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PERFORMANCE INDICATORS FOR POULTRY MANURE SUPPLY MODEL ANALYSIS

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Poultry manure occupy a significant place in the available quantities of biomass for biogas production in some countries such as Bosnia and Herzegovina (BiH). Mobilization of its unused potential and optimization of its current utilization can facilitate the further sustainable growth of the bioeconomy in these countries. For optimal planning of the logistical and process infrastructure for the production of biogas from this feedstock, as well as for estimating the investment for its development, the spatial interaction model for poultry manure supply can be a useful tool. It can be applied for the interpretation of spatial variations between observed (actual) supply quantities and model-based predictions for this biomass type. Another application is for the analysis of biomass supply performances in terms of the relationship between the usage of user capacity and the availability of biomass potential.

In this context, supply performance indicators can be introduced to describe the level of biomass potential at source or its utilization capability, or both. This paper identifies and formally describes ten indicators that can be used as biomass supply usability metrics when analyzing supply models.

Keywords: biomass supply chain optimization, biogas plant, biomass flows in supply chain, poultry manure, spatial interaction model, supply performance indicators.

1. Introduction

Biomass is at the core of the bioeconomy and the demand for biomass is increasing worldwide [1]. It is therefore of particular importance to better understand how much biomass is available [2-5] and can be mobilized and transported [6] , how much is being used [7] and for which purposes [8,9] and what are the biomass flows in the economy [10]. Biomass flows include all activities of its manipulation in the supply chain, from harvesting [11], transport

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and logistics [12], to final processing [13]. Logistic, infrastructure and all activities of supplying biomass affect the final price during its delivery to the user [14]. Even though the biomass power industry has developed rapidly in the past few years [15], it is accompanied with some problems related to biomass supply chain [16, 17] and lack of optimization biomass residue [18,19].Mobilizing unused biomass potentials and optimizing its current utilization in all aspects can facilitate the further sustainable growth of the bioeconomy. For optimal planning of the logistic and process infrastructure for biomass management, as well as for estimating the investment for its development, geographic information on the unused biomass potential and biomass supply chains models are necessary. In line with the literature review [20-24], more and more researchers have been involved in modelling and optimizing biomass supply chains.

The spatial interaction model can be a useful tool for analyzing the biomass supply chain in the planning and optimization of logistics infrastructure. It can be applied for the interpretation of spatial variations between actual biomass supply quantities and model-based predictions. Supply performance indicators can be introduced to describe the level of biomass potential at source or its utilization capability. In general, the spatial interaction model and these indicators can be applied to analyses the supply of different types of biomass. This paper identifies and formally describes the indicators for supply models analysis. Their application is shown on the spatial interaction model which is based on poultry manure quantities for 25 municipalities in two cantons of BiH.

1.1 Biomass supply chains modelling

The biomass supply chain can be described in a simpler form as the flow of biomass from land to its end use site for bioenergy production. The supply chain involves typical activities such as biomass collection, pre-processing, transport and storage (Figure 1). The supply chain can be described by a network with nodes that correspond to production activities, users, warehouses, collection points or pre-processing facilities. The nodes connected by links which can represent biomass flows [20]. Collection is related to the place where biomass occurs, and storage is most often placed where it is used. Issues about supply chain efficiency are most often related to biomass availability, transportation costs and the efficiency of using the logistics system. For supply chain planning and management, several models are recognized [20], based on operational research [25] and mathematical optimization supported by computer algorithms [26,27].

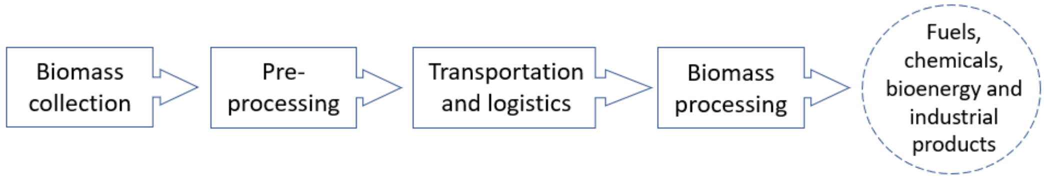

Fig. 1. Typical activities in the biomass supply chain

One of the most challenging goals for managing biomass supply chains is to design a complete multi-tier logistics system, including transportation network, raw material supply, pre-processing and distribution of biomass, also considering biomass multi-types, multi-products, and multi-modal transportation, for implementation appropriate computer models and techniques [20]. However, designing such models also requires reliable and regularly updated data that can provide them with credibility.

1.2 Online Atlas and Biomass Potential Monitoring System in Bosnia and Herzegovina

As a reliable source of information for initial research can be used statistical databases and national systems for biomass potential monitoring. This paper uses data from such a system developed in Bosnia and Herzegovina (BiH), modelled on a similar system in Germany (by German Centre for Biomass Research GmbH) [28,29].

In terms of partially available data, the process of creating the Biomass Potential Monitoring System in BiH sought to identify, collect, establish and present as much information as possible for the assessment of biomass potential at the level of state, entities, cantons and municipalities, with an appropriate level of accuracy. In this context, biomass was grouped into agricultural biomass (13 categories) and forest biomass (10 categories), since data related to these 23 categories investigated (Table 1) were largely available [29]. The monitoring system is based on the available data stored in the database linked to the available online atlas. The atlas serves as an information platform for policy makers to create decisions for sustainable use of biomass for energy production.

Table 1

Agricultural and forest biomass categories investigated in Bosnia and Herzegovina

Agricultural categories	Forest categories
Cattle manure	Annual increment deciduous
Cattle slurry	Annual increment coniferous
Poultry manure	By products of wood processing industries
Pig manure	Fuel wood coniferous
Sheep manure	Fuel wood deciduous
Pig slurry	Industrial wood coniferous
Goat manure	Industrial wood deciduous
Maize straw	Waste wood deciduous
Cereal strew	Waste wood coniferous
Corn cobs	Black liquor
Pruning residues from orchards	
Pruning residues from raspberries	
Pruning residues from vineyards	

1.3 Modelling of biomass supply and spatial interaction model

The described potential monitoring system can be used as an initial source of data for strategic analysis in terms of selection of optimal plant locations and optimization of the biomass supply chain in the transport and logistics segment (Figure 1).

In order to optimize the biomass supply chain, as a network of nodes and links, it can be developed a comprehensive model of spatial interaction between biomass users and potential biomass sources [30].

Spatial interaction model [31] of biomass supply, in simplified form (considering single region, biomass type and biomass product), may be described by expressions (1):

$$S_i^n = A_i^n Q_i \theta^n W_i^n \exp(-\beta^n c_i^n) \qquad (1)$$
$$A_i^n = 1 / \sum_n W_i^n \theta^n \exp(-\beta^n c_i^n)$$

where are:

S_i^n - spatial interaction (biomass supply quantity flow from *i*-th spatial unit to *n*-th biomass user);

i – spatial unit (an area with known quantities of biomass potential, e.g. municipality area);

n – biomass user (generator, processor or another operator);

Q_i – available quantities (e.g. unused technical biomass potential) from *i*-th spatial unit;

W_i^n – attractivity related to *i*-th spatial unit (e.g. availability of other types of biomass relevant to *n*-th user, capacity of biomass collection facilities, number of biomass sources in the spatial unit). For example, a spatial unit with more animal farms that can supply the plant is more attractive;

θ^n – attractivity related to *n*-th user (e.g. plant capacity, operational quantitative requirements of specific user, total capacity of biotech park);

c_i^n - trip costs (the duration or length of the trip from the *i*-th spatial unit to the *n*-th biomass user); In order to simplify the calculation, instead of the actual length of transport routes, can be used coefficient of tortuosity.

β^n – deterioration parameter that controls the willingness or ability to transport to n-th user (e.g. transport logistics capacity). This parameter can be further disaggregated to biomass type and biomass product type.

The sum of all biomass flows from spatial units to individual users [30] gives the total estimated quantities by users and can be expressed by equality (2):

$$TQ^n = \sum_i S_i^n \qquad (2)$$

where TQ^n presents total quantity for n-th user.

For calibration of parameters related to deterrence due to distance, it can be used one of the investigated and well described methods in literature [13,14].

However, the application of the model (with or without calibration) in the assessment of biomass source potential and user capabilities requires appropriate performance indicators.

The aim of this research is to identify, define and describe the application of indicators useful for assessment of performance related to biomass source potential and user capabilities in biomass supply spatial interaction model.

The structure of the paper is as follows: in section 2 the recognized indicators are formalized and explained; in section 3 the identified indicators are applied in model analysis, describing in sub sections 3.1 to 3.3 the web mapping system applied and a case study analysis, with a discussion of the results in sub section 3.4; conclusions are provided in the section 4.

2. Performance indicators for biomass supply model analysis

A potential application of biomass supply spatial interaction models is for the interpretation of spatial variations (at a certain level of spatial aggregation) between observed (actual) supply quantities and model-based predictions (of biomass potential). It is necessary to calibrate the model to make it useful in this regard and applicable for operational planning of unused biomass mobilization.

The other aspect of the application is for the analysis of biomass supply performance in terms of usage of the users' capacities in relation to the availability of biomass potential.

In this context, supply performance indicators can be introduced to describe the level of biomass potential at the source or usage capability at the destination or both simultaneously. When analyzing, they can be used as biomass supply usability metrics. According to the previous definition and depending on the type of information we can obtain, they can be divided into "source potential" and "destination capability" indicators whereby „source“ means a spatial unit of aggregation or a single source of biomass, and „destination“ means utilization facility, with its geographical position.

In this paper, ten indicators are identified, some of which belong to the first defined group, some to the second group, and some of which can be classified into both groups. Most indicators involve a comparison of the performance of two or more individual users, or facilities.

Below, these indicators are listed with their formal description, wherein the following codes are used with the definitions:

S_i^n - biomass supply quantity flow from i-th spatial unit to n-th biomass user;

i – spatial unit (spatial level of aggregation of quantities from biomass sources) with geographical location;

n – user of biomass or plant with geographical location.

2.1. User supply share from the spatial unit

SSU (User Supply Share from the Spatial Unit) is the destination capability indicator [30] used for biomass supply usability metrics. This can be described by the expression (3):

$$SSU_i^n = S_i^n / \sum_n S_i^n \tag{3}$$

The SSU indicator describes the level of utilization capability of individual users from a spatial unit, i.e. how the biomass supply from individual spatial units is distributed by users. This information is useful for assessing users' participation in supply and for comparing their representation at the level of individual spatial units.

2.2 Ratio of supply of users from the spatial unit and total regional supply

RUR (Ratio of User Supply from the Spatial Unit and Total Regional Supply (RUR) is the source potential and destination capability indicator [30] used for biomass supply usability metrics. This can be described by expression (4):

$$RUR_i^n = S_i^n / \sum_{in} S_i^n \tag{4}$$

The RUR indicator describes the ratio of the user supply from a spatial unit to the total biomass of the region (investigation area). This information shows how much the supply of individual users from spatial units contributes to the total available biomass of the region. On this basis, it is possible to identify variations between the users' utilization capability and the potential of the spatial units in biomass supply and compare them simultaneously.

2.3. The ratio of user supply from the spatial unit to the total user supply

RUT (Ratio of User Supply from the Spatial Unit and Total User Supply) is the destination capability indicator [30] used for biomass supply usability metrics. This can be described by the expression (5):

$$RUT_i^n = S_i^n / \sum_i S_i^n \tag{5}$$

The RUT indicator describes the distribution of individual users' supply quantities by spatial units. This information is useful for identifying those spatial units where the user has more or less supply. Based on it, it is possible to perceive variations in the supply of users between individual spatial units.

2.4 Ratio of total supply from the spatial unit and total regional supply

RRT (Ratio of Total Supply from Spatial Unit and Total Regional Supply) is the source potential indicator used for biomass supply usability metrics. This can be described by expression (6):

$$RTT_i = \sum_n S_i^n \,/\, \sum_{in} S_i^n \tag{6}$$

The RUT indicator describes the distribution of total supply from the region by spatial units. This information is useful for identifying those spatial units where the available biomass potential is concentrated. Based on it, it is possible to perceive variations in supply potential between individual spatial units.

2.5 Share of the supply of users at the regional level

SRS (User Supply Share in the Total Region Supply) is the destination capability indicator [30] used for biomass supply usability metrics. This can be described by the expression (7):

$$SRS^n = \sum_i S_i^n \,/\, \sum_{in} S_i^n \tag{7}$$

The SRS indicator describes the participation of individual users in the total supply from the region. This information refers to the utilization capability of individual users at the regional level. Based on this, it is possible to compare power between individual users in terms of utilization capability.

2.6 The ratio of the supply of individual users from the region to the production capacity of individual user

RSC (Ratio of Individual User Supply from the Region and Individual User Capacity) is the destination capability indicator [30] used for biomass supply usability metrics. This can be described by the expression (8):

$$RSC^n = \sum_i S_i^n \,/ CP^n \tag{8}$$

The RSC indicator describes the relationship between the total supply of individual users and their production capacity (minimum required quantities for the operation of the plant). This information indicates whether the user's supply capability exceeds or falls below its programmed needs. Based on it, it is possible to identify whether individual facilities have sufficient raw materials available in accordance with the planned capacity.

2.7 The ratio of total supply from the region to the production capacity of all users

RTC (Ratio of Total Region Supply and All Users Capacity) is the destination capability indicator [30] used for biomass supply usability metrics. This can be described by the expression (9):

$$RTC = \sum_{in} S_i^n \,/\, \sum_n CP^n \tag{9}$$

The RTC indicator describes the relationship between the total amount of biomass available in the region and the total production capacity of all users. This information indicates whether the supply capability of all users exceeds or falls below their needs. Based on it, it is possible to identify whether the available raw material quantity in the whole region corresponds to the total capacity of all plants, i.e. whether the capacities of the plants are oversized.

2.8. Supply ratios from the 1st third, 2nd third, 3rd third and outside the catchment area of individual users

RC1, RC2, RC3 and RCO (Supply Ratios from the 1st Third, 2nd Third, 3rd Third and Outside the Catchment Area of Individual Users) are a set of destination capability indicators used for biomass supply usability metrics. They can be described by expressions (10), (11), (12) and (13) respectively:

$$RC1^n = \sum_{iI} S_i^n \,/\, \sum_i S_i^n \tag{10}$$

$$RC2^n = \sum_{iII} S_i^n \,/\, \sum_i S_i^n \tag{11}$$

$$RC3^n = \sum_{iIII} S_i^n \,/\, \sum_i S_i^n \tag{12}$$

$$RCO^n = \sum_{iO} S_i^n \,/\, \sum_i S_i^n \tag{13}$$

where are:

i_I – a spatial unit that satisfies the condition $0 \leq C_i^n \leq 0.577\, r_{CA}^n$;
i_{II} – a spatial unit that satisfies the condition $0.577\, r_{CA}^n < C_i^n \leq 0.816\, r_{CA}^n$;
i_{III} – a spatial unit that satisfies the condition $0.816\, r_{CA}^n < C_i^n \leq r_{CA}^n$;
i_O – a spatial unit that satisfies the condition $C_i^n > r_{CA}^n$;

C_i^n – trip cost (route length) from *i*-th spatial unit to *n*-th biomass user, and

r_{CA}^n – appointed radius of the catchment area (maximum distance for biomass transport) for the *n*-th biomass user.

The RCX indicator (where character X refers to marks 1, 2, 3 and O) describes the distribution of supply for individual users, within their catchment areas (for radii of equal circular surfaces) and outside the catchment area. This information is useful for identifying and comparing the concentrations of available biomass potential in individual parts of the catchment areas (or outside them) defined by the catchment radius for individual users. Based on this, it is possible to identify the level of closeness of biomass quantities classified by different distances from the center of the catchment area.

2.9 Ratio of individual user supply in the catchment area and total supply from the region

RIC (Ratio of Individual User Supply in the Catchment Area and Total Region Supply) is the destination capability indicator [30] used for biomass supply usability metrics. This can be described by expression (14):

$$RIC^n = (\textstyle\sum_{iI} S_i^n + \sum_{iII} S_i^n + \sum_{iIII} S_i^n) / \sum_{in} S_i^n \tag{14}$$

The RIC indicator describes the relationship between the supply of individual users within their catchment areas and the total supply from the region. This information is useful for identifying and comparing the caught quantities of individual users in relation to the total available quantity in the region.

2.10 Supply ratio outside catchment areas and total supply from the region

ROC (Supply Ratio Outside the Catchment Areas and Total Supply from the Region) is the destination capability indicator [30] used for biomass supply usability metrics. This can be described by the expression (15):

$$ROC = \textstyle\sum_{iOn} S_i^n / \sum_{in} S_i^n \tag{15}$$

The ROC indicator describes the relationship between supply outside the catchment areas of all users and total supply from the region. This information is useful for identifying the level of available biomass potential outside all catchment areas in relation to the biomass available in the region.

Applying the spatial interaction model and the set of indicators described, various if-then scenarios can be investigated to mobilize unused biomass potential (for example, location a new plant and assessment of its sustainability). In this way it is possible to examine the effects on the overall biomass supply in the region of interest. The use of indicators in a model based on data from the national biomass potential monitoring system can facilitate in strategic decision-making for the development of a sustainable biomass supply system.

3. Model analysis, results and discussion

The findings of this research include definition and description of performance indicators, and their application in spatial interaction model analysis. As a case study, the specially designed model for the supply analysis was used for this purpose. Model is based on available data on poultry manure quantities for 25 municipalities in two cantons of Bosnia and Herzegovina from monitoring biomass potential system [29] and sectoral study [34]. The composition of the considered poultry manure [35] is given in Table 2.

Table 2

Chemical composition of the considered poultry manure

Parameter in %	Value
Rough moisture	19.7
pH	8.8
N	2.38
P	0.67
K	2.6
Ca	16.6
Mg	1.06
C	15.61
S	0.47

The initial purpose of the model was to determine optimal locations for biogas facilities for bioenergy production [36] in Tuzla Canton and Zenica-Doboj Canton.

As an analytical tool, a web mapping system [37,38] was used including:

- online atlas (Figure 2) to access the biomass monitoring database and
- spatial interaction modeler (set of location analysis tool).

As a prototype version of the spatial interaction modeler, according to the described functionality below, a set of tools for location analysis has been developed.

3.1 Web mapping system

Web mapping system includes two key components: an online atlas and location analysis tools [39]. Online atlas as a part of the monitoring system presents publicly available data through an online platform (Figure 2).

The spatial interaction modeler generates trip costs matrix and distance-decay function, and calculates total flows for biomass user, biomass balance for spatial units and indicators of utilization efficiency.

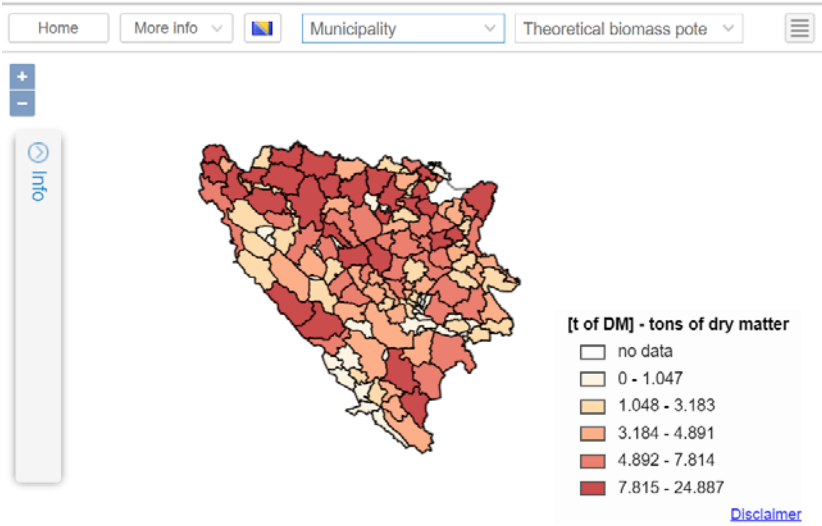

Fig. 2. The online biomass potential atlas - user interface (http://atlasbm.bhas.gov.ba/)

3.2 Spatial interaction model for the supply of biogas plants with poultry manure

The spatial interaction model was developed to determine the optimal locations for regional, off-site and on-site biogas plants. By selecting spatial units (municipalities), a trip cost matrix (C) is formed. Based on the selected parameters, the available quantities of selected biomass type (poultry manure) for the selected spatial units were defined.

Table 3 shows the optimal locations for all three types of biogas plants obtained after site location analysis.

Table 3

Optimal locations for all three types of biogas plants

Site Location	Biomass consumption capacity (t/y)	Total flows mobilizable biomass (t/y)	Nominal power in kWel	Type of biogas plant
Gracanica	50,000	44,799	3,000	Regional
Gradacac	20,000	17,155	1,000	Off-site
Visoko	2,000	< 4,440	150	On-site
Zenica	1,000	< 1,608	75	On-Site

3.3 Biomass Spatial Interaction Model Analysis and Discussion: Application of the Supply Performance Indicators

Tables 5 and 6 show indicators calculated based on formulas (3) to (15) applied to the biomass flows in spatial interaction model (Table 4). Columns 1-4 of Table 5 show shares of supply for individual users from spatial units.

For example, the supply shares for Gracanica and Gradacac facilities from the Banovici spatial unit are 87.9% and 12.1%, respectively (Figure 3). By this type of indicator, it is possible to compare the supply rates of individual facilities for each spatial unit in relative terms, but it is not possible to compare the values of individual facilities between them.

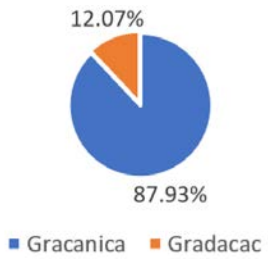

Fig. 3. The supply shares of Gracanica and Gradacac facilities in Banovici spatial unit

Table 4

The biomass flows in spatial interaction model for biogas plants

Site Location	Gracanica	Gradacac	Visoko	Zenica	Total
Nominal power	3 MW	1 MW	150 kW	75 kW	4.225 MW
Adminstrative unit	Flows (t/y)	Flows (t/y)	Flows (t/y)	Flows (t/y)	Balance (t/y)
Banovici	202.5	27.8	0.0	0.0	230.3
Gradacac	11,938.6	11,081.6	0.0	0.0	23,020.2
Kladanj	135.8	15.3	0.0	0.0	151.1
Lukavac	301.4	36.9	0.0	0.0	338.3
Srebrenik	479.6	136.9	0.0	0.0	616.5
Tuzla	1,619.6	254.1	0.0	0.0	1,873.7
Zivinice	6,516.1	949.0	0.0	0.0	7,465.1
Celic	173.3	54.1	0.0	0.0	227.4
Doboj-istok	1,504.9	204.8	0.0	0.0	1,709.7
Sapna	82.1	11.5	0.0	0.0	93.6
Teocak	564.2	108.7	0.0	0.0	672.9
Gracanica	21,797.7	2,702.9	0.0	0.0	24,500.6
Kalesija	3,268.2	423.8	0.0	0.0	3,692.0
Breza	354.2	10.5	30.4	0.2	395.2
Kakanj	340.3	14.2	6.1	2.3	362.9
Maglaj	511.0	43.1	0.0	0.1	554.2
Olovo	470.5	44.0	0.1	0.0	514.6
Tesanj	7,938.9	709.7	0.0	0.0	8,648.6
Vares	117.2	7.5	1.2	0.0	125.9
Visoko	785.4	28.2	3,626.9	0.2	4,440.6
Zavidovici	466.2	33.9	0.0	0.1	500.2
Zenica	428.4	22.4	0.3	1,339.1	1,790.2
Zepce	299.4	21.9	0.0	0.1	321.4
Doboj - jug	46.7	4.6	0.0	0.0	51.3
Usora	151.4	14.1	0.0	0.0	165.5
In total	60,493.5	16,961.5	3,665.0	1,342.1	82,462.0

Table 5

Supply Performance Indicators – SSU, RUR, RUT and RTT (values are in %)

Indicator	SSU - User Supply Share from the Spatial Unit				RUR - Ratio of User Supply from the Spatial Unit and Total Regional Supply				RUT - Ratio of User Supply from the Spatial Unit and Total User Supply				RTT - Ratio of Total Supply from Spatial
Facility Locations	Gracanica	Gradacac	Visoko	Zenica	Gracanica	Gradacac	Visoko	Zenica	Gracanica	Gradacac	Visoko	Zenica	
Column No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Spatial Unit	%	%	%	%	%	%	%	%	%	%	%	%	%
Banovici	87.9	12.1	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.2	0.0	0.0	0.3
Gradacac	51.9	48.1	0.0	0.0	14.5	13.4	0.0	0.0	19.7	65.3	0.0	0.0	27.9
Kladanj	89.9	10.1	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.2
Lukavac	89.1	10.9	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.2	0.0	0.0	0.4
Srebrenik	77.8	22.2	0.0	0.0	0.6	0.2	0.0	0.0	0.8	0.8	0.0	0.0	0.7
Tuzla	86.4	13.6	0.0	0.0	2.0	0.3	0.0	0.0	2.7	1.5	0.0	0.0	2.3
Zivinice	87.3	12.7	0.0	0.0	7.9	1.2	0.0	0.0	10.8	5.6	0.0	0.0	9.1
Celic	76.2	23.8	0.0	0.0	0.2	0.1	0.0	0.0	0.3	0.3	0.0	0.0	0.3
Doboj-Istok	88.0	12.0	0.0	0.0	1.8	0.2	0.0	0.0	2.5	1.2	0.0	0.0	2.1
Sapna	87.7	12.3	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1
Teocak	83.8	16.2	0.0	0.0	0.7	0.1	0.0	0.0	0.9	0.6	0.0	0.0	0.8
Gracanica	89.0	11.0	0.0	0.0	26.4	3.3	0.0	0.0	36.0	15.9	0.0	0.0	29.7
Kalesija	88.5	11.5	0.0	0.0	4.0	0.5	0.0	0.0	5.4	2.5	0.0	0.0	4.5
Breza	89.6	2.6	7.7	0.0	0.4	0.0	0.0	0.0	0.6	0.1	0.8	0.0	0.5
Kakanj	93.8	3.9	1.7	0.6	0.4	0.0	0.0	0.0	0.6	0.1	0.2	0.2	0.4
Maglaj	92.2	7.8	0.0	0.0	0.6	0.1	0.0	0.0	0.8	0.3	0.0	0.0	0.7
Olovo	91.4	8.6	0.0	0.0	0.6	0.1	0.0	0.0	0.8	0.3	0.0	0.0	0.6
Tesanj	91.8	8.2	0.0	0.0	9.6	0.9	0.0	0.0	13.1	4.2	0.0	0.0	10.5
Vares	93.1	6.0	1.0	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2
Visoko	17.7	0.6	81.7	0.0	1.0	0.0	4.4	0.0	1.3	0.2	99.0	0.0	5.4
Zavidovici	93.2	6.8	0.0	0.0	0.6	0.0	0.0	0.0	0.8	0.2	0.0	0.0	0.6
Zenica	23.9	1.3	0.0	74.8	0.5	0.0	0.0	1.6	0.7	0.1	0.0	99.8	2.2
Zepce	93.2	6.8	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.1	0.0	0.0	0.4
Doboj – Jug	91.0	9.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Usora	91.5	8.5	0.0	0.0	0.2	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.2

To compare the shares of supply from spatial units for all facilities in absolute terms, we can use the RUR (Ratio of User Supply from the Spatial Unit and Total Regional Supply) indicator described in columns 5-8 from Table 3. Using this indicator, we can perceive supply variations of all facilities across all spatial units (Figure 4). Using Figure 4, it can be immediately concluded that the largest quantities of biomass supply for the Gracanica facility come from the

Gracanica and Gradacac spatial units. These are also the largest supply quantities in the entire region of interest.

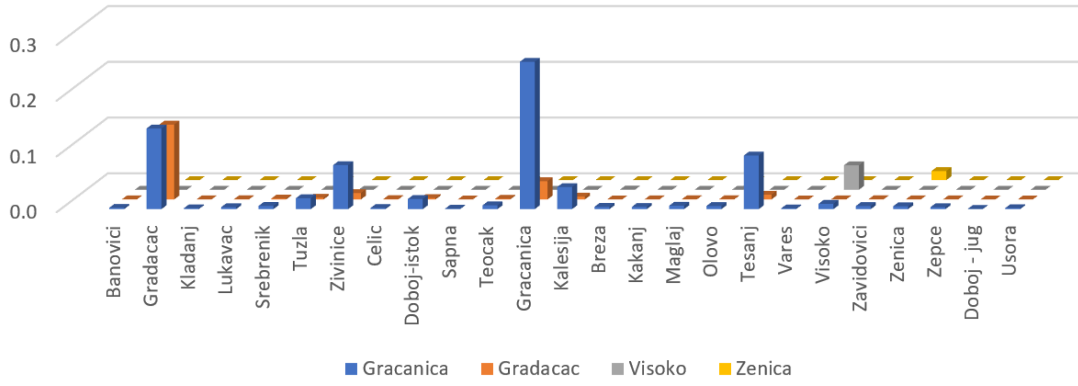

Fig. 4. Supply variations of all facilities across all spatial units

Further, using the RUT (Ratio of User Supply from the Spatial Unit and Total User Supply) indicator described in columns 9-12 of Table 5, we can perceive supply variations of each facility separately by spatial units, but cannot compare them between facilities. This information is useful for identifying the magnitude of supply from the spatial units for each facility separately (Figure 5).

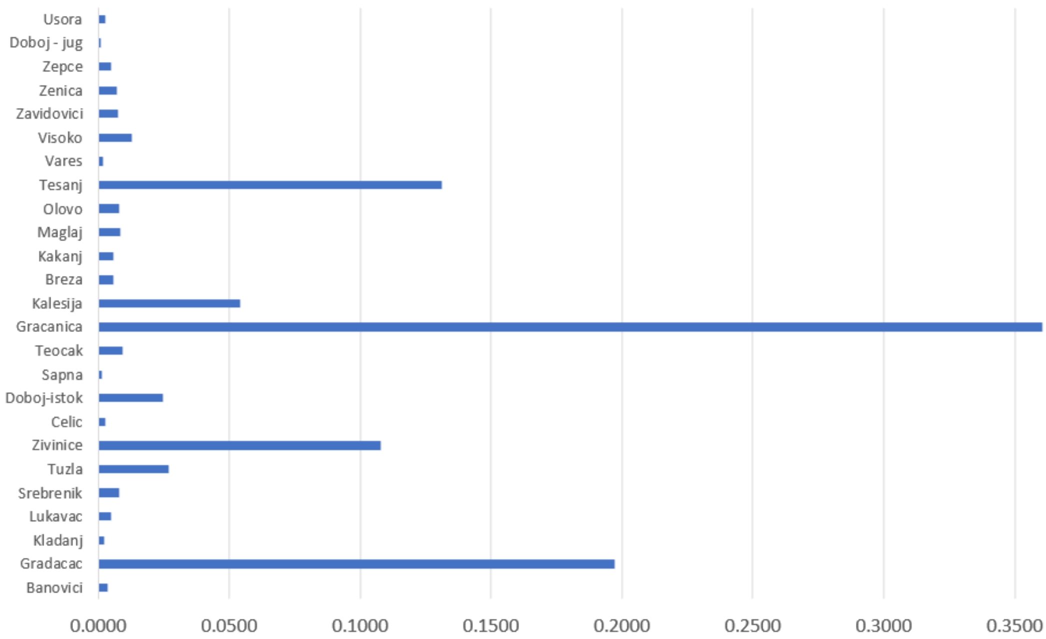

Fig. 5. Supply variations of Gracanica facility by spatial units

Information on the presence of biomass for supply by individual spatial units can be obtained by applying the RTT (Ratio of Total Supply from Spatial Unit and Total Regional Supply) indicator, whose values are shown in the column 13 of Table 5. For example, the distribution of total biomass for supply in the region can be represented by bar graph (Fig. 6), where areas with higher levels of biomass are readily identified.

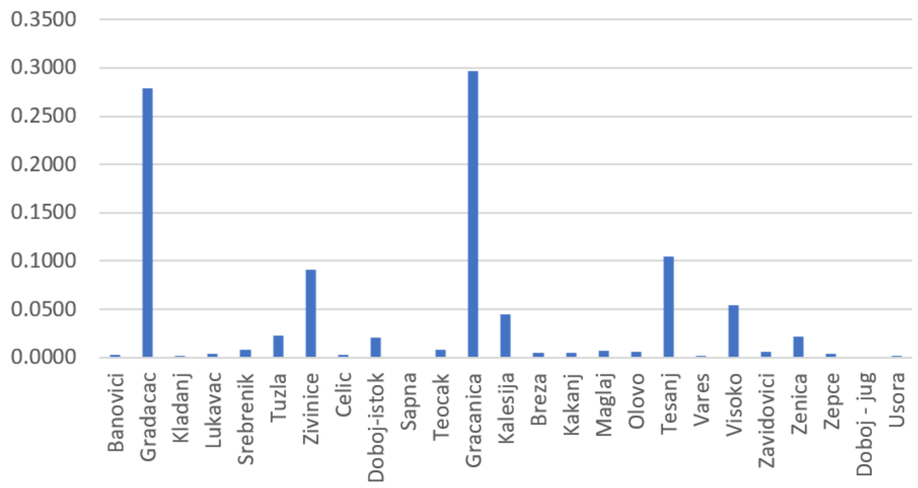

Fig. 6. Distribution of total biomass for supply in the region by spatial units

Other indicators are shown in Table 6 and refer mainly to the metrics related to facility performance. Raw 1 of Table 6 gives values for the SRS (User Supply Share in the Total Region Supply) indicator by individual facilities. Based on these, it can be concluded that most of the biomass supply belongs to the Gracanica facility. However, this does not mean that this quantity is sufficient to utilize the full capacity of the facility. The RSC (Ratio of User Supply from the Region and User Capacity) indicator in row 2 of Table 6 shows the possibility of individual facilities being able to use their full capacity. For Gracanica facility, this value is 121 %, which means that available supply quantity from the region exceeds its installed capacity. Also, the RTC (Ratio of Total Region Supply and All Users Capacity) indicator (row 3) shows that total supply quantities in the region should be sufficient for all facilities.

The efficiency of biomass supply in terms of transport and logistical needs can be seen from the set of indicators RC1, RC2, RC3 and RCO (Supply Ratios from the 1st Third, 2nd Third, 3rd Third and Outside the Catchment Area of Individual User) for the individual facilities shown in rows 4-7 from Table 6. Values for these four indicators are listed for the Gracanica facility. They show that far more biomass (73%) comes from the first (closest) part of the catchment area (with radius up to 40.4 km) compared to the more remote areas (14.3% for the 40.4-57.1 km radius, 7.3% for the 57.1-70.0 km radius and 5.4% outside the radius of the affected area). This also shows how the facility is strategically well positioned.

Table 6

Supply Performance Indicators – SRS, RSC, RTC, RCX, RIC and ROC (values are in %)

Raw No.	Indicator	Facility Locations			
		Graca-nica	Grada-cac	Visoko	Zenica
1	SRS - User Supply Share in the Total Region Supply	73.4%	20.6%	4.4%	1.6%
2	RSC - Ratio of User Supply from the Region and User Capacity	121.0%	84.8%	183.2%	134.2%
3	RTC - Ratio of Total Region Supply and All Users Capacity	113.0%			
4	RC1 - Supply Ratios from the 1st Third of Catchment Area	73.0%	66.1%	99.0%	99.8%
5	RC2 - Supply Ratios from the 2nd Third of Catchment Area	14.3%	15.9%	0.0%	0.0%
6	RC3 - Supply Ratios from the 3rd Third of Catchment Area	7.3%	1.2%	0.0%	0.0%
7	RCO - Supply Ratios Outside the Catchment Area	5.4%	16.7%	1.0%	0.2%
8	RIC - Ratio of User Supply in the CA and Total Region Supply	69.4%	17.1%	4.4%	1.6%
9	ROC - Supply Ratio Outside the CA and Total Region Supply	7.5%			

The next two indicators, RIC (Supply Ratio of Users in the Catchment Area and Total Region Supply) and ROC (Supply Ratio Outside the Catchment Area and Total Region Supply), with the values described in row 8 and 9 of Table 6 respectively, are complementary in their meaning. Namely, the first indicator shows how much of the total supply from the region is related to the catchment area of a particular facility, and the second indicator shows the total quantity outside of all catchment areas. For example, facility Gracanica uses 69.4% of the amount of biomass from the region, while other facilities use 17.1% (Gradacac), 4.4% (Visoko) and 1.6% (Zenica). In this respect, a total of 7.5% of the biomass supply outside the catchment areas remains unused, which represents the potential for planning new facilities.

In the example of a spatial interaction model for the supply of biogas plants with poultry manure it is shown how indicators can be applied to evaluate the performance of a model with a given constellation of facilities. This constellation of facilities is the result of the optimization of their locations, which was previously implemented. For the selected locations, the indicators showed positive effects in the model. The use of indicators facilitates a deeper analysis of spatial interaction models. By comparing their values, it is possible to answer, in part or in whole, important questions, such as:

- whether individual facilities have sufficient supply from particular areas or regions,
- whether the location of a facility is optimal in relation to the geographical distribution of the biomass supply,
- is there a possibility to plan new facilities and where,
- whether the total amount in the region is sufficiently exploited or a total capacity of facilities oversized,
- how much supply quantities are concentrated around the location of the facility and whether its spatial distribution meets the transport cost thresholds,
- what are the variations in the supply quantities between the individual facilities and what are between different supply areas,
- how much unused biomass can be mobilized by increasing the capacity of the existing facility, and how much by construction a new facility, etc.

Spatial interaction model may be a useful tool for analysis of the biomass supply chain in the segment of planning and optimization of transport infrastructure, logistics [40] and utilization facilities for biogas production [41].

Updating the biomass potential monitoring database, as well as launching new production capacity, will affect biomass flows. Supply performance can be measured by the indicators described. In addition, their application can also be useful for simulating various scenarios in a biomass supply model. Indicators can be used to evaluate whether a scenario has a favorable impact on an objective, or is insignificant, or counterproductive.

4. Conclusions

For optimal planning of infrastructure for the mobilization of unused biomass potential, the biomass supply model with georeferenced data about sources and users of biomass is essential. The biomass potential monitoring database with the online atlas is a reliable and official source of data, and the spatial interaction model can reflect the current status of biomass interaction in the supply system.

For the application of model and evaluation supply performance are required appropriate indicators. This paper identifies and formally describes ten indicators that can be used as biomass supply usability metrics. The method of their application is also described by the example of a spatial interaction model for the supply of biogas plants with poultry manure. An online atlas to access the biomass monitoring database and a set of tools developed for location analysis were used to analyses the model.

The use of indicators in a supply model based on online atlas data can help to make strategic decisions regarding the development of a sustainable biomass supply system. Supply performance can be measured via indicators, so they can be useful for simulating various scenarios in a biomass supply model.

The implementation of spatial interaction models and indicators to analyze the supply of other types of biomass for utilization, available in Bosnia and Herzegovina, is planned in the next steps for further development.

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