial plans of targeted pilot interventions should be developed. At a later stage the plan of promotion should be developed for identified approaches/products.

This feasibility study report covers the first part of the assignment, including the assessment and analysis with identification of respective approaches/products and development of the initial plans of targeted pilot interventions.

The study covered the general list of energy efficiency (EE) and renewable energy (RE) measures applicable for rural HHs in Armenia. The analysis for determination of feasible approaches/products focused on assessing available and technically and economically justified solutions. Brief cost-benefit analysis (CBA) was done to justify financial/economic feasibility and sustainability of the approaches/products (calculation details are provided in Annex 1). The aim was to show their applicability to rural HHs in terms of economic return, meaning that they can be implemented also at a wider scale.

Given the main aim of this assignment, in order to assess the existing options, the multi-criteria analysis (MCA) approach was undertaken. MCA is a structured approach to determine overall preferences among alternative energy options where options accomplish several objectives. It assessed the whole range of environmental (fuelwood saving, air pollution, etc.), financial (upfront investment, payback period, etc.), technical (accessibility and lifespan of technologies, etc.) and social criteria (health, wellbeing, gender aspects, etc.) and determined the most preferential options.

Based on CBA and MCA results, the initial design of the most feasible pilot interventions was developed. In addition to the factors already assessed during the CBA and MCA the following additional factors were considered: the potential to achieve results within the pilot period and with available resources, social inclusiveness and equal access, implementing partner, pilot area with suitable conditions, consideration of expectations of the main stakeholders and sustainability with consideration of its financial, institutional, social, environmental and technological aspects. The sustainability of proposed measures was considered as a priority, rather than to propose the most modern EE and RE measures and technologies. The comprehensive design of pilot interventions with details of implementation are planned as the next step.

The outline of the report chapters and content is presented below:

1) **Chapter 2** presents a brief overview of the energy situation in rural Armenia with focus on natural resource use (fuelwood/dung), including the demand and supply, sources of heating energy and energy efficiency, HH energy use patterns, etc. It also briefly presents the challenges and advantages of promoting RE and EE at HH level.

2) **Chapter 3** provides an overview of available RE and EE technologies and relevant energy sources. It summarizes the main technical pros and cons, opportunities and challenges for different solutions based on the available information and the results of field visits.

3) **Chapter 4** presents the details of cost-benefit analysis to assess the economic feasibility of a range of EE and RE options.

4) **Chapter 5** presents the details of MCA to consider the whole range of environmental, financial, technical and social criteria and determine the most preferential options for development of the targeted pilot interventions.

5) **Chapter 6** provides initial design of feasible pilot interventions. Sustainability of proposed measures was considered as a priority, rather than to propose the most modern EE and RE technologies.

2. Energy in rural Armenia

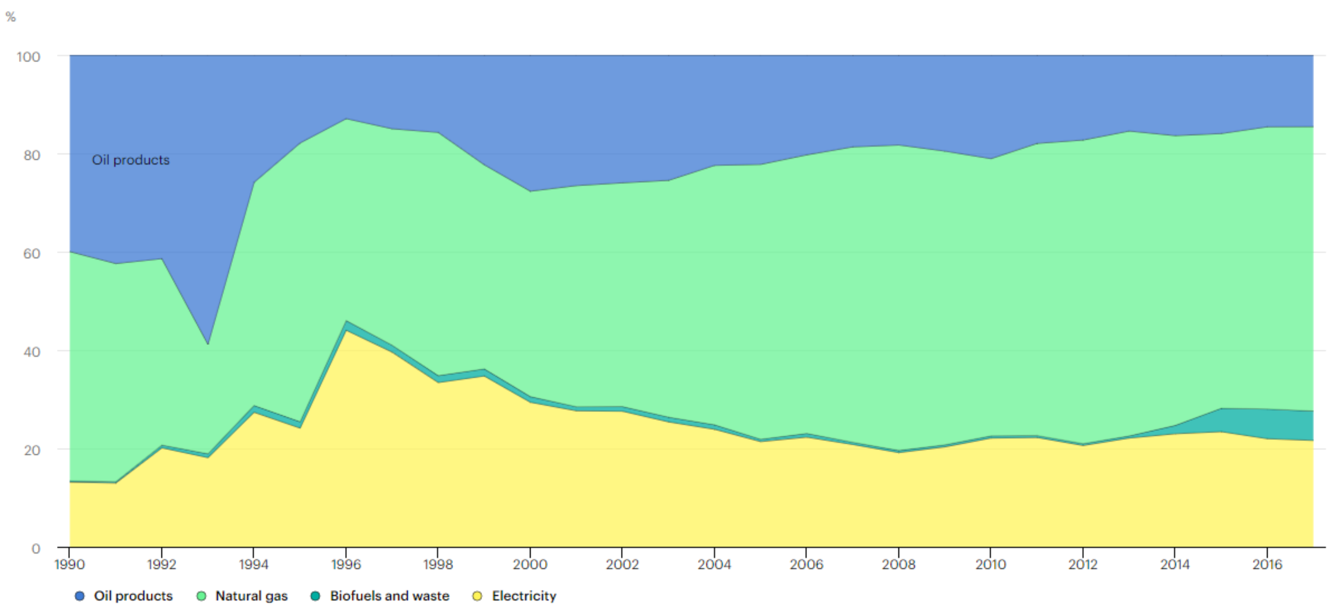
In the frames of ECOserve project a baseline study on energy demand, supply and efficiency in Armenia was conducted with the focus on rural areas and the aspects related to use of fuelwood and dung, to gain overall understanding on rural HH energy use approaches (https://biodivers-southcaucasus.org/uploads/files/Baseline_Study_ENG.pdf). This chapter summarizes the main findings of the baseline study as well as other available sources.

Energy demand, supply and efficiency

The data from 2017 showed that in Armenia the predominant fuel for heating is natural gas, in rural communities it is strongly supplemented by fuelwood and animal waste, while electricity is also used for heating (not as a primary option).

The residential sector was the largest consumer, responsible for over one third of total final energy consumption (36%), followed by the transport sector with a share of 29% in 2017. HHs consume 25% of natural gas, where natural gas is a predominant fuel in urban housing, while it is a supplement fuel in rural HHs. According to the Living Conditions Survey 2017 in rural areas 72% of HHs uses wood, and only 12% - gas. Biomass consumption is 4-6.2% of total final energy.

Figure 1: Total final energy consumption (TFC) by source,1990-2017



According to the Residential Energy Consumption Survey (2015), an average HH in Yerevan consumed 4.7 m^3 wood during the heating season, while the consumption reached 7.1 m^3 in other cities and towns. Meanwhile, the average consumption of fuelwood in villages was 8.1 m^3 per season.

The surveys revealed a big spread in prices for fuelwood sold on Armenia's territory (from AMD 12,000 to 30,000 m^3). According to the Annual Report by State Forest Monitoring Center an average price for 1 m^3 was 13600 AMD in 2017. According to data from 2019-2020 heating season the price for 1 m^3 was in the similar range of 11,000 to 30,000 AMD depending on the fuelwood quality and the distance from forest.

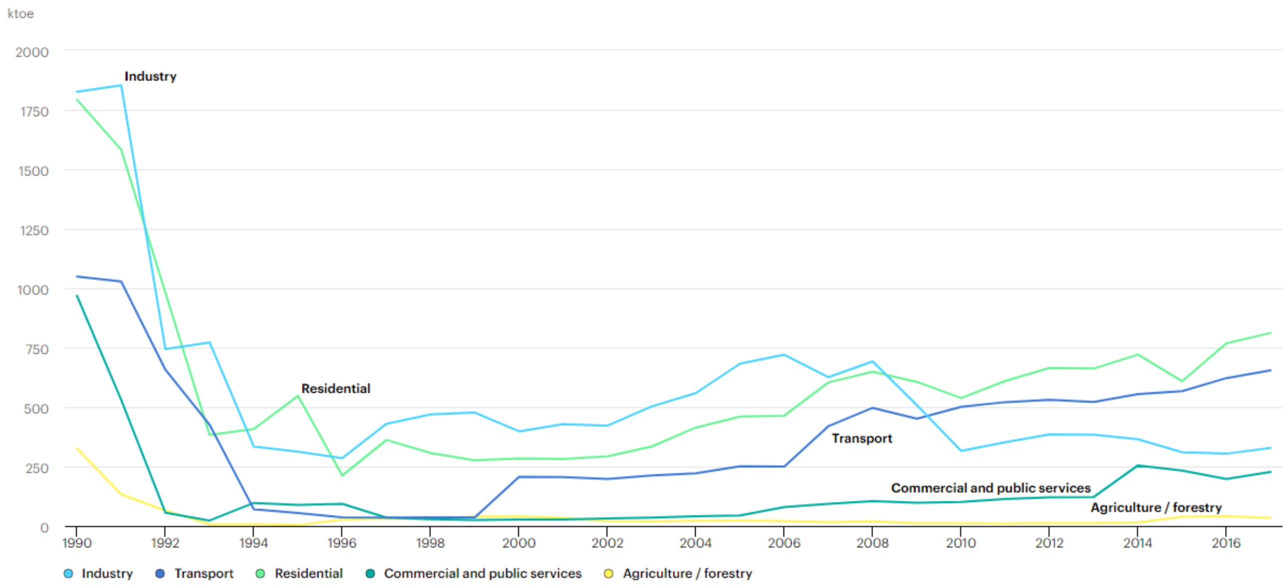
According to various assessments (2014-2018) the annual demand for fuelwood in Armenia varied from 0.5 to 2 mln m^3. This significantly exceeded the reported fuelwood supply and forest renewal capacity in Armenia resulting in forest degradation and deforestation.

Often fuelwood is complemented by animal dung, which means that the latter is no longer available as valuable organic fertilizer. Many people burn plastic, rubber and other waste, producing toxic substances which are harmful for human health. Especially women and children are affected, as they spend more time at home close to the stoves.

Rural housing

The total number of private houses is 396,948, out of which 240,921 units or 39 million m2 in rural areas. In 2017, HHs spent an average 20% of their total expenditures on electricity, heating, and hot water. The housing sector continues to grow. Since 2001 the urban housing stock has grown by 33%, while the rural housing – by 53%, the living area per inhabitant in rural communities have increased with consequent increased energy demand for heating.

Figure 2: Total final energy consumption (TFC) by sector,1990-2017

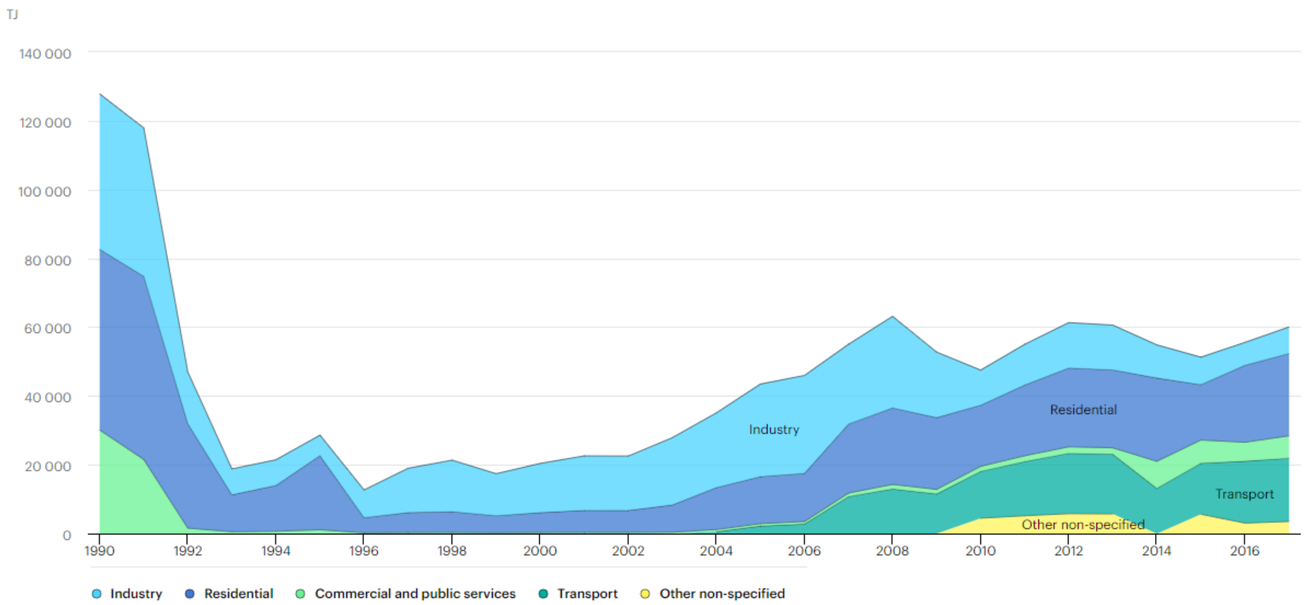


According to the results of different assessments, an average HH residential building in Armenia has 30%-50% energy savings potential.

MoTAI reports that the specific energy consumption in Armenia's residential buildings varies from 260-320kWh/m^2 to as much as 690kWh/m^2 per year. This exceeds the EU averages 3-5 times.

According to Integrated Living Conditions Survey (2017) the HHs relied on the following types of fuel for heating: natural gas – 40.2%, wood – 35.9%, electricity – 18.5% and others.

Figure 3: Natural gas final consumption by sector, Armenia 1990-2017

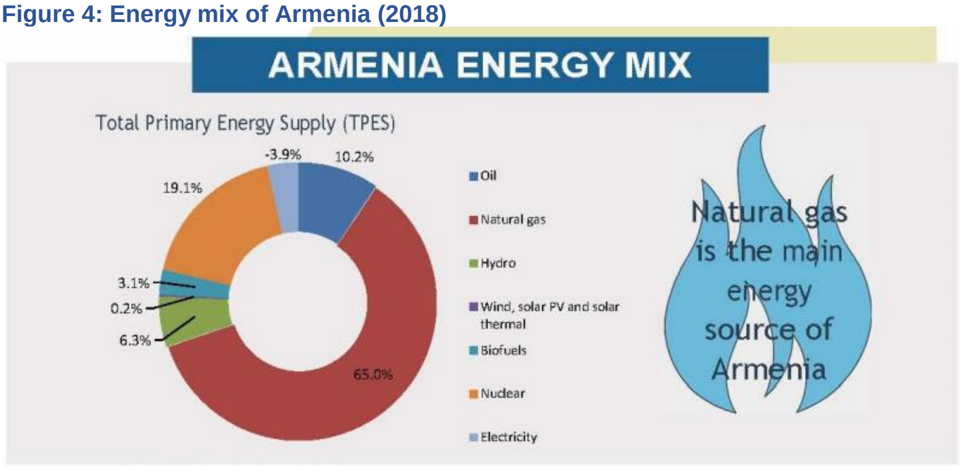


Typical 100 m^2 private stone house needs 52,159 kWh of thermal energy (degree days (DD)=3779^{o}C days, average for Armenia) for heating purposes throughout the heating season, or 348 kWh/m^2 energy.

Energy balance of Armenia 2018

Energy balance is a valuable instrument for the assessment, documentation and monitoring of the energy efficiency and other energy indicators in the country for the given year for different sectors of the economy and HHs.

Figure 4: Energy mix of Armenia (2018)



According to the Energy Balance 2018 the amounts of the hot water and electricity produced by the solar technologies increased significantly compared to 2017 due to the policy by the RA Government. The net metering method was applied for the autonomous consumers in PV sector.

Solar water heating technologies are also promoted. According to the expert estimations (based also on the customs service data) the implementation of various initiatives led to around 2.2% growth in the produced energy in 2018 compared to 2017. The share of the solar technologies in the gross domestic consumption of the renewable energy carriers significantly increased and was 2% in 2018.

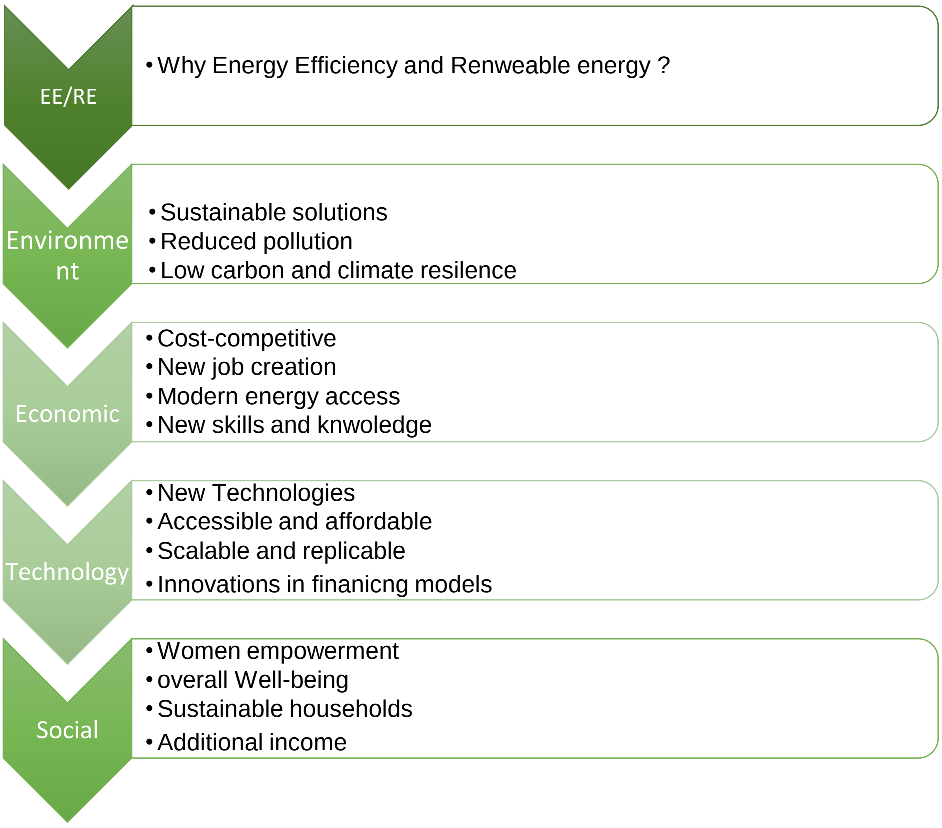
Use of EE and RE technologies in rural HHs

The opportunities to produce RE for HHs needs from sources such as solar and biomass are challenging. The communities and HHs which can utilize such resources have more potential to benefit from these energy sources. However, a range of technical, financial and behavioral factors can limit the extent to which rural HHs can take advantage of these opportunities.

In addition, homes in rural areas are typically less energy efficient and more dependent on fuelwood and dung. Application of EE technologies and utilization of available RE resources can increasingly help communities to overcome barriers to harnessing local sources and to benefit from the energy which is cheaper, more efficient, secure and reliable.

The reasons to promote EE and RE in rural areas are summarized in the figure below.

Figure 5: The reasons to use EE and RE technologies



3. EE and RE technologies and alternative energy sources

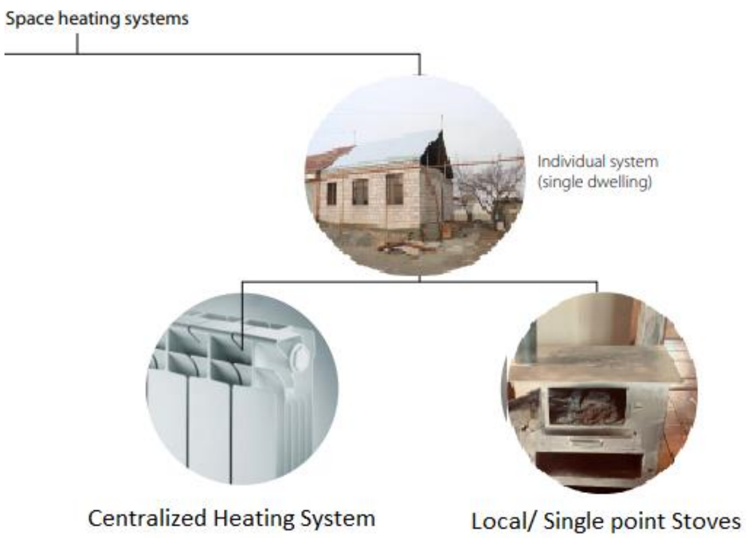
The EE and RE solutions include the technologies and alternative energy (AE) options, which can decrease the demand for fuelwood/dung. They were considered for further cost-benefit analysis and assessment to determine their feasibility for pilot projects on marketable and replicable approaches.

HH energy end-uses

At least six major energy end-uses are distinguished for the energy consumption in HHs: space heating, space cooling, water heating, cooking, lighting and electrical appliances and other use. The category identified as 'other use' can be used to consider any other energy consumption in HHs such as use of energy for the outdoor and any other activities not included into five major energy end-uses mentioned above.

Space heating refers to the use of energy to provide heat (i.e. thermal energy) in an interior area of HH. Space heating can be achieved by means of various heating systems and fuels. According to the amount of heat provided to the HH and the frequency of use, the space heating systems can be separated into main and supplementary space heating systems. The main space-heating system provides most of the heat to the HH. The supplementary space-heating equipment is used less often than the main space-heating system.
If the HH is served by the individual space heating system, it can be further divided to central heating for entire house and local heating for dedicated area or room. Central space heating provides heat for the entire HH: generally hot water with radiators providing central heating. Local space heating provides heat for a dedicated area or room: standalone stoves using wood or other fuels, fireplaces, standalone electric heaters, electric radiators, etc.

Figure 6: Space heating systems



The following types of heating system (with use of different energy sources and fuel) can be considered for HH:

- standalone stove (gas, electricity, biofuel, etc.).
- central hot water space-heating system (gas, biofuel, etc.),
- solar heating system (solar energy),
- heat pump (geothermal energy).

RE Solutions

Non-pressurized solar water heater

A single non-pressurized integral solar water heating system can contribute to monthly savings on heating water (compared to electric or gas boilers), can be integrated into the existing water heating system and has a built-in electric heating element to provide non-stop hot water on cloudy days.

Figure 7: Non-pressurized solar water heater

The non-pressurized solar heating system is very easy to use. It is a good means to bring the life quality of people of rural communities to a higher level.

In a non-pressurized integral water heater, the water gets warm in vacuum tubes and goes higher into the tank using convection mechanism. The vacuum tubes and the tank are a single (integral) unit and are installed on the roof. The water is self-driven (not under pressure) to the consumption point. The system provides hot water 12 months a year (up to boiling temperature in summer and 45-55°C in winter) during more than 20 years and is functional at down to -30°C.

Pros: easy to use and affordable, nowadays it saves more money than the loan monthly payment.

Cons: the whole system stops when a single vacuum tube gets damaged.

Pressurized solar water heater

A pressurized integral solar water heater allows to save up to 140.000 AMD a year and up to 350.000 AMD in comparison with an electric boiler (reference: Shtigen LLC). It needs less maintenance in comparison with non-pressurized integral water heaters.

These systems can be integrated into the existing water heating system and have a built-in electric heating element to provide non-stop hot water on cloudy days.

Despite the similar appearance, pressurized and non-pressurized integral solar water heaters have principal differences. A pressurized integral system drives the water to the consuming point under pressure, there is no water in the vacuum tubes, there is a copper tube with anti-freeze fluid inside, which pushes up the temperature of water in the tank. The both systems have integrated tanks and are installed on the roof. They provide hot water 12 months a year (up to boiling temperature in summer and 45-55°C in winter) during more than 20 years and are functional at down to -30°C.

Pros: the system does not stop when one of the tubes is out of order

Cons: unlike the non-pressurized integral systems, the pressurized one fills the tank with cold water when hot water is being used. That makes the hot water in the tank get cooler.

PV systems

Photovoltaic systems use semiconductor solar cells to capture the sun rays and convert that energy into electricity. Such systems allow HHs to generate electricity in a clean and reliable way that can offset the cost of future electricity costs. Most manufacturer’s warranty their products power output for a minimum of 20 years (80% of output power). However, most solar professionals agree that a system can easily last at least 25 – 30 years.

The existing regulation of Armenia allows up to 150kW for individuals (500kW for legal entities) to be installed for individual use. When the consumption is more than the generation, the difference is supplied by the grid. When the generation is excessive, the role of the accumulator is played by the grid (“Electric networks of Armenia") the PV station is connected to. Then the excess is supplied to the grid, which will later allow to get the same amount from the grid for free. The energy flow is monitored and fixed by the net metering mechanism. The wiring of the house rests intact and only the day/night meter is replaced by a bidirectional one.

Pros: relatively less service needed, long lifespan

Cons: in case of a blackout no energy could be generated

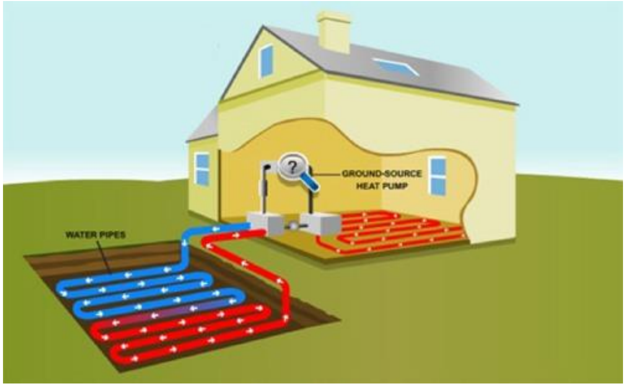
Geothermal and heat pumps

Geothermal heat pumps also called ground source heat pumps include heat pumps that use heat from a ground or shallow geothermal heat source. The heat from the heat pump can be used for space heating and domestic hot water.

Geothermal heat pump systems consist of basically three parts: the ground heat exchanger, the heat pump unit, and the air/water delivery system (ductwork/pipeline). The heat exchanger is basically a system of pipes called a loop, which is buried in the shallow ground near the building. A fluid (usually water or a mixture of water and antifreeze) circulates through the pipes to absorb or relinquish heat within the ground.

In the winter, the geothermal heat pump removes heat from the heat exchanger and pumps it into the indoor air delivery system. In the summer, the process is reversed, and the heat pump moves heat from the indoor air into the heat exchanger.

Figure 8: Geothermal heat pump working principle



The heat removed from the indoor air during the summer can also be used to heat water, providing a free source of hot water. Geothermal heat pumps use much less energy than conventional heating systems, since they draw heat from the ground.

Pros: the system consumes less energy in comparison with conventional types of heating systems

Cons: high upfront investment costs long payback period.

In case of heat pump if the air temperature outside is, say, -10°C the heat pump will harness thermal energy from that air by cooling it down to -35°C. The energy gained then is passed to the water warming it up to 35-40°C. The warm water then is used by Fan coil radiators. Heat pump allows to harness up to 4kWh by consuming just 1kWh electricity. That ratio is called Coefficient of Performance (COP). In this particular case COP=4. The less is the difference between the outside air temperature and the water temperature the higher is the COP. Usually when the outside air temperature is -15°C and the water is 40°C the COP is 2.5.

Pros**:** the system consumes less energy in comparison with conventional types of heating systems

Cons**:** high upfront investment costs, maintenance of the system is quite complex.

EE Solutions

Thermal insulation

The Database of Construction Insulation Materials (2016) was developed in the framework of UNDP Improving Energy Efficiency in Buildings project. It presents companies locally producing construction insulation materials and importing them to Armenia and blueprints technical features of their goods. The technical data on the heat insulation materials were collected directly from the listed companies[1].

The estimated values of required thickness and other technical parameters for installation of thermal insulation are presented in the Advisory Handbook on Technical Solutions for Thermal Insulation of Envelopes of Residential, Public and Industrial Buildings in Construction and Reconstruction in the Republic of Armenia[2]. It was developed and published in the frames of UNDP Improving Energy Efficiency Project. The Handbook was endorsed by the RA Minister of Urban Development (order #343 of November 6, 2013).

Thermal insulation implies insulating the walls, roof and floor. In general, this measure has a big potential to decrease the heating energy demand at HH level. When done properly it can serve for many years. However, the upfront investment cost can be rather high and the return can take many years.

Apart from thermal insulation of walls, roof and floor, the replacement of the windows and external doors has an energy saving impact at HH level, though much less than the thermal insulation.

Centralized heating systems with biomass boilers

Wood and other biomass boilers use technologies that convert biomass (including fuelwood) fuels energy to thermal energy through the following processes:

- combustion: burning fuels in the presence of oxygen,
- pyrolysis: rapid thermal degradation in absence of oxygen,
- gasification: converting biomass fuels into combustible synthetic gas.

This thermal energy is then used for space heating.

Modern certified biomass boilers burn fuelwood or other biofuel to generate heat. Biomass boilers can be used to heat spaces and water for HH and can replace existing inefficient wood or gas boilers. The imported certified boilers can have an efficiency of around 80-90%, significantly higher than many conventional fossil fuel boilers. They should be correctly installed and maintained. The main variable for efficiency of the boiler is the fuel type.

Figure 9: Biomass boiler

The boilers work by burning biomass and outputting the resulting heat for use in heating systems. The fuel - fuelwood, briquettes or others are fed (automatically, semi-automatically, or by hand) into a combustion chamber where they are ignited. The hot gas and air produced by this process travel through a flue, and are then passed through a heat exchanger, which transfers the heat to the water used in the

[1] http://nature-ic.am/en/publication/Database-of-Construction-Insulation-Materials/7297
[2] http://nature-ic.am/en/publication/Advisory-Handbook-on-Technical-Solutions-for-Thermal-Insulation-of-Building-Envelopes/7295

central heating system. Biomass boilers can usually easily be integrated with the existing water heating systems.
Pros: modern biomass combustion systems are highly sophisticated, offering combustion efficiency and low GHG emission levels.
Cons**:** relatively high investment cost, need for regular maintenance.

In **pyrogenic boilers** in a reactor (gas generator) that is optimized for heat-dependent drying and pyrolysis, solid biomass is first converted into gases and vapors. These are guided into a combustion zone (gas burner) where they are burnt with a surplus of oxygen from a secondary air inlet. The pyrolysis boilers, due to high efficiency combustion, use 3 times less fuel than ordinary boilers.
Pros: toxic components are degraded by the use of high temperatures; reduction in water volume due to the high operating temperature; possibility to reduce the demand of fuelwood or other biomass.
Cons: there is no available market ready product; wet fuelwood which is the main fuel in rural HH is not suitable for this technology; the pyrolysis process is complex and requires special skills and knowledge for operation and maintenance.

As an example of pyrogenic boiler the one offered by Barva center (operates in Talin) was designed to generate heat and hot water by the principle of double-circuit heat exchange, based on biomass (wood and agricultural waste). The pyrolysis is a long term and high efficient combustion process, based on receiving flammable gas (synthesis gas) as a result of biofuels thermochemical distillation in low oxidation conditions, as well as 90% (according to producers) efficiency of thermal energy due to its further burning.

Figure 10: Pyrogenic boiler (Barva center)

Thermal Power	20kW
Efficiency	90 %
Heating area	150-200 m^2
Fuel consumption	2-3 kg/h
Fuel	Biomass
Work duration with one loading	4-6 hours
Water tank capacity	100 l
Weight	250 kg

High efficient heating stoves

Modern imported certified wood/briquette stove models feature improved safety and efficiency - they produce almost no smoke, minimal ash, and require less fuelwood. While older uncertified stoves release 15 to 30 grams of smoke per hour, modern certified stoves produce no more than 4.5 grams per hour.

Figure 11: Example of a high efficient stove

Type of stove	Ecocamin (Russia)
Thermal Power	Up to 9kW
Efficiency	80 %
Heating area	150 m^3
Fuel consumption	2-3 kg/h
Fuel	Biomass
Work duration with one loading	Up to 6 hours
Weight	78 kg

In the Armenian market, the imported certified non-catalytic stoves are mostly presented, which do not use a catalyst, but have some internal characteristics that create a good environment for complete combustion. These are firebox insulation, a large baffle to produce a longer, hotter gas flow path, and pre-heated combustion air introduced through small holes above the fuel in the firebox.

There are different types of efficiencies often calculated for wood stoves:

- Combustion efficiency represents a calculated measurement (in percent) of how well the wood burning device is converting the wood into useable heat. It does not reflect how much of the useable heat produced is transferred to the home.
- Overall efficiency is the percentage of heat that is transferred to the space to be heated when a load of fuel (e.g., firewood, pellets) is burned. Actual efficiency will vary depending on factors such as wood moisture, appliance operation and installation (e.g., outside piping, chimney height). Overall efficiency is a better measure than combustion efficiency of the amount of heat that is delivered to the home.

Pros: woods stoves operate on the principle of radiant heat, which warms an area faster; some modern models considered “carbon-neutral”; some models can have double use, when the stove top surface is used for cooking.

Cons: due to limited capacity only partial heating of HH is possible; constant use requires a continuous supply of wood logs; the efficiency of stoves is usually lower than of the boilers.

Different models of **locally produced non-certified** stoves are available in the Armenian market. They are produced by local manufacturers, often based on the orders from individual HHs given the information on their “efficiency” by the manufacturers or those who used it.

Tavush-80 stove is an example of local efficient non-certified stove, which was designed and tested in the framework of GEF Small Grants Program. The stove is designed for the area of 60-100 m^2 (2,5-3 m high).

Figure 12: Tavush 80 stove

Based on field tests and conducted surveys in the scope of pilot testing projects the energy efficiency of the stove reaches about 70-75%. According to the stove design plan, it is conditioned by the principle of convection. The main difference from conventional stoves is additional 14 pipes 40-57 mm long, extending from the bottom of the stove to the top (total length 7 m) provide both an extra surface area and a heater, in this case increasing the volume/mass of the air, ensuring even room warming. The efficiency of the stoves was not tested in laboratory conditions.

Pros: the cost is lower compared to the imported certified models.

Cons: not suitable for wet fuelwood; compared to ordinary stoves the operation is a bit complex; minor modifications in design are needed for easy operation and suitability for briquettes.

Heat exchangers

Heat exchangers are metal structures, which are inserted into an existing exhaust pipe system in order to slow down the speed of hot air flow and to increase the rate of heat transmission into the room.

According to the expert assessment the heat exchanger can decrease the HH fuelwood demand during the winter period in the range between 25-50%. For proper functioning, the heating systems equipped with a heat exchanger need to be cleaned more frequently. In addition, when stoves are used in combination with heat exchangers it should be avoided that too much fuel material is put into the firebox at the same time. Instead, it is advisable to start putting smaller amounts of fuel material into the firebox and to add additional quantities at regular intervals. Heat exchangers can normally be re-used for several years. The advanced types of heat exchangers are equipped with air flow regulators.

Pros: additional measure for increasing overall efficiency of stoves.

Cons: less comfort level at HH due to limiting the indoor space; the need for regular cleaning.

Alternative biofuel

Biogas

Biogas is produced via anaerobic digestion (AD), which results in the production of different gases that can then be burnt to produce energy. AD is the breakdown of various plant and animal material (known as biomass) in an oxygen-free environment. Different biomass materials can be used including animal dung.

Two major gases that make up biogas are methane (CH_4), which accounts for about 60%-70% of the total and also carbon dioxide (CO_2) which accounts for 30%-40%. Small traces of other gases can be found. Overall the biogas composition depends on the inputs or feedstock that goes to AD.

Biogas can simply be burned through the combustion process to produce heat. When burned, 1 m^3 of biogas produces around 2.0/2.5 kWh of thermal energy. In addition, leftover products can be used as fertilizer.

In the framework of the EU-funded project “Integrated Support for Sustainable Economic Development in Rural Mountainous Areas of Armenia” a new biogas plant and greenhouse were built in Geghamasar, ensuring jobs for locals and making use of renewable energy.

This technology can be used in areas that are mainly engaged in cattle breeding and have sufficient quantity of dung for the cost efficient biogas production. In Armenia, there is no much experience of biogas production at HH level. Also there are no market ready technical solutions for production and utilization of biogas for heating of HHs. Therefore, biogas was not considered for further assessment in the frames of this feasibility study.

Straw briquettes

Biomass crop residues from agriculture holds a very large potential for energy production. Formed under high pressure without any binding material, the straw briquettes can be directly used for combustion. The traditional stoves need special modification to be suitable for burning briquettes. Meanwhile, they can be used in high efficient stoves without any intervention.

Figure 13: Straw briquettes production (ECOrange LLC)

Straw briquettes are prepared of the compressed straw. The most common technologies used for briquetting are piston presses with mechanical coupling and screw compaction or extrusion.

During the burning process, the briquettes produce relatively little smoke and no unpleasant odor. Burning straw briquettes do not make sparks as the firewood, which could endanger HH and the people. The table below presents the general technical characteristics of straw briquettes.

Table 1: Technical characteristics of straw briquettes

N	Item	Value
1	Internal moisture	Up to 16 %
2	Calorific value	4000-4200 kcal/kg
3	Diameter	6-6,5 cm
4	Length	5-30 cm
5	Density	600-1300 kg/m3
6	Residual ash	4-7 %

In Armenia there are few producers of straw briquettes, including the most known functioning production units in Mets Parni community (Lori marz) and ECOrange LLC (in Kotayk marz). The newly established briquetting unit in Akhuryan community (Shirak marz) is in the final phase of establishment with the plans to start functioning during 2020. There are some other not well established or regularly functioning small briquetting units in Lori, Tavush and other marzes.

At this moment none of producers have tested (straw) briquettes to obtain calorific values in certified laboratories. Therefore, the determination of mechanical, physical and thermal properties of briquettes in laboratory conditions should be organized to secure quality and sustainable production.

The production of straw briquettes in communities can create incentives for local people to cultivate not used lands for multiple benefits, thus creating new jobs and income. It can also prevent the fields from burning to get rid of the residues, which is a common practice in many regions of Armenia. Burning the fields reduces the soil fertility and creates the risk of fire spreading to nearby areas, including forests.

Pellets (produced from straw or other biomass) should also be mentioned as alternative biofuel, which has the potential to reduce the use of fuelwood. However, pellets are the better choice for public buildings and less preferred for HH use as they require specialized (and more expensive) heating devices with automated supply of fuel. Therefore, pellets were not considered for the analysis within this feasibility study.

4. Cost-benefit analysis of EE and RE measures

Cost–benefit analysis (CBA) is a recognized analytical tool for decision making. It is used most frequently in deciding how to allocate funds between competing projects, programs or interventions.

CBA takes into account all the costs and benefits of HH energy interventions. Thus, it can have an important role in guiding on decision making and investments in HH energy interventions. Demonstrating the economic benefits of investments in improving access to cleaner and more efficient HH energy practices should contribute to the sound policy-making and to overcoming the constraints on implementing HH energy interventions.

Calculation methods in cost-benefit analysis

Several methods are available to calculate the overall financial value of energy efficiency improvements so that values can be integrated into cost-benefit analysis. Three of the most common are considered for this CBA as follows:

Net present value (NPV) evaluates the overall current value of a series of cash flows, including all future cash flows. This method requires quantified values of the initial costs, the costs and benefits for the duration of the calculation period, and some basic economic equations taking into account inflation and depreciation rates over time. If multiple benefits can be translated into cash flows, they can then be integrated into NPV calculations with the likely effect of increasing value.

Internal rate of return (IRR) calculations measure the rate of growth a particular project or intervention/measure is expected to generate. It is effectively the rate of return to deliver an NPV equal to zero. IRR supports comparison of the expected value arising from a range of different projects (interventions/measures). Again, this is a monetary calculation that requires the multiple benefits outcomes to be monetized.

Simple payback period is the length of time required to recover the cost of an investment. It is calculated by comparing the cost of an individual project (intervention/measure) against the cash inflows it generates. It provides an estimate of how long it would take to fully recoup the up-front cost. These inflows tend to be based simply on reduced energy costs resulting from an energy efficiency intervention. Payback period calculations are generally used at the individual project level; they provide a simple metric to assess whether or not to undertake a project or investment – the longer the payback period, the less desirable the investment typically appears. All inputs into payback period calculations need to be monetized, which can be a challenge in a multiple benefits context. The weakness of this method is that it ignores the ongoing impacts of interventions, making it necessary to use another method (e.g. IRR, NPV) to take into account longer-term costs and benefits.

For the purposes of this study based on the general list of EE and RE technologies presented in the previous chapter, CBA was done as the basis to assess their financial/economic feasibility and identify the most feasible (scalable) pilot interventions. The CBA quantified the costs and benefits of different EE and RE measures.

The table below presents the list of EE and RE measures with their short description, for which the CBA was done.

Table 2: EE and RE measures

N	EE/RE measure name	Measure description
1	Thermal insulation of walls and roofs.	Outside walls and roofs of the HH are without thermal insulation. The measure must include installation of thermal insulation with common materials (e.g. XPS, EPS, mineral wool). Insulation of floor was not considered to avoid the additional expenditures related to renovation.
2	Replacement of windows and outside doors	This measure covers outside windows where the current windows are either single glazed / non-insulated windows or old double-glazed windows and which should be replaced. The currently installed single glazed or old double-glazed windows must be replaced by new double-glazed windows with

		modern thermal insulation glazing as a minimum standard. This measure includes also the replacement of uninsulated outside doors with new modern pre-insulated doors.
3	Replacement of heating devices	This measure means the replacement of inefficient heating devices with high efficient stoves and/or boilers
4	Installation of thermal solar systems for hot sanitary water	This measure is for production of hot sanitary water and not for the energy or heat.
5	Installation of on-grid photovoltaic system	This measure is installation of a photovoltaic system with PV panels (solar panels) for electricity production. The system should be connected to the grid.
6	Shifting from conventional type of fuels to alternative biomass fuels	This measure means shifting from firewood/dung which is the main source of heating to alternative biomass fuels, in particular straw briquettes.
7	Installation of heat pump	This measure is installation of a heat pump driven by electricity with the heat sources: ground, water or air

Input data and main assumptions used for all calculations:

The key financial indicators for different measures were calculated based on the assumption of discount rate 12% (investing in standard assets 8% plus estimated inflation rate 4%) and the given 20-year life cycle of proposed measures. Financing sources, interest for loans, loan repayments, etc. were not considered in the calculations. The table below presents the main input data for CBA for different EE and RE measures.

Table 3: Input data for CBA

N	Description	Unit of measure	Value
1	Living area of HH	m^2	100
2	Area of walls (walls are made of stone blocks; density up to 1500kg/m3, 200x200x400mm)	m^2	110
3	Area of roof	m^2	100
4	Area of windows	m^2	10
5	Area of door	m^2	3
6	Heating volume of HH	m^3	300
7	Moisture content of wood	%	40
8	Bulk density of wood	Kg/m^3	570
9	Calorific value of wood	kWh/kg	2,8
10	Specific energy output of wood	kWh/m^3	1641
11	Calorific value of straw briquettes	Kcal/kg	4200
12	Specific energy output of briquettes	kWh/kg	4,88
13	Market price of 1kg straw briquettes	AMD	80
14	Specific energy output of gas	kWh/m^3	9.3
15	Price for 1 m^3 gas	AMD	139
16	Average calorific value of dry dung	kWh/kg	3,8
17	Bulk density of dung	kg/m^3	1000
18	Specific energy output of dung	kWh/kg	3,72
19	Price for 1 m^3 of dung	ADM	15000
20	Efficiency of traditional stove	%	40
21	Efficiency of local improved stove	%	70
22	Efficiency of imported stove	%	80
23	Efficiency of local biomass boiler	%	60
24	Efficiency of imported biomass boiler	%	80

25	Efficiency of gas boiler	%	90

As the conditions for heating and access to fuelwood vary in different regions of Armenia two different cases were assessed for each EE and RE measure as per the table below.

Table 4: Input data for case 1 and case 2

Cases	Climatic conditions	°C days/year	Fuelwood price for 1m^3	Distance from forest
Case 1	Relatively warm, shorter heating season	2660	20000 AMD	Areas adjacent to forest
Case 2	Cold, long heating season	3400	30000 AMD	Areas far from forest

The sections below present the CBA and conclusions for each EE/RE measure for the cases 1 and 2. The details of calculations, cost and fuelwood savings and other technical details are presented in Annex 1.

Thermal insulation of HH (walls and roof)

Thermal insulation in buildings reduces energy consumption and provides fuel saving as well as other benefits such as eliminating condensation and mold formation. Thermal conductivity, technical applicability and CAPEX are important parameters for selection of insulation material. Insulation materials are one of the complex structural elements which should be evaluated as an integral part of the HH's design. The required thickness of thermal insulation depends on the type of insulation material and required thermal protection level of HH.
The calculations were made to determine energy needs for heating of HH before and after insulation with mineral wool as the insulation material. The density of the insulation material for walls was 80-125 kg/m^3 and for roof 40-60 kg/m^3, thermal conductivity (λ) was 0,044W/m°C.

The calculations of the energy need of HH were made for fuelwood and natural gas. It was considered that the HH has already installed centralized heating system with the boiler (efficiency 80% for fuelwood boiler and 90% for gas boiler). The energy needs for heating were calculated in accordance with "Arm CN 24-01-201 Thermal protection of buildings".

For costs and savings calculation two options were considered:
Option 1. Heating with fuelwood or gas (100% level of energy needs for heating)
Option 2. Heating with fuelwood or gas (65% of level of energy needs for heating)

The evaluation of technical parameters related to insulation of an average HH for cases 1 and 2 are presented in the tables below.

Table 5: Technical and economic parameters of thermal insulation of HH (Case 1)

N	Item	Unit	Value
1	Required thickness of thermal insulation of walls (mineral wool, density 80-125kg/m3)	m	0,08
2	Required thickness of thermal insulation of roof (mineral wool 40-60 kg/m3)	m	0,14
3	Total cost of estimated capital investments (CAPEX)	AMD	2030000
4	Energy needs for heating before insulation	kWh/ year	29950
5	Energy needs for heating after insulation	kWh/year	9681

.

Table 6: Technical and economic parameters of thermal insulation of HH (Case 2)

N	Item	Unit	Value
1	Thickness of thermal insulation of walls (mineral wool, density 80-125kg/m3)	m	0,08
2	Thickness of thermal insulation of roof (mineral wool 40-60 kg/m3)	m	0,14
3	Total cost of estimated capital investments (CAPEX)	AMD	2030000
4	Energy needs for heating before insulation	kWh/ year	38283
5	Energy needs for heating after insulation	kWh/year	12374

The details of cost and fuelwood savings for both cases and options are in Annex 1.
Thermal insulation brings to more efficient use of the energy resources for HH heating. The results of calculations show that insulating the walls and roof is economically viable. It can result in annual savings of firewood up to 70% and significantly reduce the energy expenses. However, it needs high upfront investments, which is often not affordable for average rural HHs.

Replacement of windows and outside doors

It was considered that the HH has already installed centralized heating system with the boiler with efficiency 80% for fuelwood boiler and 90% for gas boiler.
The evaluation of technical parameters related to replacement of windows and entry door of average HH for cases 1 and 2 are presented in the tables below.

Table 7: Technical and economic parameters of replacement of windows and door (Case 1)

N	Item	Unit of measure	Value
1	Total area of windows	m^2	10
2	Total area of outside door	m^2	3
3	Thermal energy losses through windows and door before EE measure	kW/year	3207
4	Thermal energy losses through windows and door after EE measure	kWh/year	1392
5	Total CAPEX	AMD	455000

Table 8: Technical and economic parameters of replacement of windows and door (Case 2)

N	Item	Unit of measure	Value
1	Total area of windows	m^2	10
2	Total area of outside door	m^2	3
3	Thermal energy losses through windows and door before EE measure	Kwh/year	4099
4	Thermal energy losses through windows and door after EE measure	Kwh/year	1779
5	Total CAPEX	AMD	455000

Energy efficient windows and doors are important for HH upgrading. Properly installed EE windows and doors make HH more comfortable with reducing fuel consumption and increasing the inside temperature as well as reducing condensation. Our calculations show that properly installed EE windows and doors can contribute to reduction of heat losses by 10-20%.

Replacement of heating devices

Replacement of stoves

For stoves the following options were considered:
1. Replacement of traditional stove with local efficient stove
2. Replacement of traditional stove with imported efficient stove

The efficiency and prices of devices were considered as follows:
- Traditional stove – efficiency 40% (the common firewood stove in rural areas)
- Locally produced efficient stove – efficiency 70% (f.e., Tavush 80 stove, non-certified, price appr. 80.000 AMD)
- Imported certified efficient stove – efficiency 80%, price appr. 250.000 AMD.

For fuels the following options were considered:
1. Fuelwood (humidity - 40%, price for $1m^3$ 20000 AMD for case 1 and 30000 AMD for case 2)
2. Shift from fuelwood to straw briquettes (calorific value 4200 kcal/kg, price for 1 kg of straw briquette= 80 AMD)
3. Shift from fuelwood/dung (30% - 70% calorific value) to straw briquettes (price of 1 m^3 of dung = 15000 AMD)

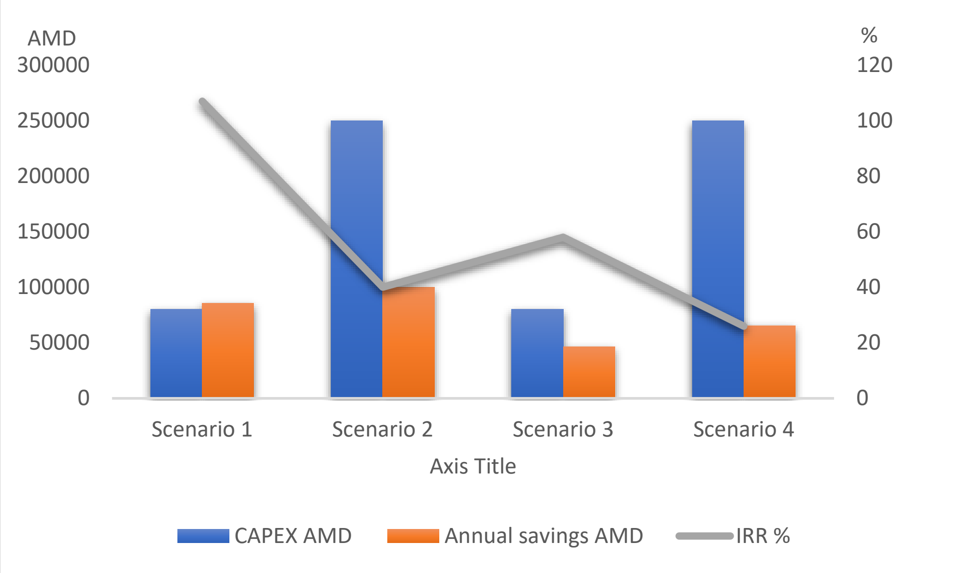
The following 6 scenarios were considered for both cases 1 and 2:
- Scenario 1. Replacement of traditional stove (efficiency 40%) with local efficient stove, fuel type: fuelwood.
- Scenario 2. Replacement of traditional stove (efficiency 40%) with imported efficient stove (estimated efficiency 80%); fuel type: fuelwood.
- Scenario 3. Replacement of traditional stove (efficiency 40%) with local efficient stove (estimated efficiency 70%); fuel type: shifting from fuelwood to briquette.
- Scenario 4. Replacement of traditional stove (efficiency 40%) with local efficient stove (estimated efficiency 70%); fuel type: shifting from fuelwood to briquette.
- Scenario 5. Shifting from fuelwood (30% of heat output) and dung (70% of heat output) to briquette consumption with local efficient stove.
- Scenario 6. Shifting from firewood (30% of heat output) and dung (70% heat output) to briquette consumption with imported efficient stove.

The details of costs and fuelwood savings and other calculations are presented in Annex 1. The main criteria for evaluation of the results and conclusion was less CAPEX and highest IRR.

For both cases 1 and 2 the scenarios 5 and 6 in terms of economic efficiency is not viable, as there are no monetary savings. However, the benefits such as overall improved living conditions of HH and possible use of dung as natural fertilizer are important to consider in the overall evaluation of the measures.

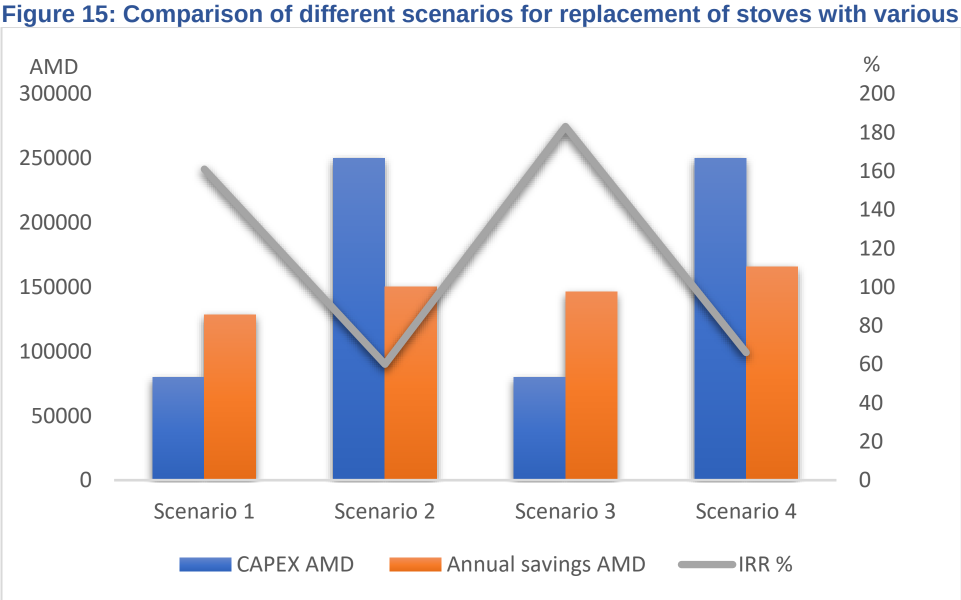
The concluding figures for scenarios 1-4 for cases 1 and 2 are presented below.

Figure 14: Comparison of different scenarios for replacement of stoves with various fuels (case 1).



As the graph above shows in terms of economic efficiency for case 1 the most preferable option is replacement of traditional stove with the local efficient stove with use of fuelwood (scenario 1).

Figure 15: Comparison of different scenarios for replacement of stoves with various fuels (case 2).



As the graph above shows in terms of economic efficiency, the most preferable option for case 2 is replacement of traditional stove with the local efficient stove, meanwhile shifting from firewood to straw briquettes (scenario 3).

Replacement of boilers

These are the cases when the HH has already installed centralized heating system (pipes, radiators, etc.) and there is no need to invest in installing of a new centralized heating system, but only in replacing the boiler. These scenarios consider replacement of traditional boiler (estimated efficiency 60%) with efficient imported boiler (biomass boiler – efficiency 80%, gas boiler – efficiency 90%).

For costs and savings calculation 2 options were considered:
Option 1. Heating with fuelwood (100% level of energy needs for heating)

Option 2. Heating with fuelwood (65% of level of energy needs for heating)

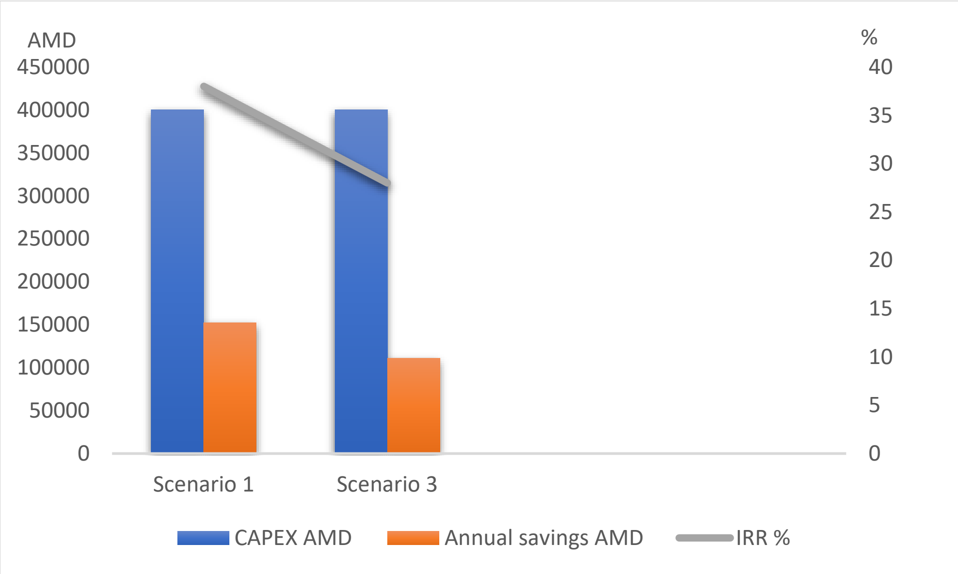
CAPEX included the price of imported biomass or gas boiler – 400.000 AMD, in case of gas boiler the cost of connection to the gas network was not included in the CAPEX.

The following 3 scenarios were considered for both cases 1 and 2:

- Scenario 1. Replacement of traditional boiler with imported EE boiler; fuel – fuelwood.
- Scenario 2. Replacement of traditional boilers with imported EE boilers; fuel – straw briquette.
- Scenario 3. Replacement of traditional boilers with use of fuelwood with gas boilers; fuel – gas.

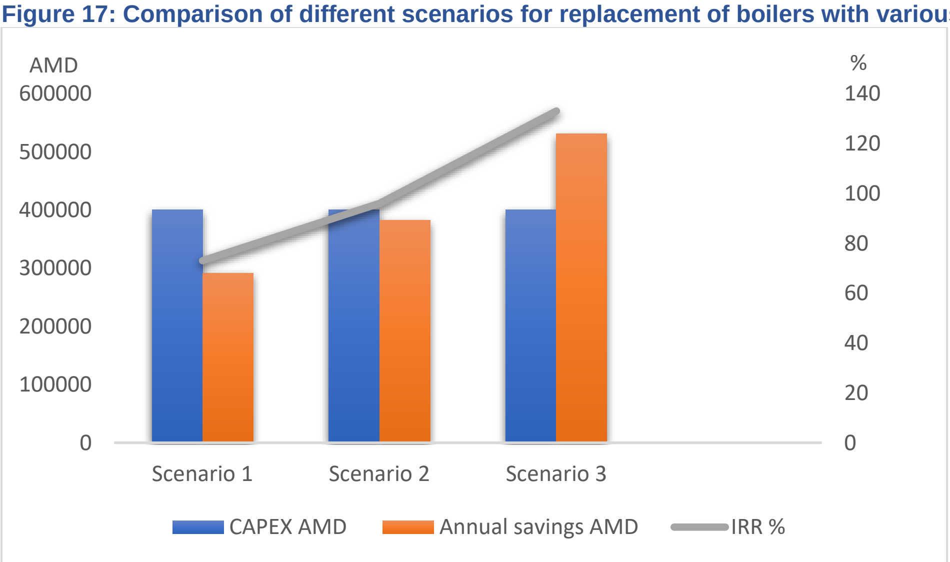
The details of costs and fuelwood savings and other calculations are presented in Annex 1. The main criteria for evaluation of results and conclusions were less CAPEX and highest IRR. In general, the replacement of inefficient boilers has lots of advantages, such as fuelwood reduction, short payback period and significant annual savings. The concluding figures for cases 1 and 2 are presented below. For case 1 the scenario 2 is not economically viable as there are no monetary savings, therefore it was not presented in the graph.

Figure 16: Comparison of different scenarios for replacement of boilers with various fuels (case 1).



As the graph above shows in terms of economic efficiency, in case 1 the most preferable is scenario 1, namely the shift to efficient boiler with use of fuelwood. Given the current market price of briquettes the shift from fuelwood to straw briquettes is not economically viable.

Figure 17: Comparison of different scenarios for replacement of boilers with various fuels (case 2).



As the graph above show for case 2 in terms of economic efficiency the most preferable option is scenario 3 (installation of centralized heating system with gas). However, the connection costs to the gas network were not considered in calculations. Moreover, not all communities in Armenia are gasified. Therefore the scenario 2 (replacement of traditional boilers with imported EE boilers with shifting from fuelwood to straw briquettes) was considered for further overall evaluation of all EE/RE measures.

Shift from traditional stoves to boilers with centralized heating system

These are the cases when HHs want to improve their comfort level and living standard and they are ready to invest in installation of a new centralized heating system with different fuels. This implies also significant increase in use of fuel (fuelwood, briquette, gas).
In this case the upfront investment cost is really high as it includes installation of the pipes, radiators, boilers and other accessories. Therefore, it does not make sense to compare this case with the cases of replacing just the device – the stove or boiler (sections 4.3.1 and 4.3.2).

When shifting from stove to the newly installed centralized heating system, the following types of boilers should be considered:

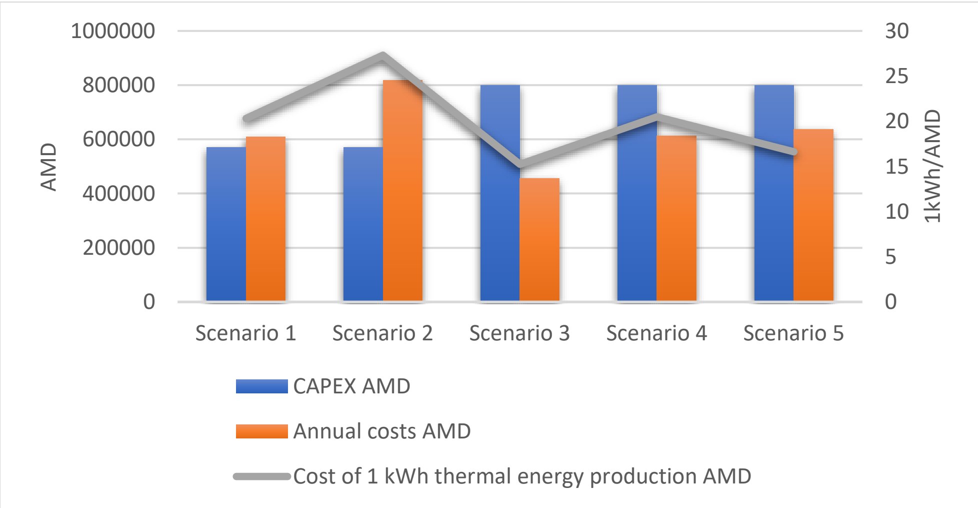
1. Locally manufactured boiler (efficiency 60%)
2. Imported certified boiler (efficiency 80%)
3. Gas boiler (efficiency 90%)

The following 5 scenarios were considered for both cases 1 and 2:

- Scenario 1. Installation of centralized heating system with locally manufactured boiler; fuel-firewood.
- Scenario 2. Installation of centralized heating system with locally manufactured boiler; fuel-straw briquettes.
- Scenario 3. Installation of centralized heating system with imported/certified boiler; fuel-firewood.
- Scenario 4. Installation of centralized heating system with imported/certified boiler; fuel- straw briquettes.
- Scenario 5. Installation of centralized heating system with gas boiler.

The details of costs and fuelwood savings, cost of 1 kWh thermal energy production and other calculations are presented in Annex 1. The main criteria for evaluation of results and conclusions were less CAPEX and cost of thermal energy. The concluding figures for cases 1 and 2 are presented below.

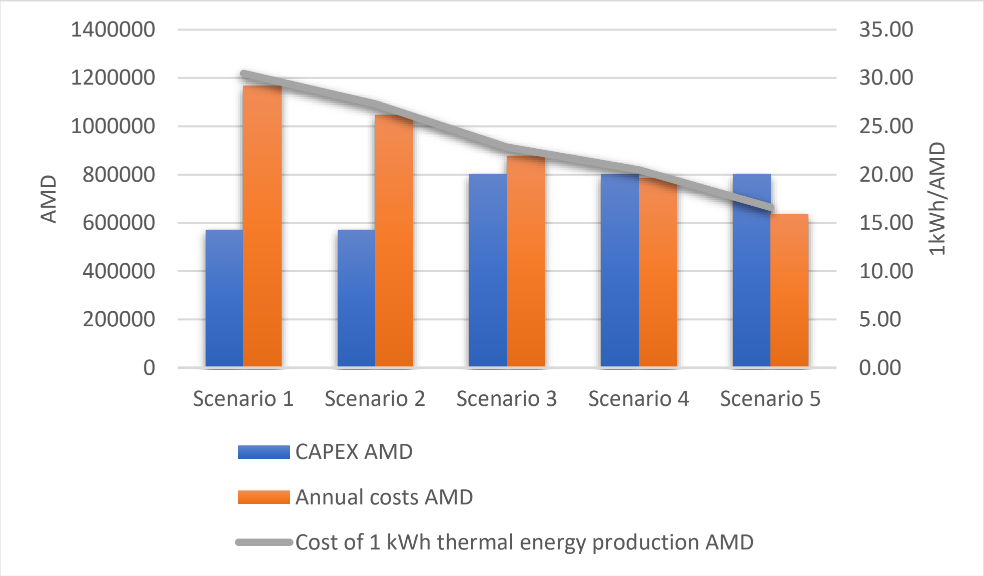
Figure 18: Comparison of different scenarios for shifting from stove to centralized heating system with different fuel (case 1)



As the graph above shows, for case 1 in terms of economic efficiency, the most preferable is scenario

3, namely installation of centralized heating system with imported/certified boiler, fuel-firewood.

Figure 19: Comparison of different scenarios for shifting from stove to centralized heating system with different fuel (case 2)



As the graph above shows for case 2 in terms of economic efficiency the most viable option is scenario 5, namely installation of the centralized heating system with gas. However, the connection costs to the gas network were not considered in calculations and not all communities in Armenia are gasified. Therefore, given the current market price of straw briquettes, the scenario 4 namely installation of centralized heating system with imported/certified boiler and with straw briquettes as fuel can be considered as the next economically most viable option.

Shift from conventional types of fuel to alterative biomass fuel

This section presents calculations with costs and benefits for different types of fuel, including fuelwood, dung, straw briquettes and gas.

The calculations were done with the following input data:

- Annual fuelwood consumption for heating: 10 m^3 and 25 m^3
- Fuelwood price: forest adjacent area (case 1) - 20000 AMD/m^3, forest distant area (case 2) - 30000 AMD/m^3
- Specific energy output of fuelwood (moisture content 40%): 1640,8 kWh/m^3
- Bulk density of wood: 570 kg/m^3
- Calorific value of straw briquettes: 4,88 kWh/kg
- Bulk density of straw briquettes: 600-1050 kg/m^3
- Market price of straw briquettes: 80 AMD/kg

The calorific value of fuelwood was calculated in accordance with Gost 33103.1 and Gost 33103.5 (2017).

Table 9: Annual costs for heating with fuelwood

N	Item	Unit value	10 m^3	25 m^3
1	Average annual fuelwood consumption per heating season	m^3	10	25
2	Fuelwood thermal output per season	kWh	16408	41019
3	Total costs for heating season (case 1)	AMD	200000	500000
4	Total costs for heating season	AMD	300000	750000

	(case 2)			

In case the fuelwood is replaced by straw briquettes in order to get the same amount of heat output the calculations are as follows:

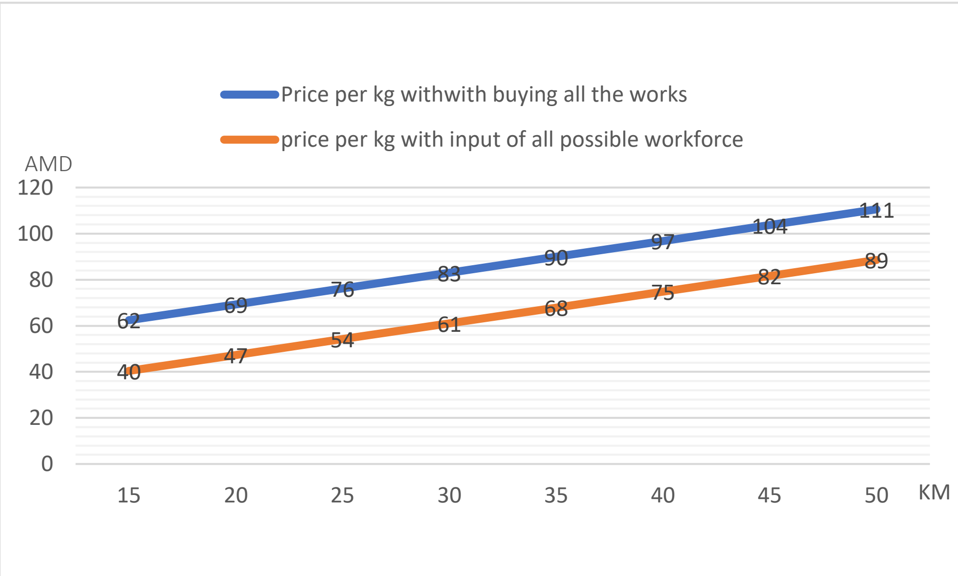
Table 10: Alternative scenario - use of straw briquettes instead of fuelwood

N	Item	Unit of measurement	Equivalent to 10 m^3	Equivalent to 25 m^3
1	Heat output	kWh	16408	41019
2	Average annual briquette consumption per heating season	kg	3361	8403
3	Total costs of briquettes for heating season	AMD	268911	672279

The conclusions from the above calculations show that the shift to straw briquette results to the savings for case 2. For 10 m^3 fuelwood with the price 30000 AMD/m^3 the savings per heating season make 31089 AMD. Considering the heat output properties, 1m^3 of firewood (30000 AMD) is equivalent to 336 kg or 0,30 m^3 (26891 AMD) of straw briquettes. For case 1 with the given input data the shift from fuelwood to straw briquette is not economically viable.

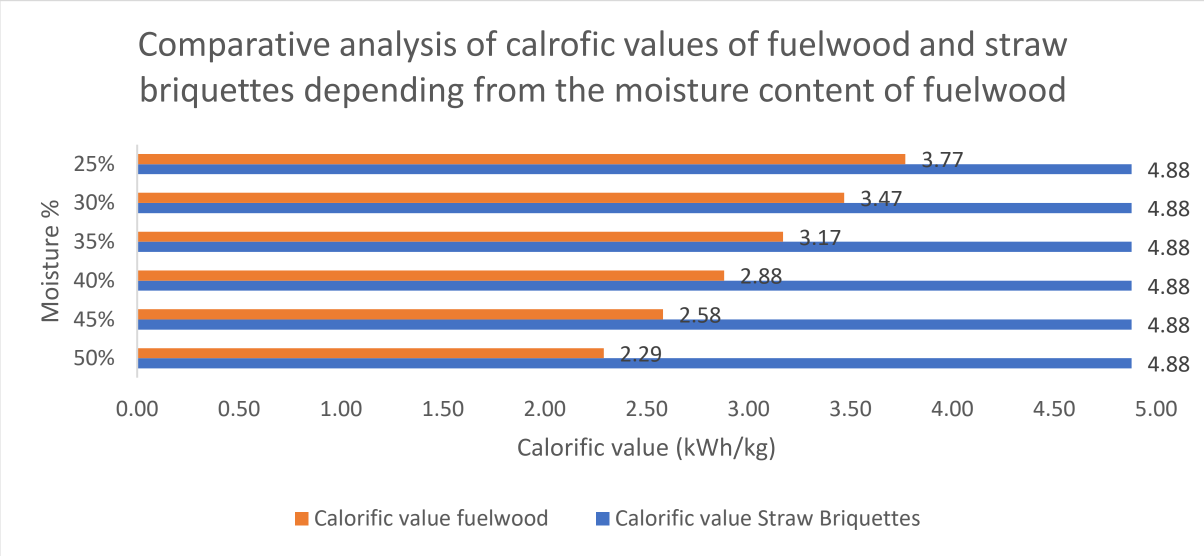
The calculations show that if the HH arranges the transportation of own residual straw to the nearby existing briquetting center, get briquettes produced and transport them back, then the price can be lower than the market price. If HH uses own residual straw and buys all the works (straw assembling, packing, loading, unloading, transportation, etc.), then up to the distance of 20 km to the existing briquetting center, the price of produced briquettes will make appr. 70 AMD/kg. If the HH inputs all the possible workforce and buys only the works, which is not possible to input (packing, transportation, etc.), then up to the distance of 40 km to the existing briquetting center, the price of produced briquettes will be appr. 75 AMD. The less is the distance, the less is the price of briquettes, which is shown on the graph below (details of calculations see in Annex 2).

Figure 20: Price of straw briquette from HHs own residual straw depending on the distance from briquetting unit



The graph below shows the comparison of calorific values of straw briquettes and fuelwood depending on the wood moisture content.

Figure 21: Calorific values of straw briquettes and fuelwood depending on wood moisture content.



The graph shows that the dryer is the fuelwood, the higher its calorific value. It shows the importance of using as dry fuelwood as possible to avoid the heat losses at HH level. This depends very much on the capacity of HHs to buy fuelwood far in advance, e.g. the beginning of summer, for which the socio-economic circumstances as well as certain administrative arrangements of the state forest management bodies can cause obstacles. Proper drying of fuelwood also depends on behavioral changes of rural population (drying fuelwood during the summer season), for which provision of respective information and awareness raising is needed.

The mix of wood and dung is one of the widely used heating options in rural HHs in many regions of Armenia. The calculations below show the costs for getting the same amount of heat output when shifting from fuelwood /dung to straw briquettes.

The calculations were done with the following input data:

- Fuelwood moisture content: 40%
- Annual fuelwood consumption for heating: 10 m^3
- Market price of dung: 15000 AMD/ m^3

Table 11: Annual costs for heating with fuelwood and dung

N	Item	Unit of measurement	Value
1	Specific energy output of fuelwood	kWh/m^3	1641
2	Specific energy output of dung	kWh/kg	3,72
3	Average annual wood consumption per heating season	m^3	3
4	Average annual dung consumption per heating season	m^3	3,1
5	Heat output of wood (40% efficiency of heating device)	kWh	1969
6	Average calorific value of dry dung	kWh/kg	3,8
7	Bulk density of dung	kg/m^3	1000
8	Heat output of dung	kWh	4594
9	Total heat output	kWh	6563
10	Total costs (forest adjacent area – case 1)	AMD	106324
11	Total costs (forest distant area – case 2)	AMD	136324

Table 12: Alternative scenario – use of straw briquettes or gas instead of fuelwood/dung

N	Item	Unit of measurement	Value
1	Calorific value of straw briquettes	kWh/kg	4,88
2	Bulk density of straw briquettes	kg/m^3	600-1050
3	Annual consumption of straw briquettes per heating season (equivalent to fuelwood and dung by heat output)	kg	3361
4	Market price of straw briquettes	kg/AMD	80
5	Total costs for heating season (straw briquettes)	AMD	268911
6	Calorific value of gas	kWh/m^3	9,3
7	Annual gas consumption (equivalent to fuelwood and dung)	m^3	784
8	Market price of gas	m^3	139
9	Total gas costs for heating season	AMD	109021

The tables above show that with the given input data the shift from fuelwood/dung to straw briquettes is no economically viable. Moreover, people often do not pay for dung produced by own life-stock (the calculations above include the market price for dung). In such cases shifting to straw briquettes considering the current market prices is even less economically viable.

The overall conclusion is that the shift from fuelwood (or fuelwood/dung) to straw briquettes can become more viable (especially for case 1) if the HHs do not buy ready straw briquettes from briquetting units for the market price, but instead go for bartering of the straw remaining in their private lands with input of their own workforce to collect it and prepare for transportation to the briquetting unit. The distance in between the community and existing briquetting unit should be considered.

Installation of solar water heaters and solar PV stations

Installation of solar water heaters

For financial calculations the saving values provided by different vendors were used (see Annex 3).
The mean average was considered for profitability calculations (details see in Annex 1).
This measure can partially cover HH needs for sanitary hot water, meanwhile it can be used as an additional measure in a package to reduce the use of fuelwood, increase the level of comfort and benefit to women. However, due to technical limitation, it cannot be used for HH heating purposes. In some cases, there are complex heating systems where solar hot water devices are used as a supplementary measure for centralized heating system. However due to the complexity in maintenance and operation it was not considered in the current study.

Installation of solar PV stations

For evaluation of installation of solar PV stations, the capacity 4kWp was considered due to limited area and bearing capacity of average HHs roof (details see Annex 1).
Due to technical limitations related to the plant capacity which depends on available roof area solar PV systems cannot be considered for covering all heating needs of HH. The PV station of respective capacity can be considered only as a supplementary measure to cover from 10 to 20 % of heating needs. In case there is possibility to install the PV station on the ground (not on the roof), then in order to cover the heating needs of an average HH with use of electricity, then the capacity 20-30 kWp should be considered.
The calculations show that installation of PV systems for heating purposes can be economically viable in case the HH at present uses electricity for heating and want to shift to PV system to continue heating with electricity. Shifting to renewable (solar) energy has clear positive environmental impact. However,

there is no evidence of common use of electricity for heating in rural HHs.

Installation of heat pumps

Depending on the technology and required capacity, the CAPEX of heat pumps varies from 5000-10000 USD. The capacity 10 kW was used for calculations as the most represented model in the market (details see Annex 1).

There is no reliable data on operation and maintenance of heat pumps at HH in RA. In general, this technology is quite complex in operation and requires special knowledge. The maintenance of the system as well as availability of resources is another barrier for its wide use. The evaluation results show that among all the assessed heating options it needs the highest upfront investments and longer payback period.

CBA conclusions

The sections above presented the CBA with financial and other parameters. This study was specifically aimed at assessing the economic feasibility of different EE and RE measures for further development of pilot interventions. Meanwhile, the end-users should be considered, in particular their readiness and willingness to make upfront investment or accept certain years for the payback period. In general, people in rural areas have problems to make upfront investment as well as they are rather reluctant to take loans from financing institutions or cannot take loans due to already existing financial commitments or obligations.

Therefore, to conclude on economic feasibility and consequently the marketability/replicability of the measures, the ones with less CAPEX and higher IRR were considered as the most feasible options to consider for pilot interventions. In case of availability of the additional financing, the priority should be given to the measures with highest NPV.

Case 1

Table 13: CBA evaluation results for case 1

N	EE and RE measure	CAPEX (AMD)	IRR (%)	NPV (AMD)
1	Replacement of traditional stoves with local efficient stoves; fuel - fuelwood	80000	107	560238
2	Replacement of traditional boilers with imported EE boilers; fuel - fuelwood	400000	38	736216
3	Thermal insulation of HH	2030000	14	276658
4	Installation of solar water heaters	400000	6	(131100)
5	Replacement of windows and outside doors	455000	2	(243413)
6	Installation of solar PV	1011870	1	(903285)
7	Installation of heat pumps	4850000	(2)	(3430806)

The results of CBA for forest adjacent areas (case 1) show that replacement of existing inefficient heating devices (stoves and boilers) with efficient devices are economically most feasible measures which ensures the highest monetary savings. Given the current market price of straw briquettes the replacement of fuelwood with briquettes is not economically feasible. However, if the briquette production is considered from HHs own straw with input of own workforce, its price can be much lower than the market price. In this case the shift from fuelwood to straw briquettes can be considered also for forest adjacent areas, which will bring also to significant reduction of fuelwood use. Therefore, this option was considered for further multi-criteria analysis and the pilot project design.

Case 2

Table 14: CBA evaluation results for case 2

N	EE and RE measure	CAPEX (AMD)	IRR (%)	NPV (AMD)

1	Replacement of traditional stoves with local EE stoves; fuel - shifting from fuelwood to briquette	80000	183	1013051
2	Replacement of traditional boilers with imported EE boilers; fuel - shifting from fuelwood to straw briquettes	400000	96	2455711
3	Thermal insulation of HH	2030000	29	2392922
4	Installation of solar water heaters	400000	12	3350
5	Replacement of windows and outside doors	455000	10	(53912)
6	Installation of solar PV	1552000	6	(578928)
7	Installation of heat pumps	4850000	5	(1936917)

The results of the CBA for forest distant areas (case 2) show that replacement of existing inefficient heating devices (stoves and boilers) with efficient devices in conjunction with shift from fuelwood to straw briquettes as alternative fuel are the most feasible measures which ensures the highest fuelwood and monetary savings. If the HHs use own straw with input of own workforce, the price of briquette can be even lower than its market price.

It should be mentioned that the combination of different EE and RE measures, in particular the replacement of inefficient heating devices with HH insulation, replacement of inefficient windows/doors, use of solar energy and others is important to ensure higher fuelwood savings. Meanwhile, this implies higher upfront investment costs, which often are not affordable for rural HHs. However, in a longer-term it can ensure high fuel-wood and monetary savings.

5. Multi-criteria assessment analysis

Multi-criteria assessment methodology

In general, the MCA is a structured approach used to determine overall preferences among alternative energy options where the options accomplish several objectives (UNFCCC 2015). The MCA is a very useful tool when a single-criterion approach falls short.
The previous chapter presented CBA for different EE and RE measures with conclusions on their marketability and replicability (scalability). However, the social and environmental impacts cannot be assigned meaningful monetary values. Meanwhile, the MCA allows to consider a full range of criteria including social, environmental, technical, and financial. Thus in this study, the MCA approach assesses each EE and RE measure on a range of weighted criteria.

Selection of criteria

In MCA approach the first step is to define the set of relevant criteria. The following set of initial criteria were defined by the assignment ToRs for preliminary assessment of possible pilot interventions:

- Relevance for target group (addressing core problem, special benefits for women)
- Potential for scalability (economically feasible, marketability and replicability)
- Social inclusiveness (gender, youth, local structures), equal access
- Potential to achieve results within ECOserve pilot period and with available resources
- Implementing partner (availability, strength, motivation, experience in the field)
- Pilot area with suitable conditions (security issues, avoid duplications, foster synergies)
- In line with expectations of the main stakeholders

The first 2 criteria from the list are of general character and relate to the concept of EE and RE measures. Therefore, they can be incorporated in MCA for overall assessment of all EE and RE measures. The rest of criteria relate to the specifics of ECOserve project such as the timeframe, implementing partners, pilot area, etc, which are recommended to consider at a later stage of defining targeted pilot interventions.
The table below presents the proposed list of criteria for MCA by categories.

Table 15: MCA evaluation criteria

N	Category/Criterion	Unit of measurement	Range
1	**Technical**	Low-Medium-High	1-3
	Accessibility: immediate accessibility for users to the technology based on the maturity of technology and easiness of gaining access.		
	Scalability: potential for marketability and replicability of the technology/measure		
	Lifespan: overall lifespan of the technology		
	Complexity: general estimation of the complexity of EE/RE technology/measure		
2	**Financial**	Low-Medium-High	1-3
	NPV: evaluates the overall current value of a series of cash flows		
	IRR: measures the rate of growth a particular project is expected to generate		
	SPP: time required to recover the cost of EE investment		
3	**Environmental**	Low-Medium-High	1-3
	GHG savings: annual greenhouse gases savings linked to energy savings		
	Air pollution: avoided indoor pollutants in the result of EE/RE measure		

	Saving of fuelwood: annual fuelwood saved in the result of EE/RE measure		
4	**Social**	Low-Medium-High	1-3
	Health and well-being: improvement of living conditions of HHs and the quality of life		
	HH income: income resulting from EE/RE measure		
	Women benefit: savings due to less illness, reduced time to prepare/maintain heating and cooking, more time for other family/personal/social needs		

Evaluation of EE and RE measures

Each EE and RE measure should be evaluated based on the defined criteria. Depending on the type of measures, a relevant score is assigned to each option. This score reflects how it performs in relation to the particular criterion. Each measure was scored against each criterion. The scoring was done based on available information and expert assessment with careful consideration of the differences in scores for each option. The tables below present the assessment of EE and RE measures against all evaluation criteria.

Color key	Performs well	Performs relatively well	Performs poorly

Table 16: MCA evaluation (technical and financial) of EE and RE measures

N	Option/Criteria	Technical				Financial		
		Accessibility	Scalability	Lifespan	Complexity	NPV	IRR	SPB
1	Thermal insulation of walls and roofs	2	2	3	2	2	2	2
2	Replacement of windows and outside doors	2	2	3	2	2	2	2
3	Replacement of heating devices with more efficient devices	2	3	3	3	3	3	3
4	Thermal solar systems for hot sanitary water	2	3	2	2	2	2	2
5	Installation of on-grid photovoltaic system	1	1	3	2	2	2	2
6	Shifting from conventional type of fuels to alternative biomass fuels	2	2	3	2	2	2	3
7	Heat pump installation	1	1	3	1	1	1	1

Table 17: MCA evaluation (environmental and social) of EE and RE measures

N	Option/Criteria	Environmental			Social		
		GHG savings	Air pollution	Fuelwood savings	Health and well-being	HH income	Women benefit
1	Thermal insulation of walls and roofs	3	2	3	3	2	2
2	Replacement of windows and outside doors	3	2	2	3	2	2
3	Replacement of heating devices with more efficient devices	3	2	2	3	3	3
4	Thermal solar systems for hot sanitary water	2	2	1	3	2	3
5	Installation of on-grid photovoltaic system	2	2	1	2	2	2
6	Shifting from conventional type of fuels to alternative biomass fuels	3	3	3	3	2	3
7	Heat pump installation	2	3	2	2	1	2

Weighting of criteria

Weighting of criteria is a crucial step in the MCA. It assesses the weight of each criterion to reflect its relative importance based on the specific objectives of MCA. Some criteria may be more important (key criteria) than the others (mid-range criteria). The key criteria should be weighed higher than the less important ones. Based on the objectives of this study the criteria in financial and environmental categories were weighted at 30% and the criteria in technical and social categories were weighted at 20%.

The complete set of applied weightings is shown in the table below.

Table 18: Weighting of criteria

N	Category/Criterion	Weight (%)
1	**Technical**	20
1.1	Accessibility	5
1.2	Scalability	10
1.3	Lifespan	2,5
1.4	Complexity	2,5
2	**Financial**	30
2.1	NPV	10
2.2	IRR	10
2.3	SPB	10
3	**Environmental**	30
3.1	GHG savings	5
3.2	Air pollution	5
3.3	Fuelwood savings	20
4	**Social**	20
4.1	Health and well-being	5
4.2	HH income	5
4.3	Women benefit	10

Then the corresponding weighting units were applied to the scored criteria to get the weighted scores for EE and RE measures[3].

Ranking of the proposed EE and RE measures

The final step in the MCA is the comparison of the weighted scores based on the criteria list in line with the key objectives of the feasibility study. It allows identification of the most feasible EE and RE measures for further assessment and development of specific targeted pilot interventions.

Table 19. Scores of EE and RE measures

N	EE and RE measures	Score
1	Replacement of heating devices with more efficient devices	90,00
2	Shifting from conventional type of fuels to alternative biomass fuels	85,83
3	Thermal insulation of walls and roofs	77,50
4	Replacement of windows and outside doors	70,83

[3] The calculation formula is $S = \Sigma S_i \cdot W_{i,}$; where S – weighted score of each option for multiple criteria, S_i – weighted score of option for $_i$ criterion, W_i – weight of $_i$ criterion.

5	Thermal solar systems for hot sanitary water	68,33
6	Installation of on-grid photovoltaic system	55,83
7	Heat pump installation	51,67

The results of ranking by the weighted scores for multiple criteria show that the replacement of existing heating devices with more energy efficient heating systems and shifting to alternative biofuels such as straw briquettes are the most feasible measures for pilot interventions. They have also relatively small upfront investment cost. The measure on installation of heat pump is the last in the ranked list conditioned by the complexity of operation and high upfront investment costs.

6. Feasible pilot interventions

Lessons learned from HH energy projects

Rural HHs of Armenia have the opportunity to shift from conventional energy towards alternative RE and EE technologies. Hence, the promotion of RE and EE is a key component of ensuring sustainable energy for the benefit of HH and society as a whole.

Given the experience of HH energy projects and their success and failure factors, the following important lessons have been identified.

- The EE and RE intervention projects should be developed considering region/population specific needs

Active participation of communities, NGOs, and the private sector is essential for HH EE projects to be successful and sustainable. Rural communities need to be involved at an early stage to ensure forest protection (in areas adjacent to forests) and use of locally available resources for heating purposes. The role of local NGOs is very crucial for organization of transition to more efficient energy technologies. In addition, special attention should be paid to meet the needs and preferences of the end-users of the EE devices and overall improvements.

- Comprehensive approach to HH energy issues is necessary

Using multiple intervention components that combine elements such as HH retrofits, replacement of inefficient devices, dissemination of EE devices and alternative HH fuels, such as briquettes from biomass, the capacity building to develop and strengthen alternative energy products and behavior change can increase the chances of successfully impacting the use of EE and RE technologies.

- Public awareness campaigns are prerequisites for successful interventions

Successful programs have paid particular attention to public awareness, education, and information campaigns. HHs need to be aware about the risks they incur by heating with inefficient stoves as well as to perceive and to be convinced about the direct and indirect benefits of EE interventions.

- Market-based approach with state/public support are key components for ensuring sustainability of EE and RE technologies;

A market-based approach in the commercialization of EE and RE projects is often viewed as the best way to ensure sustainability of programs. This is based on the evidence that subsidized programs do not continue when donor funding dries out. However, certain level of state/public funding is necessary at the initial program stages to take off. This is particularly important in rural communities where the business approach and environment are not well developed.

- Financing options for low and middle income families can gradually increase the use of more efficient technologies and facilitate HH energy transition.

Affordability of EE and EE technologies is one of key issues for wider dissemination among rural HH. Programs that have included finance options to help HHs afford more efficient technologies are quite successful. To avoid high upfront investments the majority of HHs need to have a time horizon to gradually pay for the improved living conditions. There is a big demand on subsidized projects in rural HHs.

Findings from field visits and meetings

In the frames of the feasibility study a number of meetings were implemented with different projects and initiatives, NGOs and other organizations implementing relevant activities. In addition, the fact-finding visits were implemented to the regions of Armenia (Shirak, Lori, Kotayk, etc.) to consider both forest distant and forest adjacent areas, different climatic conditions (duration and coldness of winter) and others. The field visits included the meetings and discussions with communities, briquette producers, manufacturers of heating devices, potential partners and others.

According to the findings fuelwood and dung still remain the main heating fuel for the majority of rural HHs. However, due to the increased prices of fuelwood (and strict control) during the last year some HHs shifted to other fuel, including natural gas. There are also cases when the HHs use rubber, plastic and other matters as fuel, which is harmful for health, especially of women and children who spend more time indoors. In some communities with abundant straw resource base there is a strong interest in production and use of straw briquettes as heating fuel. Many rural HHs still use locally produced single point inefficient stoves. Almost in any region there are different types of “efficient” or “good” stoves manufactured by local masters. At present in Armenia there is no established methodology, equipment or laboratory to assess the efficiency of heating devices (stoves, boilers) working on solid biofuel (fuelwood, briquette).

Meanwhile, in rural areas of Armenia a trend is towards “modern houses”. This includes the trend to have more space in the HH heated and comfort conditions in the whole living area, clean house and less need for frequent renovation due to the “not-clean” heating, aesthetic heating in terms of devices and their location in the living area. There is also the issue of resources (time, workforce, etc.) which are spent to ensure heating. This relates to the need to allocate less time and efforts to prepare fuel (fuelwood transportation, chopping, arranging, etc.) and to maintain fire (feeding in fuel, cleaning devices, etc.), which can have clear benefits to women to have more time for other purposes. Improved devices and use of clean biofuel can reduce indoor pollution and life quality.

Therefore, efficient stoves and/or boilers combined with alternative straw biomass fuel can be considered as feasible measure to reduce the use of fuelwood and dung with the benefits to women. The main barriers to deployment and dissemination of these technologies are:

1. Availability and affordability of efficient wood/biomass stoves/boilers.
2. The need for adapted technologies for use of straw briquettes in the communities with high straw resource base or access of straw briquettes.
3. Availability and affordability of alternative biomass (straw) fuel.
4. High upfront investment costs in case of shifting to centralized heating system on biofuel.
5. Insufficient awareness about the advantages of efficient devices (stoves/boilers) at HH and community level.
6. The need for a comprehensive state strategy on replacement of inefficient devices and use of alternative biofuel.

At present there are two more or less regularly functioning briquetting units in Mets Parni (Lori marz) and Zoravan (Kotayk marz) communities. The newly established briquetting unit in Akhuryan community (Shirak marz) is expected to start functioning in June-July 2020.

The market price of straw briquettes is about 80 AMD per kg (without transportation). In the forest adjacent areas, where the price of fuelwood is lower (appr. 20000 AMD), the market price of briquettes equals or can be even higher than that of the fuelwood (with consideration of the calorific values of fuelwood and straw briquettes). Meanwhile, in the far from forest areas, where the price of fuelwood is higher (appr. 30000 AMD), the market price of briquettes is lower than that of the fuelwood.

The calculations show that if the HH arranges the transportation of own residual straw to the nearby existing briquetting center, get briquettes produced and transport them back, then the price can be lower than the market price. If HH uses own residential straw (does not pay for it) and buys all the works (straw assembling, packing, loading, unloading, transportation, etc.), then up to the distance of 25 km to the existing briquetting center, the price of produced briquettes will make appr. 70 AMD/kg. In case the HH inputs all the possible workforce and buys only the works, which is not possible to input (packing, transportation, etc.), then up to the distance of 40 km to the existing briquetting center, the price of produced briquettes will be appr. 75 AMD. The less is the distance, the less is the price of briquettes.

Establishment of new briquetting facilities in the communities (or clusters of communities) with sufficient straw resource base is another option to ensure the use of residual straw and reduce the fuelwood use. Two community-based briquetting centers were established in Mets Parni and Akhuryan communities with the donor support in the frames of UNDP projects and community contribution (small proportion of the total investment). They operate through the local revolving funds.

For establishment of new briquetting units, it is suggested to consider the new financial mechanisms with cost sharing and co-financing of investments from the following potential sources:

a) Governmental subvention programs
b) In-kind and financial contribution of community/HHs
c) Financial leasing of equipment
d) Community budget
e) Loans with governmental subsidies
f) Support projects and other donors

Apart from revolving funds, the existing local non-commercial organizations functioning in the communities to provide public services can be considered for running the new community briquetting center. In any case, active involvement of community members and setting up of the management committee will be needed. The most relevant business models and technologies should be additionally studied and identified as the most functional for the Armenia conditions.

Initial design of feasible pilot interventions

The aim is to pilot marketable/replicable approaches/products for more efficient use or substitution of firewood or dung as the source of heating energy that addresses the specific benefits of women

Objectives:

1. Replacement of inefficient fuelwood stoves with more efficient stoves suitable for fuelwood and straw briquettes.
2. Improvement of the value chain for use of straw briquettes to reduce or substitute the use of firewood or dung with making use of existing briquetting facilities.
3. Improvement of indoor air conditions and benefits to women

The indicative **activities** for the pilot intervention can include:

1. socio-economic surveys in preselected communities (to identify the availability of

fuelwood/dung and other fuel, consumption patterns, HH's preferences on heating devices and methods, HHs which plan to change their heating devices (stoves/boilers) or shift to another heating system on biofuel (e.g., centralized), financial (cost-sharing) models, gender and health issues linked to heating, etc.);

2. identification of locally produced stoves and assessment of their energy efficiency, development of design documents packages for the most relevant models;
3. manufacturing and dissemination of EE stoves based on the agreed cost-sharing mechanism - contribution by HHs (in the form of bartering straw to briquettes and/or financial), communities, ECOserve and other actors;
4. Clarification of the needs and arrangements for production of briquettes from HH own residual straw, awareness raising in selected communities and support to production of straw briquettes including capacity-building;
5. Monitoring and evaluation (to evaluate the efficiency and performance of stoves, fuel use, advantages, drawbacks, impact on women, etc.).

Criteria for selection of the pilot communities:

- Forest adjacent area and far from forest area
- Cold area, long heating season
- Presence of a functioning briquetting unit at reasonable distance.
- Area with sufficient straw base
- Motivated local partners
- Previous successful cooperation

Criteria for selection of HHs (to be done in the frames of the socio-economic survey in pre-selected communities):

- HH using traditional stove with fuelwood and/or dung
- HH ready to shift (also partially) from fuelwood/dung to straw briquettes and has at least 2ha of croplands.
- HH ready to contribute (in-kind, workforce, logistics, financial, etc).
- HH with a woman and (many) kids
- Use of plastic/rubber/other toxic matters as heating fuel (additional criteria)

Sustainability of EE and RE models through pilot interventions

For EE and RE pilot interventions the sustainability is linked to the efforts needed to continue the services and practice after the project completion. It is recommended that sustainability comprises five dimensions: suitability of technology, social, institutional, financial and environmental sustainability. The proposed pilot interventions should adopt a range of measures to ensure that the practice continues after the intervention ends. They are summarized in the table below.

Table 19: Sustainability of pilot interventions

Dimensions of sustainability	Issues to address	Good practices to enhance sustainability (examples)
Suitability of technology	Relevance of proposed technology to the needs of HHs	Selection of products based on the needs of HHs
	Reliability, affordability and accessibility of proposed technology	Pilot testing of products
		QA an QC of proposed measures
		Awareness raising, trainings on new products
Social sustainability	Improvement of HH living conditions including health	Stakeholder engagement from the very beginning of the project
	Benefit for women	Capacity development of communities in operation and maintenance of proposed measures and managing social issues. The sensitivity to gender issues increases the effectiveness of pilot programs, by ensuring that the needs and concerns of women are taken into account.
Institutional sustainability	Post pilot (technical and financial) continuation of functions of created models	Capacity development of communities and local NGO`s
		Ensure the ownership by target community, HHs, other local partners
		Integrating of created successful mechanisms to state and community development projects
		Monitoring and verification system of proposed measures
Financial sustainability	Motivation of FI to support projects	Encouraging FI and MFI to finance EE and RE
	Demonstration of innovative financial mechanisms	Cooperation with other projects and partners
	Support from outside sources	Providing access to microfinance for end-users

		and to suppliers of equipment and services
	Economic feasibility	Encourage project financing through ESCO`s or community based revolving funds
	Affordability of proposed measures	
Environmental sustainability	Promotion of RE and ecofriendly EE technologies to reduce/substitute fuelwood/dung	Focus on locally produced RE and EE technologies to reduce/substitute fuelwood/dung
	Reduction of indoor air pollution	Substitution of inefficient technologies for improvement of indoor air quality
	Improvement of hygiene and sanitation	

For replicability of the pilot interventions in order to secure post pilot access to EE and RE measures the following actions should be considered:

1. Couple financial resources with technical assistance programs. Development of innovative financing mechanisms is needed for subsidies and grants on EE measures. Promotion and public awareness campaigns are crucial to showcase the benefits of EE.
2. Leverage state and community programs. The program providers should partner and pool program resources among multiple organizations serving rural customers. There is a big demand on subsidized projects in rural HHs. As an example the Armenian Renewable Energy and Energy Efficiency Fund, in partnership with ACBALeasing and GlobalCredit Credit Organizations, is investing in clean energy to raise EE in non-gasified communities in Armenia. As of 1 February 2020, in the framework of the above-mentioned initiative the EE improvement projects were implemented in 173 communities: a total of 3030 solar water heaters and 131 PV stations were installed. Given this positive experience of projects where appropriate state support and financial resources were available, it is possible to ensure the successful implementation of projects with similar nature and scope.

7. Conclusions

One of the ECOserve components relates to development and implementation of pilots on promotion of marketable and replicable approaches/products for more efficient use or substitution of firewood or dung as a source of heating energy in rural communities of Armenia that addresses the specific benefits of women. Efficient energy services can improve women's social and economic status by reducing the time and efforts for taking care of HH, providing better health and safe conditions, expanding income-generating opportunities.

The assessed EE and RE measures included thermal insulation of walls and roofs, replacement of windows and entry door, replacement of heating devices, installation of thermal solar systems for hot sanitary water, installation of on-grid photovoltaic system, shift from conventional type of fuels to alternative biomass fuels and installation of heat pump.

The cost-benefit analysis was done to justify financial/economic feasibility and sustainability of EE and RE measures for possible pilot interventions.

The criteria for conclusions in cost-benefit analysis were low upfront investment costs and higher internal rate of return. The results of cost-benefit analysis showed that in forest adjacent areas (case 1) the replacement of existing inefficient heating devices (stoves and boilers) with efficient devices are economically most feasible measures. In forest distant areas (case 2) the replacement of existing inefficient heating devices (stoves and boilers) with efficient devices in conjunction with shift from fuelwood to straw briquettes as alternative fuel are the most feasible measures which ensures the highest fuelwood and monetary savings.

Further multi-criteria analysis considered a full range of financial, technical, environmental and social issues. The cost-benefit analysis and multi-criteria analysis showed that with consideration of project criteria, the most feasible options for pilot interventions are:

1. Replacement of inefficient biomass stoves and/or boilers with more efficient heating devices.
2. Use of straw briquettes as alternative biofuel considering the use of existing briquetting facilities to produce briquettes from HHs own straw with input of own workforce.

Meanwhile, it is always important to consider the combination of different EE and RE measures, in particular the HH insulation, replacement of inefficient windows/doors, use of solar energy and others. This implies higher upfront investment costs, which often are not affordable for rural HHs. However, in a longer-term it can ensure higher fuel-wood and monetary savings.

8. References

1. International Energy Agency. Capturing the Multiple Benefits of Energy Efficiency; Paris, France, 2014; ISBN 978-92-64-22072-0
2. International Energy Agency. Key energy statistics, 2018
3. Design of typical EE houses, http://mud.am/am/catalog
4. Advisory Handbook on Technical Solutions for Thermal Insulation of Envelopes of Residential, Public and Industrial Buildings in Construction and Reconstruction in the Republic of Armenia, 2013
5. Energy demand, supply and efficiency in rural Armenia: baseline data collection and analysis, Astghine Pasoyan, Nune Sakanyan, in the frames of GIZ ECOserve, December 2019
6. Database of Construction Insulation Materials, 2016
7. International Energy Agency, Energy Efficiency, 2019
8. The Construction Climatology Code, RACN.
9. Thermal Protection of Buildings, RACN 24-01-2016
10. Residential Energy Consumption Survey, UNDP, Yerevan, October 2015.
11. RA National Statistical Service, armstat.am
12. Household’s Integrated Living Conditions Survey anonymized microdata database (by households), 2017, https://www.armstat.am/en/?nid=205
13. Handbook for Performing Feasibility Studies of Alternative Energy Systems, Sentro, 2008.
14. The findings of the surveys, focus group discussions, and measurements of the performance of the tested heat exchangers, ESAC NGO, technical report in the frames of GEF/SGP project, 2019
15. Country Profiles on Housing and Land Management, Republic of Armenia, UNECE, 2017

9. Annexes

Annex 1. CBA data and technical details for EE and RE measures

For each EE and RE measure two different cases were assessed as per the table below.

Table 1. Assessment conditions for each EE and RE measure

Cases	Climatic conditions	°C days/year	Fuelwood price for $1m^3$	Distance from forest
Case 1	Relatively warm, shorter heating season	2660	20000 AMD	Areas adjacent to forest
Case 2	Cold, long heating season	3400	30000 AMD	Areas far from forest

Thermal insulation of HH (walls and roof)

Cost and wood savings after thermal insulation
Option 1. Heating with fuelwood or gas (100% level of energy needs for heating)
Option 2. Heating with fuelwood or gas (65% of level of energy needs for heating)

Table 2. Costs and wood savings after thermal insulation at HH (Case 1, Option 1)

N	Description	Unit of measure	Fuelwood	Gas
1	Annual fuel consumption	m^3	22,8	3579
2	Annual fuel consumption after EE	m^3	7,4	1157
3	Annual costs after EE	AMD	147507	160813
4	Annual wood savings	m^3	15,4	2422
5	Annual savings	AMD	308839	336.700
6	NPV	AMD	276858	484963
7	IRR	%	14%	16%
8	Simple payback	Year	7	6

Table 3. Costs and wood savings after thermal insulation at HH (Case 1, Option 2)

N	Description	Unit of measure	Fuelwood	Gas
1	Annual wood consumption	m^3	14,8	2326
2	Annual wood consumption after EE	m^3	4,8	752
3	Annual costs after EE	AMD	95879	104529
4	Annual wood savings	m^3	10,0	1574
5	Annual savings	AMD	200746	218855
6	NPV	AMD	(530543)	(395274)
7	IRR	%	8%	9%
8	Simple payback	Year	10	9

Table 4. Costs and wood savings after thermal insulation at HH (Case 2, Option 1)

N	Description	Unit of measure	Fuelwood	Gas
1	Annual fuel consumption	m^3	29	4575

2	Annual fuel consumption after EE	m^3	9	1479
3	Annual costs after EE	AMD	282813	205551
4	Annual fuel savings	m^3	20	3096
5	Annual savings	AMD	592135	430369
6	NPV	AMD	2392922	1184615
7	IRR	%	29%	21%
8	Simple payback	Year	3	5

Table 5. Costs and wood savings after thermal insulation at HH (Case 2, Option 2)

N	Description	Unit of measure	Fuelwood	Gas
1	Annual wood consumption	m^3	19	2974
2	Annual wood consumption after EE	m^3	6	961
3	Annual costs after EE	AMD	183829	133608
4	Annual fuel savings	m^3	13	2013
5	Annual savings	AMD	384888	279740
6	NPV	AMD	844899	59500
7	IRR	%	18%	12%
8	Simple payback	Year	5	7

Replacement of windows and outside doors

Cost and wood savings after replacement of windows and doors

Table 6. Costs and wood savings after replacement of windows and doors (Case 1)

N	Description	Unit of measure	Firewood	Gas
1	Fuel consumption (equal to heat losses)	m^3	2,44	345
2	Fuel consumption after EE (equal to heat losses)	m^3	1,06	150
3	Annual savings	AMD	27658	27137
4	Annual average wood/gas savings	m^3	1,38	195
5	NPV	AMD	(243413)*	(247299)*
6	IRR	%	2%	2%
7	Simple payback	Year	16	17

* Brackets mean “minus” value.

Table 7. Costs and wood savings after replacement of windows and doors (Case 2)

N	Description	Unit of measure	Firewood	Gas
1	Fuel consumption (equal to heat losses)	m^3	3,1	441
2	Fuel consumption after EE (equal to heat losses)	m^3	1,4	191
3	Annual savings	AMD	53028	34687
4	Annual average wood/gas savings	m^3	1,77	330
5	NPV	AMD	(53912)	(190908)

6	IRR	%	10%	5%
7	Simple payback	Year	8	13

Replacement of heating devices

Replacement of stoves

Cost and wood savings after replacement of stoves for Case 1

Table 8. Scenario 1. Replacement of traditional stove (efficiency 40%) with local efficient stove (estimated efficiency 70%); fuel type - fuelwood (Case 1)

N	Description	Unit of measure	Value
1	Annual wood consumption (with traditional stove)	m^3	10
2	Heat output	kWh	6563
3	Annual wood consumption (with local EE stove)	m^3	5,7
4	Annual savings	AMD	85714
5	Annual average wood savings	m^3	4,3
6	CAPEX	AMD	80000
7	NPV	AMD	560238
8	IRR	%	107%
9	Simple payback	Year	0,9

Table 9. Scenario 2. Replacement of traditional stove (efficiency 40%) with imported efficient stove (estimated efficiency 80%); fuel type: fuelwood (Case 1)

N	Description	Unit of measure	Value
1	Annual wood consumption (with traditional stove)	m^3	10
2	Heat output	kWh	6563
3	Annual wood consumption (with imported/certified EE stove)	m^3	5
4	Annual savings	AMD	100000
5	Annual average wood savings	m^3	5
6	CAPEX	AMD	250000
7	NPV	AMD	666944
8	IRR	%	40%
9	Simple payback	Year	2.5

Table 10. Scenario 3. Replacement of traditional stove (efficiency 40%) with local efficient stove (estimated efficiency 70%); fuel type: shifting from fuelwood to briquette (Case 1)

N	Description	Unit of measure	Value
1	Annual wood consumption (with traditional stove)	m^3	10
2	Heat output	kWh	6563
3	Annual briquette consumption (with local EE stove)	KG	1921
4	Annual savings	AMD	46336
6	CAPEX	AMD	80000
7	NPV	AMD	266106

8	IRR	%	58%
9	Simple payback	Year	1,7

Table 11. Scenario 4. Replacement of traditional stove (efficiency 40%) with imported efficient stove (efficiency 80%); fuel type: shifting from fuelwood to briquette (Case 1)

N	Description	Unit of measure	Value
1	Annual wood consumption (with traditional stove)	m^3	10
2	Heat output	Kwh	6563
3	Annual briquette consumption with imported/certified EE stove)	KG	1681
4	Annual savings	AMD	65544
5	CAPEX	AMD	250000
6	NPV	AMD	409579
7	IRR	%	26%
8	Simple payback	Year	3,8

Table 12. Scenario 5. Shifting from fuelwood (30%of heat output) and dung (70% of heat output) to briquette consumption with local efficient stove (Case 1)

N	Description	Unit of measure	Value
1	Heat output	Kwh	6563
2	Annual wood consumption (with traditional stove)	M^3	3,0
3	Annual dung consumption (with traditional stove)	M^3	3,1
4	Annual briquette consumption (with local EE stove)	KG	1921
5	Annual costs (firewood and dung, 40% efficiency stove)	AMD	106324
6	Annual costs (briquettes, 70% efficiency stove)	AMD	153664

Table 13. Scenario 6. Shifting from firewood (30%of heat losses) and dung (70% heat losses) to briquette consumption with imported efficient stove (Case 1)

N	Description	Unit of measure	Value
1	Heat output	kWh	6563
2	Annual wood consumption (with traditional stove)	M^3	3,0
3	Annual dung consumption (with traditional stove)	M^3	3,1
4	Annual briquette consumption (with imported/certified EE stove)	KG	1681
5	Annual costs (firewood and dung, 40% efficiency stove)	AMD	106324
6	Annual costs (briquettes, 80% efficiency stove)	AMD	134456

Cost and wood savings after replacement of stoves for Case 2

Table 14. Scenario 1. Replacement of traditional stove (efficiency 40%) with local efficient stove (estimated efficiency 70%); fuel type - fuelwood (Case 2)

N	Description	Unit of measure	Value
1	Annual wood consumption (with traditional stove)	m^3	10
2	Heat output	kWh	6563
3	Annual wood consumption (with local EE stove)	m^3	5,7
4	Annual savings	AMD	128.571
5	Annual average wood savings	m^3	4,3
6	CAPEX	AMD	80.000
7	NPV	AMD	880.357
8	IRR	%	161%
9	Simple payback	Year	0,6

Table 15. Scenario 2. Replacement of traditional stove (efficiency 40%) with imported efficient stove (estimated efficiency 80%); fuel type: fuelwood (Case 2)

N	Description	Unit of measure	Value
1	Annual wood consumption (with traditional stove)	m^3	10
2	Heat output	kWh	6563
3	Annual wood consumption (with imported/certified EE stove)	m^3	5
4	Annual savings	AMD	150000
5	Annual average wood savings	m^3	5
6	CAPEX	AMD	250000
7	NPV	AMD	870.417
8	IRR	%	60%
9	Simple payback	Year	1,7

Table 16. Scenario 3. Replacement of traditional stove (efficiency 40%) with local efficient stove (estimated efficiency 70%); fuel type: shifting from fuelwood to briquette (Case 2)

N	Description	Unit of measure	Value
1	Annual wood consumption (with traditional stove)	m^3	10
2	Heat output	kWh	6563
3	Annual briquette consumption (with local EE stove)	KG	1921
4	Annual savings	AMD	146336
6	CAPEX	AMD	80000
7	NPV	AMD	1013051
8	IRR	%	183%
9	Simple payback	Year	0,5

Table 17. Scenario 4. Replacement of traditional stove (efficiency 40%) with imported efficient stove (efficiency 80%); fuel type: shifting from fuelwood to briquette (Case 2)

N	Description	Unit of measure	Value
1	Annual wood consumption (with traditional stove)	m^3	10
2	Heat output	kWh	6563
3	Annual briquette consumption with	kg	1681

	imported/certified EE stove)		
4	Annual savings	AMD	165544
5	CAPEX	AMD	250000
6	NPV	AMD	986524
7	IRR	%	66%
8	Simple payback	Year	1,5

Table 18. Scenario 5. Shifting from firewood (30%of heat output) and dung (70% of heat output) to briquette consumption with local efficient stove (Case 2)

N	Description	Unit of measure	Value
1	Heat output	kWh	6563
2	Annual wood consumption (with traditional stove)	m^3	3,0
3	Annual dung consumption (with traditional stove)	m^3	3,1
4	Annual briquette consumption (with local EE stove)	kg	1921
5	Annual costs (firewood and dung, 40% efficiency stove)	AMD	136324
6	Annual costs (briquettes, 70% efficiency stove)	AMD	153664

Table 19. Scenario 6. Shifting from firewood (30%of heat losses) and dung (70% heat losses) to briquette consumption with imported efficient stove (Case 2)

N	Description	Unit of measure	Value
1	Heat output	Kwh	6563
2	Annual wood consumption (with traditional stove)	m^3	3,0
3	Annual dung consumption (with traditional stove)	m^3	3,1
4	Annual briquette consumption (with l imported/certified EE stove)	kg	1681
5	Annual costs (firewood and dung, 40% efficiency stove)	AMD	136.324
6	Annual costs (briquettes, 80% efficiency stove)	AMD	134.456

Replacement of boilers

Cost and wood savings after replacement of boilers for Case 1

Table 20. Scenario 1. replacement of traditional boiler with imported EE boiler; fuel – fuelwood (Case 1)

N	Description	Option 1	Option 2
1	Annual wood consumption with traditional boiler (m^3)	30,4	19,8
2	Annual wood consumption with imported EE boiler (m^3)	22,8	14,8
3	Annual wood savings (m^3)	7,6	4,9
4	Annual savings (AMD)	152115	98875

5	NPV	736216	338541
6	IRR	38%	24%
7	Simple payback (year)	2,6	4,0

Table 21. Scenario 2. Replacement of traditional boilers with imported EE boilers; fuel – straw briquette (Case 1)

N	Description	Option 1	Option 2
1	Annual wood consumption with traditional boiler (m^3)	30,4	4985
2	Annual straw briquette consumption with imported EE boiler (kg)	7670	4985
3	Annual savings (AMD)	(5122)	(3329)
4	NPV	n/a	n/a
5	IRR	n/a	n/a
6	Simple payback (year)	n/a	n/a

As a result of this measure there are no savings.

Table 22. Scenario 3. Replacement of traditional boilers with use of fuelwood with gas boilers; fuel – gas (Case 1)

N	Description	Option 1	Option 2
1	Annual wood consumption with traditional boiler (m^3)	30,4	19,8
2	Annual gas consumption with replaced gas boiler (m^3)	3579	2327
3	Annual savings (AMD)	110947	72116
4	NPV	428716	138665
5	IRR	28%	17%
6	Simple payback (Year)	3,6	5,5

Cost and wood savings after replacement of boilers for case 2

Table 23. Scenario 1. Replacement of traditional boiler with imported EE boiler; fuel – fuelwood (Case 2)

N	Description	Option 1	Option 2
1	Annual wood consumption with traditional boiler (m^3)	38,9	25
2	Annual wood consumption with imported EE boiler (m3)	29,2	19
3	Annual wood savings (m^3)	9,7	6
4	Annual savings (AMD)	291650	189.572
5	NPV	1778460	1015999
6	IRR	73%	47%
7	Simple payback (year)	1,4	2,1

.

Table 24. Scenario 2. Replacement of traditional boilers with imported EE boilers; fuel – straw briquette (Case 2)

N	Description	Option 1	Option 2
1	Annual wood consumption with traditional boiler (m^3)	38,9	25
2	Annual straw briquette	9803	6372

	consumption with imported EE boiler (kg)		
3	Annual savings (AMD)	382319	248507
4	NPV	2455711	1456212
5	IRR	96%	62%
6	Simple payback (year)	1,0	1,6

Table 25. Scenario 3. Replacement of traditional boilers with use of fuelwood with gas boilers; fuel – gas (Case 2)

N	Description	Option 1	Option 2
1	Annual wood consumption with traditional boiler (m^3)	389	25
2	Annual gas consumption with replaced gas boiler (m^3)	4575	2974
3	Annual savings (AMD)	530679	344941
4	NPV	3563874	2176518
5	IRR	133%	86%
6	Simple payback (year)	0,8	1,2

Shift from traditional stoves to boilers with centralized heating system

Cost and wood savings for cases 1 and 2

Table 26. Comparison of different scenarios for shifting from stove to centralized heating system with different fuel (case 1)

N	Description of scenario	CAPEX (AMD)	Annual fuel consumptions (m^3 or kg)	Annual costs (AMD)	Cost of 1 kWh thermal energy production (AMD)
1	Installation of centralized heating system with locally manufactured boiler; fuel-fuelwood (m^3)	570000	30,4	608461	20,32
2	Installation of centralized heating system with locally manufactured boiler; fuel-straw briquettes (kg)	570000	10226	818111	27,32
3	Installation of centralized heating system with imported/certified boiler; fuel-firewood (m^3)	800000	22,8	456346	15,24
4	Installation of centralized heating system with imported/certified boiler; fuel-straw briquettes (kg)	800000	7670	613583	20,49
5	Installation of centralized heating system with gas boiler (m^3)*	800000	3579	497514	16,61

* The cost of connection to the gas network was not considered in CAPEX.

Table 27. Comparison of different scenarios for shifting from stove to centralized heating system with different fuel (case 2)

N	Description of scenarios	CAPEX (AMD)	Annual fuel consumptions (m^3 or kg)	Annual costs (AMD)	Cost of 1 kWh thermal energy production (AMD)
1	Installation of centralized heating system with locally manufactured boiler; fuel-firewood (m^3)	570000	38,9	1166598	30,47
2	Installation of centralized heating system with locally manufactured boiler; fuel-straw briquettes (kg)	570000	13071	1045705	27,32
3	Installation of centralized heating system with imported/certified boiler; fuel-firewood (m^3)	800000	29,2	874949	22,86
4	Installation of centralized heating system with imported/certified boiler; fuel-straw briquettes (kg)	800000	9803	784279	20,49
5	Installation of centralized heating system with gas boiler (m^3)*	800000	4575	635920	16,61

* The cost of connection to the gas network was not considered in CAPEX.

Installation of solar water heaters

Cost and wood savings for cases 1 and 2

Table 28. CAPEX and financial efficiency of SWH for case 1

N	Description	Unit of measure	Value
1	CAPEX (volume 300l)	AMD	400000
2	Annual energy savings	kWh	2380
3	Annual firewood savings	m^3	1,8
4	Annual savings	AMD	36000
5	NPV	AMD	(131100)
6	IRR	%	6%
7	Simple payback	Year	11,1

Table 29. CAPEX and financial efficiency of SWH for case 2

N	Description	Unit of measure	Value

1	CAPEX (volume 300l)	AMD	400000
2	Annual energy savings	kWh	2380
3	Annual firewood savings	m^3	1,8
4	Annual savings	AMD	54000
5	NPV	AMD	3350
6	IRR	%	12%
7	Simple payback	year	7

Installation of solar PV stations

Cost and wood savings for cases 1 and 2

Table 30. CAPEX and financial efficiency of Solar PV (4 kWp) for case 1

N	Description	Unit of measure	Value
1	CAPEX	AMD	1552000
2	Heat output	kWh	5700
3	Firewood savings	m^3	4,3
4	Annual savings	AMD	86849
5	NPV	AMD	(903285)
6	IRR	%	1%
7	Simple payback	year	17,9

Table 31. CAPEX and financial efficiency of Solar PV (4 kWp) for case 2

N	Description	Unit of measure	Value
1	CAPEX	AMD	1552000
2	Heat output	kWh	5700
3	Firewood savings	m^3	4,3
4	Annual savings	AMD	130274
5	NPV	AMD	(578928)
6	IRR	%	6%
7	Simple payback	year	12

Installation of heat pumps

Cost and wood savings for cases 1 and 2

Table 32. CAPEX and financial calculations of heat pumps (case 1)

N	Description	Unit of measure	Value
1	Heat pump capacity	kW	10
2	CAPEX	AMD	4850000
3	Annual fuelwood savings	m^3	20
4	NPV	AMD	(3430806)
5	IRR	%	(2)
6	Simple payback	Year	26

Table 33. CAPEX and financial calculations of heat pumps (case 2)

N	Description	Unit of measure	Value
1	Heat pump capacity	kW	10
2	CAPEX	AMD	4850000
3	Annual fuelwood savings	m^3	20
4	NPV	AMD	(1936917)
5	IRR	%	5%
6	Simple payback	Year	12

Annex 2. Economic feasibility of producing straw briquettes in existing briquetting facilities

The calculations show that if the HH arranges the transportation of own residual straw to the nearby existing briquetting center, get briquettes produced and transport them back, then the price can be lower than the market price of briquettes (80 AMD/kg).

One option is when the HH uses own residual straw and pays for all the works and services (option 1). Another option is when the HH uses own residual straw and pays only for the works and services, which are not possible to do with input of own workforce (option 2). The tables below present input data and calculations for both options.

Table 1. Input data

N	Description	Unit
1	One truck capacity	120 stacks
2	Transportation	500 AMD/km
3	Stack making	120 AMD/stack
4	Upload and download of stacks	100 AMD/stack
5	Upload and download of briquette bags*	100 AMD/bag

Table 2. Use of own residual straw and buying all the works and services (option one)

N	Distance from briquetting unit, km	Total distance, km	Total cost AMD/kg	Total costs including contingency (10%), AMD	Briquette cost, AMD/kg
1	15	30	45400	49940	62
2	20	40	50400	55440	69
3	25	50	55400	60940	76
4	30	60	60400	66440	83
5	35	70	65400	71940	90
6	40	80	70400	77440	97
7	45	90	75400	82940	104
8	50	100	80400	88440	111

If HH uses own residual straw (does not pay for it) and buys all the works (straw assembling, packing, loading, unloading, transportation, etc.), then up to the distance of 20 km to the existing briquetting center, the price of produced briquettes will make appr. 70 AMD/kg.

Table 3. Use of own residual straw and buying only the works and services, which is not possible to input (option two)

N	Distance from briquetting unit, km	Total distance km	Total cost, AMD/kg	Total costs including contingency (10%), AMD	Briquette cost, AMD/kg
1	15	30	29400	32340	40
2	20	40	34400	37840	47
3	25	50	39400	43340	54

4	30	60	44400	48840	61
5	35	70	49400	54340	68
6	40	80	54400	59840	75
7	45	90	59400	65340	82
8	50	100	64400	70840	89

In case the HH inputs all the possible workforce and buys only the works, which is not possible to input (packing, transportation, etc.), then up to the distance of 40 km to the existing briquetting center, the price of produced briquettes will be appr. 75 AMD. The less is the distance, the less is the price of briquettes.

Conclusions

Option 1. the production of straw briquettes from residual straw is feasible for the communities located up to 25 km, the cost of briquette production will be appr. 76 AMD

Option 2. the production of straw briquettes from residual straw is feasible for the communities located up to 40 km, the costs for briquette production will be appr. 75 AMD

Annex 3. Companies providing EE and RE technologies and services in RA

Solar PV and solar water heaters			
1	Eco Step Solar Energy Solutions LLC	Address	51 Gai Ave, Yerevan 0076
		Tel.	077 388338
		URL	https://ecostep.am/
2	Shtigen LLC	Address	23 Davit Anhaght Street, Yerevan
		Tel.	(011) 230023
		URL	https://shtigen.com/hy/
3	Redinet CJSC	Address	24/7-24/8 Azatutyan Ave, Yerevan 0014
		Tel.	(010) 249106
		URL	https://redinet.am/
4	Optimum Energy LLC	Address	Abelian St, Yerevan
		Tel.	(011) 200200
		URL	http://optimumenergy.am/
5	SOLARON LLC	Address	25/1 Arshakunyats str., Yerevan 0013
		Tel.	(010) 440055
		URL	https://solaron.am/
6	OHM ENERGY	Address	15 Alek Manukyan St, Yerevan 0070
		Tel.	(011) 220880
		URL	N/A
Biomass heating systems			
7	Jermin LLC	Address	7/1, Shrjantsik tunnel, Yerevan
		Tel.	(010) 286776
		URL	www.jermin.fo.ru
8	Termowatt LLC	Address	1/123 Artsakh ave.,Yerevan
		Tel.	(010) 430744
		URL	https://termo.am

ECOserve

ENVIRONMENT, CLIMATE, OPPORTUNITIES

for people and nature

Management of natural resources and safeguarding of ecosystem services for sustainable rural development in the South Caucasus (ECOserve)

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

59 Hanrapetutyan st., 9th floor
0010 Yerevan, Republic of Armenia
T +374 10 510065
I www.giz.de
http://biodivers-southcaucasus.org/