THE ASSESSMENT OF THE SUPPLY CHAIN RISKS OF ELECTRICITY NETWORK OF RA

Introduction

The research is dedicated to the modeling and analysis electric power market of RA in the context of supply chain management, to develop a supply chain network model for electric power, as well as for modeling several different types of decision-makers' behavior in the electricity market under condition of uncertainties. Electricity supply and consumption are integrated in flow processes, which can be represented by the supply chain. In fact, there are numerous risks related to the electricity supply chain networks that comprise hundreds of companies with several tiers. Thus, that is necessary to create models, methods and mechanisms that allow efficient management of energy flows within different risk scenarios.

After Soviet Union collapse the electric power network design has been changed. The reforms had their positive results but there are a lot of challenges concerning of the infrastructure of the network. For example, the losses in the transmission and distribution networks have been 15.1% of the electricity production in 2010, but in 2015 it was 13%, while electricity consumption during these years increased by 1.6%.

Currently, the energy sector of Armenia is one of the cost-effective branches of the country’s economy that is operated in fully capacity. Armenia fully covers energy demand in the internal market and exports electricity to Georgia, as well as successfully performs an electricity exchange with Iran on mutually beneficial basis. Armenia can meet only 35% of the total demand for energy with its domestic resources, thus it is highly dependent on imported energy resources.

The power market of RA is split into three functional areas: generation, transmission and distribution. The main market players are the following: Generating companies, Transmission Company – High Voltage Electric Networks Closed Joint-Stock, Distribution Company – Electric Networks of Armenia CJSC, which is the sole buyer of power from all generating companies and the sole seller of power to all the customers of the RA at tariffs set by the PSRC of Armenia.

Hence the tariffs structure are based mainly of the network design and electricity sector jurisdiction. Described tariffs system first of all affect on the residential sector (they consume more than 60% of electricity) and it brings to energy poverty in our country[1]. So Armenia needs to improve the tariffs mechanism, also the ways of used investments, control system and healthy market structure. We argue that there can be potential solutions of these problems, for example we suggest the modeling of tariffs, when the determining factor is considered to be the level of welfare of the poorest population[2]. We can separate supply side efficiency and demand side efficiency in the supply chain. In Armenia we see the main problem for the end users of the electricity supply chain. In recent 10 years electricity price for the population has increased about 90%, but average income hasn't been increase at the same rates.

Furthermore, it is expected that the increase of tariffs will be continued in the coming years concerning the increase of primary energy prices all over the world. Poor Armenian households spent roughly 10 percent of their total household budgets on the electricity and gas, which is defined as living on the edge of "fuel poverty", so continued tariff increases will increasingly push lower-income Armenians toward the brink of fuel poverty.

Today, Armenia has sufficient electricity-generating capacity but in total the electricity demand is expected to grow at two-three per cent annually, and it is projected that demand will exceed supply because much of the installed capacity is old, and requires modernization or replacement: 38% of this capacity has been in operation for more than 30 years. The primary equipment at the thermal power plants (TPPs) has reached 200 thousand hours of use, and does not conform to internationally recognized technical and ecological criteria. 70% of the equipment at the hydro-power plants (HPPs) has been in operation for more than 30 years (50% for more than 40 years).

Decision-making problems in energy markets are faced with uncertainty, which significantly impacts on price, demand, intermittent production, equipment availability, etc. Moreover, in particular cases the information about electricity consumption could be inadequate or have an interval or fuzzy description.

Supply chain network for electric power market of Armenia

Armenia's power market is not competitive. Although some unbundling has taken place, Armenia's power market remains a monopoly under a single-buyer market structure. Network model of the supply chain of electrical energy of RA consists of four main components: *generators, distributor, transmission service provider, consumer demand, the*

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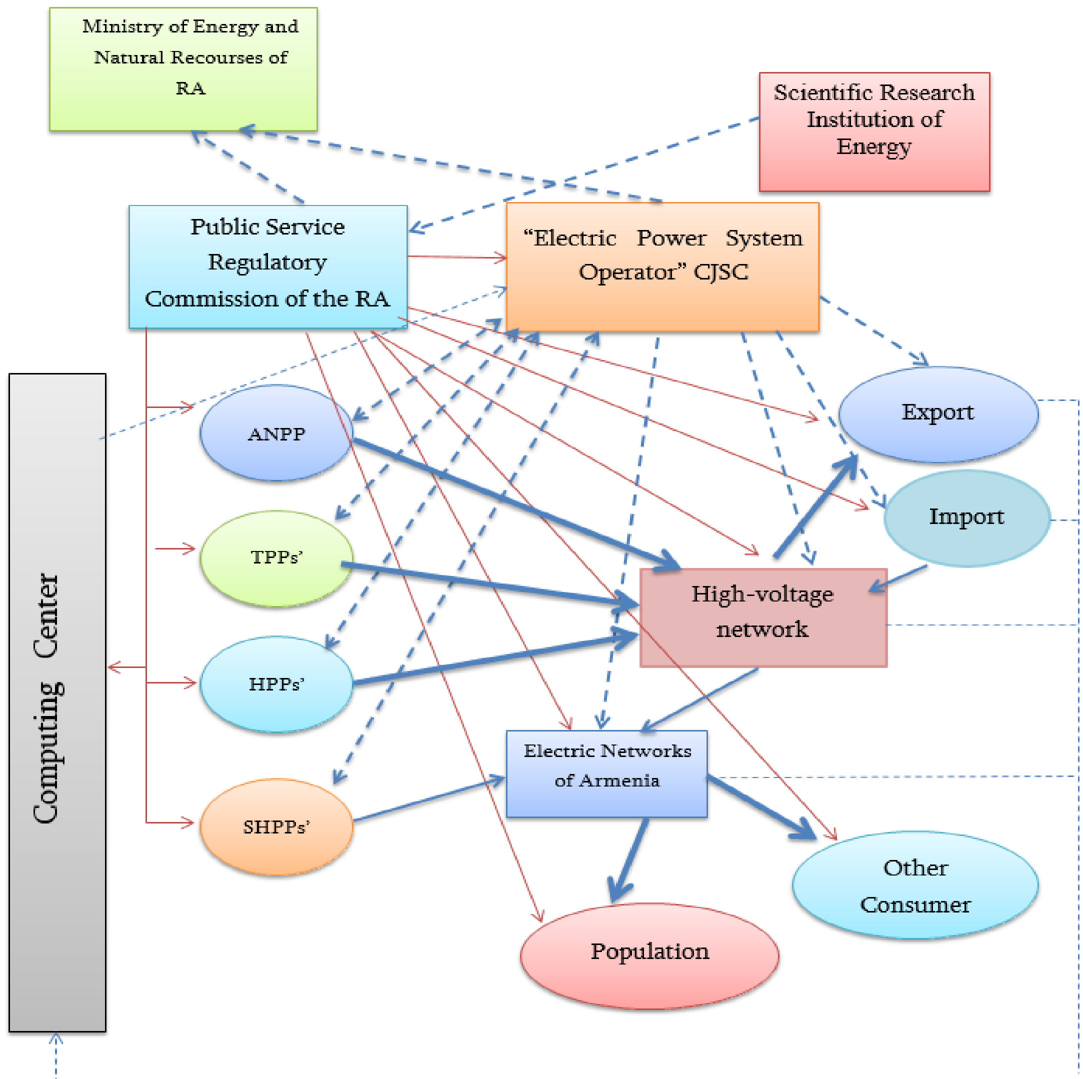
[1] V.S. Marukhyan *"The analysis and evaluation dynamics of electric power consumption by population in RA"*, Journal of Finance and Economics, Yerevan 2013, 11-12(161-162), p.p. 79-81

[2] V.S. Marukhyan "Modeling of Electricity Tariffs for the population of Armenia". Information Technologies and Management, 2015, pp. 85-90.

independent system operator. The functional structure of the Armenian power system is shown in Figure 1.

Figure 1

The Electric Power Supply Chain Network



The electric power sector of Armenia consists of three parts:

- ✓ the first part involves stations producing electrical energy: thermal power plants, nuclear power, hydroelectric power stations and small renewable energy;
- ✓ the second part consists of power transmission components (high-voltage electric networks 110-220 kW);

- ✓ grated part consists of the distribution units (mains voltage of 110, 35, 10, 6 and 0.4 kV).

In the Figure 1 the acts show information and energy flows through the nodes in the network.

Unlike the supply chain structure of competitive energy market Power system operator has the exclusive rights to planning and coordinating the production, distribution, import and export of energy, as well as the predicted balance of the network. The power system operator every year estimated the balance of the network based on the proposals of the market participants. The wholesale power market of Armenia has no elements of competition; it is fully regulated. Only legal entities can participate in the power sector; unbundling between generation, transmission, distribution, and other activities is required by the law.

. The main market players are the following.

- Generating companies:
  - Armenian NPP;
  - Hrazdan Thermal Power Plant (TPP);
  - Yerevan TPP;
  - Sevan-Hrazdan Cascade of HPPs;
  - Vorotan Cascade of HPPs, and
  - Small HPPs and a Wind power plants.
- Transmission Company – High Voltage Electric Networks Closed Joint-Stock Company (CJSC) – is a company transmitting power produced by the generating companies to the distribution company, as well as transporting both electricity imports and exports from/to neighboring countries.
- Distribution Company – Electric Networks of Armenia CJSC – is the sole buyer of power from all generating companies and the sole seller of power to all the customers of the RoA at tariffs set by the PSRC of Armenia.

The difficulties of the construction supply chain for the energy market of RA are

- ✓ Public services regulator, PSRC regulates tariffs on the market for all market participants and electricity prices are set by an independent regulatory
- ✓ distribution company is the only buyer in the market
- ✓ Uncertainties in electricity consumption

- ✓ There are no comprehensive or consistent documents on Market Rules; only generation regulations presented in several decisions adopted by the Regulators. Despite considerable effort to develop a Grid Code, it has not yet been adopted.

The wholesale power market has the following regulations and characteristics:

- ✓ Generation is fully regulated with no competition. The Regulator permits one license for construction and operation. Generators have no permit to sell electricity to customers. A generation unit may export electricity only when the internal market is saturated and the sale does not contradict the interests of internal customers. Moreover, according to the Energy Law, only the most expensive generation can be exported, which practically means that Hrazdan TPP and Hrazdan Unit5 are the only generation units available for export. The amount of produced electricity is set as a "preliminary value" in the contracts6 between the DSO and generation units. Therefore generation units do not have any responsibility for the "contracted" electricity.
- ✓ Transmission is fully regulated. The Regulator permits one license to a TO for construction and management of the assets. There are no defined rules for third party nondiscriminatory access to the transmission system.

- ✓ Distribution is fully regulated. The Regulator permits one license for construction and operation. Until February 2016, distribution held exclusive rights for the supply of electricity to customers.7 There are no clear regulations for unbundling distribution from supply. De facto, the DSO is the only supplier and acts as a monopoly. The DSO purchases electricity from the national generating companies at regulated prices and on the basis of direct contracts. As a consequence, the wholesale market is a monopsony, with the DSO acting as a single buyer. The Regulator has not set the distribution tariffs. This fact restricts customers from importing electricity from neighboring countries because a legal basis is lacking. All the financial flows of the power sector go through the DSO. This creates higher risks for the market participants and customers when the forecasted generation mix is not "achieved" for any reason. In a situation when the DSO is not stable financially, especially if near bankruptcy, it could lead to the collapse of the power system. Such a situation arose during a recent crisis in the power sector of Armenia. Neither electricity nor capacity is a contractual value for the customers. Even large customers do not have any responsibility for the "contracted" electricity or capacity. Thus, the system annual balance creates direct risks for the DSO, but not for a generation unit or a single customer. Those risks are covered by the end-user tariffs based on the ex-post assessments.

- ✓ The ISO acts based on the Regulators' permit (license). The Regulator sets monthly fees for the services of the ISO. The ISO is responsible for the operation and economic dispatch of the wholesale power market. The EU, for operation of the power sector, applies three general models: ISO, TSO, and Ownership Unbundling. Armenia is closest to the ISO model. However, the TSO model, which includes ISO and TO in one entity, is more responsible, trans-parent, and powerful in terms of financial stability since it owns and operates all transmission assets. Therefore, the GoA can switch to the TSO model if it is not planning to privatize HVEN.

- ✓ The Settlement Center acts based on the Regulators' permit (license) as well with regulated monthly fees. The Settlement Center is responsible for metering and billing issues on the wholesale market. The Settlement Center has no other essential activities. In EU power markets, this role is usually expanded to act as a MO with responsibility for organizing power markets.

The electricity sector has significant role in ensuring the public security, social policy and economic development. Electricity supply and consumption are integrated flow processes, which can be represented by the supply chain. A mix of policy, legal, regulatory, and institutional reforms has achieved remarkable result. The main objective of supply chain management is to enhance the operational efficiency, probability and competitive position of a firm and its supply chain partners.. Through the supply chain we develop a supply chain network model for electric power market of RA, where every node describe the various decision-makers in electricity market, and tiers show electricity flows between nodes. For supply chain networks of power markets that comprise hundreds of companies with several tiers, there are numerous risks to tackle, generally these risks can be classified into two types: risks arising from within the supply chain network and risks external to the network. The attribute of operational risks are due to the interactions between firms across the supply chain network, such as supply risk, demand risk and trade credit, technical risks, distribution risks and etc. Disruption risks arise from interactions between the supply chain network and its environment, such as terrorism, or natural disasters.

Objectives

Liberalization and privatization in the electricity industry have led to increasing competition and uncertainties among utilities, particularly while managing electricity flows in the network. The main purpose of the paper is to conduct impact analysis of risk factors in electricity supply chain management of RA. The objectives are followings:

- The problems which relate to the decision-makers' behaviors and their relationships in the electricity market of RA.
- Identifying supply chain system process in the risky situations and production activities.
- Analyzing optimal flow distribution by minimizing risks/threats and maximizing opportunities/profits of the system.

Models

Electricity is provided by:

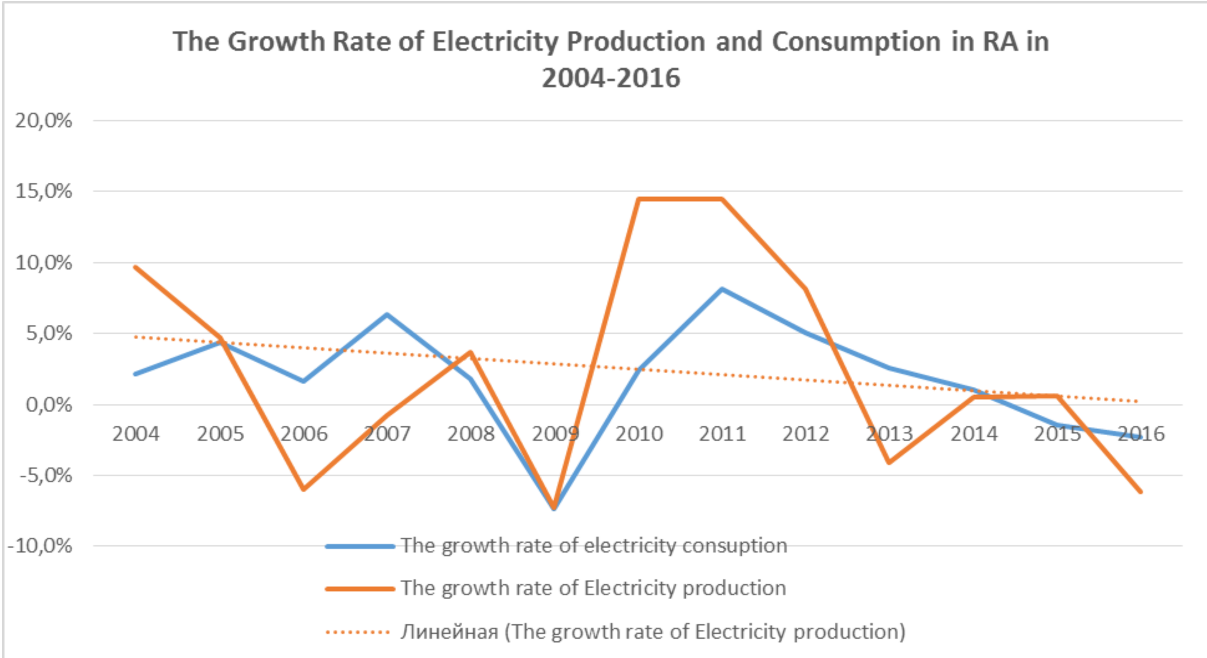
✓ A nuclear power plant which provides about 30-40% of internal demand;

✓ Hydroelectric plants (total installed capacity of approximately 1,000 MW) satisfy 20-35% of the country's needs depending on level of precipitation, which varies significantly. Besides, the hydropower generation is declining due to limitations associated with irrigation purposes of the hydro plants;

✓ The remaining electricity demand is satisfied by thermal power plants (total installed capacity of 1,350 MW, which can burn either oil or natural gas). The share of the thermal plants in the generation mix of the country is on average 30-35%.

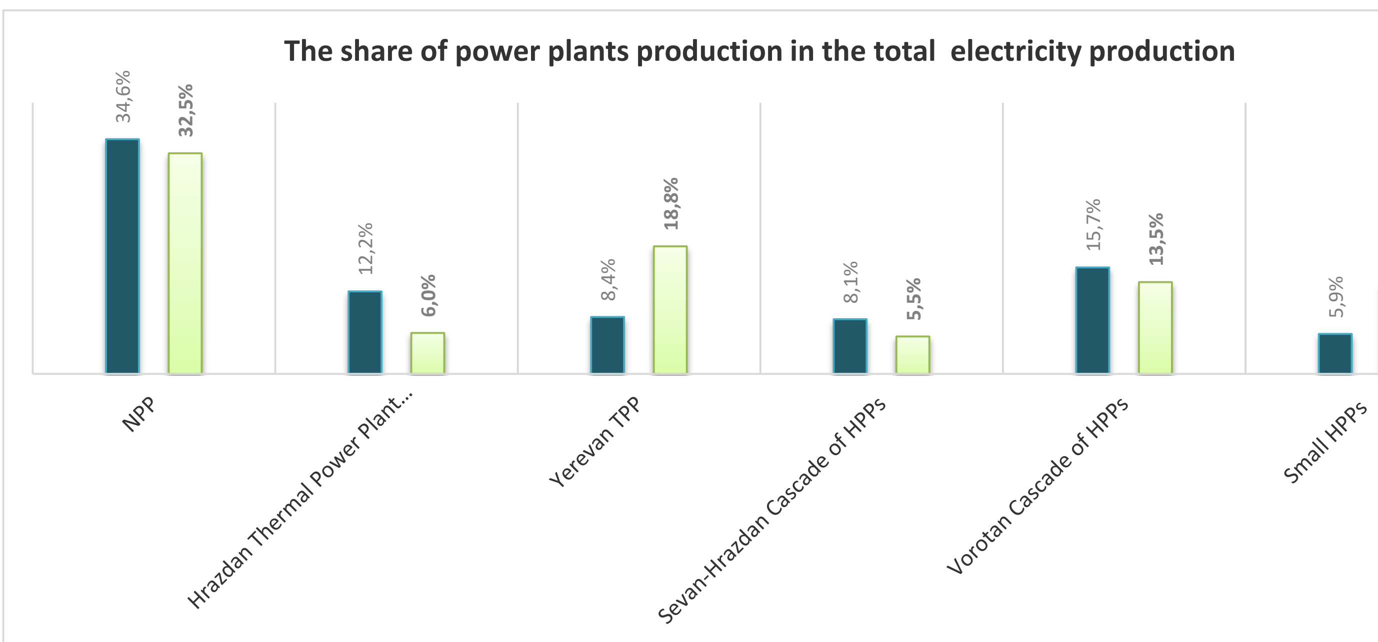
Presented data concerns period of 2001-2016 historical time series of electricity production, distribution and consumption (yearly, quarterly and monthly). The data showed that electricity demand increase about 4 percentage during last years, and as per the forecast about 2 % growth will occur.

Figure 2



Due to production growth the electric power station's production weights of total production has been changes essentialy. For example, the weight of SHPPs increased from 2% (2003) to 10.2% in 2015 (See Figure 3).

Figure 3



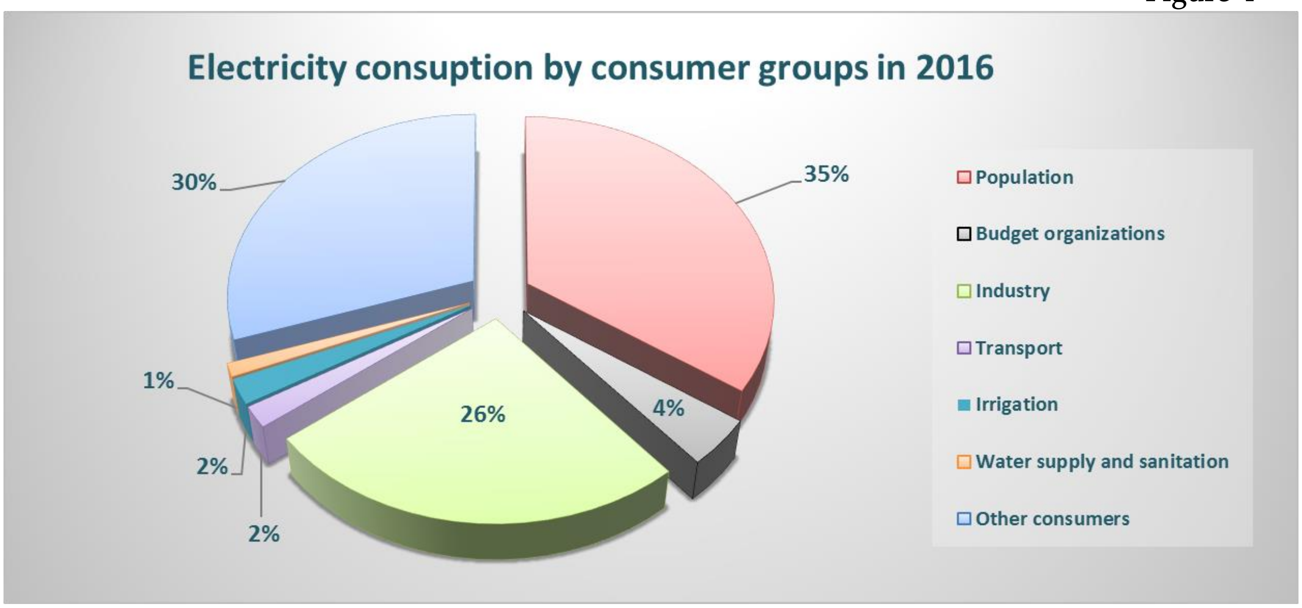
Armenia has limited energy resources. Electricty production mainly depends from import of energy resourses: natural gas from Russia and Iran, nuclear fuel from Russsia. Thus electricity production depends from imported natural gas, as we have already maintioned above about 25% of electricity production are provided by thermal power plants. The share of nuclean power plant can change around 10 percent which is explained by the installed capacity of nuclean power blog. In 2007, the Public Services Regulatory Commission (PSRC) set renewable energy feed-in tariffs for small hydropower plants (SHPPs), wind, and biomass to stimulate private investment. The feed-in tariff regime guarantees purchase all of the power generated by renewable energy plants for 15 years. Therefore we estimated electricity production function depended from use of natural gas in the electric power production. Econometric model is follow.

$$Q_{et} = 154.43 + 0,64 * Q_{et-1} + 0,75 * Q_g \qquad (1)$$
$$\qquad\qquad (9,69) \qquad\qquad (3,77)$$

where Q_{et} is electricity production, Q_{et-1} electricity production in previews month and Qg is use of natural gas from electric power objects. The data covers the period from 2003 to 2016 monthly basis. The model is significant, the positive coefficient of the natural gas argues the fact that approximately 30% of imported natural gas is used for electric power production.

According to Armenia's National Statistical Service, population consumption share of the total electricity consumption is 35% in 2016 (Figure 4), 26 percent consume industry, 4.% budget organizations, etc. The large part of demand goes to population and industry.

Figure 4



We estimated the change in demand of electricity consumed by the population by ARIMA (Auto Regressive Integrated Moving Average) method. The best model was ARIMA (4,1,0).

$$\Delta E_{Pt} = 3,41805 - 0,46817 * \Delta E_{Pt-1} - 0,63320 * \Delta E_{Pt-2} - 0,44145 * \Delta E_{Pt-3} + 0,29082 \Delta E_{Pt-4} \qquad (2)$$

where ΔE_{pt} is difference of electricity consumption by population at t time. The data covers the period 2003-2016 in quarterly basis. The model shows that electricity consumption growth currently depends on its lagged values of the previous four quarterly, this explains that the consumption function is periodic and has a seasonal characteristics.

Electricity consumption function has seasonal characteristics: it is decreasing in spring or summer times, and increasing in winter and autumn

For many large groups of electricity consumers (for example population) natural gas and electricity are alternatives. Therefore, it is assumed that changes of the price of natural gas will cause fluctuation in electricity consumption.

Over the last ten years the prices of natural gas for consumers have been changed 7 times, so the the available historical set is small to use classical regression analysis.

Traditional approaches of forecasting and evaluating electricity load include regression and interpolation factors, that can occur some problems. We used regressions based on fuzzy logic to forecast dependent variable under the uncertainties

This suggested method is intending to use optimally the available data and gives the decider the opportunity to intervene and to use his experience in order to improve the quality of predictions. The present paper considers the model of Tanaka

Model assumptions

- relationship is given by a fuzzy function
- consumption is observed as a dependent variable, and explanatory variables the price of natural gas and seasonal variable
- method are making use of triangular fuzzy numbers
- the model data cover the period from 2003 to 2013. Each year separated the two season: spring-summer, fall-winter.
- Weighted average method of defuzzification have been used

The fuzzy linear reggresion model will be .

$$C_{el} = \widetilde{\beta_0} + \widetilde{\beta_1} p_g + \tilde{\beta}_2 w \qquad (3)$$

Where C_{el} is electricity consupmtion, p_g is a price of natural gaz, w is the weight of seasonal consumption in total consumption. ` $\widetilde{\beta_0}$, $\widetilde{\beta_1}$ $\tilde{\beta}_2$ are symmetric fuzzy numbers presented by . $\widetilde{\beta_0} = (m_0, c_0)$, $\widetilde{\beta_1} = (m_1, c_1)$, $\widetilde{\beta_2} = (m_2, c_2)$, where c_j and wj are respectively its center and its width.

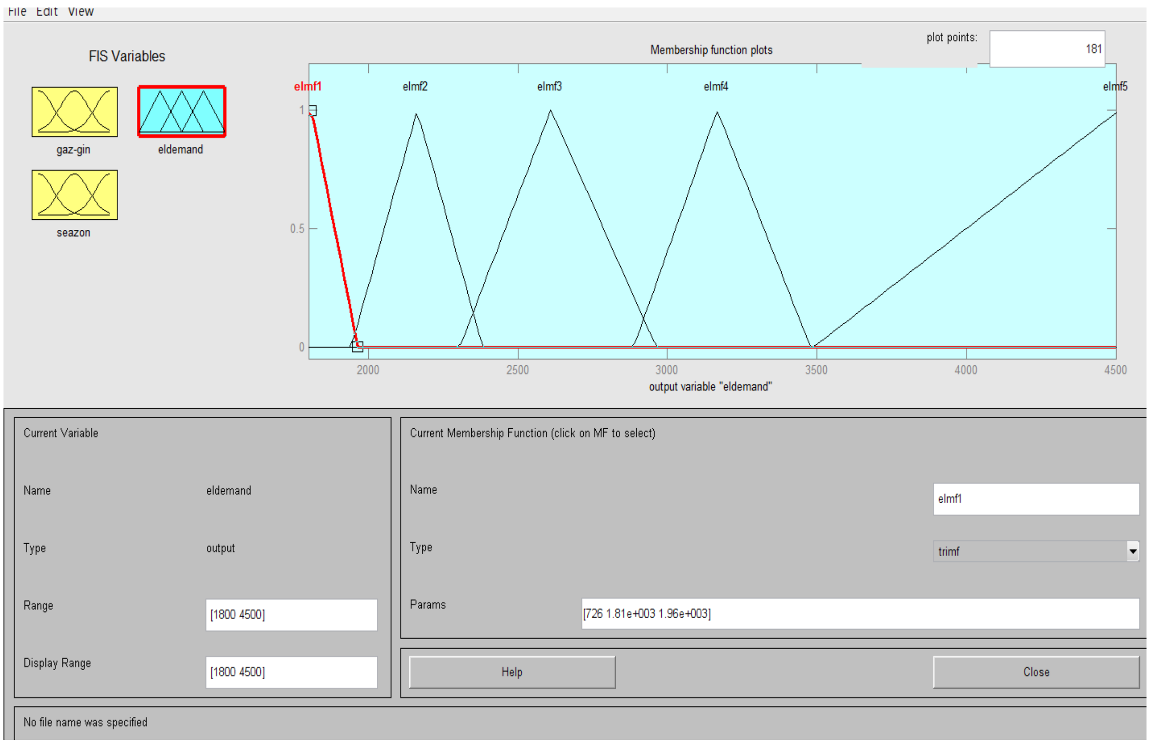
We derived the membership functions, which can be attached to the level fuzzy function. Here we will focus on the triangular membership function.

$$\mu_Y(y) = \begin{cases} 0 & y \le y_a \\ \frac{y-y_a}{y_m-y_a} & y_a \le y \le y_m \\ \frac{y_b-y}{y_b-y_m} & y_m \le y \le y_b \\ 0 & y \ge y_b \end{cases}$$

Where $\mu_Y(y)$ –is a membership function, Y_L, Y_U provide the curves for which the grade of the membership starts from zero, y_m provide the level for which the degree of membership reaches 1(for exmple center of that interval).

Picture 1.

Membership functions of model parameters in MATHLAB

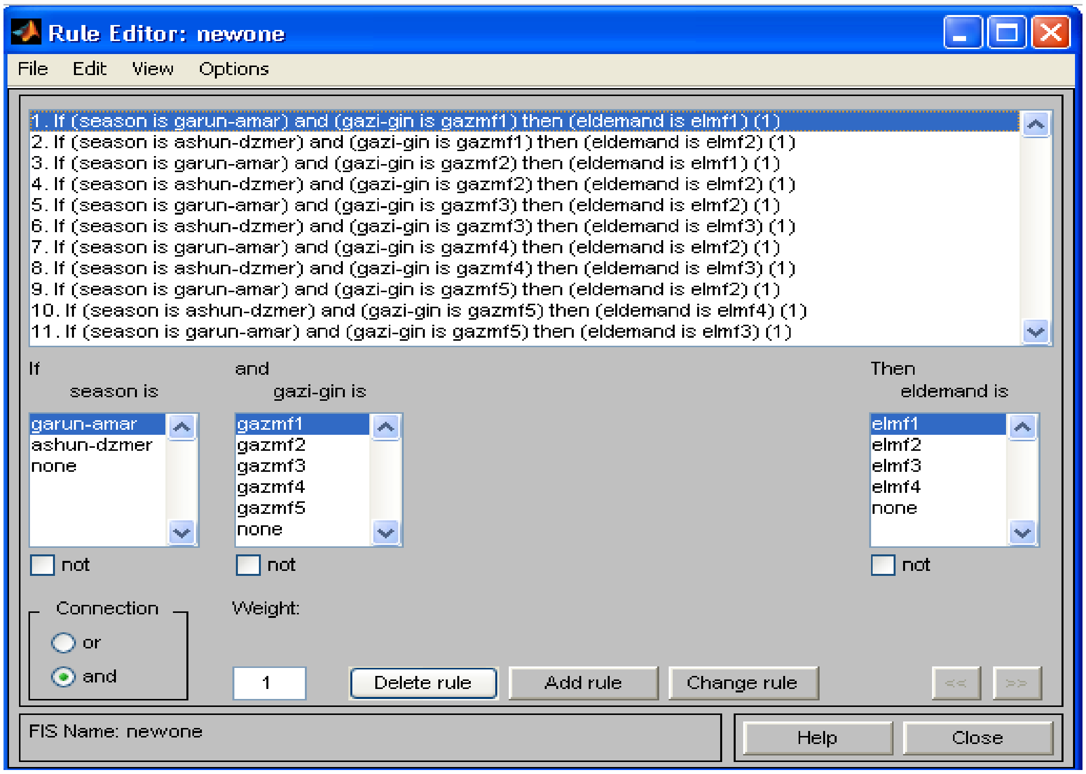


In this paper we built membership functions both for dependent and independent variables, where in all cases for all parameters we observed triangular fuzzy functions. Then we formulated fuzzy rules for dependent and independent variables. The following fuzzy logic have been used for estimating the electricity consumption.

If the weather is warm and the price of natural gas is rising, then the power consumption varies in a certain interval.

Picture 2

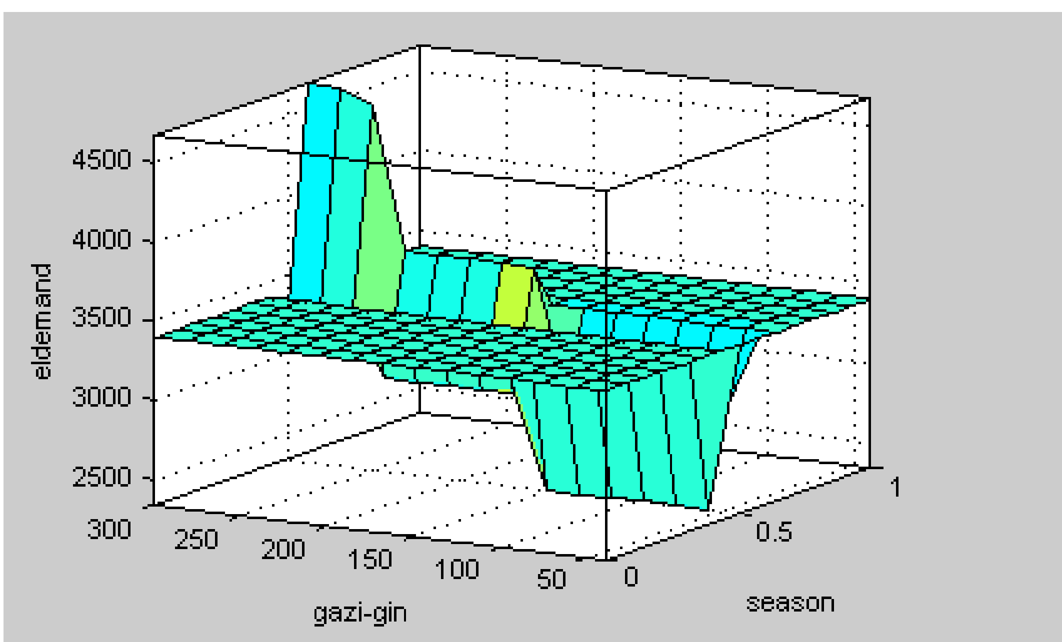
Rules Editor in MATHLAB



After all, we can construct the fuzzy surface.

Picture 3.

Fuzzy surface



In Picture 3 eldemand is a level of electricity consumption, gaz_gin - the average price of natural gas, season- is seasonal dummy variable. Through the surface is presented electricity load in RA. As you can see from the picture load has a peaks depending on the seasonality of demand function of electricity. At the peak time electricity load is providing by the small hydropower plants. The basic share of load provides nuclear plant in RA.

To get rid of uncertainties we use Weighted average method of defuzzification. For the discrete data it is calculated by this way.

$$Y=\mathrm{Defuzz}(\tilde{Y})=\frac{\sum \mu_Y(y)y}{\sum \mu_Y(y)}$$

If the independent values are also uncertain, it is possible to use the same logic for estimating its values. For every different combination of independent variables we receive different value of defuzzification. Thus if we assume that the price of natural gas is 129 dram for 1 cubic meters, and the weather is cold fall-winter period of the year, then the electricity demand is 2910 mln kWh for observed 6 months (see Pictures 4a)).

a) b)

If we assume that the price of natural gas is increased by 171 dram for cubic meters and the weather is still cold, then the electricity consumption will be 3680 mln kWh (see Picture 4 b)) due to the model.

We introduce a new approach fuzzy linear regression to estimate electricity demand in RA, which depends on the price of natural gas and the period of the year

Risk Analysis

There are three main components in the energy supply chain:

The energy commodity: either the generation of electricity at power plants or the production of natural gas

Network services: which includes transmission or moving the energy in high volumes from their sources toward end users and distribution or supplying and metering energy to end users' premises

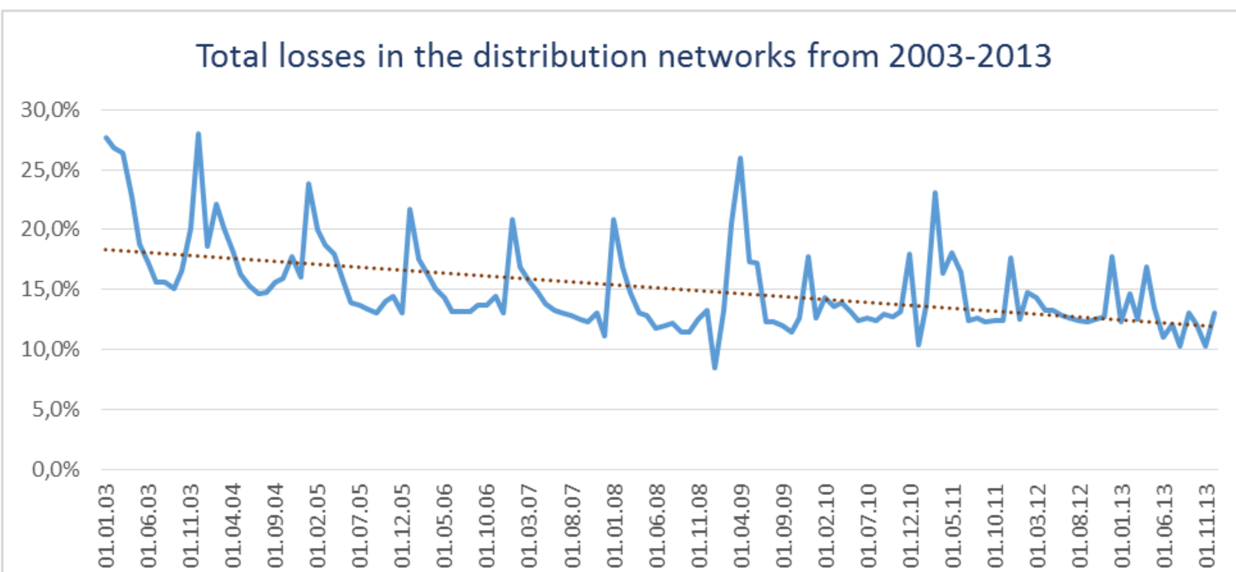
Retail services: billing and managing price risk for end users.

Each of these components may be undertaken by separate businesses.

We study losses of electric power network of Armenia as a risk factor of coordination sustainable supply chain. Calculation of electric power losses are the most important indicators of seller-buyer, supplier-consumer mutual financial relationships

The losses in the transmission and distribution networks have been 15.1% of the electricity production in 2010, but in 2015 it was 13%, while electricity consumption during these years increased by 1.6%(See Figure 4). The investments have been executed through the state budget include credits. The credits further repayment however, is implemented through the tariff. That sould be noted, the state expenditures in the electro energy sphere are considered to be rather small part of the state budget: in 2003 it was only 3,6 % of the total cost, and in 2013 it was 0,5%.It was revealed that investment and regulation area for small hydropower producers in Armenia are quite favorable. As it is shown in the graph the losses describe seasonal characteristics and from 2003 to 2013 it is decreased.

Figure 4



The Electricity Supply chain losses are recorded in high voltage networks and distribution networks. The distribution networks losses are: losses from trade and technological losses.

We built optimization problem to define optimal level of the electric power production and and supply which will minimize the losses of the supply chain network of electric power. This means also hat we will have received optimal weighted average price at which electricity supplier for the intermediate company (the company's chain of High Voltage Electric supply). If the purchase price of electricity is the least, the sale price will be minimal. That is mean that we will have optimal situation for three players (generator, supplier and consumer) of the supply chain network of electric power

Optimization problem will be follow.

$$w_1q_1 + (q_1 - w_1q_1 + q_2)w_2 \to min \tag{4}$$

$$q_1 + q_2 \le \hat{q} \tag{4.1}$$

$$q_1 - q_1w_1 + q_2 - (q_1 - q_1w_1 + q_2)w_2 = \widetilde{d_{el}} \tag{4.2}$$

$$a\hat{q} \le q_2 \le \underline{q_2} \tag{4.3}$$

where w_1 technological losses of high voltage electricity networks in percentage of entry of electric power and w_2, respectively, the Electricity Networks of Armenia company's losses. Losses are considered as parameters of the request. qi s the quantity of electricity flow to high-voltage electricity networks, q_2 is the production of small hydropower plants(see Figure 1), q1- and q2 are the variables of the problem.

The objective of optimization problem is to determine the levels of production, in which case the total losses will be minimal. (4.1) shows that the number of production has to be less than initially estimated level of electricity production,(4.2) shows that supplied electricity will be equal to the estimated demand(we have already represented above the estimation and forecast of demand by fuzzy linear regression analysis). (4.3) we put quantitative limits as defined by the limitations of small hydropower production level. The installed capacity of the production volume corresponding to the total electricity load is the weight of a small hydropower plant, where a- is a parameter produced by small hydropower plants in recent years. After solving these model we get the optimal prices for consumers in the electric power market for Armenia which is much less that the current prices about 40 percent, that's mean that the regulation of market isn't effective and needs reforms.

As a result, we offer a dynamic model, where you can change the price of natural gas, choose the season and after receive an optimal flow of electricity from generator to consumer , in which case there will be minimum losses within the system. The advantage of this model is that it works even when the available historical set is small, the assumptions related to the data are not gathered, the relationship between input and output is vague, the variables can be themselves fuzzy, it is possible to use logical elements that adapt to any situation and the market model.

During the coordination of the supply chain it should be considered in determining the development trends that directly affect major economic sectors, particularly energy. For the evaluation scenarios of electricity demand we base for the economy's future growth in the GDP forecast. Then we suggested different scenarios of electricity production and distribution which is shown in table 1.

Table 1

Year-1	***2016***	***2019***	***2024***
GDP (%)	***3,50***	***4,50***	***6,00***
Year	***2017***	***2020***	***2025***
Demand of electric power(%)	1,07	1,38	1,83
Electric power production(mln kWth)	***7573,65***	***7594,28***	***7625,24***
ANPP	1996,3	2002,3	2011,2
Vorotan HPP	1165,6	1288,1	1157,9
Sevan-Hrazdan HPP	1044,9	1008,4	1058,3
Yerevan TPP	1233,4	1197,4	1248,1
Hrazdan TPP	1083,6	1047,2	1097,2
SHPPs	***645,85***	***647,79***	***650,69***
High Voltage Electric network	6629,7	6649,6	6679,5
Electricty Networks of Armenia	7275,535	7297,4	7330,2
Inner Consumption	***6441,10***	***6549,85***	***6579,27***
Population	2318,8	2325,8	2336,2
Other Consumer	4122,3	4134,7	4153,3

As a result, the proposed model can be expanded by adding variables that are related to environmental issues, ecological risks and other stochastic components.

Methods

The solution of optimization problem yields the equilibrium electric power flows from manufacturer to supplier in which case electricity supplier will obtain maximum profit. We use econometric linear regression and nonlinear regression analysis. We use multiple regression analysis to estimate electricity demand of population depending of relative price of electricity and gas, energy intensity of GDP and consumption of gas.

In some cases information about electricity consumption could be inadequate or have an interval or fuzzy description. Traditional approaches of forecasting and evaluating electricity load include regression and interpolation factors may lead to some problems. We used regressions based on fuzzy logic to forecast dependent variable under the uncertainties, additionally to estimate the RA electric consumption logic terms of fuzzy the logic has been applied, affiliation triangular functions have been built for both dependent and independent variables. We presented the use of fuzzy regression analysis method to estimate electricity demand under uncertainty, and as a result we define electricity consumption level depending on season and price of importing natural gas. We are able to define the membership functions, which can be attached to the level fuzzy function. To get rid of uncertainties we use weighted average method of defuzzification. If the independent values are also uncertain, it is possible to use the same logic for estimating its values.

The risks of supply chain network in general can be classified into three different categories: risks of the company that are involved in the supply chain, risks that arise in the whole supply chain and risks external to network and its environment. To respond to the risks of supply chain management, we applied to likelihood or probability method for qualitative and quantitative assignment, conditional value at risk, and an efficient Monte Carlo simulation method, as well as the sample average approximations was adopted.

The variational inequality formulation is utilized to provide qualitative properties of the equilibrium electric power flow and price pattern of the supply chain of electricity network.

Results

We grouped the whole field of supply chain risks into a risk catalog, and then we use it as a resource for managing the risks and make different decisions in the energy market of RA. Conclusions are as follows:

- ✓ we presented the use of fuzzy regression analysis method to estimate electricity demand under uncertainty,

- ✓ we derive equilibrium electricity flow in the electricity market of RA based on the supply chain network approach, and optimal weighted average tariff of sales,
- ✓ we also described the role of each unit of the electricity system in electric power system and the behavior of electric power supplier in RA, its profit maximization problem and constrains,
- ✓ we illustrated risk management scenarios according to the optimal production and distribution quantities of electric power network of RA,
- ✓ we illustrated electricity demand scenarios according to different levels of economic growth and corresponding scenarios optimal production and distribution quantities of electric power, as well as the weighted average price of sales.

Achieved results can be used in the long-term development plans for Ministry of Energy and Natural Recourses and in the strategic planning processes for Public Services Regulatory Commission of the RA.

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