# SELECTION OF OPTIMAL INVESTMENT PORTFOLIO IN ORDER TO PROVIDE GEORGIAN ENERGY SAFETY WITHIN THE MEDIUM TERM

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***Anticipated rates of deficit power in autumn-winter period are specified based on comparative analysis of expected medium term parameters of power generation and power demand in Georgia and the ways to reduce the deficit by increasing power generated as a result of putting the power plants into the operation within the established terms defined under the seleted optimal investment portfolio are shown.***

***For increasing local potential to satisfy Georgian power demand by generating power, method for selecting the optimal investment portfolio for providing Georgian energy safety within the medium term is elaborated based on which the optimal portfolio for the investments to be implemented in Georgian energy section was selected.***

**Key words:** ***energy resources, investment portfolio, estimated deficit, integrity of sets.***

**Economic crisis in the world and intense increase of prices on energy resources make any country face the necessity of implementing effective measures and use as much of its own energy resources as possible for achieving energy independence. As analysis shows [4,10], according to the energy balance of Georgia, almost 65% of the demand on the energy resources is satisfied by import.**

**Fulfillment of the set objective is possible by selecting the optimal investment portfolio in energy sector based on deep scientific analysis. Pre-condition of the portfolio selection should be determination of expected medium term parameters, identification of power capacities required for providing the energy safety according to estimated parameters and elaboration of the medium term complex programme for exploiting the capacities according to the availability of local renewable resources.**

**Problems relating to the medium term forecast of the energy safety and selection of the optimal investment portfolio are not properly studied in Georgia. There has not been scientifically justified method for the selection of the optimal investment portfolio in the energy sector elaborated. Large volume of research works [1-3, 4, 6-8] were conducted by the authors of this report in order to eliminate this problem.**

**As a result of performed researches the medium term forecast of the power demand in Georgia (2011-2020) at 95% reliability probability was carried out based on actual power balance of the recent years [1, 8, 11] taking into the account the factors affecting the power demand in Georgia [2]. Upper and lower limits of the forecast were determined. Calculation results are provided in table 1.**

**Forecast of Power Demand in Georgia, million kW.h**

**Table 1**

| Year | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| Base line | 9,1077 | 9,2326 | 9,6144 | 10,049 | 10,125 | 10,335 | 10,8253 | 11,0395 | 11,09 | 11,503 |
| Upper limit | 10,465 | 10,793 | 11,108 | 11,884 | 12,12 | 12,706 | 13,179 | 13,569 | 14,178 | 14,494 |
| Lower limit | 7,7499 | 7,6722 | 8,1214 | 8,2147 | 8,13 | 7,965 | 8,018 | 8,51 | 8,001 | 8,513 |

**Given that main sources covering power consumption in Georgia are the existing hydropower plants, the anticipated medium term parameters of power generated by hydropower plants are defined in low, average and high hydrological conditions based on high-factor mathematical model (considering rehabilitation effect). Obtained results are given in table 2.**

**FORECAST OF POWER GENERATION AT FUNCTIONING HYDROPOWER PLANTS, MILLION KW.H**

**Table 2**

| Year | Low hydrology | | | Average hydrology | | | High hydrology | | |
|---|---|---|---|---|---|---|---|---|---|
| | Winter | Summer | Total | Winter | Summer | Total | Winter | Summer | Total |
| 2011 | 2301 | 3649 | 5950 | 3068 | 4450 | 7518 | 4002.4 | 5073 | 9075.4 |
| 2012 | 2317.3 | 3674.6 | 5991.9 | 3089.7 | 4481.3 | 7571 | 4016 | 5096 | 9112 |
| 2013 | 2333.7 | 3701 | 6034.7 | 3111.6 | 4513.4 | 7265 | 4045 | 5144.8 | 9189.8 |
| 2014 | 2350 | 3726.5 | 6076.5 | 3133.1 | 4544.5 | 7677.6 | 4072.9 | 5180 | 9252.9 |
| 2015 | 2366.4 | 3753 | 6119.4 | 3155.2 | 4576.8 | 7732 | 4101.7 | 5216.6 | 9318.3 |
| 2016 | 2382.7 | 4024.5 | 6408.2 | 3177 | 4908 | 8085 | 4130 | 5398.8 | 9528.8 |
| 2017 | 2399 | 3804.8 | 6203.8 | 3199 | 4640 | 7839 | 4158.7 | 5243.2 | 9401.9 |
| 2018 | 2415.4 | 3852.8 | 6268.2 | 3220.5 | 4698.5 | 7919 | 4186.6 | 5261.7 | 9448.3 |
| 2019 | 2431.9 | 3856.9 | 6288.8 | 3242.5 | 4703.5 | 7946 | 4215.2 | 5267.3 | 9482.5 |
| 2020 | 2448 | 3882 | 6330 | 3264.3 | 4734.7 | 7999 | 4243 | 5302 | 9545 |

**Under comparative analysis of the data provided in table 1 and table 2, anticipated deficit value between the power demand and its satisfaction by means of available water resources is determined. Dynamics of the deficit value change and the forecast are provided on fig. 1.**

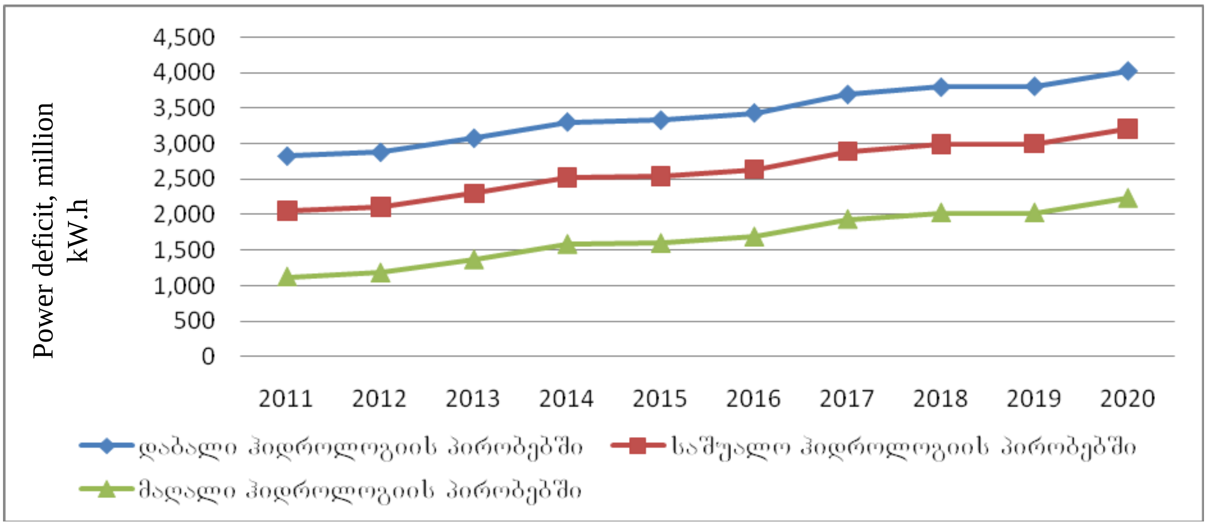



**Fig. 1. Forecast of Georgian Power Deficit, million kW.h**

**Therefore the main principle for developing the optimal investment portfolio for energy projects is assumed to be the selection of those plants out of the full list [11] of the power plants suggested for the construction by Georgian Ministry of Energy, construction of which is realistic and their timely operation in autumn-winter period will satisfy the country's demand of power at a maximum level. Based on the above mentioned, 23 medium and large hydropower plants out of more than 50 hydropower plants to be constructed in Georgia in future were subject to technical and economic analysis. Partially**

**uncertain economic, technical and climate factors affecting the plants make the performance of full analysis impossible. Under such conditions, traditional mathematical aspects, theory of probability and mathematical statistics cannot consider various fuzzy aspects [9,10] which is why it is necessary to apply such a theoretic approach which will allow to make optimal decision by approximate modeling of subjective and partially uncertain information.**

**The objective set can be solved under the theory of "fuzzy logics" [10]. This theory allows to make optimal decision by processing incomplete information on any object and instruments based on fuzzy set integrity.**

**In order to solve this problem the software package Fuzzytech created based on mathematical modeling of linguistic betterment was applied and general algorithm of the investment portfolio [9] according to this package has the following form:**

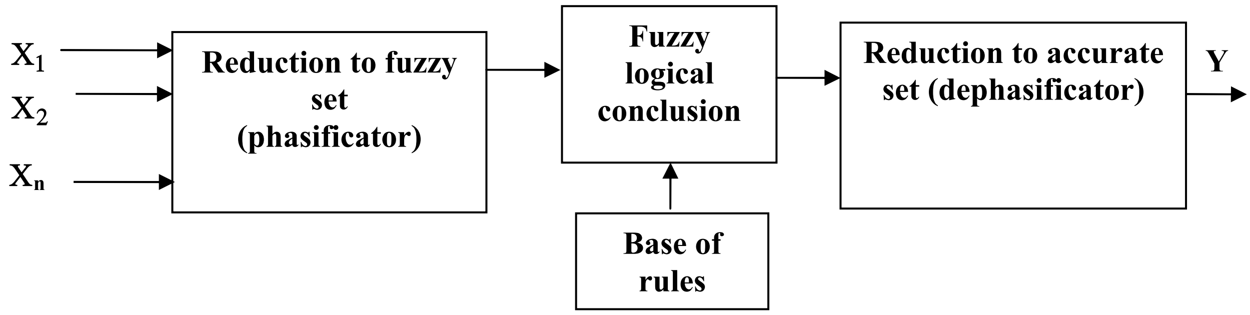



**Fig. 2. Fuzzy Logical Diagram**

**Here, the combination of characteristics of the investment object can be presented in form of $X_1$, …, $X_n$. {X} value system should be selected in such a way that it should fully evaluate the efficiency of the investment project. For the purposes of satisfying the requirement set forth, hydropower plants selected by us for the analysis were rated according to 10 characteristics, their values were determined based on relevant analysis and put into the table 3.**

**$X_1$, …, $X_{10}$ characteristics and functional dependence of the evaluation of Y investment project condition have the following form:**

$$Y = \psi(X_1, X_2 ... X_{10}), \qquad (1)$$

**where $\psi$ is procedure containing the base of rules and connects $X_1$, …, $X_{10}$ characteristics with complex characteristics of the evaluation of the Y investment project condition. In our case, based on mini-max principle [5], more than 10000 rules are generated for each investment object.**

### Input Information, Characteristics of Hydropower Plant Candidates

**Table 3**

| N | Hydropower plant names | Power generation, million kW.h<br>$X_1$ | Specific value of 1 MW.h construction, $million<br>$X_2$ | Specific value of 1 MW construction, $million<br>$X_3$ | Capacity use factor, %<br>$X_4$ | Profitability at $1<br>$X_5$ | Construction duration, year<br>$X_6$ | Coverage of winter deficit, $<br>$X_7$ | Effect of additional use of water<br>$X_8$ | Social effect<br>$X_9$ | Environmental impact<br>$X_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Paravani | 425 | 0.29 | 1.6 | 62 | 0.187 | 3 | 4.67 | 0 | Medium | Medium |
| 2 | Namakhvani | 1677 | 0.6 | 2,22 | 42.5 | 0.94 | 6 | 20.4 | 0 | High | High |
| 3 | Chorokhi | 304 | 0.22 | 1.4 | 72 | 0.25 | 4 | 3.3 | 0 | Low | Low |
| 4 | Mtkvari | 200 | 0.325 | 1.51 | 53 | 0.93 | 5 | 2.5 | 0 | " - " | " - " |
| 5 | Khobi | 439 | 0.35 | 1.8 | 59.3 | 0.158 | 3 | 5.2 | 0 | Medium | Medium |
| 6 | Tekhura | 490 | 0.31 | 1.42 | 61.9 | 0.179 | 3 | 5.2 | 0 | High | " - " |
| 7 | Khudoni | 1500 | 0.47 | 1 | 24.5 | 0.119 | 5 | 17.1 | 1 | High | High |
| 8 | Nenskra | 1200 | 0.67 | 1.84 | 58 | 0.77 | 5 | 7.2 | 0 | " - " | Medium |
| 9 | Alpana | 356 | 0.3 | 1.5 | 57.7 | 0.183 | 3 | 3.3 | 0 | Medium | Low |
| 10 | Stori | 237 | 0.38 | 1.75 | 53.2 | 0.141 | 2 | 2 | 0 | " - " | " - " |
| 11 | Oni | 1556 | 0.426 | 2.35 | 63 | 0.128 | 5 | 15.9 | 0 | High | High |
| 12 | Kheledula | 427 | 0.355 | 1.79 | 57.5 | 0.148 | 3 | 3 | 0 | Medium | Low |
| 13 | Zoti | 144 | 0.55 | 2.22 | 46 | 0.099 | 5 | 1.5 | 0 | Low | " - " |
| 14 | Khelvachauri | 144 | 0.217 | 1.4 | 73 | 0.255 | 4 | 1.6 | 0 | Medium | " - " |
| 15 | Tsdo | 296 | 0.35 | 1.77 | 59.1 | 0.155 | 3 | 2.7 | 0 | " - " | " - " |
| 16 | Nakra | 190 | 0.32 | 1.76 | 61 | 0.176 | 2.6 | 2.7 | 0 | Low | " - " |
| 17 | Zestaponi | 210 | 0.6 | 2.33 | 45 | 0.093 | 3 | 2.5 | 0 | Medium | " - " |
| 18 | Bakhvi | 260 | 0.267 | 1.55 | 63.3 | 0.21 | 3 | 3.1 | 0 | Low | |
| 19 | Dariali | 521 | 0.345 | 1.65 | 66 | 0.157 | 3 | 5.2 | 0 | High | Medium |
| 20 | Magana | 223 | 0.278 | 1.51 | 61.6 | 0.19 | 3 | 1.6 | 0 | Low | Low |
| 21 | Lukhuna | 185 | 0.275 | 1.7 | 70 | 0.2 | 4 | 2 | 0 | " - " | " - " |
| 22 | Cascade of river Paravani (Akhalkalaki, Abuli, Arakali) | 278 | 0.287 | 1.76 | 69 | 0.198 | 2.5 | 4 | 0 | " - " | " - " |
| 23 | Jejora | 231 | 0.311 | 1.8 | 65 | 0.177 | 3 | 2.5 | 0 | Low | Low |

**According to the established rules the impact of change of each $X_1, \ldots, X_{10}$ characteristic on Y value is determined. The mentioned dependence can be mathematically written in a following way:**

$$r(Y) = \delta_i r(X_i), \qquad (2)$$

**where,**

$$r(*) = \begin{cases} 1, \text{if parameter } (*) \text{ increases;} \\ -1, \text{if parameter } (*) \text{ decreases;} \end{cases}$$

$$\delta_i(*) = \begin{cases} 1, \text{if increase of } X \text{ causes increase of } V; \\ -1, \text{ if increase of } X \text{ causes decrease of } V. \end{cases}$$

**According to the expression (2) and under expert evaluation, the matrix of the impact of the investment project characteristics versus the output information is obtained. The data are included in table 4.**

**Table 4**

| Condition of the investment project | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | Growth | Growth | Growth | Growth | Growth | Growth | Growth | Growth | Growth | Growth |
| Efficiency of the investment project | Increases | Decreases | Decreases | Decreases | Increases | Increases | Decreases | Increases | Decreases | Decreases |

**Interactive block diagram (Fig. 3) of the course of fuzzy modeling process was drafted in order to process the presented input information (phasification) and obtain the final result (dephasification) with fuzzytech.**

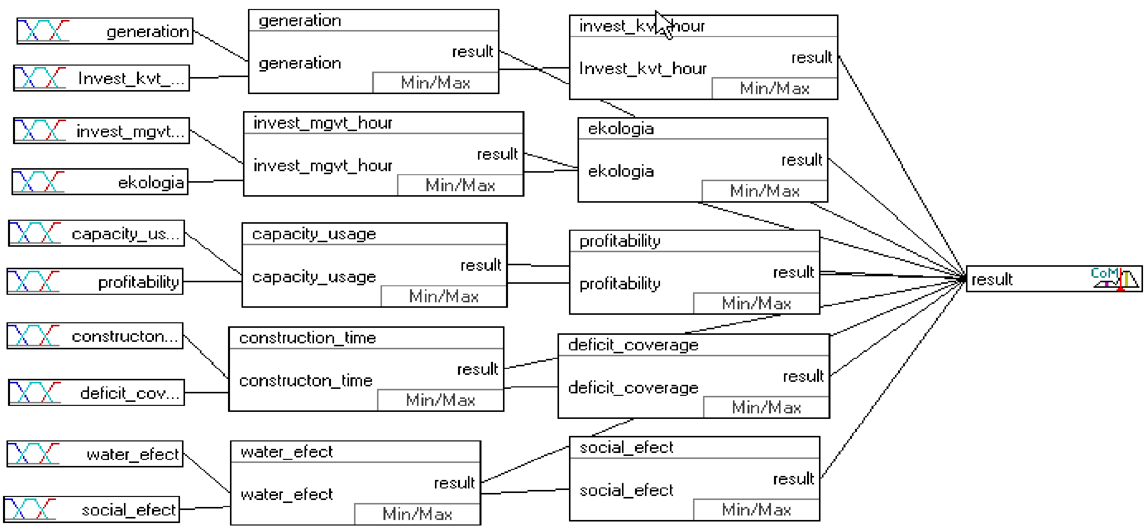



**Fig. 3 Interactive Block Diagram of Fuzzy Modeling**

**Three alternative approaches for integrated research of the selection of the optimal investment portfolio are reviewed. The first – where all characteristics of the investment projects are presented by equal weight factors, the second – by prevalence of weight factors of economic characteristics, the third – by prevalence of weight factors of technical characteristics.**

**Certain scores were assigned to each investment project according to the weight factors of the input characteristics and according to the level of their impact on general characteristics under the calculations conducted on the basis of the software package Fuzzytech. The results are provided in table 5.**

**Three portfolios were selected based on the evaluation of the investment projects, potential to generate power in autumn-winter period by hydropower plants to be constructed,**

**provision of maximum decrease of the share of power totally generated by thermal power plants described in table 5. (see table 6.).**

**Research Results**

**Table 5**

| Location | Scores assigned | | | | | |
|---|---|---|---|---|---|---|
| | In case of equal impact of all the factors (alternative 1) | | In case of the prevalence of technical characteristics (alternative 2) | | In case of the prevalence of economic characteristics (alternative 3) | |
| | Power plant | Score | Power plant | Score | Power plant | Score |
| 1 | Khudoni | 6.14 | Oni | 6.35 | Chorokhi | 6.13 |
| 2 | Khelvachauri | 5.93 | Khudoni | 6.31 | Khelvachauri | 6.12 |
| 3 | Chorokhi | 5.89 | Khelvachauri | 5.67 | Lukhuna | 6.1 |
| 4 | Oni | 5.79 | Lukhuna | 5.63 | Bakhvi | 6.09 |
| 5 | Bakhvi | 5.75 | Chorokhi | 5.58 | Khudoni | 6.01 |
| 6 | Tekhura | 5.64 | Tekhura | 5.38 | Jejora | 5.86 |
| 7 | Jejora | 5.63 | Bakhvi | 5.34 | Magana | 5.8 |
| 8 | Magana | 5.35 | Jejora | 5.33 | Tekhura | 5.79 |
| 9 | Dariali | 5.34 | Nenskra | 5.18 | Paravni cascade | 5.77 |
| 10 | River Paravani cascade | 5.32 | Dariali | 5.16 | Alpana | 5.69 |
| 11 | Paravani HPP | 5.31 | Namakhvani | 5.11 | Dariali | 5.56 |
| 12 | Alpana | 5.2 | Khobi | 4.99 | Paravani HPP | 5.55 |
| 13 | Lukhuna | 5.09 | Paravani HPP | 4.98 | Nakra | 5.43 |
| 14 | Khobi | 5.08 | River Paravani cascade | 4.86 | Oni | 5.34 |
| 15 | Nakra | 5.05 | Magana | 4.8 | Kheledula | 5.25 |
| 16 | Nenskra | 4.96 | Alpana | 4.79 | Khobi | 5.24 |
| 17 | Kheledula | 4.96 | Kheledula | 4.59 | Tsdo | 5.22 |
| 18 | Tsdo | 4.8 | Nakra | 4.58 | Stori | 4.86 |
| 19 | Namakhvani | 4.55 | Tsdo | 4.3 | Nenskra | 4.76 |
| 20 | Stori | 4.51 | Stori | 4.1 | Mtkvari | 4.25 |
| 21 | Mtkvari | 3.95 | Zestaponi | 3.72 | Namakhvani | 4.16 |
| 22 | Zestaponi | 3.91 | Zoti | 3.71 | Zoti | 3.93 |
| 23 | Zoti | 3.83 | Mtkvari | 3.7 | Zestaponi | 3.86 |

**The research run under the above method for the selection of the optimal investment showed that from three alternatives provided in table 6 the alternative 3 satisfies the investment portfolio requirements most of all.**

**Investment Portforlios**

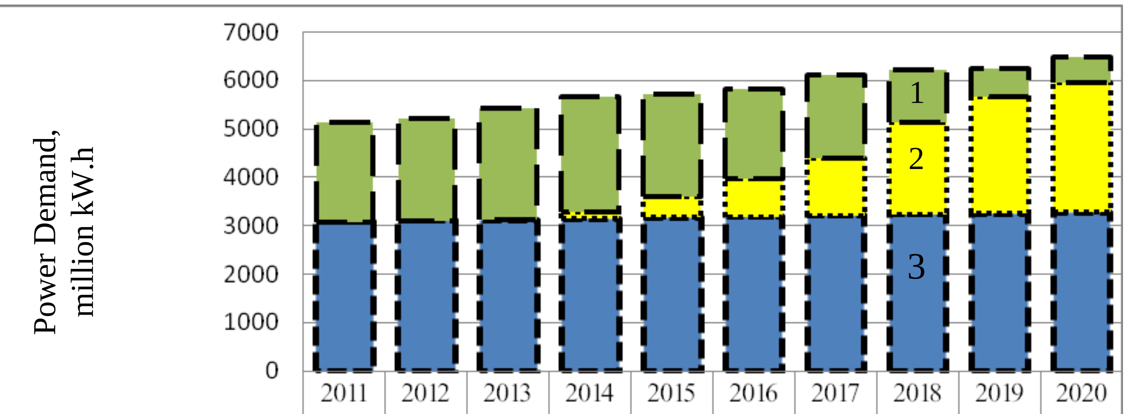
**Table 6**

| Portfolio | Power generation, million kW.h | Specific value of 1 MW.h construction, $million | Specific value of 1 MW construction, $million | Capacity use factor, % | Profitability, % | Coverage of winter deficit, % | Installed capacity, MW | Investment, $million |
|---|---|---|---|---|---|---|---|---|
| 1 | 7102 | 0.362 | 1.49 | 46.6 | 0.148 | 77.37 | 1737 | 2573.5 |
| 2 | 8068 | 0.48 | 1.67 | 40 | 0.112 | 83.5 | 2309.4 | 3861.9 |
| 3 | 7825 | 0.36 | 1.5 | 48 | 0.15 | 83.07 | 1879.6 | 2828.2 |

**Optimal Investment Portfolio**

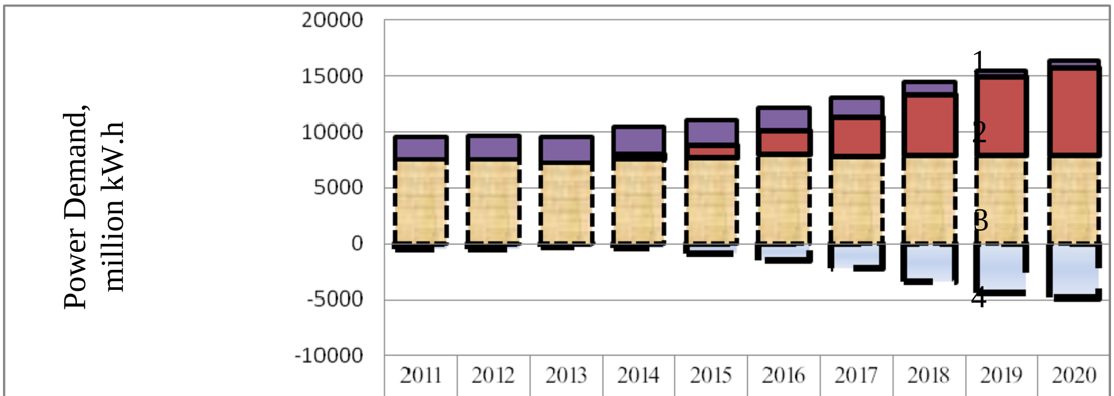
Table 7

| | HPP | Installed capacity, MW | Power generation, million kW.h | Construction cost, $ million. | Specific value of 1 MW construction | Generation in winter, million kW.h | Generation in summer, million kW.h | Capacity use factor, % | Profitability, % | Year of putting HHP into operation | Coverage of winter deficit, % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Paravani | 78 | 425 | 125 | 0.29 | 150 | 275 | 62 | 0.187 | 2014 | 4.67 |
| 2 | Chorokhi | 48 | 304 | 67 | 0.22 | 105 | 199 | 72 | 0.25 | 2017 | 3.3 |
| 3 | Tekhura | 105 | 490 | 150 | 0.31 | 166 | 324 | 61.9 | 0.179 | 2015 | 5.2 |
| 4 | Khobi | 86 | 439 | 155 | 0.35 | 166 | 273 | 59.3 | 0.158 | 2018 | 5.2 |
| 5 | Khudoni | 700 | 1500 | 700 | 0.47 | 550 | 950 | 24.5 | 0.119 | 2018 | 17.1 |
| 6 | Alpana | 70 | 356 | 105 | 0.3 | 106 | 250 | 57.7 | 0.183 | 2016 | 3.3 |
| 7 | Bakhvi | 45 | 260 | 69.6 | 0.267 | 101 | 159 | 63.3 | 0.21 | 2017 | 3.1 |
| 8 | Dariali | 109 | 521 | 180 | 0.345 | 166 | 355 | 66 | 0.157 | 2020 | 5.2 |
| 9 | Lukhuna | 30 | 185 | 51 | 0.275 | 65 | 120 | 70 | 0.2 | 2016 | 2 |
| 10 | River Paravani cascade | 45.4 | 278 | 80 | 0.287 | 126 | 152 | 69 | 0.198 | 2015 | 4 |
| 11 | Oni | 282 | 1556 | 664 | 0.426 | 511 | 1045 | 63 | 0.128 | 2019 | 15.9 |
| 12 | Magana | 41.3 | 223 | 62 | 0.278 | 53 | 170 | 61.6 | 0.19 | 2017 | 1.6 |
| 13 | Jejora | 40 | 231 | 72 | 0.311 | 81 | 150 | 65 | 0.177 | 2016 | 2.5 |
| 14 | Nakra | 35 | 190 | 61.6 | 0.32 | 86 | 104 | 61 | 0.176 | 2016 | 2.7 |
| 15 | xKhlvachauri | 22.4 | 144 | 31.3 | 0.217 | 52 | 93 | 73 | 0.255 | 2017 | 1.6 |
| 16 | Tsdo | 57.8 | 296 | 102.7 | 0.35 | 86 | 210 | 59.1 | 0.155 | 2020 | 2.7 |
| 17 | Kheledula | 84.7 | 427 | 152 | 0.355 | 97 | 330 | 57.5 | 0.15 | 2019 | 3 |




| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. თესების წარმოება | 2057 | 2106 | 2298 | 2371 | 2100 | 1858 | 1704 | 1087 | 583 | 541 |
| 2. ახალი ჰესების წარმოება | 0 | 0 | 0 | 150 | 442 | 780 | 1188 | 1904 | 2415 | 2667 |
| 3. არსებული ჰესების წარმოება | 3068 | 3089.7 | 3111.6 | 3133.1 | 3155.2 | 3177 | 3199 | 3220.5 | 3242.5 | 3264.3 |

**Fig. 4. Forecast of Autumn-Winter Power Balance of Georgia**




| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. თესების წარმოება | 2057 | 2106 | 2298 | 2371 | 2100 | 1858 | 1704 | 1087 | 583 | 541 |
| 2. ახალი ჰესების წარმოება | 0 | 0 | 0 | 425 | 1193 | 2155 | 3513 | 5452 | 7008 | 7825 |
| 3. არსებული ჰესების წარმოება | 7518 | 7571 | 7265 | 7677.6 | 7732 | 8085 | 7839 | 7919 | 7946 | 7999 |
| 4. ჭარბი ელ.ენერგია | -467 | -443.7 | -308.8 | -425.2 | -899.9 | -1463.5 | -2231.9 | -3392.6 | -4447.5 | -4863 |

**Fig. 5. Forecast of Annual Autumn-Winter Power Balance of Georgia**

## As a result of the research conducted:

1. **method of selecting the optimal investment portfolio for providing Georgian power safety within the medium term is elaborated;**
2. **optimal porfolio of the investment projects to be implemented in Georgian energy sector is selected;**
3. **estimated rates of deficit power during autumn-winter period are specified based on comparative analysis of the power demand in Georgia and anticipated medium-term patameters, the ways to reduce deficit by increasing the generation of power obtained as a result of putting hydropower plants identified under the selected optimal investment portfolio into the operation within the established terms are shown.**

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