Suitable Land Slots for SRC plantations

Multi Criteria Decision Analysis

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Summary

If bioenergy is to provide expected contributions both to the EU 2030 and global effort to keep the temperature rise below 2°C by 2100 as set by Paris Agreement, a dialogue with the existing and potential biomass suppliers must be established.

In the long run, the expected contribution of bioenergy would emerge on a level playing field only if bioenergy succeeds in balancing out all the three pillars of sustainability: economic feasibility, environmental friendliness and social acceptance. Bioenergy is a dynamic and complex topic that involves a variety of experts to evaluate all the aspects of using biomass for energy, which includes resources from local renewable sources to GHG mitigation tools to local socio-economic effects and drivers. As all biomass projects are deeply engrained in the community during the entire project lifetime and beyond, meeting local sustainability conditions in bioenergy is as important as meeting the global ones. It is hard to expect that each and every bioenergy project would get full attention to verify its sustainability but if the framework is correctly set, it is reasonable to assume that the biomass contribution to global climate change mitigation efforts would be greater.

This report applies a multicriteria decision making analysis called fuzzy analytical hierarchical process (fAHP) on the example of a biomass source: short rotation coppice (SRC) to inform an SRC policy by assisting in the selction of the most suitable land slots for growing. It allows identification of the most suitable land slots for SRC plantations not upon technical grounds, but preferred criteria of the stakeholders where preferred priorities, organised under the three pillars of sustainable development, become the basis for a dialogue and engagement of technical criteria. fAHP transforms a problem into a hierarchy, and surveys the preferences by using weighted pair-wise comparisons of the three sustainability criteria and related alternatives. The report provides a detailed methodology, survey, and responses in the Appendices to avoid repetition.

There is an intuitive claim that biomass policy has to be tailored for a geographical area of an administrative unit where biomass is about to be produced. For that reason, the methodology is applied on three different groups: IEA Bioenergy Task 43 members (Task 43), Canadian and Croatian stakeholders at national level involved in tailoring the SRC policy.

The results indicate that there are differences in preferences as to which land slots are the most suitable for dedicated SRC plantations. When deciding on the optimal SRC policy mix, Task 43 members gave the highest priority to the economic feasibility of SRC plantations, whereas Canadian and Croatian stakeholders preferred environmental aspects as the main criteria. In all three groups, social aspects are perceived as the least important criteria to build a SRC policy mix and this aspect of sustainability is to be achieved as a side effect of other priorities.

When ranking the nine priorities given in the survey, Task 43 and Canadian results show clear direction how to select SRC land slots and tailor SRC policy with extracting four priorities more relevant on the expense of the other half. Results from Croatia are more unambiguous with as much as six priorities clustered in three groups with similar weight which reflects the need to reconsider the background and priorities towards SRC and beyond.

Interestingly enough, despite the differences in arranging the optimal SRC policy mix (F-4), in the case of SRC plantation analysis, all top four priorities carried out over 50% of the total weight and three priorities emerged in the top four for all targeted groups of experts:

- Danger from negative impact on soil due to inappropriate agricultural practice,

- Engagement of un-utilized agricultural land, and
- Creation of new business opportunities.

The environmental alternative "Ecosystem services (environmental)" has been placed among the top three in the case of Canada and Croatia, and above the average (5th) in the case of Task 43. The pattern disappears in the priorities beyond top four alternatives.

This could represent a pattern and further research is needed to be exercised on a larger geographical area.

Priority "Local renewable energy production" was ranked low by all three groups, although this alternative was weighted as the fifth priority by importance in the Canadian case due to the high weight of the environmental criteria.

The most suitable land slot for SRC plantations would vary from economically feasible land slots at non-utilized agricultural land that ensure and/or allows bioenergy production and land slots that allow economically feasible ecosystem services: land slots overburden with nutrients (excess nitrogen or phosphorus) in the vicinity of water supply or wastewater treatment plants (WWTP) (Task 43) to land slots on un-utilized agriculture land that need ecoservices and create new business opportunities for local renewable energy production (Canada) and land slots on un-utilized agriculture land that need ecosystem services and provide attractive economic opportunities for young rural population (Croatia). Acknowledging the differences among the geographical/administrative units, technical analysis would build upon the results to determine the size of the land slots that allow economic feasibility, particular ecosystem services in demand, SRC varieties and weight them over the next best alternative either for land use or environmental or social effect the SRC are to provide… with finalizing the land slots in a precise GIS selection.

This technique allows the policymaker to focus on the perceived priorities of the bioenergy supply chain in question through a survey of the people actually involved in the supply at different levels. The small sample size needed for this technique make re-surveying a realistic possibility thus making it a decision-making aid suitable to a dynamic environment. The survey method also enables a type of dialogue among a variety of experts (growers, scientists, environmentalist etc.) and the decision-makers. This assists the decision maker to designate a responsible body to develop policy that meets the desires and needs those impacted by the policy, as revealed through the survey process.

It is reasonable to assume that this methodology, but with different set of alternatives under the main criteria of sustainability, would be applicable for other bioenergy supply chains as it is easily inserted as a pre-step in GIS tools for allocation and scenario building in terms of landscape management (e.g. BEAST: The Bio-Energy Allocation and Scenario Tool or as the next step in studies that consider land availability for bioenergy feedstocks (e.g. IEEP's study "Data sources to support land suitability assessments for bioenergy feedstocks in the EU – a review").

Introduction

Currently, bioenergy is the largest global renewable energy contributor with unique advantages among renewable energy sources (e.g. energy storage, base energy supply, efficient heat supply, various biofuels) [1]. Bioenergy has the potential to contribute greatly to global climate change mitigation efforts both as a substitute for fossil fuels and for carbon storage. This potential can be realized only if a sustainable supply of bioenergy is achieved. Sustainability is not only related to environmental protection but also includes economic feasibility and social acceptance. Bioenergy is a dynamic and complex topic that involves a variety of experts to evaluate all the aspects of using biomass for energy, which stretches from local renewable source to GHG mitigation tool over local socio-economic effects and drivers. This complexity of bioenergy is transferred to a lesser extent to each individual bioenergy project. It is hard to expect that each and every bioenergy project would get full attention to verify its sustainability but if the framework is set right, it is reasonable to assume that the biomass contribution to global climate change mitigation efforts would be greater.

EU has mandated an ambitious goal for renewable energy share of at least 27% by 2030 [2] that will be challenging but not impossible to accomplish. Studies [3,4,5] have indicated that the 2030 goal would be difficult to achieve without having additional biomass supply. The focus on bioenergy supply should shift from forests to bioenergy crops and agriculture residues when looking at 2030 and beyond [6] in order to create additional biomass feedstock. Given the global objectives of Paris Agreement [7], the status of bioenergy requires a tripling of its contribution to global energy supply by 2050 to avoid exceeding the 2°C target according to scenarios from both the IEA and IRENA [1].

As long as externalities are not reflected in the energy price, the most important driver for bioenergy is a suitable set of policies to steer the investments towards sustainable solutions. The "suitability" is the nexus of the future outcomes that bioenergy will achieve. The European Community (EC) has already highlighted "an improved bioenergy sustainability policy" as one of the concrete specific objectives of the overall target in 2030 [2]. The challenge is how to set a bioenergy policy to accelerate the desirable side-effects and minimize or avoid the down sides.

In the long run, the expected contribution of bioenergy would fold out on a level playing field only if bioenergy succeeds in balancing all three pillars of sustainability: economic feasibility, environmental friendliness and social acceptance [8,9]. Bioenergy is deeply embedded in all three dimensions of sustainability within the community where a part or the whole supply chain occurs. That is why a consistent bioenergy policy must be carefully tailored to meet not only the technical requirements of environmental protection and bioenergy supply but also to relate to the social and economic drivers of the community that vary from case to case. Multi-dimensionality of bioenergy systems is an advantage when achieved but, simultaneously, a strong handicap if not managed properly. When conducting a policy, efforts of complementary authorities must be synchronized in order to optimize the effect of the available measures. However, in the implementation of a bioenergy policy, it is often a question of authority: who is in charge and which office or ministry (economy, environmental protection or social affairs, energy) should take the lead. Only if proper social and economic drivers are triggered, sustainable biomass supply will be unlocked [10] for participation in the global climate change mitigation actions.

On the example of short rotation coppice (SRC) plantations, this paper proposes a methodology for forming a suitable bioenergy policy for that specific source of additional biomass supply. The methodology employs a multi-criteria decision analysis (MCDA) to detect the desired shares of sustainable policy mix by measuring correspondent weights and prioritizing drivers attached. As bioenergy feedstock has numerous pathways [11,12], the methodology is demonstrated on the case of a specific bioenergy topic: planting SRC plantations for additional bioenergy supply within bioeconomy. In this case, the goal is to achieve optimal sustainability of SRC plantations by identifying the preferred land slots in the accordance to the (local) preferences and perceptions that fuel the drivers behind this particular bioenergy supply chain.

SRC are biomass production systems cultivated for energy purposes using fast-growing tree species with the ability to regenerate from the stumps after harvest, which occur in short intervals (e.g. 2-6 years). The management practices for SRC (e.g. soil preparation, weed control, planting, fertilization, harvest) are more similar to agricultural annual crops than forestry. The species currently used in commercial SRC plantations in Europe and Canada are tree species such as willows, poplars, acacia, robinia, eucalyptus and other fast-growing tree species with good coppice ability that produce much biomass even under very short harvest intervals. Long-lasting studies on SRC have come to the conclusion that SRC plantation can be a sustainable option for biomass supply, especially in local biomass supply chains [13,14] but rarely achieve economic feasibility especially when compared to other agricultural crops [15;16]. Success stories of SRC are case-specific [17] and difficult to transfer from one location to another [18,19]. Even the research in the leading SRC countries was provoked more by social criteria than creating additional biomass supply [20]. Compared to forest biomass, woodchips from SRC plantations have high water content and post-harvesting activities are as much important as growing the biomass. This fact, in addition to the transportation costs, make SRC plantations a dependent variable of a (local) supply chain that has to be set up to support the demand for such fuel.

Assuming that parameters for growing SRC as a bioenergy source (e.g. yield per species/clone; agro-inputs demand on different soil types, ecoservices provided, post-harvest activities, biomass quality, cost per hectare, assigned GHG emission savings) are known or easy to estimate for the area on which bioenergy policy will apply, this paper investigates:

1. Which aspect of sustainability should take the lead when implementing the SRC plantation policy.
2. The intensity and the mix of the most desirable socio-economic-environmental benefits from SRC plantations.
3. Preferences with land slots features to isolate land slots where most of the preferences will be accomplished.

The objective of this paper is to provide a scientific support to the intuitive claim that bioenergy policy must be custom-made on each administrative unit where it is expected that such bioenergy projects will occur. In contrast to a "black box approach", this paper presents a simple and transparent methodology that assists decision-maker(s) when creating a national and/or regional bioenergy policy. The methodology allows quick understanding of a complex issue based both on the expertise and preferences of the stakeholders. It identifies and embraces national/regional priorities and the preferred composition of all three sustainability dimensions within each bioenergy system. The outline of the bioenergy issue, analysis and interpretation of the results are provided by bioenergy experts, while preferences and priorities are given by involved stakeholders of different profiles that capture economic, social and environmental aspects including political dimension of people whose lives will be affected by a bioenergy policy.

Methodology

The methodology consists of three parts. First, establishing a hierarchy and ranking the conflicting or inhibiting alternatives of plausible trade-offs with economic, social and environmental components of sustainable policy mix within the administrative region that could occur from by planting SRC plantations. This will be done by processing targeted expert preferences with multi-criteria decision analysis (MCDA): fuzzy analytical hierarchical process (fAHP). The second part outlines policy issues and the third part relates the survey results with the ranked preferences to steer the selection of land slots.

FUZZY ANALYTICAL HIERARCHICAL PROCESS

The relationships between criteria for choosing the most suitable land slots for SRC plantations could be contradictory, inhibiting, boosting and/or neutral which calls for MCDA with multiple competing goals. There are numerous methods that help decision makers to identify and select preferred alternatives when faced with a complex decision problem characterized by multiple objectives [21]. The main objective of using MCDA is to facilitate rational and efficient choices which will enable policy shaping and ensure that public values are reflected in that policy [22]. This analysis focuses on identifying the "preferred" land slots type by including the feedback from the stakeholders of a specific administrative unit in accordance to the leading aspect of sustainability where the implementation of SRC plantations will occur.

MCDA methods have become increasingly popular in decision-making for sustainable energy because of the multi-dimensionality of the sustainability goal and the complexity of socio-economic and biophysical systems [23]. This is in contrast to models that may only consider profitability or jobs created or land-use change minimized, as a standalone criterion. AHP was developed in late 1980s by Prof. Thomas Saaty and it continues to be among the three (in addition to PROMETHEE and ELECTRE) most popular MCDA methods applied on sustainable energy planning [22,24,25,26]. AHP uses four main steps in solving a complex problem [26] by establishing relationships between criteria affecting the problem: (1) structuring the decision problem into a hierarchical model; (2) obtaining the weights for each criteria in accordance to Saaty's scale of importance (Table 1); (3) finding the score of each alternative for each criteria; (4) obtaining an overall score for each alternative.

Table 1 Integer values and interpretation of Saaty's value scale [27]

a_{ij} value	Interpretation
1	Objectives *i* and *j* are of equal importance
3	Objective *i* is weakly more important than objective *j*
5	Experience and judgements indicate that objective *i* is strongly more important than objective *j*
7	Objective *i* is very strongly or demonstrably more important than objective *j*
9	Objective *i* is absolutely more important than objective *j*
2,4,6,8	Intermediate values, for example, a value of 8 means that objective *i* is midway between strongly and absolutely more important than objective *j*

Despite its favourable qualities [23,24,25,26] and small sample size needed to obtain the results [27], AHP has been criticized for its inability to grasp incomplete information on the topic, inherit uncertainty and imprecision associated with the mapping of decision-makers' perceptions to exact numbers [28] and reluctance or inability to assign exact (integer) numerical values to the comparison judgements given the scale 1-9. Bioenergy itself is a multidisciplinary topic which deployment triggers trade-offs in all dimensions of sustainability. In other words, decision-makers are rarely in a position to have complete information and deep knowledge on all the dimensions with which bioenergy interacts [29]. As bioenergy projects meet all the pitfalls of the classical AHP by its very nature, fuzzy logic is employed to replace exact (integer or crisp) with fuzzy numbers when evaluating pair-wise comparisons. Fuzzy logic can better capture the uncertainty in human judgements when dealing with vague information. Fuzzy set theory is integrated to overcome the ambiguity in the preferences. In the literature, different studies had used fuzzy analysis in energy planning and energy policy [22,30,31,32,33,34]. Thus, a fuzzy version of fAHP has been selected as the most suitable MCDA for determining the priority policy goals and most suitable land slots for SRC plantations. It is still transparent, simple and able to handle both quantitative (e.g. yield, costs, water demand) and qualitative (according to the preferences) data related to SRC growing while decoupling a complex problem (SRC policy) into a hierarchy. In addition to fuzzy logic, as a measure to mitigate difficulty to respond to the preference of decision-makers by assigning a specific number, verbal equivalents are introduced [34,35,36].

The following text explains to the detail the concept, methodology and mathematical background of fAHP to calculate weights of the pair-wise comparisons in fuzzy sets based on several literature sources [34,35,37]:

Step 1: Organise the problem in a hierarchical structure

The complex problem on which decision is to be made is decomposed into a hierarchical form with a goal on the top and criteria (and sub-criteria if needed) at layers below with the alternatives at the end. Relationships between the layers are established.

Experts provide pair-wise comparisons at all levels of hierarchy using the verbal expressions to which triangular fuzzy number (TFN) is assigned (Table 2) [35].

Table 2 Triangular fuzzy conversion scale [35]

Linguistic scale	TFNs	Reciprocal TFNs
Equally important	(1, 1, 1)	(1,1,1)
A bit less/more important	(2/3, 1, 3/2)	(2/3, 1, 3/2)
Much less/more important	(3/2, 2 ,5/2)	(2/5, 1/2, 2/3)
Significantly less/more important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
Extremely less/more important	(7/2, 4, 9/2)	(2/9, 1/4, 2/7)

Step 2: Check the consistency of the pair-wise comparisons

A judgmental matrix, the pair-wise comparison matrix (***A***), is formed using linguistic terms that include the verbal judgments of the decision-makers. Decision-makers answers and given weights from the pair-wise comparisons are transformed into a matrix ***A*** to proceed with the mathematical processing of the model. That is, the pair-wise comparison matrix ***A*** is constructed in which the elements a_{ij} inside the matrix can be interpreted as the degree of the precedence of the i^{th} criterion over the j^{th} criterion.

$$\boldsymbol{A}=[a_{ij}] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{21} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix}$$

To transform the verbal judgments into numerical quantities, the middle value of TFN is used.

When constructing the pair-wise comparison matrix, the following rules must be verified:

- If $a_{ij} = \propto$, then $a_{ij} = 1/\propto$.
- If criteria i is judged to be of equal relative importance as criteria j, then $a_{ij} = a_{ij} = 1$ and $a_{ij} = 1$ for all i.
- If all the comparisons are perfectly consistent, then the relation $a_{ik} = a_{ij} = a_{ik}\ \forall\ i,j,k$.

To recover the vector W = [w1,w2, . . . , wN] from ***A***, which indicates the weight that each criteria is given in the pair-wise comparison matrix, the following two-step procedure is used:

- For each of the ***A***s column divide each entry in column *i* of ***A*** by the sum of the entries in column *i*. This yields a new matrix, called $\boldsymbol{A}_{norm}$ (for normalized) in which the sum of the entries in each column is 1.

- Estimate W_i as the average of the entries in row *i* of $\boldsymbol{A}_{norm}$.

To ensure that the priority of decision criteria is consistent, for each matrix a Consistency Ratio (CR) has to be verified [27] with the ratio of Consistency Index (CI) and Random Index (RI).

$$CR=CI/RI$$

Namely, classical AHP allows inconsistencies in giving the priorities of the pair-wise comparisons but up to the point where the decision–maker's comparisons are probably consistent enough to give useful estimates of the weights for their objective. For a perfectly consistent decision–maker, the i_{th} entry of AW^T=n(i_{th} entry of W^T). This implies that the perfectly consistent decision–maker has $CI = 0$. $CR > 10\%$ indicates that the degree of inconsistency might lead to a misleading or meaningless results.

CI is obtained through the largest eigenvector of the matrix ***A*** or λ_{max}

$$CI=(\lambda_{max}-n)/(n-1)$$

where λ_{max} is calculated as:

$$A \cdot w= \lambda_{max} \cdot w$$

and *w* stands for the eigenvector of the matrix ***A***, computed using the equation:

$$w = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{1/n}}$$

where *n* is the number of criteria being compared in this matrix. The largest eigenvalue λ_{max} of ***A*** can be estimated by:

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)_i}{w_i}$$

The denominator *RI* is given as it represents the average consistency index of a randomly generated pair-wise comparison matrix of a similar size (Table 3).

Table 3 RI for different values of n [27]

n	2	3	4	5	6	7
RI	0	0.58	0.90	1.12	1.24	1.32

Step 3: Construct fuzzy positive matrices

The score of pair-wise comparisons are transformed into linguistic variables which are represented by a positive triangular fuzzy number (TFN). According to Buckley [38], the definition of the fuzzy positive reciprocal matrix is as follows:

$$\tilde{A}^k = [\tilde{a}_{ij}^k]$$

where $A^{\sim k}$ is a fuzzy positive reciprocal matrix of decision–maker k. $\tilde{a}_{ij}^k$is the relative importance between i and j of the decision–criteria. Thus the same rules are valid as constructing the first pair-wise comparison matrix ($\tilde{a}_{ij}^k$=1, ∀ i=j, $\tilde{a}_{ij}^k$= 1/($\tilde{a}_{ij}^k$) , ∀ i,j=1,2,…,n) and two additional matrices are shaped based upon the lower and upper band values of TFN. The same procedure of consistency check is applied as described in the step 2.

Step 4: Calculate fuzzy weights

After synthesizing the decision–makers' pair-wise comparison matrices, the fuzzy weights are calculated according to the Lambda–Max method proposed by Csutora and Buckley [37]. The procedure of the Lambda–Max method is described as follows:

1. Let $\propto = 1$ in obtaining the positive matrix of the decision–maker k, $\tilde{A}_m^k = [a_{ijm}]_{n\,x\,n}$, and let $\propto = 0$ in obtaining the lower bound and upper bound positive matrix of decision–makers k, $\tilde{A}_l^k = [a_{ijl}]_{n\,x\,n}$ and $\tilde{A}_u^k = [a_{iju}]_{n\,x\,n}$, respectively. Using the weight calculating process of AHP, the weight vector can be derived as $W_m^k = [w_{im}^k]$, $W_l^k = [w_{il}^k]$, and $W_u^k = [w_{iu}^k]$, $i = 1, 2, \dots, n$.
2. In order to minimize the fuzziness of the weight, two constants, M_l^k and M_u^k are computed using the following equations:

$$M_l^k = min\left\{\frac{w_{im}^k}{w_{il}^k}\middle| 1 \le i \le n\right\}$$

$$M_u^k = min\left\{\frac{w_{im}^k}{w_{iu}^k}\middle| 1 \le i \le n\right\}$$

   The lower and upper bound weight are defined as:
   $W_l^{*k} = [w_{il}^{*k}]$, $w_{il}^{*k} = M_l^k w_{il}^k$, $i = 1, 2, \dots, n$
   $W_u^{*k} = [w_{iu}^{*k}]$, $w_{iu}^{*k} = M_u^k w_{iu}^k$, $i = 1, 2, \dots, n$
3. By computing W_l^{*k}, W_m^k and W_u^{*k}, the fuzzy weight matrix for decision–maker k can be acquired as $\widetilde{W}_i^k = (w_{il}^{*k}, w_{im}^k, w_{iu}^{*k})$, $i = 1, 2, \dots, n$.

Step 5: Integrate the fuzzy weights of each decision–maker and aggregate the group decisions

The geometric average is applied in order to obtain the aggregate of the fuzzy weights, as in the following equation:

$$\overline{\widetilde{W}}_i = \left(\prod_{k=1}^{K} \widetilde{W}_i^k\right)^{1/K}, \ \forall k = 1, 2, \dots, K.$$

Where $\overline{\widetilde{W}}_i$ is the aggregated fuzzy weight of criterion i of K decision–makers, $\widetilde{W}_i^k$ is the fuzzy weight of criterion i of decision–maker k, and K is the number of decision–makers.

Step 6: Obtain final ranking of criteria

Based on the equation proposed by Chen [39], a closeness coefficient (CC) defines the ranking order of the decision elements by using the equation listed below:

$$CC_i = \frac{d^-(\widetilde{W}_j, 0)}{d^+(\widetilde{W}_j, 1) + d^-(\widetilde{W}_j, 0)}, \ , \ i = 1, 2, \dots, n, \ \ 0 \le CC_i \le 1$$

Where CC_i is the weight for criterion i, $d^-(\widetilde{W}_j, 0)$ and $d^+(\widetilde{W}_j, 1)$, computed by using the two equation below, are the distance measurements between two fuzzy numbers:

$$d^-(\widetilde{W}_j, 0) = \sqrt{\frac{1}{3}\left[\left(\overline{W}_{il}^* - 0\right)^2 + \left(\overline{W}_{im} - 0\right)^2 + \left(\overline{W}_{iu}^* - 0\right)^2\right]}$$

$$d^+(\widetilde{W}_j, 1) = \sqrt{\frac{1}{3}\left[\left(\overline{W}_{il}^* - 1\right)^2 + \left(\overline{W}_{im} - 1\right)^2 + \left(\overline{W}_{iu}^* - 1\right)^2\right]}$$

Step 7: Defuzzification of fuzzy estimates to assess the decision (goal)

Best Non-fuzzy Performance (BNP) values [36,40] are gathered based on Centre of the Area (COA) defuzzification method. The COA is a simple method that doesn't require introduction of the preferences of any decision–maker participating in the problem evaluation. It is calculated by using the equation below:

$$BNP_i = LR_i + \frac{(UR_i - LR_i) + (MR_i - LR_i)}{3 + LR_i};\ \forall i$$

Where UR_i, MR_i and LR_i denote the maximum, the median and the minimum values of the experts' estimations as integrated by the geometric average method.

POLICY OUTLINING

Three components of sustainability are placed as the main criteria (policy goals) in fAHP to be ranked and weighted by the preferred importance of a given set of targeted experts. Sustainability criteria were generated from the two deliverables [41] of an Intelligent Energy Europe project SRCplus. The goal assumes that the decision to grow biomass as SRC for energy, complying with all FAO recommendations on good agriculture practice [42], is in place and one has to decide on the location for plantations.

The result will identify which aspect of sustainability should lead in creation of the sustainable bioenergy policy when bioenergy supply from SRC plantations is considered. Depending on the governance structure, the result will suggest which authority should be in charge and include SRC plantations in its policy implementation measures and tools.

LAND SLOTS SELECTION

Land slots are determined indirectly – by matching the preferred alternatives of the preferred sustainable policy mix with the descriptive features of land slots. The descriptive features vary according to the dominant policy goals where the obtained weight identifies the intensity of the measure and necessity of cross-sector cooperation. A narrative description gathered from literature on land slots features based on an absolute dominance of one of the three criteria follows. In reality, this would be most likely a combination of at least two out of three types of land slots.

Preferred land slots under the Economic criteria

Production of biomass supply by SRC plantation or providing ecosystem services through SRC plantations on the open market must be an attractive investment that generates acceptable profit in comparison to the other entrepreneurial opportunities in the region or to the land use. As any other business, this is achieved by cost minimization and/or profit maximization, constrained by government regulations (e.g. environmental protection, good agriculture practice).

For SRC plantations under the Economic criteria, land slots selection assumes the following settings [9,15,16,17,43]:

- fields with minimum agro-inputs: sufficient nutrients, water supply in place, pest resistance, available local workforce
- soils with maximum outputs: sufficient nutrients and water supply, most appropriate clones for the specific soil type
- larger patches of land

- competition with other agricultural activities related to conventional agriculture, land use or with other ecosystem services available on the market
- ability to achieve a condensed (local) supply chain with existing infrastructure (e.g. heating network) and expensive fossil fuel to substitute (e.g. heating oil)
- Direct Land Use Change and Indirect Land Use Change dLUC and iLUC
- Financial rate of return (FRR) determines the investment decision but ERR (Economic rate of return) is also observed.
- Private sector driven.

Land slots that would meet the stated settings for achieving economically feasible SRC plantations are the best quality soil types of arable land with little irrigation demand. Since SRC cultivation is rarely competitive with conventional agricultural crops grown on arable land, the investor would prefer abandoned arable land where establishment of SRC does not assume high costs. This would also eliminate the false but still resonating food vs. fuel debate. The investor would look for low-cost source of nutrients that could be either supplied from the soil or in vicinity of wastewater treatment plant (WWTP) from which either wastewater or sewage sludge could be used as fertigation (combined fertilization and irrigation). This both links the SRC investment to ecosystem services but with focus set on profit. Soil remediation is perceived not more than as a positive externality, unless providing ecosystem services is the core business opportunity. Land slots around communities with expensive heating systems would be attractive. Mid-term energy demand to meet the exploitation period of the SRC plantation (ca 20 years) should be ensured by eliminating land slots around communities with high migration rate, negative birth rate and an elderly population. Any market distortion (investment subsidies, available development funds) that makes the FRR more attractive will support SRC plantations. It is very likely that investors will avoid land slots with challenging economic feasibility such as poor quality soils (low yield) and long-time abandoned farmland (expensive clearing, weed control). On the other hand, the government has to exclude land slots which miss-management could have unrepaired consequences on the soil and overall environment by placing a regulation restriction.

Preferred land slots under the Social criteria

Production of bioenergy is perceived as a by-product of a social effect that is intended to be achieved by planting SRC. Overall costs of SRC plantation are to be equal or similar to the social measure(s) tackling the same issue (e.g. employment, specific health issue, preventing the youth exodus). Community (public sector, including para-public companies, NGOs) are leading parties in this case: from identifying the social issue that can be addressed by establishing SRC plantations to launching the overall (local) supply chain or somehow ensuring mid-term demand for bioenergy produced. A rational spending of taxpayers' money is still an important part of the decision but the profit maximization is constrained by the targeted social effect and can be equal to zero. However, land slots that have better commercial alternatives than establishing SRC plantations should be left to generate profit as social criteria allow wider span of suitable land slots. For example, land clearing costs can be rather high and hurt the investment according to the FRR. But, if land clearing costs are equal to the unemployment benefits for the number of jobs created, land slots such as uncultivated farmland covered with shrubs or even converting abandoned perennial crops (orchards, vineyards) to SRC plantations are considered.

For SRC plantations under the Social criteria, land slots selection assumes the following, not concluding, settings [8,9,11,12,18,20,44,45]:

- Land slots around communities that (will) receive social aid from the budget or has the average income lower than the average national income per capita.
- Variety of common age land slots: abandoned farmland of lower commercial value.
- SRC plantations on private land that will be contracted for bioenergy supply and cooperation agreement (community ensures extension service, inputs and purchases all yield).
- Multiplier effect is closely monitored and quantified
- All externalities are quantified and monetized (e.g. employment benefits of expected number of persons employed, both directly and indirectly, from SRC plantations, cost of treatments of respiratory diseases and sick leaves due to the poor combustion of the existing fuels for heating, effects to jobs generated from installing new heating systems suitable for SRC).
- Lower carbon footprint influences the decision.
- Larger patches of land slots are preferable but not eliminating criteria.
- ERR determines the decision but FRR is also looked.
- Community driven/local authority

Preferred land slots that meet social criteria are those that fulfil the above profile and generate most of the desired social effect in the community. Simultaneously, the community with sufficient commonage to meet the planned bioenergy demand has to have either adequate work force to meet the created job demand or count on the external labour. External labour attraction would be a different social measure than job creation: it prevents youth exodus to urban areas and re-populates the community due to the rural-to-rural job migration. Symbiosis with ecosystem services is welcomed as this improves ERR. However, the decision on pursuing SRC plantation is not related to the efficiency of environmental improvement but to the specific social measure in question. In order to avoid negative impacts on soil and overall environment due to the inappropriate agriculture practice, land slot that are already marked as vulnerable (e.g. NATURA 2000, Biosphere reserve) should be excluded from social criteria.

Preferred land slots under the Environmental criteria

Features of land slots under social and environmental criteria greatly overlap, especially in the framework of low carbon economy. Still, only land slots that allow realization of ecosystem services from SRC plantations are those land slots that fall under environmental criteria due to their demand for environmental prevention, protection or remediation measures. Overall cost (including externalities) of SRC plantation are equal or similar to the environmental protection measures that achieve the same effect (e.g. preventing the soil erosion by placing a PVC net, other soil remediation/water purification techniques) and its carbon footprint justifies the implementation to the alternatives.

For SRC plantations under the Environmental criteria, land slots selection assumes the following, not concluding, settings [8,9,11,12,18,20,44,45,46,47]::

- Location and the shape of SRC plantation are determined by the ecosystem services in demand (wind barriers, shelterbelts, buffer stripes, phytoremediation…)
- All externalities are quantified and monetized.
- Carbon footprint of overall supply chain is calculated and compared to the competing environmental protection measures, including the substitution effect from replacing fossil fuels with locally supplied biomass.
- ERR determines the decision by comparing it to the next alternative.
- Land slots that need ecosystem services: areas around WWTP, polluted (agricultural) land, shelterbelts, buffer areas for water surfaces…
- Land slots that are within nature protected areas provided that the ecosystem services in question are the most suitable environmental protection/remediation measure.
- Land slots at former cropland have the advantage over grassland since planting SRC on former cropland has higher potential on carbon sequestration than grassland
- The investment is driven by either community/local authority, a private entity that needs ecosystem services under social responsibility or a private entity that is specialized in environmental protection/soil and water remediation
- Supply chain is both supply (e.g. private entity in demand for ecosystem services equivalent environmental protection measure grows SRC plantations and offers bioenergy at market or uses for own purposes) and demand driven (e.g. community action on water streams eutrophication – publicly owned heating/power plant or contract arrangement with private entity – harvesting service provided by community utility company at cost price). SRC plantations based on the environmental criteria must be implemented and monitored by a qualified organization to record the efficiency of ecosystem services provided and prevent possible malpractice.

It is claimed that SRC plantations have a competitive advantage over static environmental protection measures as they provide valuable positive externalities: bioenergy supply and social benefits, which improves the overall ERR. In this case, those two externalities are included in ERR but the main decision point is specific ecoservices (ecoservices in demand) from SRC against the competing environmental measure.

DATA GATHERING

The goal of finding the optimal land slots for planting SRC as a bioenergy source has been organized as a hierarchy with three criteria and three alternatives for each criteria (Figure 1). Criteria ranking will define desirability of the features for the land slots, not only in terms of soil type but also on the community populating the area. The layout of the hierarchy was developed upon criteria and alternatives identified in an EU co-funded project (SRCplus) [41,46] that promotes sustainable SRC plantations.

The hierarchy was transformed into a survey with weighted pair-wise comparisons (Appendices).

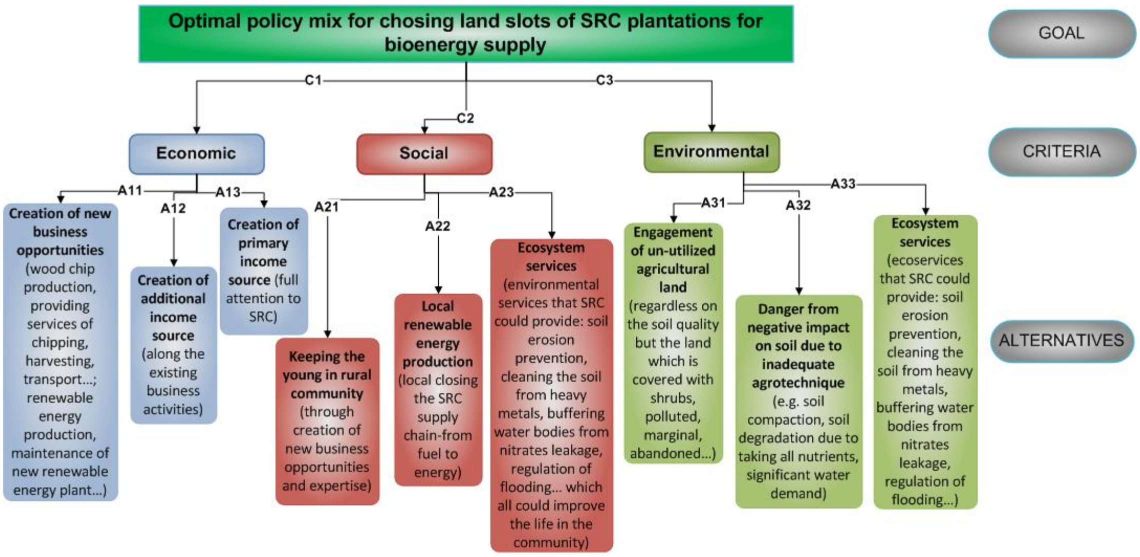

Figure 1 Hierarchical structure of the model for finding optimal SRC land slots for bioenergy supply

The same survey was conducted within the three different targeted groups of selected experts: IEA Bioenergy Task 43: Biomass Feedstocks for Energy Markets (hereafter: Task 43) group members; Canadian and Croatian bioenergy experts and stakeholders involved in creating national bioenergy policy.

The idea of having three different targeted groups of experts is to present the differences in policy approach and, consequently, land slots selection between a general view (no particular area to apply the criteria), an example of a geographically large country with net energy exports (Canada) and a small country with net energy imports (Croatia).

To achieve the minimum of four consistent answers per criterion and alternatives, more than four targeted experts were asked to fulfil the survey. However, each responder was asked to rank the criteria and alternatives according to the importance on a scale from one to three, one being the most important, without attributing the weight to that importance. The contrast of simple ranking that covers values from the total group against the consistent pair-wise comparisons gives the information if the consistent answers still express the values of the group.

Details on data gathering for each group are shown below:

IEA Bioenergy Task 43: During the Task 43 meeting, by the end of October 2015, the concept, methodology and survey were introduced to the Task members. At the same event, the paper version of the survey was handed out. Task 43 experts completed the survey during the day.

Canada: Surveys were e-mailed to a number of colleagues with knowledge of SRC in July of 2015. A variety of disciplines were targeted including those with expertise in economics, sociology, forestry, and agriculture. Fourteen requests were made and ten replies received.

Croatia: Five stakeholders involved in creating the national SRC policy in a form of a law were targeted as the experts for the survey. Firstly, the survey was sent by e-mail preceded by a phone call in July 2015. Only one reply was received, even after several phone reminders. The second attempt to obtain survey results occurred at the national IEA Bioenergy meeting in October 2015. The purpose of the meeting was presenting the IEA Bioenergy and the new triennium of Task 43 to the relevant bioenergy stakeholders (including those working on SRC policy). All participants were invited to fill out the survey on the spot.

After eliminating the surveys with unsuitable replies (e.g. double circling or skipping answers) and applying the step 2 of the mathematical background on the responses, the general outcome of the survey are set in Table 4.

Table 4 The outcome of fAHP survey on SRC plantations by targeted group of experts

Item	IEA Bioenergy Task 43	Canada	Croatia
Number of targeted experts/responses	21/14	14/9	19/16
Number of consisted answers:			
C1-3	13	7	14
A11-3	8	6	7
A21-3	6	5	6
A31-3	7	6	9

Results

Ranking of main policy mix criteria by BNP value from aggregated fuzzy weights in comparison with simple ranking gives the same results in all cases (Figure 2) which confirms the policy direction even if some experts' opinion is excluded from the further analysis due to the non-consisted answers (**Error! Reference source not found.**). In all three groups, the trilogy of bioenergy sustainability by SRC plantations is emphasized in respect to the statistically average importance or 33%. General order of simple ranking and weights of all three criteria overlap in all three cases but the weights differ.

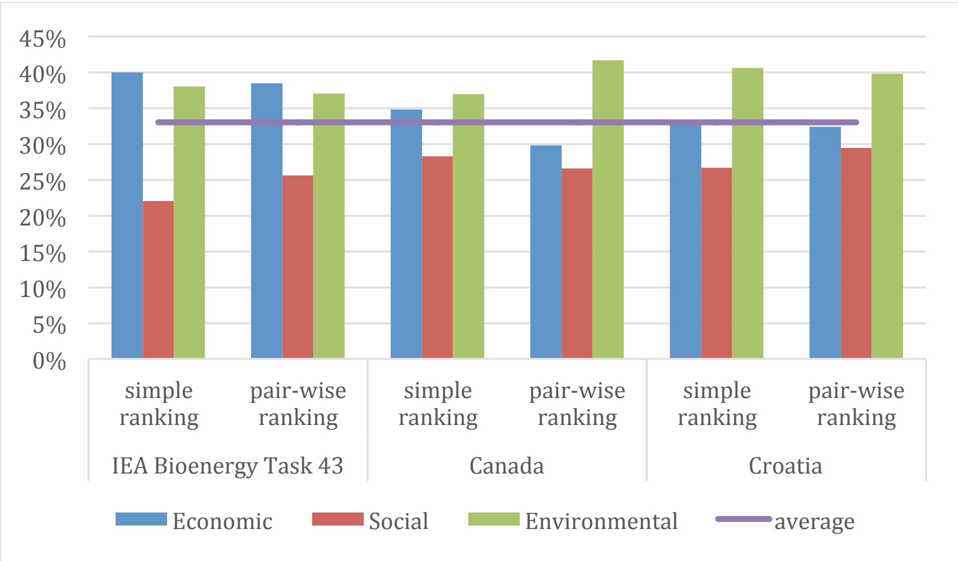

Figure 2 Comparison of results obtained from simple and pair-wise weighted ranking of policy goals on SRC plantations

The pair-wise comparison matrix of the expert evaluation in criteria level continues on consisted answers. The matrices with full answers for each targeted expert group are presented in the Appendix II.

Aggregated fuzzy weights ($\widetilde{W}_i$) of the three main criterions (C1, C2 and C3) for each targeted group of experts are calculated following the steps 3 - 5 (Tables 5-6).

Table 5 Aggregated fuzzy weights of main policy criterion per targeted expert group

Criterion	Task 43	Canada	Croatia
$\tilde{\overline{W}}_{C1}$	(0.3333, 0.3805, 0.4417)	(0.2361, 0.3049, 0.3546)	(0.2752, 0.3187, 0.3789)
$\tilde{\overline{W}}_{C2}$	(0.2263, 0.2531, 0.2892)	(0.2100, 0.2723, 0.3164)	(0.2492, 0.2892, 0.3452)
$\tilde{\overline{W}}_{C3}$	(0.3310, 0.3664, 0.4154)	(0.3431, 0.4228, 0.4863)	(0.3445, 0.3921, 0.4579)

Table 6 Aggregated fuzzy weights of alternatives per targeted expert group

Alternatives	Task 43	Canada	Croatia
$\tilde{\overline{W}}_{A11}$	(0.1095, 0.1496, 0.2085)	(0.0720,0.1238, 0.1610)	(0.0931, 0.1208, 0.1629)
$\tilde{\overline{W}}_{A12}$	(0.0911, 0.1234, 0.1704)	(0.0655,0.1110, 0.1451)	(0.0723, 0.0919, 0.1223)
$\tilde{\overline{W}}_{A13}$	(0.0805, 0.1075, 0.1488)	(0.0400,0.0701, 0.0915)	(0.0838, 0.1060, 0.1408)
$\tilde{\overline{W}}_{A21}$	(0.0589, 0.0815, 0.1206)	(0.0376,0.0593, 0.0832)	(0.0889, 0.1181, 0.1648)
$\tilde{\overline{W}}_{A22}$	(0.0599, 0.0819, 0.1191)	(0.0749,0.1174, 0.1630)	(0.0652, 0.0861, 0.1196)
$\tilde{\overline{W}}_{A23}$	(0.0656, 0.0898, 0.1317)	(0.0610,0.0956, 0.1316)	(0.0643, 0.0850, 0.1184)
$\tilde{\overline{W}}_{A31}$	(0.0935, 0.1231, 0.1698)	(0.0744,0.1173, 0.1727)	(0.0935, 0.1213, 0.1619)
$\tilde{\overline{W}}_{A32}$	(0.0992, 0.1310, 0.1816)	(0.1015,0.1504, 0.2155)	(0.1130,0.1464, 0.1900)
$\tilde{\overline{W}}_{A33}$	(0.0857, 0.1123, 0.1556)	(0.1044,0.1551, 0.2228)	(0.0963,0.1245, 0.1645)

Tables 5-6 are defuzzified according to the step 6-7 in Methodology section. BNP value of criteria and corresponding alternatives are presented in the tables 7-10.

Table 7 Defuzzified BNP value of criteria and corresponding alternatives - Task 43

Policy criteria	Weight	Alternatives	Weight with the policy goal	Aggregated weight
Economic	0.3852	Creation of new business opportunities	0.3979	0.1559
		Creation of additional income source	0.3278	0.1283
		Creation of primary income source	0.2869	0.1122
Social	0.2562	Keeping the young in rural community	0.3331	0.0870
		Local renewable energy production	0.3333	0.0869
		Ecosystem services	0.3667	0.0957
Environmental	0.3709	Engagement of un-utilized agricultural land	0.3424	0.1288
		Danger from negative impact on soil due to inadequate agro-technique	0.3649	0.1373

Policy criteria	Weight	Alternatives	Weight with the policy goal	Aggregated weight
		Ecosystem services	0.3134	0.1179

Table 8 Defuzzified BNP value of criteria and corresponding alternatives - Canada

Policy criteria	Weight	Alternatives	Weight with the policy goal	Aggregated weight
Economic	0.2985	Creation of new business opportunities	0.3884	0.1189
		Creation of additional income source	0.3504	0.1072
		Creation of primary income source	0.2191	0.0672
Social	0.2662	Keeping the young in rural community	0.2200	0.0601
		Local renewable energy production	0.4343	0.1184
		Ecosystem services	0.3524	0.0961
Environmental	0.4174	Engagement of un-utilized agricultural land	0.2861	0.1225
		Danger from negative impact on soil due to inadequate agro-technique	0.3649	0.1558
		Ecosystem services	0.3765	0.1608

Table 9 Defuzzified BNP value of criteria and corresponding alternatives - Croatia

Policy criteria	Weight	Alternatives	Weight with the policy goal	Aggregated weight
Economic	0.3242	Creation of new business opportunities	0.3825	0.1256
		Creation of additional income source	0.2914	0.0955
		Creation of primary income source	0.3362	0.1102
Social	0.2945	Keeping the young in rural community	0.4143	0.1239
		Local renewable energy production	0.3020	0.0903
		Ecosystem services	0.2983	0.0892
Environmental	0.3982	Engagement of un-utilized agricultural land	0.3115	0.1256
		Danger from negative impact on soil due to inadequate agro-technique	0.3721	0.1498
		Ecosystem services	0.3188	0.1284

The outcome of the Task 43 weighting of three policy dimensions of biomass sustainability clearly gives the advantage towards economic feasibility of (0.3852) production of bioenergy from SRC plantations where business opportunities would be recognized by the market. It is closely followed by environmental trade-offs (0.3709) from planting SRC. Here the market would represent either a private company that is involved in bioenergy business or that provides soil/water remediation services. Both criteria are getting their advantage by leaving the social criteria (0.2562) out.

In the Canadian case, even stronger priority is outlined in creating the policy towards bioenergy production on SRC plantations: environmental criteria (0.4174) is taking its above average weight on the expense of both economic (0.2985) and social (0.2662) criteria.

In the Croatian case, prioritizing on of the three dimensions of sustainable policy is as strong as in the Task 43 and Canadian cases although environmental component dominates (0.3982) on the expense of the social (0.2945) and economic criteria (0.3242).

Table 10 Ranking of perceived priorities when deciding on the suitable land slot per targeted expert group

Rank	Task 43		Canada		Croatia	
	Perceived priority	**W**	**Perceived priority**	**W**	**Perceived priority**	**W**
1	Creation of new business opportunities	0.1559	Ecosystem services (environmental)	0.1608	Danger from negative impact on soil due to inappropriate agricultural practice	0.1498
2	Danger from negative impact on soil due to inappropriate agricultural practice	0.1373	Danger from negative impact on soil due to inappropriate agricultural practice	0.1558	Ecosystem services (environmental)	0.1284
3	Engagement of un-utilised agricultural land	0.1288	Engagement of un-utilised agricultural land	0.1225	Creation of new business opportunities	0.1256
4	Creation of additional income source	0.1283	Creation of new business opportunities	0.1189	Engagement of un-utilised agricultural land	0.1256
5	Ecosystem services (environmental)	0.1179	Local renewable energy production	0.1184	Keeping the young in rural community	0.1239
6	Creation of primary income source	0.1122	Creation of additional income source	0.1072	Creation of primary income source	0.1102
7	Ecosystem services (social)	0.0957	Ecosystem services (social)	0.0961	Creation of additional income source	0.0955
8	Keeping the young in rural community	0.0870	Creation of primary income source	0.0672	Local renewable energy production	0.0903
9	Local renewable energy production	0.0869	Keeping the young in rural community	0.0601	Ecosystem services (social)	0.0892

Ranking of priorities (Table 10) together with policy mix (Figure 2) is the equivalent to the "executive summary" of the fAHP analysis for the politicians or other decision – makers. Priorities are clearly ranked in the order of the importance and their relationships are established in a form of aggregated weights.

Interestingly enough, despite the differences in arranging the optimal SRC policy mix (F-4), in the case of SRC plantation analysis, all top four priorities carried out over 50% of the total weight and three priorities (Table 10) emerged in the top four for all targeted groups of experts:

- Danger from negative impact on soil due to inappropriate agricultural practice,
- Engagement of un-utilized agricultural land, and
- Creation of new business opportunities.

The environmental alternative "Ecosystem services (environmental)" has been placed among the top three in the case of Canada and Croatia, and above the average (5th) in the case of Task 43.

The pattern disappears in the priorities beyond top four alternatives.

Yet, fAHP allows to establish an evident difference among the criteria how to implement the policy mix in different groups as it assigns preferences to the sub-criteria or priorities.

The pair-wise comparison gave a clear priority when setting the SRC policy: the first four priorities are carrying more than half of the total weight in all cases: 55%, 56% and 53% for Task 43, Canada and Croatia.

The more weight is placed on the less priorities, the preferences are more unique either due to the high level of knowledge or joint preferences. This is the example of preference ranking for Task 43 and Canadian stakeholders where the first two preferences were quite close or equal to 16% which is 5 pp more than the average. On the contrary, the results from Croatian stakeholders are more indecisive and the first priority is defensive – preventing danger from the negative impact, while the other two groups are proactive in engaging "business opportunities" and "ecosystem services". The strongest preference is having 15% while the following four alternatives above the average are all concentrating between 12 and 13%. With such hesitation in giving preferences in the pair-wise comparisons, even the preference "Keeping the young in rural community" from Social criteria emerged as a priority above average. In this case, it would be advisable to inform more the stakeholders on the topic of SRC and redo the survey.

"Local renewable energy production" as social measure is ranked at the bottom with importance less than the average for both Task 43 (0.0869) and Croatia (0.0903) which gives the clear signal to the policy creation where social aspects of bioenergy system remain to be important but should not be pushed in front of economic feasibility and environmental protection criteria. The difference is Canada where "Local renewable energy production" is ranked as 5th, and has the weight slight above the average (0.1184) entering the upper half of the policy outlining criteria.

Discussion

In general, along with bioenergy supply, there are numerous benefits assigned to SRC cultivation [41,44,45,46], but the local features define if those benefits are actually achieved. For example, if there is lack of contaminated soil in a specific region, the benefit that SRC provides soil remediation does not apply. A desirable land slot type would be the type of land where SRC has the largest preferred impact (e.g. job creation, soil decontamination, erosion prevention, profit) or meeting local socio-economic demand (e.g. employment, ageing population, low income community) of a certain geographical area (country, region, community, administrative unit). However, sometimes "desirability" can be complex (e.g. erosion prevention is important but not as much as an employment booster but the investment in local district heating network is not profitable) and has to be organized according to the priorities.

According to the results of the fAHP analysis, preferable land slots for planting SRC plantations would differ by target group which reflects in different settings of policy, responsible authority and implementation tool. This does not presume that the least favored preference or dimension will be excluded from the policy mix. On the contrary, all dimensions and priorities will occur to some extent but the focus will be on the perceived relevance of the stakeholders that allows efficiency and efficacy in policy implementation.

As the decision – makers have limited time, the results should be presented in a condensed and visually attractive manner in a form of "Executive summary". This form of representation respects the limited time and allows transferring the message easily, even for a non-bioenergy expert. The decision – maker feels confident in the material and results. Details on calculations and survey results ought to be given as a supplement, not the main material.

EXECUTIVE SUMMARY: THE OPTIMAL LAND SLOTS FOR SRC PLANTATIONS ACCORDING TO TASK 43

Eleven different studies reviewed under the EU project S2Biom [49] indicate that a dedicated production of industrial crops on released agricultural land could provide as much as 138-242 million tons y-1 or 13-18% of the total biomass which can be technically available within Europe by 2030 under sustainable practices. There is available land in Europe for dedicated production of industrial crops as this previously farmed land has been abandoned for a number of reasons including overexploitation, pollution, climate change and/or exodus from rural areas [49].

Based on the stakeholders' preferences on planting SRC plantations for bioenergy supply, the SRC policy would be led by economic criteria, closely supported by environmental protection measures (**Error! Reference source not found.**).

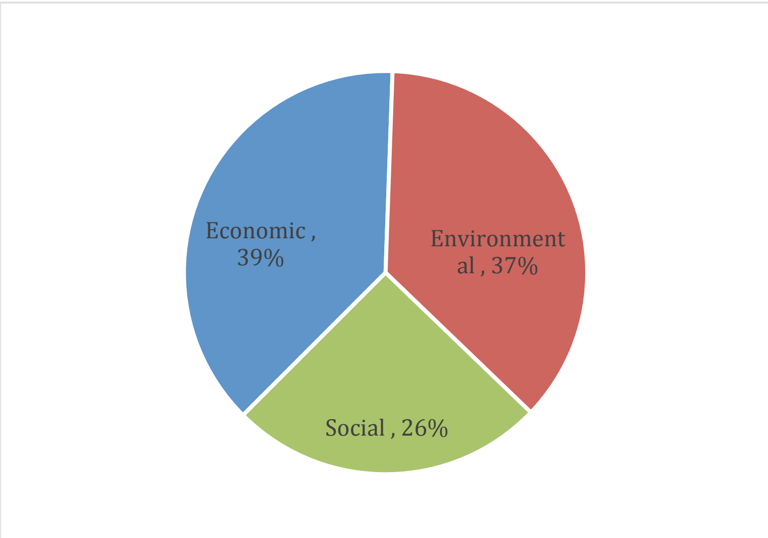

Figure 3 Preferred policy mix for creating a SRC implementation policy (Task 43)

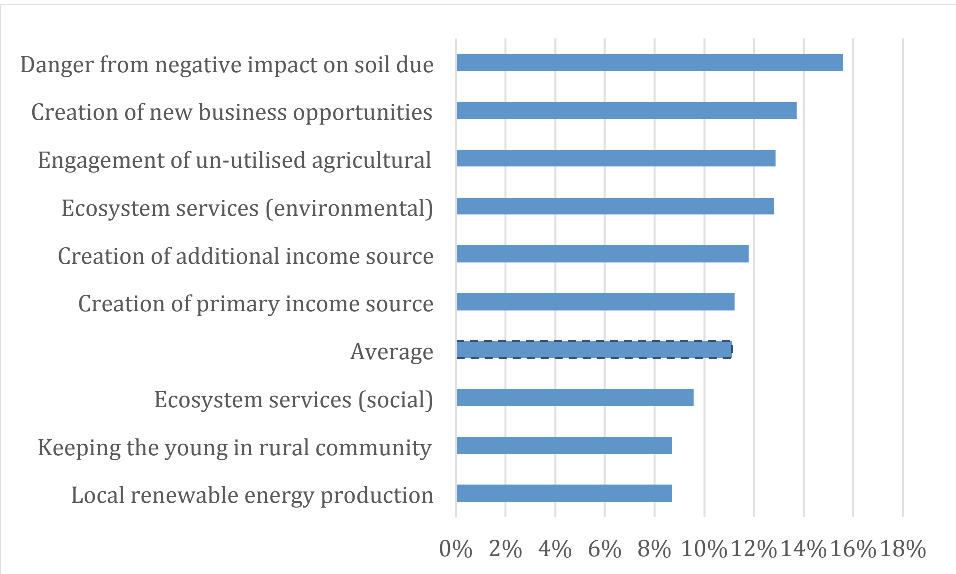

Figure 4 Ranking of preferences/concerns related to SRC plantations for bioenergy supply (Task 43)

The preferences/concerns with weight given more than the average are the main issues to be considered when tailoring implementation policy on planting SRC for bioenergy supply. The upper four preferences make 55% of the total weight (Figure 4). By focusing implementation measures on the upper four preferences, the other listed will not be excluded but will toggle along spontaneously.

Optimal land slots for planting SRC: economically feasible land slots at non-utilized agricultural land that ensure and/or allows bioenergy production and land slots that allow economically feasible ecosystem services: land slots overburden with nutrients (excess nitrogen or phosphorus) in vicinity of water supply or WWTP. Yet, land slots in vicinity to nature vulnerable areas that do not combine ecosystem services are to be excluded. It is expected that land slots will be of larger size but the actual dimension should be calculated based on the national parameters. Policy implementation towards SRC plantations should be in a form of providing unbiased information to the private sector (e.g. SRC growing parameters (yield, necessary inputs, clones…), stakeholders (bioenergy operators, providers, cutting services). This information spreading should be preceded with clear and easy to monitor system boundaries in terms of preventing danger from negative impacts on soil.

EXECUTIVE SUMMARY: THE OPTIMAL LAND SLOTS FOR SRC PLANTATIONS ACCORDING TO CANADIAN STAKEHOLDERS

Canada has only 6% of land suitable for farming and only 0.5% [48] is designated as Class 1: "Soils in this class have no significant limitations in use for crops. The soils are deep, are well to imperfectly drained, hold moisture well, and in the virgin state were well supplied with plant nutrients. They can be managed and cropped without difficulty. Under good management they are moderately high to high in productivity for a wide range of field crops." [50]. When considering policy towards SRC growing for bioenergy purposes, the policy mix should be led strongly by environmental criteria to which both economic and social criteria are bounded (Figure 5).

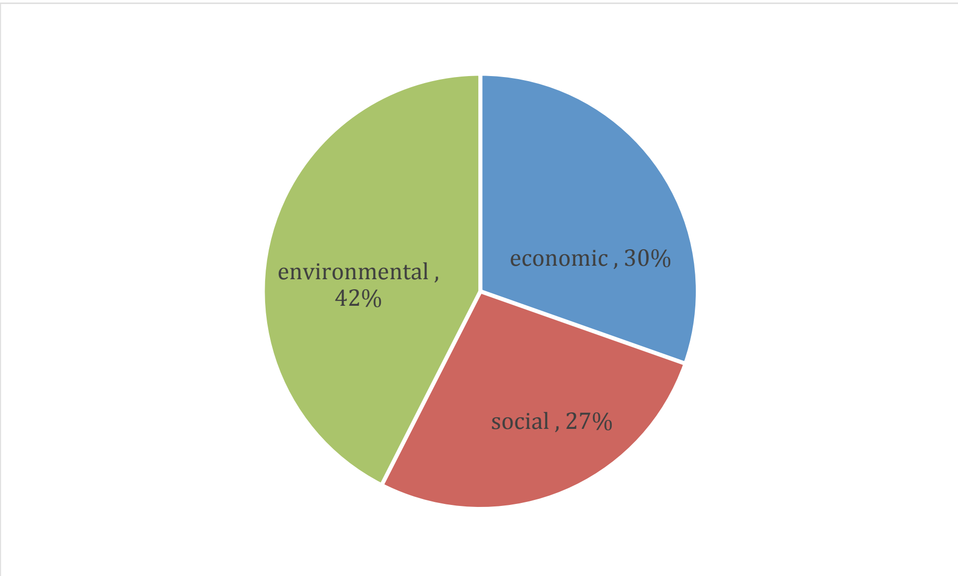

Figure 5 Preferred policy mix for creating a SRC implementation policy (Canada)

The preferences/concerns with weight given more than the average are the main issues to be considered when tailoring implementation policy on planting SRC for bioenergy supply. The upper two preferences are close to 16% which is clear differentiation from both the average (11%) and the following three preferences that have gained the priority (~12%) (Figure 6). By focusing implementation measures on the upper two or all five preferences, the other preferences listed will not be excluded but will toggle along spontaneously.

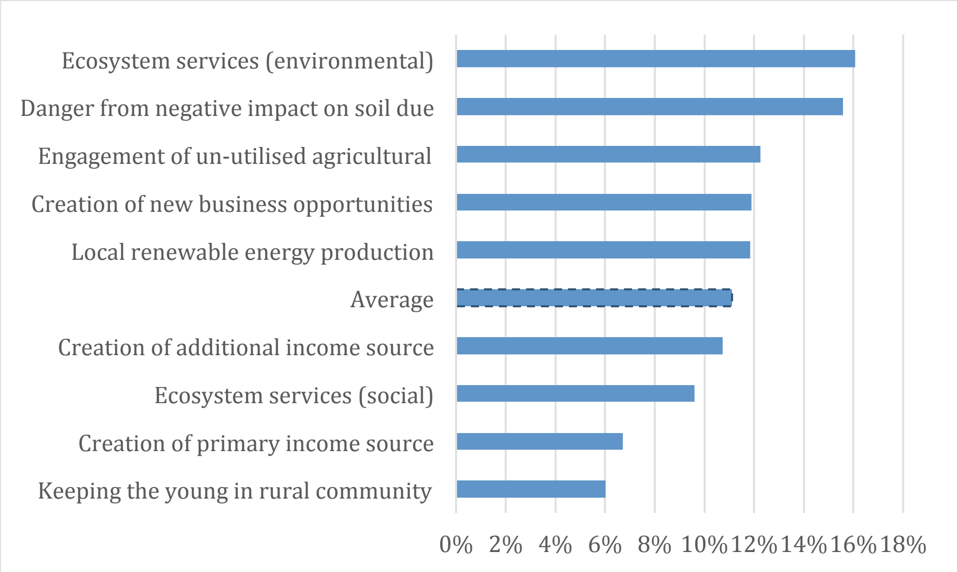

Figure 6 Canada policy building priority rankings of having bioenergy from SRC plantations

Land slots on un-utilized agriculture land that need ecoservices are identified as desirable area for growing additional biomass supply from SRC plantations. Those land slots are to be selected on the ecoservices effect provided by SRC only. The effect of the ecoservices are to be evaluated and closely monitored by a specialized authority (e.g. concession, ecoservices rights) that belong to the environmental protection governance. Policy implementation should fall under the responsibility of environmental protection national/regional ministry where land slots on former farm land that need ecoservices would be identified, evaluated for SRC plantation ecoservices ERRs. Those land slots that justify such soil/water remediation or/and protection measure, should be sent for public bid for ecoservices or included in national/regional environmental improvement plans. Private initiative to grow SRC will be led always by FRR but if farmers are educated on the possible benefits from combining SRC planation with a growing cattle business, the water streams could be kept clean.

EXECUTIVE SUMMARY: THE OPTIMAL LAND SLOTS FOR SRC PLANTATIONS ACCORDING TO CROATIAN STAKEHOLDERS

Eleven different studies reviewed under the EU project S2Biom [49] indicate that a dedicated production of industrial crops on released agricultural land could provide as much as 138-242 million tons y-1 or 13-18% of the total biomass which can be technically available within Europe by 2030 under sustainable practices. There is available land in Europe for dedicated production of industrial crops as this previously farmed land has been abandoned for a number of reasons including overexploitation, pollution, climate change and/or exodus from rural areas [49]. In Croatia, about half of the agriculture area or 1 million ha [51] is left uncultivated and turning to forest.

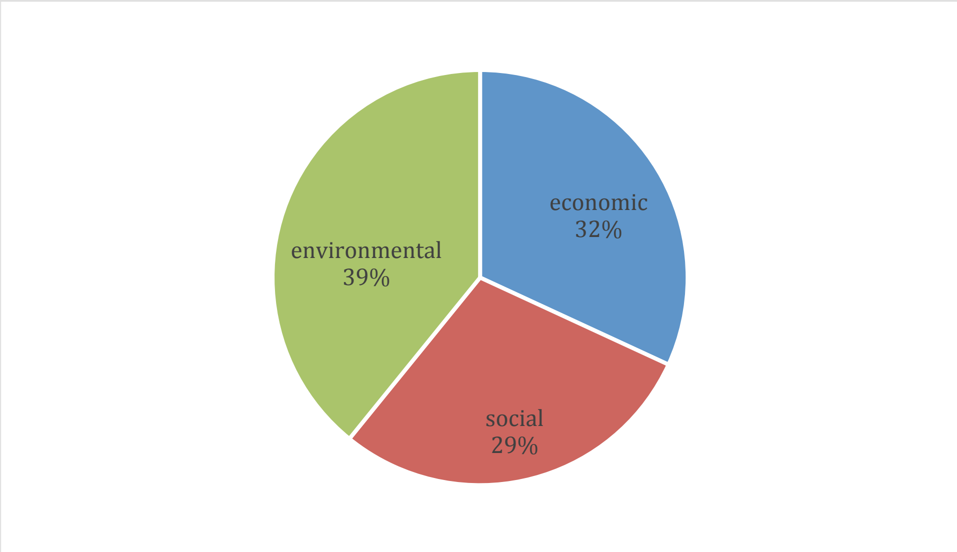

Figure 7 Preferred policy mix for creating a SRC implementation policy (Croatia)

Based on the stakeholders' preferences on planting SRC plantations for bioenergy supply, the SRC policy would be led by environmental criteria, followed by economic and social measures (**Error! Reference source not found.**).

As much as two thirds of priorities were ranked more important than the average and only one priority, which was defensive, gained ~15% weight, followed by other four with 12-13%. The priorities are dispersed and would be recommended to redo the survey after getting more familiar with the topic.

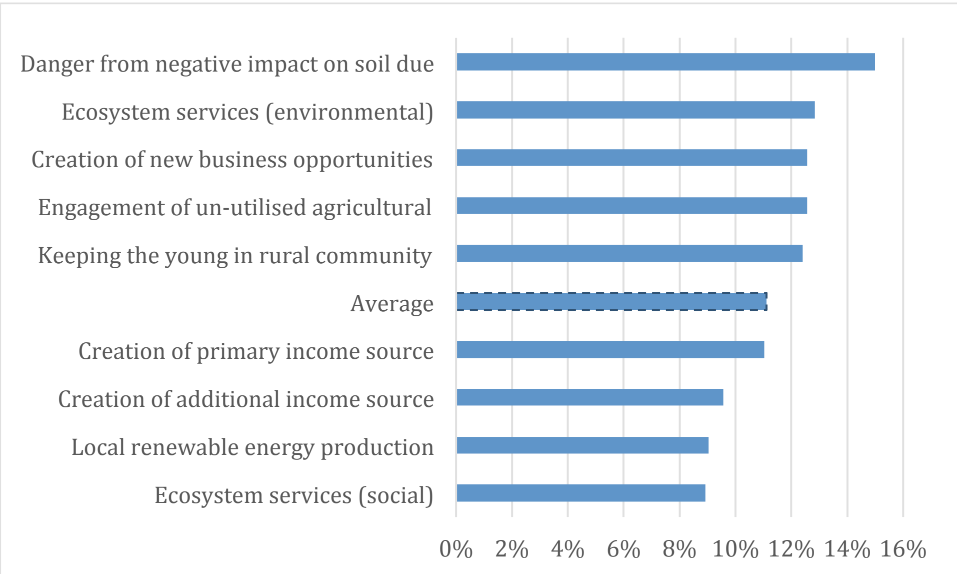

Figure 8 Croatian priority ranking bioenergy from SRC plantations

Yet, on the basis of the available results the optimal land slots for SRC plantations in Croatia would be land slots on non-utilized agriculture land where SRC plantations can achieve primary income source and create new business opportunities in areas with young(er) population. Environmental protection authority will select the land slots suitable for SRC plantations. The second step would be to identify what land slots on the un-utilized agricultural land achieve the highest ERR together with FRR. Those land slots should be highlighted either through existing agriculture subsidies (e.g. Common Agriculture Policy) or vulnerable land slots should be excluded from where SRC ecoservices are allowed until knowledge base is established. Close monitoring or management of SRC plantations from specialized authority is required.

Conclusions

In general and at specific project level, bioenergy is a dynamic and complex topic that must meet all three dimensions of sustainability. By applying fAHP on such a complex topic it is transformed to a hierarchy that enables even lesser informed stakeholders to form an opinion or preference on the alternatives.

The analysis provides methodology for a unique approach to developing a bioenergy (here on the case of SRC plantations) policy utilizing a subset of MCDA, specifically fAHP. This technique allows the policymaker to focus on the priorities of the bioenergy supply chain in question through a survey of the people actually involved in the supply at different levels. The small sample size needed for this technique make re-surveying a realistic possibility thus making it a decision-making aid suitable to a dynamic environment. The survey method also enables a type of dialogue among a variety of experts (growers, scientists, environmentalist etc.) and the decision-makers. This assists the decision -maker to designate a responsible body to develop policy that meets the desires and needs those impacted by the policy, as revealed through the survey process.

Having the results in a visual layout in a one-page Executive summary, allows policy maker to grasp the facts on policy building without being distracted with the science behind it. Even more, if the facts and results are to be revised, the methodology is simple and transparent to follow which supports the comfort in deciding.

It is reasonable to assume that this methodology would be applicable for other bioenergy supply chains. Indeed, the alternatives to each sustainability criteria could be identified by detecting the local perceptions, too. While it can probably be used across supply chains, the results provided here demonstrate that policies are region-specific; we cannot expect policies that are suitable in one area will be applicable in other areas.

An extension of this work is, depending on the preferences and priorities of different stakeholders, administrative units with land slots can be extracted from maps (e.g. soil, habitat) or statistics (e.g. demography, economic data).

This technique allows the policymaker to focus on the perceived priorities of the bioenergy supply chain in question through a survey of the people actually involved in the supply at different levels. The small sample size needed for this technique make re-surveying a realistic possibility thus making it a decision-making aid suitable to a dynamic environment. The survey method also enables a type of dialogue among a variety of experts (growers, scientists, environmentalist etc.) and the decision-makers. This assists the decision -maker to designate a responsible body to develop policy that meets the desires and needs those impacted by the policy, as revealed through the survey process. It is reasonable to assume that this methodology would be applicable for other bioenergy supply chains as it is easily inserted as a pre-step in GIS tools for allocation and scenario building in terms of landscape management (e.g. BEAST: The Bio-Energy Allocation and Scenario Tool [43] or as the next step in studies that consider land availability for bioenergy feedstocks (e.g. IEEP's study "Data sources to support land suitability assessments for bioenergy feedstocks in the EU – a review" [51]).

SRC+ IEA Bioenergy

Dear,

Short Rotation Coppice (SRC) is becoming an important bioenergy supply source that affects rural communities.

We kindly ask you for few minutes of your time to answer the questionnaire below and help us to establish socio-economic influences attached to SRC plantations growing on agricultural land.

Before you start, please circle or write your area of expertise:

a. Forestry
b. Agriculture
c. Environmental protection
d. Local government
e. Regional government
f. National government
g. Development agency
h. Public institution, which one: __________
i. Something else?

Why are you interested in SRC?

Thank you!

EIHP SRC+ team and IEA Bioenergy Task 43

SRC+ IEA Bioenergy

1. When deciding on location for a SRC plantation, the most important criteria should be:

(Please, order the criteria according to the importance based on your opinion; 1 being the most important, 3 is the least important)

☐ Economic criteria
☐ Social criteria
☐ Environmental criteria

2. When deciding on location for a SRC plantation, which criteria would be, in your opinion, the most important?

(Circle the word in middle to make the statement valid, according to your opinion):

Economic criteria is ***less equal more*** important than **social criteria**.

Please circle the weight to that difference:

A bit less/more important
More less/more important
Significantly less/more important
Extremely less/more important

Economic criteria is ***less equal more*** important than **environmental criteria**.

Please circle the weight to that difference:

A bit less/more important
More less/more important
Significantly less/more important
Extremely less/more important

Social criteria is ***less equal more*** important than **environmental criteria**.

Please circle the weight to that difference:

A bit less/more important
More less/more important
Significantly less/more important
Extremely less/more important

Extremely less/more important

7. Within environmental criteria of a SRC plantation location, how would you value the following options:

(Please, order the criteria according to the importance based on your opinion; 1 being the most important, 3 is the least important)

☐ **Engagement of un-utilized agricultural land** (regardless on the soil quality but the land which is covered with shrubs, polluted, marginal, abandoned...)

☐ **Danger from negative impact on soil due to inappropriate agricultural practices** (i.e. soil compaction, soil degradation due to taking all nutrients, significant water demand...)

☐ **Ecosystem services** (ecoservices that SRC could provide: soil erosion prevention, cleaning the soil from heavy metals, buffering water bodies from nitrates leakage, regulation of flooding...)

8. When deciding on a SRC plantation location, which environmental options should be given priority: *(circle the word in middle to make the statement valid, according to your opinion):*

Engagement of un-utilized agricultural land is ***less equal more*** important than **danger from negative impact on soil due to inappropriate agricultural practices.**

Please circle the weight to that difference:

A bit less/more important

More less/more important

Significantly less/more important

Extremely less/more important

Engagement of un-utilized agricultural land is ***less equal more*** important than **ecosystem services.**

Please circle the weight to that difference:

A bit less/more important

More less/more important

Significantly less/more important

Extremely less/more important

Ecosystem services are ***less equal more*** important than **danger from negative impact on soil due to inappropriate agricultural practices.**

Please circle the weight to that difference:

A bit less/more important

More less/more important

Significantly less/more important

Extremely less/more important

Thank you!

EIHP IEE SRC+ team & IEA Bioenergy Task 43

Appendices II: Survey results

Table 11 Survey results: fuzzy values for Task 43 members

	C1:C2	C1:C3	C2:C3	A11:A12	A11:A13	A12:A13	A21:A22	A21:A23	A22:A23	A31:A32	A31:A33	A32:A33
E1	(3/2,2,5/2)	(5/2,3,7/2)	(3/2,2,5/2)	(3/2,2,5/2)	(5/2,3,7/2)	(3/2,2,5/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(2/3,1,3/2)	(2/3,1,3/2)
E2	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/3,1,3/2)	-	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)	(1,1,1)
E3	(5/2,3,7/2)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(2/7,1/3,2/5)
E4	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)
E5	(5/2,3,7/2)	(5/2,3,7/2)	(2/5,1/2,2/3)	-	(3/2,2,5/2)	(5/2,3,7/2)	(2/5,1/2,2/3)	(2/3,1,3/2)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(2/5,1/2,2/3)
E6	(5/2,3,7/2)	(5/2,3,7/2)	(5/2,3,7/2)	(2/3,1,3/2)	(3/2,2,5/2)	(5/2,3,7/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(7/2,4,9/2)
E7	(7/2,4,9/2)	(2/5,1/2,2/3)	(2/9,1/4,2/7)	(2/3,1,3/2)	(3/2,2,5/2)	(7/2,4,9/2)	(2/9,1/4,2/7)	(2/9,1/4,2/7)	(3/2,2,5/2)	(3/2,2,5/2)	(2/9,1/4,2/7)	(7/2,4,9/2)
E8	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	-	-	-	(3/2,2,5/2)	(1,1,1)	(5/2,3,7/2)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)
E9	(1,1,1)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	(3/2,2,5/2)	(3/2,2,5/2)	-	-		(5/2,3,7/2)	(2/7,1/3,2/5)	(7/2,4,9/2)
E10	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(5/2,3,7/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(5/2,3,7/2)	(2/7,1/3,2/5)	(2/3,1,3/2)	(5/2,3,7/2)	(2/5,1/2,2/3)
E11	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	-	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(3/2,2,5/2)
E12	(5/2,3,7/2)	(5/2,3,7/2)	(2/3,1,3/2)	(3/2,2,5/2)	(3/2,2,5/2)	-	(2/3,1,3/2)	(2/3,1,3/2)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(2/3,1,3/2)
E13	(3/2,2,5/2)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(3/2,2,5/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(7/2,4,9/2)	(3/2,2,5/2)	(5/2,3,7/2)	(2/3,1,3/2)	(5/2,3,7/2)	(3/2,2,5/2)
E14	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)

Table 12 Survey results: fuzzy values for Canadian stakeholders

expert	C1:C2	C1:C3	C2:C3	A11:A12	A11:A13	A12:A13	A21:A22	A21:A23	A22:A23	A31:A32	A31:A33	A32:A33
E1	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)	(2/3,1,3/2)	(5/2,3,7/2)	(2/3,1,3/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)
E2	(5/2,3,7/2)	(5/2,3,7/2)	(2/7,1/3,2/5)	(2/3,1,3/2)	(2/7,1/3,2/5)	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)
E3	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(2/3,1,3/2)	(3/2,2,5/2)	(2/3,1,3/2)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(2/3,1,3/2)	(3/2,2,5/2)	(2/3,1,3/2)	(2/3,1,3/2)
E4	(2/3,1,3/2)	(2/7,1/3,2/5)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/5,1/2,2/3)	-	(2/3,1,3/2)	(2/3,1,3/2)	(2/7,1/3,2/5)	(3/2,2,5/2)
E5	(1,1,1)	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(2/3,1,3/2)	-	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)
E6	(1,1,1)	(2/7,1/3,2/5)	(2/3,1,3/2)	(3/2,2,5/2)	(5/2,3,7/2)	(2/3,1,3/2)	(2/5,1/2,2/3)	-	(2/3,1,3/2)	(2/9,1/4,2/7)	(2/9,1/4,2/7)	(2/3,1,3/2)
E7	(2/3,1,3/2)	(2/3,1,3/2)	(2/7,1/3,2/5)	(2/3,1,3/2)	(5/2,3,7/2)	(5/2,3,7/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/7,1/3,2/5)	(5/2,3,7/2)	(2/3,1,3/2)	(5/2,3,7/2)
E8	(2/3,1,3/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/3,1,3/2)	(2/3,1,3/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(3/2,2,5/2)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(2/3,1,3/2)
E9	(1,1,1)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(2/3,1,3/2)	(3/2,2,5/2)	(5/2,3,7/2)	(2/3,1,3/2)	(2/7,1/3,2/5)	(2/3,1,3/2)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(5/2,3,7/2)

Table 13 Survey results: fuzzy values for Croatian stakeholders

	C1:C2	C1:C3	C2:C3	A11:A12	A11:A13	A12:A13	A21:A22	A21:A23	A22:A23	A31:A32	A31:A33	A32:A33
E1	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(2/3,1,3/2)	(5/2,3,7/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(5/2,3,7/2)	(2/3,1,3/2)	(5/2,3,7/2)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(5/2,3,7/2)
E2	(1,1,1)	(2/3,1,3/2)	(1,1,1)	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(1,1,1)	(2/3,1,3/2)	(1,1,1)	(1,1,1)
E3	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(3/2,2,5/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(3/2,2,5/2)	(2/3,1,3/2)
E4	(1,1,1)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(1,1,1)	(3/2,2,5/2)	(2/3,1,3/2)	(5/2,3,7/2)	(5/2,3,7/2)	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)
E5	(1,1,1)	-	-	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	-	(1,1,1)	-	-	-

E6	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)	(5/2,3,7/2)	(1,1,1)	(2/3,1,3/2)	(2/7,1/3,2/5)	(2/3,1,3/2)	(1,1,1)	(1,1,1)	(2/3,1,3/2)
E7	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(5/2,3,7/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(2/3,1,3/2)	(2/9,1/4,2/7)
E8	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(2/3,1,3/2)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
E9	(2/3,1,3/2)	(2/3,1,3/2)	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)
E10	(1,1,1)	(1,1,1)	(1,1,1)	-	(1,1,1)	-	(1,1,1)	(1,1,1)	(1,1,1)	-	(1,1,1)	-
E11	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)	(1,1,1)	(2/3,1,3/2)	(1,1,1)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)
E12	(1,1,1)	(1,1,1)	(1,1,1)	(5/2,3,7/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)	(3/2,2,5/2)	(1,1,1)
E13	(5/2,3,7/2)	(1,1,1)	(2/7,1/3,2/5)	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)	(1,1,1)	(5/2,3,7/2)
E14	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)	(1,1,1)
E15	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(3/2,2,5/2)	(5/2,3,7/2)	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(3/2,2,5/2)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(3/2,2,5/2)
E16	(2/3,1,3/2)	(2/9,1/4,2/7)	(2/9,1/4,2/7)	(2/5,1/2,2/3)	(2/7,1/3,2/5)	(2/5,1/2,2/3)	(7/2,4,9/2)	(2/5,1/2,2/3)	(7/2,4,9/2)	(2/3,1,3/2)	(2/3,1,3/2)	(3/2,2,5/2)

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