FUZZY-ANP BASED RESEARCH ON THE RISK ASSESSMENT OF BIOGAS PRODUCTION FROM AGRICULTURE BIOMASS

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ABSTRACT

Due to the European Union policy in promotion of the use of renewable resources for energy production, biogas production from agriculture biomasses is becoming more popular in Latvia. At the moment there are 32 biogas stations that produce biogas from agriculture biomass, and building of around 20 more is planned. Biogas production from agriculture biomass includes several complicated processes: growing of green biomass; preparation and storage of biomass for use in the reactor; running of the biogas plant, and monitoring of biogas production; cogeneration and use of the produced electricity and heat, and utilization of digestate. All these production processes are affected by various risks that can be divided into several groups: personnel, production, property, logistic, environment and legislative. In the present research risks were identified by experts and producers of biogas. Besides identifying the risks, biogas producers also evaluated the probability that the risk event will occur as well as the potential significance of the consequences of risk occurrence. The use of the Fuzzy-Analytic Network Process (ANP) method gave a possibility of evaluating the mutual impact of risks as well as the risk management alternatives.

Keywords: Analytic Network Process (ANP), Fuzzy-ANP, risk assessment, biogas production.

1. Introduction

Following the world tendencies, the topicality of renewable energy production in Latvia is increasing. Currently, most of the electricity from renewable resources in Latvia is obtained from hydropower plants, but 1% of electricity is produced by cogeneration of biomass, which is seen as a perspective source for increasing renewable energy production while utilising food and agriculture waste, thus contributing to the sustainability principles of the production cycle. The development of biogas production plants is largely encouraged by funding from the EU structural funds, Cohesion fund, and European Agriculture Fund for Rural Development available from the government of Latvia and the EU in the past few years (Rivza, 2012).

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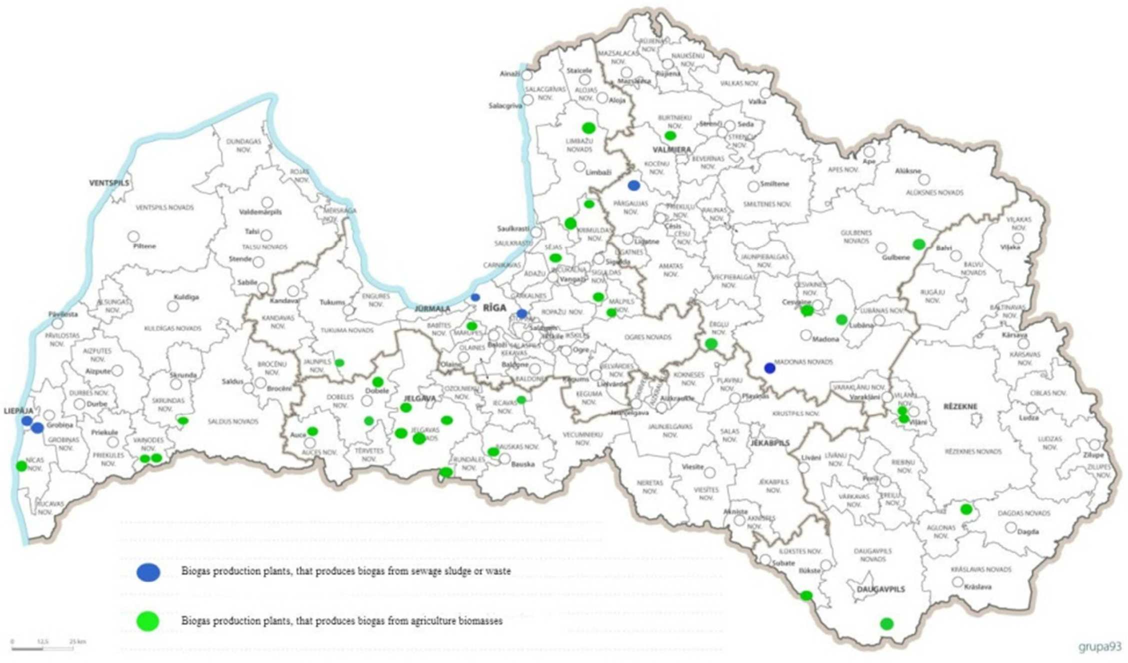
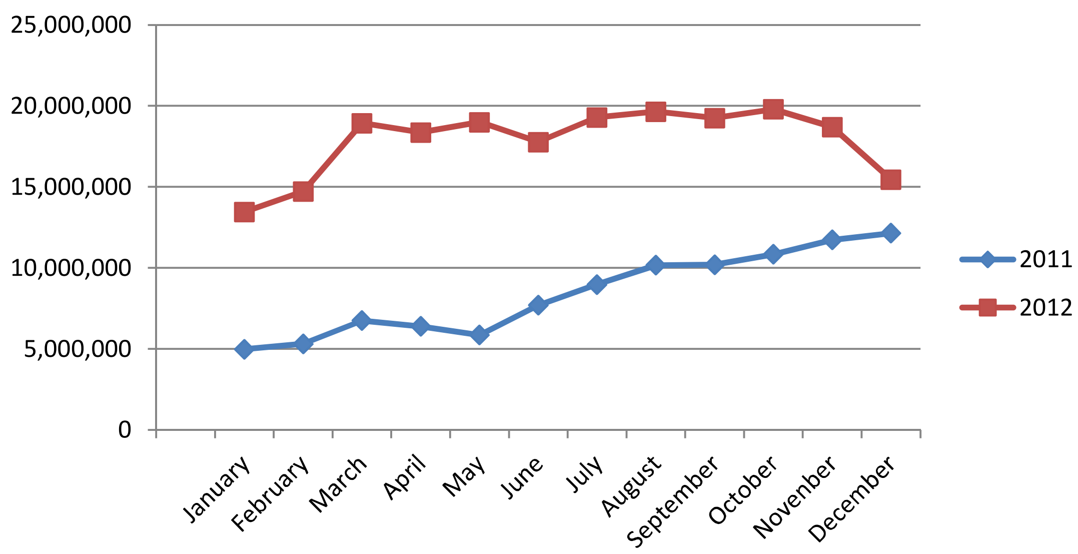
At the moment there are 38 biogas production plants working in the territory of Latvia – 6 of them are producing biogas from waste and sewage sludge and 32 produce biogas from agriculture biomasses. In 2012, biogas stations produced 214.34 GWh of electricity, which is a rather big increase compared to the 100.96 GWh produced in 2011 (Figure 2). Such increase in production was made because of the support mechanisms for renewable energies – above-mentioned EU funding for investments in building biogas production plants and advantageous purchase tariffs for the produced energy.



Source: made by the authors, using data of the Ministry of Economics of the Republic of Latvia.
Figure 1. The mapped location of the biogas production plants in Latvia.



Source: made by the authors, using data of the Ministry of Economics of the Republic of Latvia.
Figure 2. The dynamics of electricity produced from the biogas in Latvia in the years 2011 and 2012, KWh.

As biogas production is a new sector in Latvia, there are several risks, that that have not yet been studied and defined, and an attention should be paid to the estimation of the significance of these risks and to the choice of risk management alternatives.

2. Methods and Results

The input data for the use of Fuzzy-ANP was obtained from the risk evaluation performed in the 15 biogas production plants that produce biogas from agriculture biomasses. The risk evaluation form was prepared by the authors of the paper together with three experts – two producers of biomass and one representative of the Latvia Biogas Association. The evaluation form included 24 risks that were divided into six groups: personnel, production, property, logistic, environment and legislative risks.

The risk evaluation form was based on the literature review showing that the risk classification in this field is mostly related to the cause of risk. Dominating groups among others are technological, environmental, legislative, financial and investment risk groups (Olivier, s.a., Financial Risk Management, 2004, Froggatt, Lhan, 2010., Ferraris, s.a.), less common are such groups as social, macroeconomic, resource, short-term and long-term operating risks and reputation risks (Financial Risk Management, 2004, Froggatt, Lhan, 2010, Aragonés-Beltrán, Pastor-Ferrando, 2009).

Table 1. Classification of assessed risks.

Risk group (cluster)	Risk
1.Personnel	1.1.Responsibility of the personnel 1.2. Qualification and experience 1.3. Work safety violations
2.Production	2.1. Low-quality biomass 2.2. Instability of the microbiological processes in the bioreactor 2.3. Technical problems with the units 2.4. Operation problems of the cogeneration equipment 2.5. Utilization possibilities of the produced biogas 2.6. Connection with the state electricity network 2.7. Utilization possibilities of the produced heat 2.8. Delayed accessibility of service, and parts for technical equipment
3.Property	3.1. The outer security of the energy production plant and other production facilities 3.2. Fire and lightning security 3.3. The risk of the inaccessibility of financial resources incl. crediting for investments in the enterprise 3.4. Credit risk (for covering the existing liabilities)
4.Logistic	4.1. Irregular supply of biomass 4.2. Problems with storage of digestate 4.3. Problems with storage of biomass 4.4. Accidents during the transportation of biomass 4.5. Accidents during the transportation of digestate
5.Environment	5.1. Problems with using the digestate for fertilization (meteorological effects, complaints from the local inhabitants, etc.) 5.2. Environment risks that may arise when using the digestate for fertilization
6.Legislative	5.1. Changes in energy policy 5.2. Changes in the purchase tariffs of heat or electricity

Source: made by the authors.

Experts were asked to assess the probability of the risks to occur in the scale of 1 - 5 points (from unlikely to frequent), to assess the potential losses of the risk occurrence in the scale of 1 - 5 points (from negligible to catastrophic) and choose one or several risk management alternative for each risk form the list of five alternatives (Rivža, 2012) – risk avoidance, risk reduction; risk acceptance, risk transfer and diversification.

After obtaining the results from the expert evaluation, the linguistic scale, in which the probability and significance of risks were assessed, was transferred into triangular fuzzy scale as shown in Tables 2 and 3.

Fuzzy set theory was first developed by Zadeh in 1965. He was attempting to solve fuzzy phenomenon problems, including problems with uncertain, incomplete, unspecific, or fuzzy situations. (An Integrated approach..., 2012). The concept of fuzzy numbers originates from the fact that many qualitative phenomena in the real world cannot be expressed by precise and certain numbers (Ranjbar, Khatami, et.al., 2006, Zegordi, et.al., 2012). Fuzzy set theory is more advantageous than traditional set theory when describing set concepts in human language. It allows us to address unspecific and fuzzy characteristics by using a membership function that partitions a fuzzy set into subsets of members that ‘‘incompletely belong to” or ‘‘incompletely do not belong to” a given subset (An Integrated approach..., 2012).

In this study fuzziology was used to process the judgements of the experts and get values for further use in the ANP. Although combining the use of Fuzzy numbers with decision making methods is criticised (Saaty, Tran, 2007, Saaty, Tran, 2010), in this case it was used to make the transition from the two risk evaluation linguistic values for probability and significance of each risk to one defuzzification value that can be used for further calculations.

The most suitable for our research was the triangular fuzzy function due to its applicability in representing the particular linguistic variables and simplicity in modelling easy interpretations (Torfi, et al., 2010). It can be described with the following mathematical expression (Ross, 2005):

$$\mu_A(x) = \begin{cases} 0 & if\ x \le a \\ \dfrac{x-a}{b-a} & if\ a \le x \le b \\ \dfrac{c-x}{c-b} & if\ b \le x \le c \\ 0 & if\ x \ge c \end{cases} \qquad (1)$$

Table 2. Triangular fuzzy scale for evaluation of the probability of risks.

Linguistic scale	**Characterization**	**Triangular fuzzy scale**
Unlikely	Could happen only under rare conditions	(0, 0.125, 0.25)
Seldom	Could happen though unlikely	(0.15, 0.30, 0.45)
Occasional	Could happen during one year	(0.35, 0.50, 0.65)
Likely	Could happen once in several month	(0.55, 0.70, 0.85)
Frequent	Mostly happens at least once a month	(0.75, 0.875, 1.0)

Source: made by the authors.

Table 3. Triangular fuzzy scale for evaluation of the significance of risks.

Linguistic scale	**Characterization**	**Triangular fuzzy scale**
Negligible	Up to 1% from the total budget of the enterprise	(0, 0.0075, 0.015)
Minor	1-5% from the total budget of the enterprise	(0.005, 0.025, 0.055)
Moderate	5-10% from the total budget of the enterprise	(0.045, 0.0775, 0.11)
Critical	10-25% from the total budget of the enterprise	(0.09, 0.195, 0.30)
Catastrophic	Above 25% from the total budget of the enterprise	(0.20, 0.60, 1.0)

Source: made by the authors.

After defining the fuzzy scale for significance and probability, it should be connected with both risk evaluation elements. From the analysis of the scientific literature on the notion of risk (Hardaker, Huirne, 2004, Baoding, 2011, etc.) and the principles of risk definitions by German sociologist Ortwin Renn (Renn, 2008) authors suggest the following definition of the term ”risk’’:

Risk is the multiplication of the probability of an event occurrence and its significance level of potentially unfavourable consequences.

This can be mathematically described as:

$$\text{Risk} = \text{Probability (of an event)} \times \text{Significance (loss)} \qquad (2)$$

And if, in compliance with the equation (2), the two fuzzy functions of probability and significance are multiplied (Meixner, 2009), the risk as a fuzzy function value is obtained (Table 3). In such a way the risk becomes a fuzzy function, but in order to use these variables further on, the defuzzification process was done - for each fuzzy value a scalar value was calculated using the centroid method (Ross, 2005). For this purpose we used MATLAB Fuzzy Logic Toolbox (Defuzzification Methods, 2013).

Table 4. Risk defuzzification.

Linguistic scale	**Triangular fuzzy scale**	**Defuzzification value**
Unlikely with negligible loss	(0, 0.00187, 0.00375)	0.0019
Unlikely with minor loss	(0, 0.00687, 0.01375)	0.0069
Unlikely with moderate loss	(0, 0.01375, 0.02750)	0.0138
Unlikely with critical loss	(0, 0.03750, 0.0750)	0.0375
Unlikely with catastrophic loss	(0, 0.1250, 0.250)	0.125
Seldom with negligible loss	(0, 0.00337, 0.00675)	0.0034
Seldom with minor loss	(0.00075, 0.01275, 0.02475)	0.0128
Seldom with moderate loss	(0.00675, 0.02812, 0.04950)	0.0281
Seldom with critical loss	(0.01350, 0.07425, 0.1350)	0.074
Seldom with catastrophic loss	(0.030, 0.240, 0.450)	0.2400
Occasional with negligible loss	(0, 0.00487, 0.00975)	0.0049
Occasional with minor loss	(0.00175, 0.01875, 0.03575)	0.0188
Occasional with moderate loss	(0.01575, 0.04362, 0.07150)	0.0436
Occasional with critical loss	(0.03150, 0.12325, 0.1950)	0.1133
Occasional with catastrophic loss	(0.070, 0.360, 0.650)	0.3600
Likely with negligible loss	(0, 0.00637, 0.01275)	0.0064

Continuation of Table 4.

Linguistic scale	**Triangular fuzzy scale**	**Defuzzification value**
Likely with minor loss	(0.00275, 0.02475, 0.04675)	0.0248
Likely with moderate loss	(0.02475, 0.05912, 0.09350)	0.0591
Likely with critical loss	(0.04950, 0.15225, 0.2550)	0.1522
Likely with catastrophic loss	(0.110, 0.480, 0.850)	0.4800
Frequent with negligible loss	(0, 0.0075, 0.0150)	0.0075
Frequent with minor loss	(0.00375, 0.02937, 0.0550)	0.0294
Frequent with moderate loss	(0.03375, 0.07187, 0.110)	0.0719
Frequent with critical loss	(0.0675, 0.1837, 0.30)	0.1838
Frequent with catastrophic loss	(0.150, 0.5750, 1.00)	0.5750

Source: made by the authors.

Defuzzification value was then determined for each of the previously evaluated risks by two elements of risk evaluation – probability and significance (Tables 4) and adapted to the particular risk evaluation (Table 5) by calculating modal evaluation values for significance and probability from the expert evaluation for each of the 24 evaluated risks and finding the respective defuzzification value from the Table 4.

Table 5. Fuzzy values.

Risk group (cluster)	**Risk**	**Mode (from the survey)**		**Defuzzification value**
		Probability	**Significance**	
1.Personnel	1.1.	Occasional	Minor	0.0188
	1.2.	Seldom	Minor	0.0128
	1.3.	Unlikely	Minor	0.0069
2.Production	2.1.	Occasional	Critical	0.1133
	2.2.	Occasional	Critical	0.1133
	2.3.	Occasional	Critical	0.1133
	2.4.	Likely	Catastrophic	0.4800
	2.5.	Occasional	Catastrophic	0.2400
	2.6.	Likely	Catastrophic	0.4800
	2.7.	Unlikely	Negligible	0.0019
	2.8.	Occasional	Minor	0.0188
3.Property	3.1.	Unlikely	Negligible	0.0019
	3.2.	Unlikely	Catastrophic	0.125
	3.3.	Occasional	Catastrophic	0.2400
	3.4.	Seldom	Catastrophic	0.0049
4.Logistic	4.1.	Occasional	Critical	0.1133
	4.2.	Unlikely	Moderate	0.0138
	4.3.	Unlikely	Negligible	0.0019
	4.4.	Unlikely	Negligible	0.0019
	4.5.	Unlikely	Negligible	0.0019
5.Environment	5.1.	Occasional	Negligible	0.0049
	5.2.	Unlikely	Negligible	0.0019
6.Legislative	5.1.	Frequent	Catastrophic	0.5750
	5.2.	Frequent	Catastrophic	0.5750

Source: made by the authors.

Table 6. Supermatrix reflecting connections of two risk groups – Personnel risks and Production risks.

		Personnel risks					Production risks					
	Nr.	1.1.	1.2.	1.3.	2.1.	2.2.	2.3.	2.4.	2.5.	2.6.	2.7.	2.8.
Personnel risks	1.1.	0.000	0.000	0.000	0.800	0.800	0.333	0.000	0.000	0.000	0.000	0.000
	1.2.	0.000	0.000	0.000	0.200	0.200	0.333	0.000	0.000	0.000	0.000	0.000
	1.3.	0.000	0.000	0.000	0.000	0.000	0.333	0.000	0.000	0.000	0.000	0.000
Production risks	2.1.	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
	2.2.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2.3.	0.000	0.000	1.000	0.000	0.000	0.667	0.000	0.000	0.000	0.000	0.500
	2.4.	0.000	0.000	0.000	0.000	0.000	0.000	0.499	1.000	0.000	0.000	0.500
	2.5.	0.000	0.000	0.000	0.000	0.000	0.000	0.396	0.000	1.000	0.000	0.000
	2.6.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2.7.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2.8.	0.000	0.000	0.000	0.000	0.000	0.333	0.105	0.000	0.000	0.000	0.000

Source: made by the authors using superdecisions.com software

The ANP was performed using *superdecisions.com* software, the module of all risk groups (see Table 1) as clusters and risks as nodes in those clusters were formulated and connected with the unilateral and multilateral connections between and within clusters, depending on logical connectivity of these risks. The evaluation was made with the acquired defuzzification values that were transferred into the 1-9 point scale established by prof. Saaty (Saaty, 1990, 2008). When the defuzzification values were adjusted to the nine point scale, the pairwise comparison was done with the risks that had been previously connected within or between the clusters.

Table 6 illustrates the evaluation of risks in two risk groups – Personnel and Production. To use the ANP model further, also the risk management alternatives were evaluated in respect to all the risks in the module, but in the evaluation of alternatives the summed evaluation from experts for the suitability of each alternative for each of the risks is used.

3. Conclusions

Sector of biogas production in Latvia is a new sector that is subjected to various risks, therefore comprehensive risk determination and classification is an important precondition to successful and meaningful risk management.

Use of Fuzzy-ANP method in risk management gives an opportunity to perform the risk assessment by including tangible and intangible factors, and to evaluate various dependencies between risks and alternatives, making it a valuable tool for risk assessment.

The use of the fuzzy values for evaluation helps to deal with uncertain, incomplete or unspecific values that are characteristic to risk assessment. In this paper the fuzzy values were used to transfer two linguistic components (probability and significance) of risk evaluation to one value indicating risk level that can be further used in ANP.

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