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Renewable Energy Potential and Its Utilization in Georgia

Demur Chomakhidze[1]* and Maia Melikidze[2]

[1]*Doctor at Economic Science, Georgian Technical University, Tbilisi, Georgia*
[2]*Renewable Energy, Business and Technology University, Tbilisi, Georgia*

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***Corresponding author:** *Demur Chomakhidze, Doctor at Economic Science, Georgian Technical University, Tbilisi, Georgia, E-mail: demurchomakhidze@yahoo.com; maiamelikidze@yahoo.com*

Abstract

The paper quantitatively and qualitatively describes the renewable energy resources of Georgia taking into account the domestic and regional contexts. It is mentioned that Georgia is rich with renewable energy sources and at some point substitutes fuel resources (oil, natural gas) in the country. In particular, run-of-the-river power plants, generating 3.27 MM.kWh energy on each square kilometer of the territory. As a southern country, Georgia is located in so-called "World Solar Zone" and during the year the number of sunny days exceeds 250 days while wind energy supplies in specific zones exceed 4.5bln. KWh annually. The country is also rich with underground thermal waters. In this paper an assessment of the utilization of renewable energy resources is also presented. Utilization of hydro power resources is more advanced. However, according to the data, in 2016 Georgian HPPs used only 11.4% of their technical capacity and 23.6% of their economic potential. It's also mentioned that utilization of solar and wind energy and thermal water is at the initial stage. As for biodiesel, it is a perfect, high quality fuel, that is not only on equal level with petroleum diesel, but also prevails it with a whole set of characteristics. Price of bio diesel is more or less sustainable and it successfully competes with petroleum diesel.

All the above mentioned are quite important aspects, however main advantage of biodiesel is that it is renewable, ecologically clean fuel. Biodiesel does not contain lead and the atmosphere is not polluted with heavy minerals, carbon dioxide, a bunch of carcinogens and harmful substances after its use. This paper is one of the researches in which the complexity of renewable energy sources of Georgia and their utilization are described. Based on the statistical data, it's proved that hydro energy resources have a leading role.

Keywords: Renewable energy; Hydro energy resources; Solar energy; Wind energy; Energy balance

Introduction

This paper explores characteristics of Georgia's renewable energy resources for the entire country as well as at the regional level. Georgia is quite rich in renewables that could supplement the lack of heating resources (fossil fuel) throughout the country. The article assesses the utilization conditions of renewable energy resources, whether or not Georgia is in favorable situation in terms of hydro energy resources. However, according to the data of 2017 hydro power plants generated solely 11.4% of its technical capacity and 23.6% of economic potential, when solar and wind energy utilization is at an early stage of its development. The study provides proposals for far more appropriate utilization of the aforementioned resources. Current energy balance of Georgia is in great deficiency while the country is rich with renewable energy resources. This indicates that promotion and development of renewable energy should be the primary goal of the country.

Hydro power resources

The Power Potential of the Rivers

Natural abundance of river networks contributes to Georgia's energy potential mainly. The very fact that Georgia generates electricity through hydropower stations partially compensates the fuel deficit of the country. Georgia has rich hydropower potential due to the mountainous terrain. Caucasus and small Caucasus mountains have explicitly high slant and the rivers of those mountains can have high hydropower potential due to the ability of gaining high pressure in small distances. The statement is especially true for the western Georgia [1].

All told, there are 26 thousand rivers in Georgia, with total length of 60 thousand km. The rivers with entire length of 25km and less account for 99.3% of the whole amount of the rivers and for 76% of the total length of all rivers. Total volume of water flow is 52.8 km^3, while the absolute water resources of Georgia reach 61.5 km^3. If we add the amount of fresh water including the glaciers, lakes, reservoirs and wetlands, the amount of entire water resources will increase up to 96.5 km^3 [2].

According to "Hydro Project", 319 out of total amount of rivers have significant hydropower potential, with potential capacity of 15.63mln kW and average annual generation of 135.8 bl. kWh, as a whole. 208 out of these rivers are small and medium sized rivers with potential capacity of 14.78GWh and 129.5TWh. The rest 111 rivers have potential of 851 thousand kW (7% of total capacity of the rivers). The energy of total surface waters of Georgia accounts for 228.5 TWh, with corresponding capacity of 26.1 GWh.

According to the studies, if we take into account the theoretical amount of hydropower potential of the main rivers in Georgia, we can calculate the amount of river flows per square meter, accounting for 3.27 GWh for the entire country; 5.06GWh for Eastern Georgia and 1.73 GWh for Western Georgia. In terms of absolute numbers, we can see that 228.5TWh (72.1%) falls on the west of Georgia and 63.7TWh (27.9%) – on the eastern Georgia [3].

If we separate the potential of small, medium and large rivers, we can assume that they account for 60% (135.8 TWh) of total energy potential of surface waters with additional 40% (92.7bl. kWh) falling on the waters from the mountains (see table 1.1):

Hydropower Sources	Capacity GWh	Energy TWh	%
Total potential of surface water flows	26.08	228.5	100
Theoretical potential of large, medium and small rivers (319 rivers)	15.62	135.8	59.5
Theoretical potential of water flow from mountains	10.46	92.7	40.5

Table 1: Hydropower sources.

Theoretical hydro potential of large and medium rivers is 136TWh, which is 3.4% of the total hydro potential of all rivers on the territory of former soviet republics. Technical hydro potential of Georgia is 81bl. kWh; while economic hydro potential amounts to 39 TWh. Hydro potential per each square meter of the current territory of Georgia is 1943ths kWh, one of the highest figures worldwide. Georgia occupied on third place in the USSR countries by per capita hydro potential and was above the average the USSR indicator by 41.7% [4].

Additionally, favorable condition for HPP construction is that 40% of technically possible hydro potential of all 319 rivers is concentrated on eight main rivers (Mtkvari, Rioni, Enguri, Tskhenistskali, Kodori, Bzifi, Khrami and Aragvi). Economic potential for main rivers of Georgia is given in table 2. The abovementioned hydro potential of Georgia (135.8 TWh) reflects capacity of 319 small and medium rivers.

It is well-known that the seasonal distribution of the potential hydro capacity is theoretically dependent only on the seasonality of the river flows. Also, the reallocation throughout a year is possible by construction of conventional HPPs. This is why the seasonality of water flow, considering overall energy situation, is the most important for development of country's thermal-electric complex.

According to the data of January 1, 2018 there are 67 operational HPPs, 19 of which are large and medium sized, and 48 are small sized HPPs (see table 3).

5 HPPs, 4 small and one medium sized have been commissioned in 2016 with total capacity of 116.7MW. Accordingly, in the beginning of 2017 there were 72 operational HPPs with total installed capacity of 2921.66MW. Most of them are located in the west of Georgia (within Enguri and Rioni river basins). Almost half on annual generation is supplied by 7 conventional HPPs, with total installed capacity of 1991MW and annual generation more than 5TWh. Total installed capacity of existing 12 seasonal HPPs is 646MW, while 48 small deregulated (below 13MW) HPPs (total installed capacity of 162MW) supply only 5% of total generation.

The total reservoir volume of conventional HPPs is 2259 mn. m^3 (within it 1425mn. m^3 is useful volume). Major parts of existing HPPs are old and need modernization in order to increase the efficiency. In most cases, the filling-and-emptying plan is not fulfilled as designed and no energy is accumulated for periods of deficit.

We have had a boost in HPP construction over recent years; in particular, 18 HPPs, with total installed capacity of 174MW were commissioned in 2010-2018.

Name of the River	Annual Economic Potential bl. kWh	Share from Total Economic Potential %
Enguri	10,7	27,4
Rioni with Tskhenistskali	8,3	21,3
Kodi	5,7	14,6
Alazan of Tusheti	3,8	9,7
Mtkvari with Aragvi	3,5	9
Bzifi	2,5	6,4
Khrami and Faravani	2,0	5,1
Shaori and Tkibuli	0,8	2,1
Small rivers	1,7	4,4
All	39,0	100,0

Table 2: Current situation and challenges. Economic potential for main rivers of Georgia [5].

N	Name of HPP	Generation (GWh)	Installed capacity (MW)	Comparing the year 2017 to 2015 in %	
				Generation	Capacity
I	II	III	IV	V	VI
1	Enguri	3566,94	1300	108,5	100
2	Vardnili	664,70	220	119,2	100
3	Khrami 1	191,81	112,8	85,07	100
4	Khrami 2	294,05	114,4	86	100
5	Jinvali	288,66	130	71,1	100
6	Vartsikhe Cascade	823,48	184	107,9	100
7	Rioni	294,66	51	95,9	106,25
8	Gumati	314,59	69.5	111,4	101
9	Lajanuri	385,57	113,7	102,07	100
10	Dzevruli	148,29	80	126,6	100
11	Shaori	145,55	40,32	137,06	105
12	Zahesi	176,82	36,8	95,1	100
13	Ortachala	65,81	18	83,5	100
14	Atskhesi	92,78	18,4	159,3	115
15	Chitakhevi	86,59	21	91,67	100
16	Satskhenisi	25,28	14	138,5	100
17	Khadori	111,99	24	82,5	100
18	Larsi	69,56	19	102,67	100
19	Faravani	380,97	86,54	93,55	100
20	Small HPPs	590,76	177,191	116,1	110,19
21	Total HPPs	8718,86	2830,651	104,7	100,9

Table 3: Installed capacity and generation of HPPs in Georgia, 2017 [6].

Since Georgia gained independence, 26 hydro power plants have been put into service overall, out of which 5 HPPs were of medium capacity and 21 of small capacity. Medium capacity HPPs are the following: Larsi, Faravani, Dariali, Khelvachauri 1, Shuakhevi. In 2017 these HPPs generated 826 mln. KWh. and small HPPs 243,4 mln. KWh. electricity. In total, in 2017 electricity generation by HPPs increased by 4,7% in comparison with the year 2015 in Georgia.

With the use of modern achievements in hydro construction it is possible to construct dozens of large and medium-sized economically feasible HPPs. Despite this, the utilization level of hydro potential is still low. Hydro generation in 2016 reached 9.2TWh, only 11.4% of technical capacity and 23.6% of economic capacity.

The main challenges for the study of hydro potential and its application are the following:

1. Recalculation of hydro potential.
2. Construction of conventional HPPs with seasonal regulation, increasing the winter generation.
3. Construction of conventional HPP complexes as far as possible.
4. Construction of hydro hubs, which will create possibility for water flow to be regulated and utilized for irrigation, water supply and electricity.
5. Placing the list of actions on the agenda for safety and

recovery of the black sea coast from the damages caused by a decrease of sediments from the rivers.

6. Full utilization of the economically feasible local hydro potential.

Solar energy

Solar energy potential

Considering geographical location of Georgia, solar radiation effectiveness and duration is quite high. In majority of Georgian regions annual duration of sunny days varies within 250-280 days, which (considering ratio between the day and night hours) equals 1900-2200 hours a year. Annual solar radiation varies according to regions between 1250-1800 kWh/m^2. Overall, solar potential of Georgia is estimated at 108 MW, equivalent to 34 ths. tones of heat [7].

Maximum solar radiation reaches 10kWh/m^2 in summer and 4-4.5kWh/m^2 in sunlit days of winter. Annual maximum for solar radiation was seen in Rodionovka – 2633hours, while the minimum was observed in Sairme- 1147 hours. Annual solar radiation of the selected regions of Georgia is represented in table 4.

Current Situation and Challenges

At present approximately up to 50,000 solar collectors are being installed for hot water supply, mostly used to deliver hot water for bathroom and kitchen, heating of swimming-pools and for heating of houses in winter months. Also, small-sized photovoltaic solar panels are quite well-spread within population, mostly with the capacity between 20-2000 watts. According to the information provided by the association "SunHouse", there are up to 400 solar photovoltaic systems installed in Georgia, with the total capacity of 90 kW. According to the leading engineering supermarket "Qebuli climate", they have sold and installed up to 5700 solar collectors for water-heating [8].

On July 30th, 2016 Tbilisi international airport installed the solar panels for electricity generation with the assistance of Japanese companies. Average capacity of the system is 316kW, annual generation 337kWh, covered area – 4000m^2, CO_2 emission decrease – 187 ton. Generated electricity is used for lighting the terminals. Recently, in October 2018 solar micro station was put into service in Lagodekhi, eastern Georgia. Moreover, one of the companies operating on Georgian market offers for US$ 2.2 solar mono-crystal 1W batteries, prepared according to German technologies.

Ministry of Energy and "Headwall Power International" have signed memorandum for the research of energy potential in Gardabani municipality. According to memorandum, Headwall Power International with its partner "solar power company" has been studying energy potential in Gardabani over 12 months.

Stations	Elevation (m)	Perpendicular surface (kWh /m^2)	Horizontal surface (kWh /m^2)
Senaki	40	1317	1329
Sokhumi	116	1351	1415
Anaseuli	158	1198	1303
Tbilisi	428	1861	1402
Telavi	568	1350	1408
Tcalka	1457	1386	1457
Jvari Pass	2395	1503	1586
Kazbegi	3653	1706	1790

Table 4: Annual solar radiations for the selected regions of Georgia.

On 30th of June, 2016 Memorandum of Understanding was signed between the Government of Georgia and a state-owned company Georgian Energy Development Fund to ensure the study/analysis of the solar power data in Sagarejo Municipality, Kakheti region. Installed capacity of the solar power plant is 5 MW and estimated annual generation is 6 900 000 KWh. Feasibility study by the company has already been prepared. Currently, terms of the memorandum of understanding are being negotiated with Ministry of Economy and Sustainable Development of Georgia and consultant is preparing the tender documentation for EPC (Engineering, Procurement, and Construction) contractor.

Wind Energy

Wind Energy Resources

Average annual wind speed in Georgia is 0.5- 9.2 meters/second. In some regions it exceeds 15 m/sec. According to existing studies the total wind energy potential equals 1 450 MW with average annual generation of 4,160 GWh [9]. Georgia is located on the north edge of the high pressure subtropics zone and has high impact of north semi-sphere circular processes, with total direction from the west to the east. Georgia's geographical complexity determines the diversity of climate in its territory. Wind regime on the territory of Georgia is due to the character of the general circulation of the atmosphere, geographical location and relief. Georgia is under the influence of medium and subtropical deployment of air circulation and the conditions of this circulation are defined as changes in the dynamic movement of the dynamic anti-cyclone and the polar front position, as well as the atmospheric processes, in the medium and tropical divisions.

During the warm period of the year Georgia is under the influence of the eastern branch of the Azor anticyclone, the high pressure zone in the highlands of the Caucasus is established and in this period the continuity of the western direction is rising. In the Kolkheti lowland and the current coastal areas, the winds of the West and Southwest are surging from the sea to terrestrial areas, whose replication reaches 60%. In the foothills and hills of the Caucasus dominate East and south east winds, while in Javakheti Mountains mostly northwest winds are dominant.

Due to the influence of the West of Siberian Anticyclone in winter, low pressure zone is established on the Black Sea, while in the central regions of Transcaucasia, the pressure is higher. Considering the same circumstances, in the Kolkhida Valley and Rioni Gorge east winds are dominant; whose replication reaches 45-60%. In the foothills and hills of the Caucasus, the north and north-east winds are increasing their duration. In Javakheti mountainous regions the south and south-east directions are dominant with 60% repentance rate.

Almost all of the country mountainous circulation is well represented, characterized by daytime periodicity. During the day, wind blows from low areas to the mountains and during the night wind blows on the opposite side of the mountains. In the Black Sea coastal areas, the breeze is added to the mountainous circulation. In this case, when the breeze and mountain circulations are compatible, wind is strengthening.

Georgia possesses wind energy potential, which is practically not used. According to special studies, theoretically wind energy supply in Georgia is 1.3 * 10^{12} kWh annually, while the potential of the wind with the speed over 4.0 m/s is almost 4,5 TWh annually.

According to the wind energy natural potential, the territory of Georgia has four zones:

1. High Speed Zone - mountains of Southern Georgia,

Kakhaberi valley and the central part of the Kolkheti lowland. The duration of the working period is more than 5000 hours per year.

2. Partly high-speed and low-speed zone - Mtkvari basin from Mtskheta to Kakhaberi valley. Duration of the working period is 4500-5000 hrs. per year.
3. Effective exploitation zone of low-speed wind farms - Gagra ridge, Kolkheti lowland and lowlands of eastern Georgia.
4. The limited use zone for low-speed wind farms - Iori highland and Sioni reservoir.

The frequency of strong winds in Georgia is observed in mountain peaks and passes, for example in Mta-sabueti, where the number of strong winds is high. Here the average annual wind speed is higher than in other areas – 9.2 m/s [10].

Current Situation and Challenges

In Gori municipality six 3.45 capacity wind turbines (turbine model: V117-91.5HH), with diameter of 117 meters, were installed in 2016 with total installed capacity of 20.7 MW, and annual generation of 88 GWh. It will annually reduce up to five tons of greenhouse gas.

A total of 34 million dollars were spent on building it. The project was financed by EBRD with a $ 22 million loan. The wind power plant belongs to "Qartli Wind Farm" LLC, the company's founder is state. Gori wind farm commenced functioning in December 2016. And in 2017 the very station generated almost 100 mln. KWh. It has continued functioning successfully in 2018 [11].

The electricity generated by the wind power plant will be purchased at the pre-determined tariff. ESCO has obligation for 10 years to buy 100% electricity generated by the station for $ 6.89, undertaken by the Memorandum of Understanding signed between Qartli wind farm, Government of Georgia, Georgian State Electrosystem and Electricity System Commercial Operator (ESCO). The tariff is approximately equivalent to value of the imported electricity.

Georgia has a significant potential of wind energy and several studies of wind power plants have identified the areas for potential wind farm construction:

1. Poti-50 MW, annual generation110 GWh;
2. Chorokhi-50 MW station, annual generation120 GWh;
3. Kutaisi-100 MW power plant, annual generation 200 GWh;
4. Mta-Sabueti N1- 150 MW power plant, annual generation 450 GWh;
5. Mta-SabuetiN2 - 600 MW station, annual generation 2 000 GWh;
6. Gori-Kaspi-200 MW power plant, annual generation 500 GWh;
7. Caravan - 200 MW power plant, annual generation 500 GWh;
8. Samgori-50 MW power plant, annual generation 130 GWh;
9. Rustavi - 50 MW power plant, annual generation150 GWh;

As it was already mentioned Georgia is a rich country with renewable energy sources, from which a large energy potential falls on water resources. According to the share of water resources per capita, Georgia is one of the leading nations worldwide, but nowadays only 18- 20% of the technical potential of water resources is used. On the other hand, due to the seasonality of the energy sector, the use of wind energy potential is of particular importance in the winter months, when the potential of water resources in Georgia is falling.

Everything depends on the natural conditions of the place defined for the construction of the station; concerning the fact that wind energy is more expensive than hydro energy, we also need to note that in contrary, the wind energy is much cheaper than import and thermal generation, especially in winter period when hydro generation is not enough to satisfy the demand of Georgian population [12].

Bioenergy

Bioenergy Resources

Unfortunately, there is no complete fundamental survey of the energy potential of Georgia's biofuel. Only assessment studies have been conducted, based on which you can make optimistic conclusions [13]. Hereby, biodiesel is an alternative, renewable energy that is so important for modern world [14].

The quantity of different types of biomass waste with their energy potential and the value of its savings are given in table 5.

Table 4.1

Energy Potential of Various Biomass Wastes of Georgia, [2]

Biomass Species	Quantity (103 Ton)	Energy (109 kwh)	Cost (106 US$)
Waste of granular and leguminous crops	870	1,3	80
Livestock and poultry wastes	1670	6,9	176
Household waste	900	0,6	14
Wastes from Tbilisi sewage water treatment equipment	250	1,0	57
Wood and its waste	700	2,7	125
Total	4390	12,5	452

This table gives us the idea that biomass energy can save up to US$ 500 million of money spent on expensive imported energy resources. Besides the existing potential, in the unused agricultural areas of Georgia, it is possible to build energy plantations that will positively affect Georgia's bioenergy resource amount. With the calculation of experts, from 6000 hectares of rapseed 5000 tons of biodiesel, 10 000 tons of copton and 18,000 tons of dry mass can be obtained. Cultivating perennial crops of euonymus (spindle tree) can be considered as a prospective option as well. For its cultivation moist or semi-wetted area is needed. With a single sowing, it yields the harvest for 10 years. Productivity of Western Georgia (where the area of semi-wetted area comprises tens of thousands of hectares) makes up to 20-25 tons of dry mass per hectare. Heat energy of 12500 MJ (3400 kWh) is obtained by burning dry part of 1 ton silfia. Thus, the silfia energy potential on 1 hectare is 20 * 3400 = 68000 kWh. With the calculation of experts, the price of 1 liter biodizel received from Silfia will not exceed 0.6$.

One of the priorities is the introduction of biotechnology, particularly biogas plants. There are several good factors for its development, within them one of most important is annually renewable biomass resources, which can be used to provide 14–17% of the energy demand for agriculture. The residual biomass is estimated at 1.6 million m^3 annually as a result of grain cultivation in Georgia.

Currently, the total number of cattle is 1048500. Each year up to two million of residual biomass is collected in Georgian farms, which is an important resource for improving the energetic, economic and environmental conditions of the country. Complete energy potential of livestock and poultry waste is equivalent to about 6.9 billion kWh and 734 million m^3 of natural gas.

Other positive factors for the use of biogas plant: Biogas obtained through biogas equipment can be used directly or we can get some electricity. In addition, it has the following positive features: Biomass obtained from biogas plant is the best organic fertilizer, compared to manure of livestock the bio-fertilizer contains 30% more natural nitrogen. By its use the productivity is increased by 10-15%. This decreases the utilization of chemical fertilizers and allows reducing the pressure on groundwater.

Current Situation and Challenges

During 1948-1961 in the Institute of Agricultural Mechanization of Georgia a number of constructions of biogas installations were created. In 1959, this Institute built in Krtsanisi the biogas farm for 200 livestock.

All operational biotechnology was constructed with the support of international donor organizations within 1994- 2007. More than 400 devices are functioning currently. Most exceptional construction types are following: machine with strong dome, with floating cover in a style on Indian Gobar; high-efficiency biogas equipment made from polymeric-fiber material; methane tanks working on surface in thermophilic regime; most common equipment are 6m^3 (residuals of 4-6 cattle) Chinese ones with strong dome and Indian ones with floating cover and minor changes.

In the cold regions of Georgia, there are two main for keeping proper temperature inside the bio-equipment: hot water heating (by biogas, electricity, firewood, solar water heater and other means) and arrangement of heat insulation (one or more layers of Soil, hay, glass-cloth). Initially the water is heated by firewood and later by generated biogas. For thermophilic conditions, the internal temperature should be 45-65°C. However, it is difficult to maintain this temperature without heating in cold climatic conditions.

The metal biogas plant working in thermopile mode is distinguished with high intensity (3-4 m^3 biogases per day from 1 m^3 bio-reactor volume).

The machine assembled in a special factory and later transported and installed on site. Such a device (capacity of 2 m^3 bio-reactor) was installed in peasant's family in Lisi and functioned for 5 years, giving the family steadily received biogas and reduced cost for liquid gas and wood.

Their price is quite high, as it is impossible to have serial production of such equipment. The price of biogas equipment differs between US$ 2000-3000 depending on type, size, raw material processing and location. In addition, all the above mentioned equipment should be installed by qualified specialists.

Conclusion

Existing industrial results clearly indicate that our scientific hypothesis is correct. Nowadays, 80% of consumed electricity is produced from renewable energy resources. Volume of generated electricity from wind farm and first results should be noted as well. However, public awareness regarding development and promotion of renewable energy should be raised as it's crucial for future actions. Sometimes construction of new generation capacities, especially building of new hydropower plants are impeded due to the ecological and environmental requirements.

This research shows that hydro energy has the leading role for development of renewable energy sector. In 2017 about 59.4% of total energy generation was renewable energy while biofuel constituted 27.4%. Utilization of solar energy, wind energy and thermal waters is at the initial stage. Biomass, preferably wood, is used in the decentralized regions which causes unsystematic deforestation. It should be noted that, this trend should be changed in the future and other alternative resources have to be utilized since forest protects soil and has ecological function. Therefore, development of renewable energy shall be in compliance with the requirements of environment protection. Law on Renewable Energy, which doesn't exist at this moment, should be adopted in the nearest future. Further detailed studies are needed in this field for more utilization of solar, wind and hydro energy resources taking into account the ecological factors and requirements.

Conflict of Interest

All the authors declared that they have no conflict of interest to disclose.

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***Corresponding author:** Demur Chomakhidze, Doctor at Economic Science, Georgian Technical University, Tbilisi, Georgia, E-mail: demurchomakhidze@yahoo.com; maiamelikidze@yahoo.com

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