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Application of Multi Criteria Decision Making for the Selection of Optimal Solid Wood Fuel Supply

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Abstract - **Production of solid fuels from wooden biomass is defined with appropriate energy chain of supply. The notion of energy chain concept has been defined as the trajectory of energy transformations from the fuel source or energy sources to useful energy form to end users. Supply chain for production solid fuels from wooden biomass is also energy chain with high importance in biomass energy planning. In this paper, base for testing and research is developed mathematical model in previous published paper with preliminary note titled as "Multi-Criteria Optimization Concept for the Selection of Optimal Solid Fuels Supply Chain from Wooden Biomass" at Croatian Journal of Forest Engineering. Three supply chains have been included in comparison: production of wood chips at the terminal – variant 1, production of pellet – variant 2 and production of wood chips by means of a mobile chipper in a forest – variant 3. The VIKOR methodology is used for total ranking all mentioned chains. Real input data have been used for mathematical calculation correspond to Bosnia and Herzegovina conditions.**

Keywords - forest biomass; wood chips; pellet, energy chain; multi-criteria optimization; VIKOR method.

I. Introduction

The multi-criteria supply chain optimal strategy developed by Vasković [1] based on four criteria: energy efficiency of the production, economy of the production, environmental issues (represented mainly by the greenhouse gaseous (GHG) emissions like CO_2 in this case) and specific investment cost per totally installed power of all machines and plants in the observed solid wood fuel supply chains. The authors in published paper [1] investigated the production of solid biofuel including different options, such as production of briquettes, pellets and wood chips using wood residues from forest cutting, mills or sawmills in different logistic composition of supply chains. In addition to the different criteria cited above, variation of the moisture content of the biomass is applied for all the parameters, which are depending of the moisture content. The developed mathematical model describes the most commonly used elements in wood supply chains such like: chainsaws, trucks, mobile chippers, terminals, factories, rotary dryers, pellet plants, etc. After modelling of different logistics structure supply solid fuels from biomass, their comparison is done with the use of VIKOR multi-criteria method for optimization. The VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje in Serbian, means Multi criteria Optimization and Compromise Solution) method introduced the multi criteria ranking index based on the particular measure of closeness to the ideal/aspired level solution and was introduced as one applicable technique to implement within MCDM. VIKOR method is a multi-criteria decision making (MCDM) or multi-criteria decision analysis method. It was originally developed by Serafim Opricovic to solve decision problems with conflicting and non-commensurable (different units) criteria, assuming that compromise is acceptable for conflict resolution, the decision maker wants a solution that is the closest to the ideal, and the alternatives are evaluated according to all established criteria. VIKOR ranks alternatives and determines the solution named compromise that is the closest to the ideal.

Each supply chain of solid fuels described with four aforementioned criteria. The determination of the optimal variant of supply chains depending on the (different units) criteria and mutually opposing criteria, VIKOR method is very useful and the proposed model is very practical in decision making for the selection of better variants for solid fuels supply chain.

A. *Short overview of research and literature in area of supply chains based on biomass*

The complexity of forest bioenergy supply chains which is partly resulted from complexity in forest industries supply chain in general. Forest industries consist of different related and interconnected sectors, products and markets [2]. In addition, other kinds of biomass supply chains have different complexity depending on type of biomass.

The study developed by Bennamoun [3] shows that the dry matter loss DML (Dry Matter Loss in terms of wood materials.) directly linked to the moisture content of biomass residues. Consequently, introducing the variation of the moisture content of the studied material can be an important element for the development of a realistic model and simulation of a supply chain strategy. Moisture content in wood is negative factor for economy and energy efficinecy of supply chain. With high moisture content we have negative impact to efficiency and production cost (we need heat for drying, balast in transport etc.) All modeled elements in this model, there are in conection with moisture where is wood materials included. Taking advantage of the solar radiation to reduce the moisture content of the biomass during outdoor storage and before long distance transportation can be a real advantage that can additionally reduce the transportation cost of forest biomass residues to the plant.

Also, problem of exploitation wood timber and methods for obtaining energy from biomass have researched by Halilović [4]. Energy index has been calculated for two different ways of production wooden chips and for their defined logistical composition supply [5].

A number of papers reviewed the literature related to different parts of the bioenergy supply chain. Jebaraj and Iniyan have prepared overview of energy models and allocated a small section of renewable energies in their paper to biomass and a section to optimization models in energy systems in general [6].

Optimization techniques have been applied for modelling supply chains in different industries including forest industries and biomass application [2]. Modelling of the supply chains and their optimization has the advantage in providing the optimum solution based on defined criteria which describes supply chain. Using optimization techniques in designing and management of forest bioenergy supply chain can result in better performance which helps making this energy economically acceptable [7].

Authors in [8], studied methods and literature on optimum location of forest biomass-biofuel facilities and did not consider other decisions in the supply chain.

Most of the objective functions and optimizations of energy supply are chains based on economic parameters in different reviewed literature. Based on the review of the literature and previous research, it is possible to describe the energy chains with more universal and different criteria for evaluating quality and quantity of produced energy. Also, the developed universal criteria enables the comparison of different types of energy chains with different stages in energy conversion.

More and more researchers have been involved in modelling and optimizing biomass supply chains. Paper developed by [9] presents an overview of biomass supply chains. After an outline of the main definitions and a description of typical activities in biomass supply chain; a classification of optimization methods and models developed in this context is detailed. Finally after review, a critical look at current researches and possible new directions are presented.

Optimal biomass energy supply chain can be chosen by using multi criteria optimization which fulfils previously defined sustainability criteria. This selected energy chain is very close to ideal solution in terms of sustainability [10]. Ideal solution is the theoretically best opportunity, the realisation of which is imaginary but desirable from point of view of the solution. In VIKOR method ideal solution is given from described alternatives with defined criteria. Optimal is the best working possibility which can be achieved under real circumstances. Optimal is the best solution for given boundary conditions from defined criteria for all alternatives in optimization matrix.

Pokehar and Ramachandran in they work gave an overview of the literature on existing applications for Multiple Criteria Decision Making (MCDM) in sustainable energy planning. MCDM techniques offer solutions to problems involving multiple and contradictory objectives. Several methods are based on weighted averages, setting priorities, ranking, fuzzy principles and their combinations, are the basic for the adoption of energy planning decisions [11].

All these studies did not find the universal method for optimal design of the forest biomass fuel supply chain under variable conditions analysis. Especially for conditions of optimization, which include several different criteria such as technical, logistics, energetic, economic or environmental factors. This is a good direction for the development of optimization criteria and approach to optimization method of bioenergy chains.

II. PROBLEM DESCRIPTION AND THEORETICAL ANALYSIS

Before selecting the optimum variant of fuel production from wood biomass, it is necessary to define the optimization criteria. The following criteria have been defined in previous paper [1]:

- consumed energy per 1 kWh of the lower heating value of produced biofuel, kWh/kWh (K 1);
- energy chain production cost per 1 kWh of the lower heating value of produced biofuel, EUR/kWh (K 2);
- CO_2 emission in the total chain due to the fossil fuels consumption for 1 kWh of the lower heating value of produced biofuel, kg/kWh (K 3);
- specific investment cost per totally installed power of all machines and plants in the energy chain, EUR/kW (K 4).

For the selection of the optimum variant of an energy chain of supply, VIKOR method by Opricović, [12] has been selected, as it was completely adjusted to the given problem. For the adopted criteria (K 1 , K 2 , K 3 , K 4), an equal degree of importance has been taken at the selection of the optimum variant of an energy chain for biomass fuel supply. The equal weight method (EW) requires minimal knowledge about priorities of criteria and minimal input of decision maker. If the decision maker has no information about true weights than the true weights could be represented as a uniform distribution on the unit n – simplex of weights defined by conditions (1). The n – simplex of weight is a geometric object. For instance, with n = 2 criteria and no information 2 – simplex of weights is a set of points lying on the segment line between points on coordinates (1,0) and (0,1).

Equal priority in weight of criteria is very logical, for case in this paper. We need max energy efficiency, minimum of production cost, minimum in investment and minimum of CO2 emission. This approach in decision of optimal solution in renewable energy production is only right way. Also, criteria with preference could be applied. But, that type research going in more comprehensive calculation and more conclusions could be done.

The approach of reduction to primary energy form has enabled a mathematical estimation of the total energy consumed for the production of particular types of wood fuels. With this approach, the consumed thermal energy and electricity could be summed and comparable. For mentioned model testing and specific numerical calculations for the selection of the optimum variant of an energy chain of supply, it is necessary to provide good input data, and based on them to verify the model and check its practical applicability.

III. MATERIALS AND METHODS USED IN THE STUDY AND RESEARCH PROCEDURE

As the material for research in this study, previous results will be used, as well as practical, scientific, technical and other achievements in the area of modelling of energy chains for solid biofuels production. The available technologies in the field of cutting, collection and transportation of biomass, technologies for preparation of biomass and biofuels, technologies for biomass combustion and energy production will be built in the model structure with all transferring functions. Multi criteria methods for decision making and selection of an optimal energy chain variant will be used. In this study, VIKOR multi criteria method has been applied for the selection of the optimal supply chain. The process of research and results presentation within this paper requires the application of many combined methods of scientific-research work. These are the following ones:

- Inductive and deductive methods,
- Methods of analysis and synthesis,
- Mathematical modelling,
- Numerical simulations of the model,
- Engineering methods of solving,
- Experimental methods.

The model testing and verification of the results obtained by numerical calculations for real energy chains and energy production plants. For the model, it is necessary to make an adequate program in a software package to increase the automation of the desired data calculation. The output results from the model should give answers to the characteristics of adequate energy chains for biomass supply and behaviour of particular elements of the observed energy chain pursuant to changeable conditions at energy market and changeable prices of energy. The multi-criteria optimization method occurred exactly from the striving towards a sustainable concept of the development of mankind. Because of that, the chosen methodology for the selection of optimal variant of energy production from biomass is good enough for the solving of this problem.

IV. MODEL TESTING CASE FOR THE SELECTION OF AN OPTIMAL WOOD FUEL SUPPLY

Within the testing of a model for the selection of an optimal wood fuel supply variant, three supply chains have been included: production of wood chips at the terminal – variant 1, production of pellet – variant 2 and production of chips by means of a mobile chipper in a forest – variant 3. The prices of wood waste and biomass are variable and depend on many factors. In the model for calculation, the current values of the prices of wood residue from the saw mills from municipality Han Pijesak (Bosnia and Herzegovina) have been taken. In Table 1 and Table 2, there are overview of characteristic calculations from the model and the most significant conditions used at the selection of optimal wood fuel supply variant. Calculation in developed model depends of:

- Selection of facility and technology for energy production.
- Selection of optimal fuel production depends on: the type of biomass, used machinery in the collection and processing of biomass, ground configuration, the price of fossil fuels, the price of electricity, transport distance, humidity of biomass, selection and design of energy chains based on the use of various technologies for processing technology, impacts of bioenergy markets and other factors.
- Prices of fossil fuels: oil, gasoline, 1 EUR per litre for Bosnia and Herzegovina.
- Wood biomass humidity w=50%.
- ehwo =19,49 MJ/kg lower heating value for dry wood.
- Type of biomass: wood, fir.
- Electricity price: 0,09 EUR/kWh.
- Transport distance: total distance transport 90 km.
- Average consumption of machine participants in the chain taken from literature: Krajnc N, (2011) Wood Energy Technologies. Partnership Programmes – TCDC/TCC –TCP/YUG/3201 (D). Belgrade.
- Price of wood waste from the sawmill: 0,0563 EUR/kWh.
- Drying for pellet production from 50% to 12 %.
- Workers; daily wage = 12-15 Eur/day.
- Wage for driver of trucks=25 Eur/day.
- The model take real capacities of individual plants from the Sarajevo-Romanija region for sawmill, pellet plant and the cost of wood waste.

For more information you can find in doctoral dissertation by [13]. The input of a real status of the production of these fuels, the data from sawmills and companies in the Republic of Srpska and Bosnia and Herzegovina have been used, and for that purposes the following companies should be mentioned: “Company for making of wood packaging and production of eco briquettes – pellets, EU PAL L.L.C. Pale”, sawmill “GOD” L.L.C. Han Pijesak, sawmill “MTK OMORIKA” L.L.C. Han Pijesak, Company for transportation of timber and assortments “KINGDOM” L.L.C. Han Pijesak.

For the consumption and specifications of the wood machines and mechanization included in the wood fuels production process, the results of a study from literature [14] have been used in testing this model. The data on chipping at the terminal and its capacity for the production of wood chips have been taken as one of the offered technological solution for the supply of the heating plant in the city of Prijedor with wood chips.

TABLE I. Basic input parameters for testing model at the selection of an optimal wood fuel supply variant

CHAINS FOR PRODUCTION WOOD FUELS			
Description of chains for production wood fuels	Production wood chips at terminal	Pellet production	Mobile chiper
wet	50%	50%	50%
Type of biomass	fir	fir	fir
Elements in chain	chainsaw, tractor, crane, truck, sawmill, forklift, woodchips terminal	chainsaw, tractor, crane, truck, forklift, drying, pelletizing plant	chain saw, skidder, mobile chipper, truck for wood chips
Transport distances	roundwood transport distance 60 km + residue from sawmill , slabs transport 30 km = 90 km	round wood transport distance 60 km + residue from sawmill , slabs transport 30 km = 90 km	work at forest 1 km + 90 km transport wood chips volume container 60 m^3

TABLE II. Calculated criteria for optimization for wood supply chains

CHAINS FOR PRODUCTION WOOD FUELS			
Tags: 1, 2, 3 on figures from 1 to 4	Production wood chips at terminal	Pellet production	Mobile chiper
Energy efficiency	0.94	0.68	0.97
Specific investement cost per kW	5.329×10^3	5.263×10^3	2.347×10^3
Specific production cost per kWh	17.248×10^{-3}	22.37×10^{-3}	12.867×10^{-3}
Specific emission CO_2 kg/kWh	12.365×10^{-3}	51.695×10^{-3}	4.342×10^{-3}

V. RESULT

With the application of a model created in Mathcad software for the calculation and composition of wood fuels supply chains, the optimization criteria have been obtained which have been used for the selection of the optimal wood fuel supply variant. The optimization matrix consists of 4 criteria (with equal weight of importance, 0.25) for each of the analyzed energy chains. To get a better overview of all the obtained results, all the calculated criteria will also be presented graphically for the mentioned wood fuel production variants in the continuation of the text.

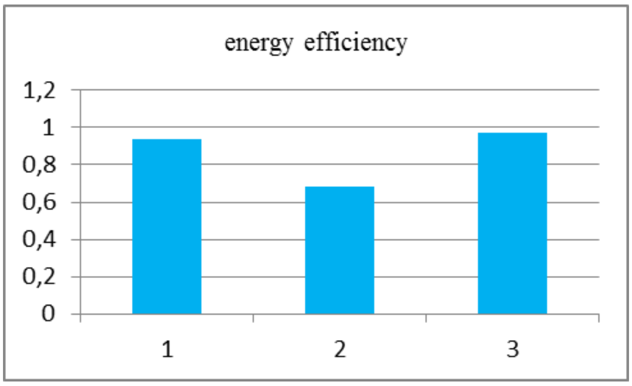

Figure 1. Energy efficiency of supply chains for production solid wood fuels (1-terminal, 2-pellet plant, 3-mobile chipper)

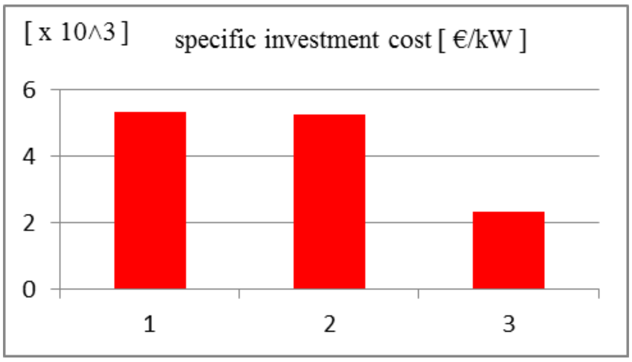

Figure 2. Specific investment cost per supply chains for production solid wood (1-terminal, 2-pellet plant, 3-mobile chipper)

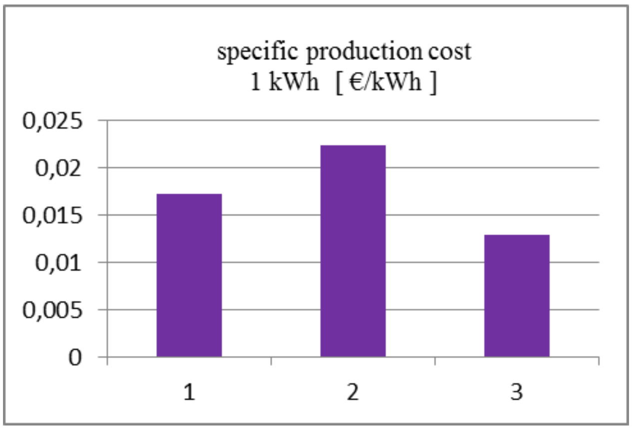

Figure 3 Specific production cost per supply chains for production solid wood (1-terminal, 2-pellet plant, 3-mobile chipper)

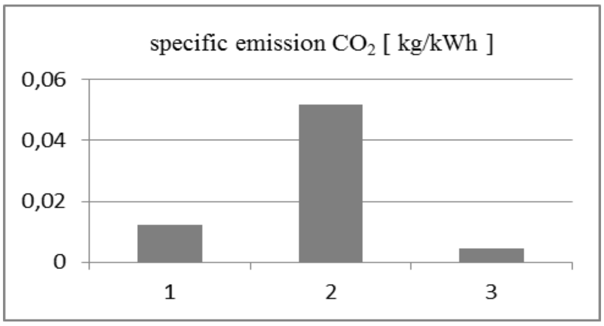

Figure 4. Specific emission per supply chains for production solid wood (1-terminal, 2-pellet plant, 3-mobile chipper)

In the following table, an overview of production costs for fuel obtained pursuant to the parameters in Table 1 and Table 2 are given.

TABLE III. Overview of production prices for solid wood fuel per ton

PRICE PRODUCED TONS OF FUEL € / T		
Wood chips from terminal	Pellet plant	Wood chips-mobile chipper
40,8	**104,7**	**30,5**

Developed model has demonstrated that the optimal variant of chipping supply is with the help of a mobile chipper, the column 3 in Table 1 and Table 2. All calculations have been carried out with the help of equations from (1) to (36) in previously published paper presented as preliminary note [1]. According to the VIKOR method calculation [12], after all calculations, matrix Q has following values:

$$Q = [q = 0; q = 0{,}703, q = 1] \quad (1)$$

For calculation values in matrix Q j equations from 8 to 17 have been applied [1]. Optimal variant is defined with minimal value in matrix Q. The amount at q=0 corresponds to minimal and it is variant with mobile chipper. This optimal solution has both the necessary stability of solution and sufficient advantage in relation to the second-ranking variant, i.e. the production of wood chips at the terminal. Then, these two conditions are defined with next equation [12]:

- Acceptable advantage

$$Q(a'') - Q(a') = \geqslant DQ \quad (2)$$

in our case:

$Q(a'') - Q(a') = 0{,}703 - 0 = 0{,}703$; where: a’’ is the second-position alternative on the rank list (Q):

$$DQ = 1/(m-1). \quad (3)$$

This is advantage threshold, in our case

$DQ = 1/(m-1) = 1/(3-1) = 0{,}5$;

where: M is the number of alternatives (energy chains).

- Acceptable stability

The alternative a’ should also be ranked as the best in S and/or R rank (matrix). In that case, the solution has been selected correctly. For our case: and this condition is satisfied and optimal solution with mobile chipper is properly selected. For our case:

$R = [R = 0; R = 0{,}251, R = 0{,}257]$

and

$S = [S = 0; S = 0{,}427, S = 0{,}994]$

These two conditions are satisfied and optimal solution with mobile chipper is properly selected. The production of wood chips at the terminal is slightly worse regarding the criteria of energy efficiency in relation to the production of wood chips with the help of mobile chippers. However, in all the other criteria, it is significantly worse than the option of mobile chipping. Of course, the production of wood chips at the terminal makes sense when there is a need for large quantities of this fuel. The third-ranking variant in this analysis is the production of wood pellet and that variant is the worst pursuant to all optimization criteria. The pellet production makes sense when the fuel is transported for the supply of remote power plants to decrease the transportation costs. In general conclusion, it can be seen that the increased number of elements in an energy chain negatively effects its quality via the adopted criteria. Also, from Table 2 and diagrams given in figures 1 – 4, by a simple overview it can be concluded that the best variant is exactly the production of wood chips by means of a mobile chipper. A logical explanation why the production of wood chips has a significant advantage in relation to other variant is the fact that a very small number of mechanization, machines and number of people which are included in this production chain. It is interesting to conclude that the application of mobile chipper, besides sawmills, is one of the possible variants which would be very efficient and applicable in practice in Bosnia and Herzegovina conditions.

VI. CONCLUSION

The significance of energy production from biomass is especially emphasizes in recent time. Basically, the most significant part in the process of energy production from biomass is the chain of supply and production of fuel from biomass. If it is possible to perform the minimization of costs of energy production from biomass, significant savings occur, especially in the financial aspect. Due to the fact that there are different opportunities for composition of energy supply chains and the ways of energy production from biomass, it is necessary to make a unique mathematical approach to this problem. With the mathematical model, it is possible to systemize different types and a great number of parameters. Exactly that is the main issue which solves the problems regarding the composition of energy supply chains from biomass. By the mathematical model developed in this paper, adequate criteria have been defined to describe the supply chains based on wood biomass, which are adapted to the process of multi criteria optimization. Such an approach combines the most important specific criteria for the description of the entire energy production chain and gives the possibility of comparing the energy chains and selection of an optimal variant for production of fuels from wood biomass. The optimal variant is obtained on the basis of multi criteria optimization, by using the adapted VIKOR method. Together with the numerical calculations, it has been demonstrated that the model gives very usable data which can be used in the evaluation of the process of solid fuels production from wood biomass. On the basis of the adopted input data, the model calculates the price of a ton of wood chips produced at the terminal, the price of a ton of pellet and the price of wood chips obtained with the assistance of a mobile chipper. There are the numerical values of the prices of produced energy, specific investments, specific carbon dioxide emissions, as well as the energy factors which completely describe the technology applied in the observed energy chains of production. On the basis of that, the developed mathematical model for the selection of an optimal chain of supply with fuels from biomass, is used for ranking and evaluation of energy chains from the best towards the worst variant. This approach can be useful tool for definition optimal fuel mix in overall structure of production fuels from wooden biomass. It could be new direction in research.

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