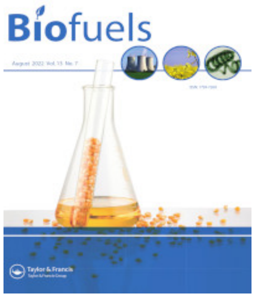

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Positioning the biofuel policy in the bioeconomy of the *BioEast* macro-region

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ABSTRACT

This study outlines and reviews the concerted biofuels' policy for transport of eleven countries in central and eastern Europe (BioEast macro-region). Policy preferences collected from relevant government representatives of the region are analyzed using choice architecture and fuzzy Analytical Hierarchy Process. The experts' preferences concerning criteria related to land use, decarbonization and development of a national market are ranked with similar importance, with a slight preference for the latter. The results demonstrate a great variation in the priorities for forming and implementing biofuel policies in the region, strongly related to national realities (e.g. available land for biofuel production, target fulfilment). Countries delaying in their biofuel targets aim at policies that fulfil internal demands without considering other criteria related to land use issues and own sources. The results show a general agreement (95% consensus) of having about 66% of renewable energy in transport covered from biofuels resulting from domestic biomass supply. Yet, there are differing preferences in the policy options at country level, which makes a single consensus policy for the macro-region challenging. Finally, the results highlight the different degrees of policy intervention that are implicit in the policy preferences of the national decision makers.

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AHP; biofuels policy; mandated share; decarbonization; transport

Introduction

The EU ambition to become climate neutral by 2050 with an economy of net-zero greenhouse gas (GHG) emissions requires attention on both sides of the market in decreasing the use of carbon and switching production to non-fossil or renewable carbon. As expressed in the Circular Economy Action Plan, Europe must reconsider trade-offs concerning land resources to support its bioeconomy development with an increased biomass demand [1]. Moreover, the European Green Deal commits to resource efficient and competitive forestry and agriculture systems with no net GHG emissions while fulfilling a range of environmental externalities [2]. Europe's dedicated vision towards a sustainable and circular bioeconomy increases the demand for biomass as a source of renewable carbon, carbon storage in materials and soil, and carbon stock to absorb the excess carbon from the atmosphere. Although considered a renewable source, biomass is limited by its growth cycles and the land required for its growth, pointing at the need for rational policies and priorities for biomass use within the cascading use. At the same time, there seems to be a delay in adapting policy measures to minimize the negative externalities and inability to reflect GHG savings in market prices [3,4].

The energy sector is a horizontal sector of each society where secure, sustainable, competitive and affordable energy is a cornerstone of each modern energy policy [5–7]. In the EU, this is to be achieved by a fully integrated European energy market taking climate implications into account [8]. Yet, the energy sector is the largest anthropogenic GHG emitter, where the transport sector represents the main challenge to curb the GHG emissions [9]. Biofuel policies are related to the limited biomass supply in connection to land availability and productivity as well as to diminishing waste streams due to the waste hierarchy [10,11]. The necessary biomass, however, has different sources, since biofuels entail first generation, generated by agricultural crops and including ethanol and biodiesel, based on traditional processes such as fermentation and esterification, and second generation, from lignocellulosic materials, municipal waste and forest and agricultural residues, usually based on more complex technologies (for a review of the technologies, see [12,13] for the maturity of the technologies in the region, see [14]).

The biofuels policy balances between the growing demand for biofuels and the limited biomass supply, from agricultural and forest sources, not only in terms of quantities but also in terms of net GHG emission savings [15–17]. Failing to recognize the biofuels demand from energy policy and bridge it over with the available biomass supply can make the existing agriculture policy obsolete, including all other biomass supply sectors, such as forestry, aquaculture and waste. Biofuels represent the only sector of both the current and future bioeconomy with a mandated share expressed in the Renewable Energy Directive (so called REDII, [17]), later to be translated to the National Energy Climate Plans to each Member State. While RED II

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mandates a share of "Renewable Energy in Transport" (RES-T), much of the efforts to meet the 14% target by 2030 will still depend on biofuels. False premises or lack of coordination between the energy sector demand for biomass with national bioeconomy strategy development efforts would hinder the transition to a circular and sustainable bioeconomy.

This is particularly relevant in Central and Eastern Europe. In this area, eleven countries (Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia and Slovenia) have organized themselves within the Central-Eastern European Initiative for Knowledge-based Agriculture, Aquaculture and Forestry in the Bioeconomy. The BioEast Initiative offers a shared strategic research and innovation framework for working towards sustainable bio-economies in the region (see: https://bioeast.eu/). This macro-region entails large amounts of productive agricultural and forest lands, but also underutilized biomass potential [18,19], insufficient infrastructure and missing links between industries [20,21]. The *BioEast Initiative* considers bioeconomy as a chance to reduce the internal EU's disparities by expanding knowledge base and supporting evidence-based policies.

To achieve the RES-T targets while considering the unified European energy market and its energy situation and policies, policy makers in each *BioEast* country must create a concerted set of policies to integrate additional biomass demand along the bioeconomy framework. Concerted policy occurs when the policy topic exceeds the authority of a single ministry and several sectors must engage to develop a policy. Biofuel policy is a typical example of a concerted policy as the energy sector sets the quantity of demand (e.g. mandated share of biofuels in determined future), transport sector sets the quality of demand (e.g. what kind of features a biofuel should have to meet the existing demand, vehicle fleet and infrastructure) and agriculture, forestry and waste sectors are supplying biomass to produce biofuels. Yet, in the case of biofuels for transport policy, having biomass engaged for biofuel production in a country does not ensure that the produced biofuels will be placed at the national market to meet the mandated share. Implemented measures should aim to make the best of the increased biomass demand and gradually transit to circular and sustainable bioeconomy, supported by a gradual, adaptive and innovative governance approach that allows policy learning [22,23].

The present paper outlines and reviews the possible outcomes of concerted biofuel policies in the *BioEast* macro-region countries resulting from the expressed preferences by national stakeholders. It addresses the current preferences and directions in the biofuel policies in the area, the consensus in biofuel policies integrated among the different countries and the assessment of the biomass supply and biofuel demands based on the responses. The policy preferences on RES-T are analyzed using choice architecture where stakeholders are guided through the main aspects of the complex renewable energy in transport policy, in which biofuel policy is embedded as an option. The results should serve as a starting point for the inter-ministerial discussion, supported with the expert opinion or scenario analysis. As such, the approach involves the policy makers directly in the trade-offs and commonalities in between the sectors which later allows higher quality in inter-ministerial discussion.

Material and methods

The possible options for the RES-T sector were first assessed and listed, based on the current criteria [17] and alternatives in the area [24,25]. Resulting from this analysis, a set of alternatives were presented following the *choice architecture* approach [26]. The transport fossil-free alternatives estimated to be feasible by 2030 were listed as options for the stakeholders, structured in a hierarchy with three main criteria and nine final alternatives on biofuel policies (Figure 1). In addition, two additional questions were added concerning the source of biomass for biofuels: whether from own sources or imports and whether from by- and waste streams or from sustainably grown biomass.

This structure aimed to reduce the number of attributes and not to overwhelm the decision-maker when considering the trade-offs [27] but simultaneously include the main criteria identified in the so-called RED II [17]: energy demand (calculation rules with regard to the minimum shares of renewable energy in the transport sector, Article 26) and sustainability in terms of GHG savings from the alternative and land use (Sustainability and greenhouse gas emissions saving criteria for biofuels, bioliquids and biomass fuels, Article 29). The choice architecture was then arranged for the stakeholders in a form of a questionnaire.

The comparisons related to biofuels were designed to be analyzed following an approach based on fuzzy Analytical Hierarchy Process (AHP, [28,29]). In the questionnaire, the experts (*judges*, in AHP terminology) had to choose the most preferred option based on pairwise comparisons of each criterion and alternative. The perceived importance of each option was expressed with alternatives to the verbal judgements that were later replaced by fuzzy numeric values (1 to 7, following Table 1). Buckley's [28] approach was applied by constructing a fuzzy pairwise comparison matrices and verifying the consistency of the answers.

The first node in the choice architecture was defined as a choice between "e-mobility" or "biofuels", which was only used to assess the potential size of the biofuel market based on the experts' responses. The first node in the biofuel's hierarchy related to three main criteria: land use (A1), decarbonization (A2) and biofuel demand (A3). Each of these criteria had three resulting alternatives, which made the final node in the hierarchy.

The stakeholder's responses of the pairwise comparisons were analyzed constructing fuzzy pairwise matrices. A fuzzy geometric mean [28, 30] was computed for each criterion, to compute the weights for each option. The value a_{ij} represents the pairwise comparison between the alternative i and j. Based on this, $\tilde{a}_{ij}$ are the triangular fuzzy values $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, being l and u the *lower* and *upper* limits, respectively, and m the membership function of the triangular fuzzy number $\mu(x)=1$, following:

$$\mu(x) = \begin{cases} \frac{x-l}{m-l}, & x\epsilon[l,m] \\ \frac{u-x}{u-m}, & x\epsilon[m,u] \\ 0, & otherwise \end{cases} \tag{1}$$

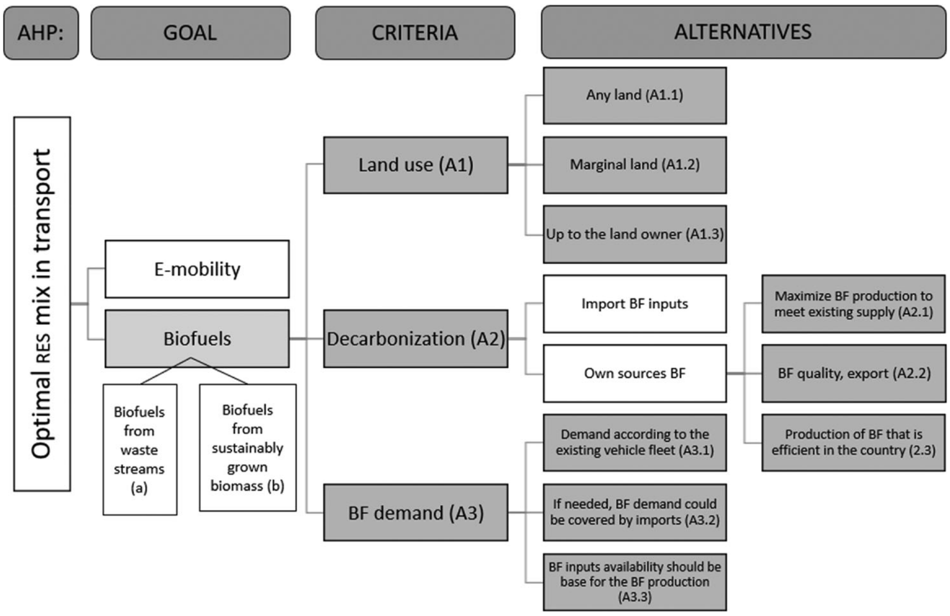

Figure 1. Embedded hierarchy of biofuels' policy in choice architecture for concerted policy (grey cells represent Analytical Hierarchy Process hierarchy); BF = Biofuels.

Table 1. Judgements used to weight the pairwise comparisons made by the experts. AHP: Analytical Hierarchy Process.

Verbal judgements [29]	Representation of verbal judgements	Crisp AHP scale [29]	Numeric values fuzzy AHP scale	
			Triangular fuzzy value	(Reciprocal)
A is extremely important than B	–	9	–	–
A is very strongly more important than B	A≫>B	7	(6, 7, 7)	(1/7, 1/7, 1/6)
A is strongly more important than B	A≫B	5	(4, 5, 6)	(1/6, 1/5, 1/4)
A more important than B	A > B	3	(2, 3, 4)	(1/4, 1/3, 1/2)
A is as important as B	A = B	1	(1, 1, 1)	(1, 1, 1)

Using these values, a fuzzified reciprocal square matrix $\tilde{A}$ was constructed, based on Meixner [31]. The crisp value m_{ij} was used to calculate the sum of values for each row of the matrix (PV), to simplify the calculations, so the eigen vector was obtained by:

$$Wp = \frac{PV}{\sum PV} \tag{2}$$

and the maximum eigen value (λ_{max} of a n x n pairwise comparison matrix, being n was the number of alternatives) was then calculated by:

$$\lambda_{max} = \sum a_{ij} W_p \tag{3}$$

The resulting maximum eigen value was used to calculate a consistency ratio - CR for each respondent's value [32], following:

$$CR = \frac{\lambda_{max} - n}{n-1} RI^{-1} \tag{4}$$

where RI is the random consistency index, being 0.58 when $n = 3$ (see e.g. [32]). The closer the CR is to 0, the more consistent the answers (i.e. when, A > B and B > C, then necessarily, A≫C, proving consistency). Except the additional questions concerning sources of biomass for biofuels, all other responses in the architecture included three alternatives, which is the minimum number necessary to estimate the CR. To be considered in the analysis, the respondents had to show a CR < 20%.

All alternatives were then combined in a weighted sum considering the fuzzy weights of each criterion (using the geometric mean of the l_{ij}, m_{ij} and u_{ij} values), and the Best Non-Fuzzy Performance (BNP) was estimated [33,34]. This resulted in an overall ranking of the alternatives and a set of preferred alternatives was identified.

The questionnaire was sent to representatives of the governments of all eleven BioEast countries. The survey had two collection steps: in February and October 2019 *via* the BioEast Initiative network and was sent out through the National Contact Points closely working with the high-level ministry representative sitting in at the board, the highest decision body of the BioEast initiative, to reach the decision-makers. Based on the ranking results, the experts' preferences were translated into an assessment of the biofuels' market size and the biomass supply streams, including imports of biomass.

After collecting the experts' preferences, the biofuel experts can then construct the biofuels policy following the methodology stipulated by law, if any, and verify how realistic those preferences are or verify the feasibility and costs through trade-offs. The outcome can be contrasted with the general goal on the spillovers of the policy to introduce a discussion on possible compromises: discuss the results of the experimental biofuels policy with the decision-makers, raise awareness of unintended consequences and reiterate the pairwise comparison with gained knowledge or expand the alternatives, if necessary.

Finally, the assessment of the policy maker's preferences was compared to the profile of the countries analysed, including current indicators related to the country's biofuel capacity [35], land-uses from the Corine databases [36] and population and percentage of RES-T [35]. These indicators are the basis for the interpretation of the overall preferences by country.

Results

Profile of the stakeholders

There were 41 expert replies from all eleven BioEast countries with a dominant background from the agriculture sector, followed by energy-biomass at national level/ministry and public institutions. The responses by country ranged from one for Romania and Slovakia, to nine from Croatia ($N = 9$) (Table 2). The profile of the respondents included 56% of policy-oriented and 32% research-oriented stakeholders, whereas biomass market stakeholders represented 12% (i.e. a representative of an administrator of the unit, biomass buyer, energy plant operator, lignin-based biomass producer or technology transfer, among others). Concerning experience, 59% of the respondents have less than 4 years of experience on the topic, whereas 34% of the respondents reported more than 6 years.

Macro-region preferences

In total, 133 comparisons passed the threshold of consistency (CR < 20%) and were included in the analysis. From these, 87 passed the stricter threshold (CR < 10%). When sizing the biofuels market (Figure 2), the preferred share of biofuels in the optimal renewable energy in transport mix was expressed at roughly 2/3 (63%) with e-mobility contributing preferably with 37% (BF/e in Figure 2). Further partitioning indicated a larger preference for producing biofuels from waste streams and agri-residues (BFa: 66%) than biofuels from sustainably cultivated biomass (BFb: 33%).

The choice architecture partitioning indicated a strong unity of preferences within the BioEast macro-region in choosing "Biomass supply should occur from own (national) resources" (94.9%) over imports of biomass. This preference highlights the need for a strong coordination between the energy policy (mandated RES-T share) and agriculture policy (or, furthermore, a comprehensive bioeconomy policy). Although bioenergy is placed as the last cascade of biomass use within the circular and sustainable bioeconomy, biofuels in transport constitute the only mandated biomass demand by 2030. The production of biofuels creates a significant biomass demand where, roughly, a 50k t biorefinery requires about 300 kt biomass annually, but the 0.05 ktoe in produced advanced biofuels represents less than 1% in the current biofuel supply among all BioEast countries.

The partitioning with simple ranking at the beginning of the AHP hierarchy (criteria) was indecisive whether to give priority to the *land use* or the *decarbonization* criterion (both 34.1%) when deciding on the optimal share of biofuels in the transport sector. The same partitioning but as a weighted pairwise comparison within the fuzzy AHP framework (Figure 3) gave more preference to the *national fuel market* criterion (A3: 43%) over the *decarbonization* criterion (A2: 31%) and *land use criteria* (A1: 26%), when aggregated for the whole macro-region. Contrasting the preferred criteria to the evidence-based policy options, choosing such biofuels that would fit the existing national fuel market features such as fossil fuel type demand (petrol, diesel, alternative fuels), infrastructure and vehicle fleet, is a reasonable preference. The vehicle fleet in the BioEast macro-region is on average 14.7 years old, whereas Lithuania, Estonia and Romania have the oldest fleets, with vehicles older than 16 years on average [37]. The dominant fuel in road transport is diesel fuel, with a marginal share of CNG cars, suitable for CBM as the biofuel alternative. The average share of alternative fuels (including various gaseous transport fuels) represents only 2.4% of the total transport fuel demand in the BioEast macro-region, with only Poland (13.7%), Latvia (6.4%) and Slovakia (2.1%) with shares of alternative fuels above 1% [37]. Having in mind that the RES-T share is fixed at the 14% of the national demand for fuels that can be reached with different multipliers per RES type [17], all alternatives of available biofuels are to be considered.

The aggregated ranking of alternatives for the macro-region weighted three alternatives above the average weight of 0.11, using a 20% consistency threshold. These alternatives entailed about 46% of the cumulative weighted preferences. The highest ranked alternative according to the expressed preferences outlines what kind of biofuels would be preferred to meet the mandated share. A strong preference at aggregated level was that, if needed, biofuels demand could be covered by imports (A3.2: 18%). This preference was supported by the next two highest ranked alternatives: biofuels demand should be adjusted to the existing vehicle fleet (A3.1: 15%) and maximization of biofuels production to meet the existing transport fuel supply (A.2.1: 13%). With this, a strong commonality of a concerted biofuels policy surfaces: producing such biofuels that would have a minimal intervention on the infrastructure, vehicle fleet and, in general, mimic the existing fossil fuel supply without harming the environment.

Pairing the ranking of the preferences with the evidence-based policy options, it is realistic to source for biofuels imports if the domestically produced biofuels do not meet the mandated demand. Based on the expressed opinion of decision makers, the preferred biofuels in the optimal renewable energy in transport mix would be those that have the minimum influence on the existing infrastructure and the existing vehicle fleet and could be made from own biomass originated from by- and waste streams. The biofuels that fit those preferences would be biodiesel from the used cooking oil, advanced biofuels made from lignocellulose biomass (straw and crop residues) as well as, to lesser extent, biogas from waste and manure as a compressed biomethane (CBM). This gives valuable information to the policy maker on the approximate demand for biofuels as well as for biomass from national resources, costs in the biorefinery investments against the volume and costs of the imported biofuels. The decision-making process can continue with specified expert scenario development: whether to source for the second-best option of producing biofuels from sustainably grown biomass (biofuels from food and feed, advanced biofuels from perennial grasses or short rotation coppice) before the imports and, if yes, to which extent. The difference with this approach in framing the concerted policy is that the decision-makers are now well informed on the background behind the scenario alternatives.

Clusters were formed when investigating the lower ends of the hierarchy, concerning the criteria to be prioritized to achieve effective biofuel policies from stakeholders at national level (Figure 4). In some cases, all three criteria were ranked in a similar weight (Estonia), resulting in

Table 2. Profile of the eleven studied countries defined as the *BioEast* macro-region. (Reference year for the data: 2018. n.d: no data available, RES-T: Renewable Energy in Transport).

Country	Population (x 1M)	RES-T (%)	Responses (N)	Utilised Agricultural Area (x 1000ha)	Liquid biofuels production capacity (x1000 t)	Other areas on the farms (x1000ha)	Unutilised agricultural area (x 1000ha)
Bulgaria	7.00	8.06	3	4468	27	20	1.86
Croatia	4.08	3.89	9	1562	n.d	22	21.71
Czechia	10.65	6.52	8	3455	180	65	0.48
Estonia	1.32	3.29	4	995	n.d	46	0.81
Hungary	9.77	6.9	3	4670	538	198	15.57
Latvia	1.92	4.73	3	1930	19	183	15.24
Lithuania	2.79	4.33	3	2924	159	60	12.73
Poland	37.97	5.63	3	14405	909	749	82.32
Romania	19.41	6.34	1	12502	80	231	100.83
Slovakia	5.45	6.96	1	1889	126	28	0.64
Slovenia	2.08	5.5	3	488	n.d	15	10.16

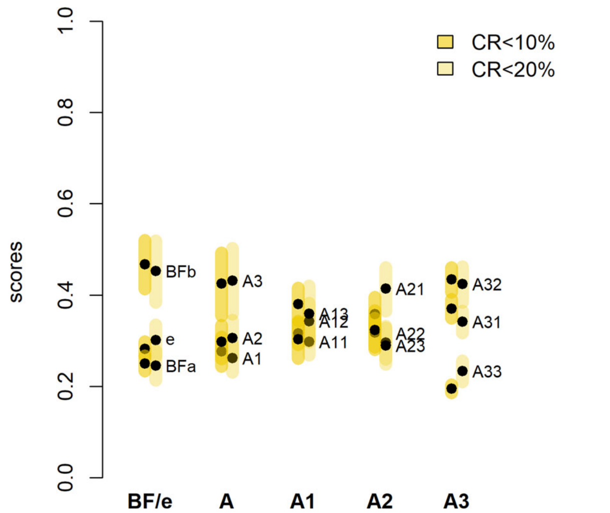

Figure 2. Fuzzy weights and Best Non-fuzzy Performance (BNP) value for each alternative. BF/e (optimal mixture of renewable energy in transport) alternatives are e: e-mobility, BFa: agri-residues/waste-based biofuels, BFb: grown biomass for biofuels. BFa and BFb together result in A (*biofuels*), with criteria A1: land use, A2: decarbonization, A3: national fuel market. The BNP is expressed with the black points, and the vertical lines entail from the lower and upper values of a triangular fuzzy number. The shade of the colour refers to the consistent thresholds CR < 10% (dark colour) and CR < 20% (light colour).

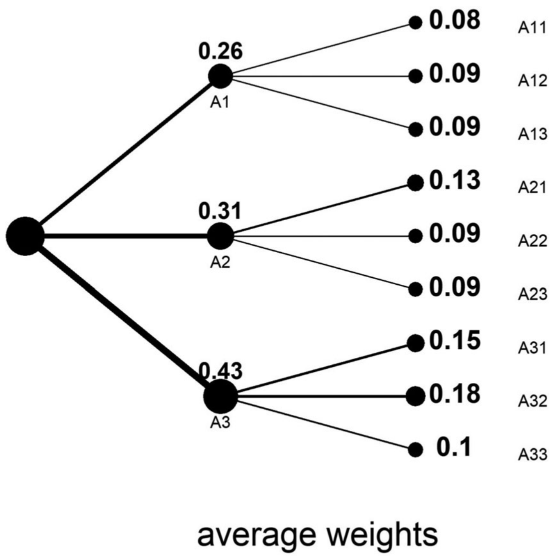

Figure 3. Overall assessment of the biofuel alternatives (first node, biofuels, has a value = 1). The nodes represent the Best Non-fuzzy Performance (BNP) value for each criterion (A1: land use, A2: decarbonization and A3: national market) and sub-alternative for each country. The average estimates are made using a 20% consistency threshold.

prioritizing only A1.1 growing sustainably biomass for biofuels on any land, among several alternatives with

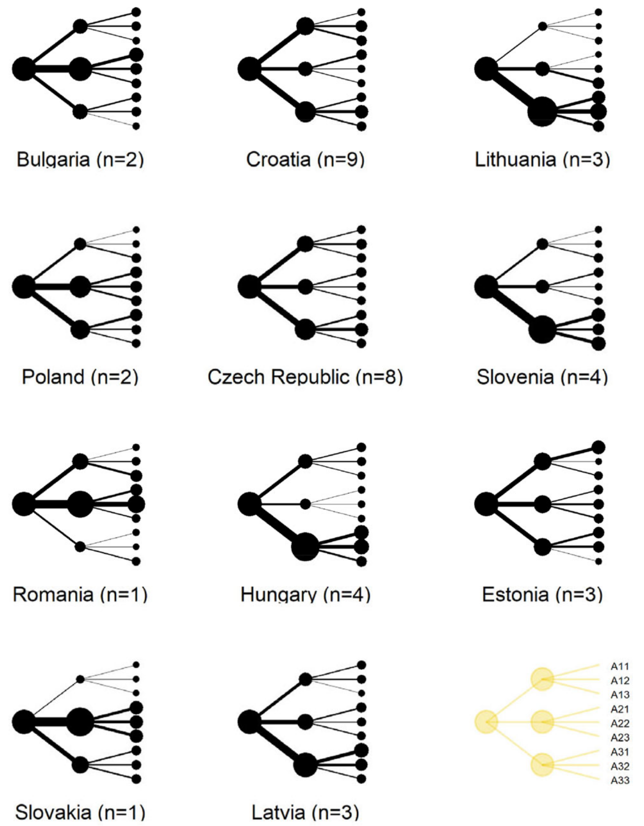

Figure 4. Assessment of the biofuel alternatives by the country's national contact experts. The size of the nodes represents the Best Non-fuzzy Performance (BNP) value for each criterion (A1: *land use*, A2: *decarbonization* and A3: *national market*) and sub-alternative for each country. Only experts (n) within the 20% consistency threshold were included.

approximately the same weight. In other cases, strong priority of a criterion over the others was evident in the analysis. Stakeholders from a group of countries (Slovakia, Romania, Bulgaria, Poland – in order by weight) favoured transport decarbonisation criteria (A2) as the lead for the trade-offs in concerted biofuels policy or for producing biofuels that would achieve the most GHG emission savings per volume. Stakeholders from other countries (Lithuania, Hungary, Slovenia, Latvia, Croatia, Czechia) put more weight on criteria for outlining the biofuels policy based on the given demand for biofuels (A3) in their country (Figure 5). It is worth mentioning that both Croatian and Czech stakeholders gave a slight advance of A3 criteria over the A1 land use, which softens the prioritization of A2 over other criteria when considering the trade-offs.

Among those weighting higher the A2 criterion, the Slovakian stakeholder was indecisive among the

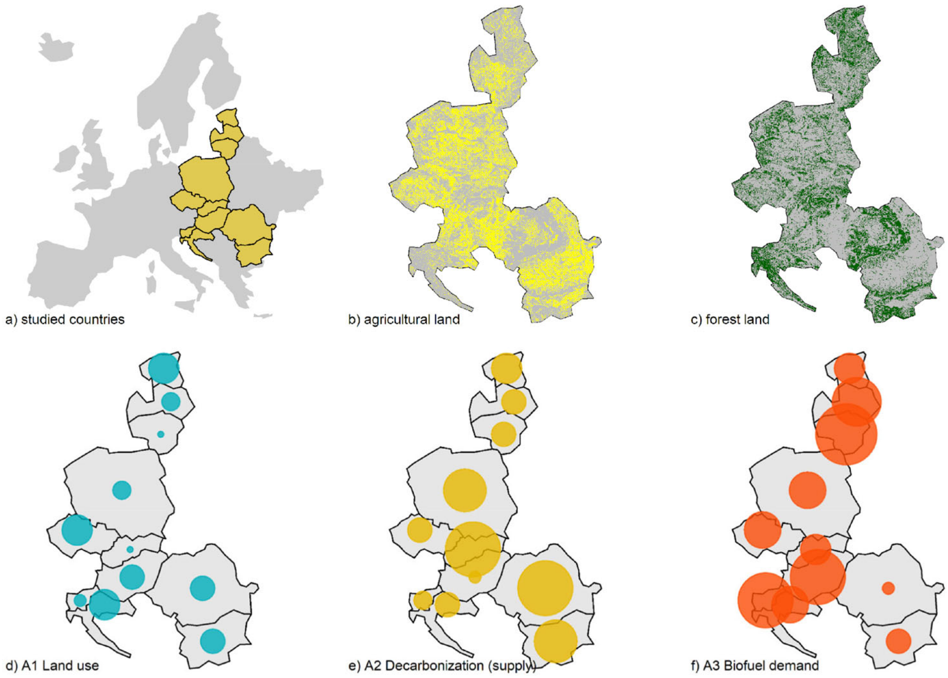

Figure 5. Characterization of the macro-region and resulting weight for the criteria related to biofuel market alternatives: a) countries included in the study ($N = 11$) defined as the *BioEast* region, b) distribution of agricultural and c) forest lands in the region. Results of the relative preference weights of each criterion: d) *land use*, d) *decarbonization* and f) *biofuel demand* (the darker the colour, the higher the weight for each criterion).

alternatives, the Romanian stakeholder aimed for quality biofuels that would be exported (A2.1) whereas both Bulgarian and Polish stakeholders prioritized the maximization of biofuel production to substitute the existing supply of fossil fuels (A2.2) without tapping into the vehicle fleet and infrastructure outline. The second-best option was perceived as A2.1. for Poland, whose stakeholders gave the least weight to A2 in this cluster of countries, the A3 alternative, producing biofuels according to the existing vehicle fleet (A3.3), which supports the priority of A2.2, has been given weight.

The larger cluster, gathered around the A3 criteria, has further grouped around the two alternatives where one was just slightly preferred over the other: A3.1 biofuel demand is to be according to the existing vehicle fleet (stakeholders from Hungary, Slovenia, Latvia) and A3.2 if needed, biofuel demand could be covered by the imports (stakeholders from Lithuania, Croatia, Czechia). Croatian, Czech and Estonian experts form an additional cluster with a slight advantage for market alternatives over land use. Both Croatian and Czech stakeholders prefer the use of marginal land for sustainable biomass growing for biofuels.

In addition, the alternatives for each criterion were ranked concerning the degree of policy intervention implied. By these means, the criteria A1.2 (use of land restricted only to marginal land), A2.3 (only biofuel production efficient in the country) and A3.3 (biofuel input availability should be the base for biofuel production) were grouped together and characterized as higher policy intervention alternatives. Implementation of decisions related to these criteria can be directly imposed by policy-making from related ministries and were therefore grouped together. On the other end, criteria A1.3 (follow own preferences of farmer), A2.1 (maximize production to meet supply) and A3.2 (meeting the demand with imports) can be considered as giving a larger room to market mechanisms for the regulation of supply and demand (Figure 6).

The results showed different degrees of policy intervention according to the collected stakeholders' preferences by country and alternative. Overall, the preferences related to land use (A1) seem to avoid high degrees of policy intervention (restrictions) or market regulation. Croatian and Czech experts prefer biomass for biofuels sustainably grown only in marginal land whereas Estonian, Romanian and Polish stakeholders would prefer that either the market or the landowner decides where the biomass for biofuels will be grown. The stakeholders' options related to decarbonization (A2) seem to prefer stricter policy intervention in Poland, Slovakia and Lithuania, and favour more market regulations in the case of Romania. Concerning the national transport fuel market demand (A3), stakeholders' preferences are moderately inclined to market regulation in all countries except in Romania. For all criteria averaged, Estonian response reflected the lowest degree of policy intervention in the preferences.

Discussion

The present paper outlines concerted biofuels policy in a form of a choice architecture where stakeholders are guided through the main aspects of the complex biofuel policy as a constituent part of the renewable energy in transport mix for a mandated share. One of the strengths of this research concerns the involvement of relevant stakeholders in the concerted policy decision process. All stakeholders addressed are main actors in decision-making for biofuel policies at national level, either as ministry representatives or research entities. Ministries have a national contact point for the *BioEast Initiative* that in their turn delegate tasks to the national experts to provide input for issues under focus, as in this case for biofuels, and incidentally for the survey presented. In this sense, the results presented are directly based on the preferences of the persons ultimately involved in policy decisions.

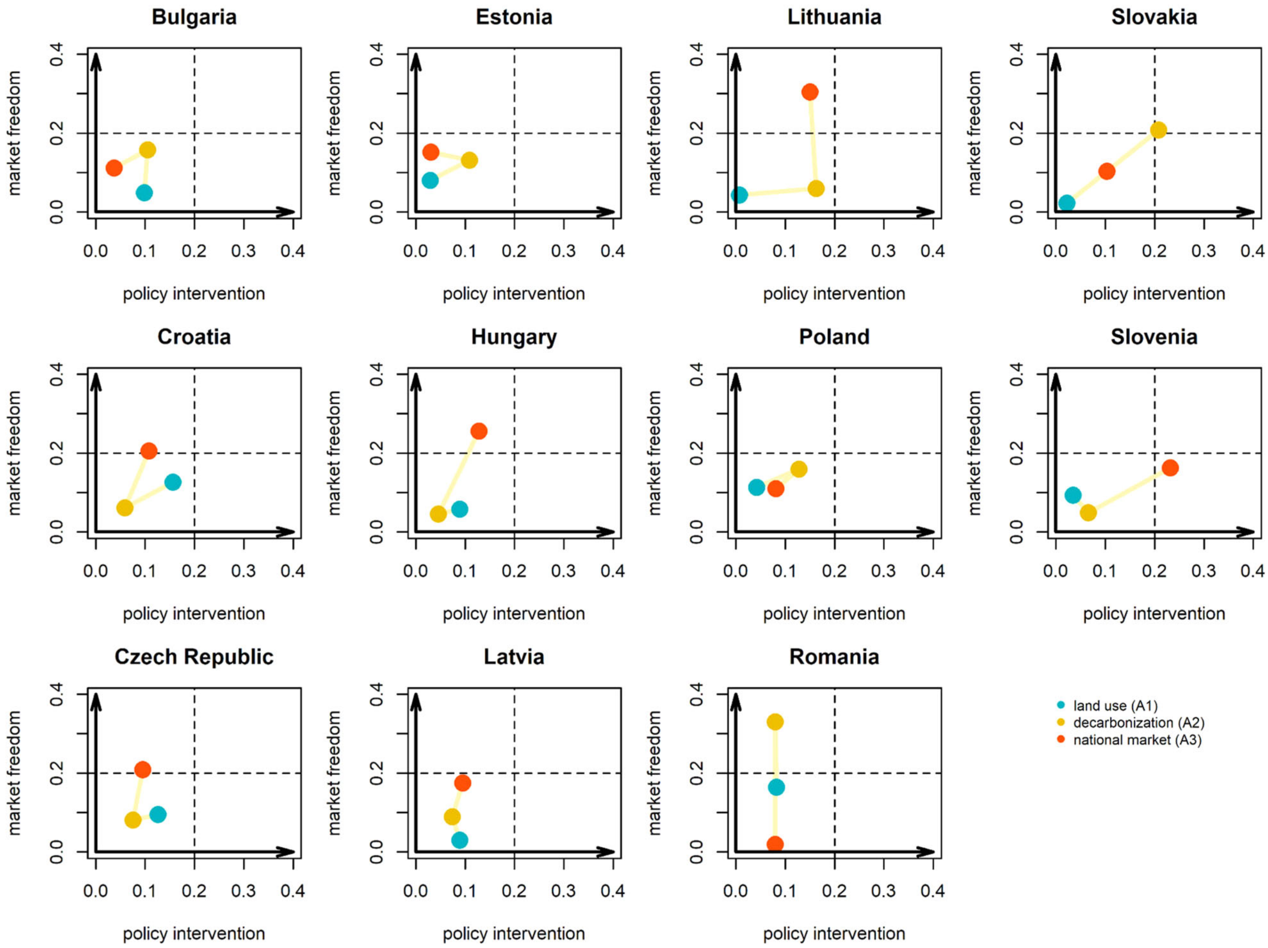

Figure 6. Illustration of the degree of policy intervention based on the preferences of the country's national contact experts. *Policy intervention* refers to the aggregated weighted preferences for alternatives A1.2, A2.3 and A3.3 (most restrictive), and *market self-regulation* for A1.3, A2.1 and A3.2 (least restrictive). The dots represent the criteria A1 (*land use*), A2 (*decarbonization*) and A3 (*national market*).

The background of the survey participants was mainly related to policy and research, with only a marginal representation of biomass market stakeholders, which could be a realistic illustration of the general background of the contact points. The contact points closely work with the high-level ministry representative sitting in the BIOEAST Board, the highest decision body of the Initiative. The response rate, therefore, means that the study includes a large percentage of the target population of policy makers, and the number of experts is in the same range than previous studies. For example, D'Adamo *et al*, [38] included 20 experts for analysing the trajectories of each member state of the European Union to achieve their RES-T goals, Schillo *et al*, [39] included 33 experts when analysed biofuels policies in Canada, and Chanthawongab and Dhakal [40] included 36 experts to analyse biodiesel and bioethanol policy development in Thailand, among others. In fact, Saaty and Özdemir [41] addressed specifically the issue of representativity and number of experts needed and concluded that expertise is the main factor to have into account; in some cases, a single expert may be the basis of analysis and targeting to increase the sample size by adding additional judges may compromise the accuracy if their expertise is not at the same level.

It is relevant to stress that the analysis of stakeholders' preferences on policy is a rather complex one, and it often requires expertise in several different fields, which is difficult to achieve in early career stages, as reported by the majority of the BioEast stakeholders. In addition, decisions can be in many cases based on incomplete data and high uncertainty regarding the effects [33,34,42]. This limitation was addressed through partitioning, which was employed to ensure that stakeholders consider all aspects of biofuel policy, regardless of their dominant expertise of the concerted policy in question. Bond *et al.* [43] showed that there is a benefit of explicitly mapping decision-making options as the stakeholders tend to recall only about half of them, even if they are familiar with the topic. Renewable energy in transport policy is limited to four non-dominating aspects (imports, biofuels, advanced biofuels, electricity) and their partitioning to encourage reasoning of trade-offs [27] needed in the three main policies (agriculture, transport, decarbonisation) [17].

The implemented approach collects the preferred experts' views on biofuels policy from different policy sectors, regardless of their dominant expertise, but simultaneously insists that each aspect of the concerted policy must be considered and weighed. While being aware that the approach is not conducted in perfect conditions with a balanced team of experts from all areas of the concerted policy, it reflects the policy framing reality where the perfect environment with sufficient time and resources is rarity rather than practice. The advantage of the approach is a time-efficient collection of preferences on biofuels policy from different sectors (or administrative units or bodies) in a structural and systematic approach. The preferences are then translated to an actual policy outline, which can be later verified for applicability, costs and necessary trade-offs. As such, the stakeholders are gaining knowledge on the origin of the trade-offs, even if they do not have full background knowledge on the topic. For instance, Croatian experts indicated strong agreement on having biofuels from own biomass supply (as in all the other cases, nearly 95% of the responses) but limiting that biomass supply only on waste streams (66%), and, later preferring mainly abandoned or marginal land for growing biomass sustainably for biofuel (90%). Contrasting this outcome with the national strategic investment in a 55 000 t lignocellulosic bioethanol biorefinery is indicating that the collected preferences are not realistic to support national biofuels production [44]. This helps the whole decision-making group (regardless of the background) identify trade-offs among the alternatives and options to be considered. The interpretation is a good start for adaptive policy making [45]: on the one hand, keeping these preferences in biofuel production, being aware that the mandated share, or even the planned biorefinery biomass supply will not be met, and on the other hand, to cover the rest with imports, to negotiate options to increase biomass supply or to opt for the second-best choice once the best choice for producing biofuels is exhausted.

The choice architecture approach was linked with fuzzy AHP for the analysis, which is a multi-criteria decision-making methodology [28,29, 46]. This combination facilitates the perceptions of experts on the aspects of the concerted biofuels policy with weighted pairwise comparisons collected in a form of a survey and offers a suitable platform for the analysis of these complex alternatives under uncertainty. Additionally, it is suitable to mathematically weight the partitioned choices. For its simplicity, transparency and learning experience among the participants of different background, AHP has been continuously placed among the top multi-decision criteria analyses for more than two decades (e.g. see reviews in [47–49]). However, the classic AHP assumes complete information on the topic and handles the inaccuracy while articulating the perceptions through crisp numerical values [48, 50]. For this reason, AHP methods have incorporated new approaches to improve the method, such as fuzzy AHP where crisp values are replaced with a triangular fuzzy number [51] to mitigate the lack of knowledge on the topic that would result in hesitation [28], which was better suited for the case presented. In fact, fuzzy AHP has demonstrated a good performance in studies related to energy planning (e.g. [52,53]. Chanthawong and Dhakal [40] presented a comprehensive review of the use of fuzzy AHP (alone or combined with other methods) in energy and natural resources policy, and provided 17 study cases distributed in Europe, America and Asia, mostly produced in the last years, reflecting the increasing applicability of the approach.

The overall results show a preference for the biofuel demand criterion, particularly towards acceptance of biofuel imports by external markets to fulfil the demand and lower preference on imported biomass to produce biofuels. Similarly, the stakeholders' opinion emphasized maximizing biofuel production to meet existing demand and estimate the demand according to the existing vehicle fleet. This strong commonality reflects national preferences on biofuel type differently: Slovakia, Hungary, Slovenia, Bulgaria, Romania, Czechia are countries with high likelihood of meeting the mandated share for RES-T by 2020 (all at $\geq$7.8% in 2019) whereas Poland, Croatia, Latvia, Estonia and Lithuania record shares are between 4% and 6% (Table 2). Lithuania and Latvia are countries that struggle with decarbonization of the transportation and storage sector, which is the top GHG emitting sector by economic activity, as well as with meeting the mandated share of RES-T by 2020 [35]. The same sector is recorded as the third emitting GHG sector by economic activity in Bulgaria, Czechia, Estonia, Hungary and Romania. In those countries, meeting the need for decarbonization of the existing bioeconomy will be a challenge, as well as developing new bio-based sectors on waste and by-streams with the biofuel demand [14]. Alternatives to diesel in any form would seem plausible for those countries, as diesel powered vehicles are dominant in light commercial vehicles (90%), freight transport (98%), whereas diesel use is lower in the rest of the countries of the macro-region, varying from 69% in Hungary to 86% in Lithuania. In this context, the BioEast macro-region has about 3.2 Mt and 94 Mt of biodiesel and bioethanol production capacity, respectively; 80% of the production capacity is in Poland, Czechia, Romania, Bulgaria and Hungary although not all biofuel capacity is active [54]. Cellulosic bioethanol (advanced biofuels) is foreseen or started the operation in Romania (50 kt), Croatia (55 kt), Slovakia (50 kt) and Poland (25 kt). Different approaches will be taken towards synchronizing the biomass demand for biofuels with the other biomass demands for supplying the renewable carbon across the economy. However, the existing capacities are mostly related to the first generation biofuels that are the least sustainable biofuel production alternative [16].

The rest of the alternatives were ranked collectively with the same level of preference (Figure 3). The consensus policy derived from this process would lead to a focus regulatory effort on the demand side of biofuel markets. Previous studies have stressed that excise duties seem to be the most cost-effective instrument for encouraging the use of biofuels for transport at EU level [55], although the total exemption from existing excise duties would not be enough to make production viable. However, there was a great variation between the criteria to be considered for forming and implementing biofuel policies in the BioEast region (Figures 4 and 5). Stakeholders that have both substantial areas of available agricultural land (e.g. Bulgaria, Poland, Romania, Hungary) as well as current production of first generation biofuels, seem to prioritize criteria related to own-sources supply that besides satisfying the internal market also allow exports. These countries have succeeded in relative higher percentages of renewable energy in transport than others in the region, except for Poland. At the same time, Poland presents much lower agricultural yield, which is also reflected in the biofuel productivity of the country, when compared to Czechia and Slovakia [56].

In the case of the Estonian experts, the results reflect a higher preference for land uses criteria, which could be related to the lower agricultural output and the limitations in biofuel potentials which make difficult the substitution of fossil fuels [57], and the lowest renewable energy in transport share compared to its Baltic neighbours [58]. This can be linked to the fact that Estonia was the last EU country to adopt a biofuel mandate as a response to the RED legislation of 2009; it happened in 2017, for the legislation to be in force in 2018, and may have resulted in low intervention strategies and views for the biofuel market [59]. However, this approach did not seem to have a result since Estonia was until 2017 the country with the far lowest share of RES-T in the EU (0.42%). Right after the adaptation of the Estonian biofuel mandate, a sharp increase of the RES-T share was reported (3.30%) that can probably be solely attributed to the adaptation of the specific targets.

The study is largely addressing the levels 4 and 5 of the Metcalfe scale of policy coordination [60], which studies divergences and searches for agreement among ministries and agencies within some policy dimension. Since the BioEast initiative aims to establish a new governance entity, certain convergence is expected regarding biofuel policy; the survey has revealed substantial commonalities but also differences in preferences between the national contact experts in the implementation and degree of intervention. The results do reflect a consistent policy approach on the broad base but there are differences within each country depending on the criteria used. For *land use*, experts from Estonia, Lithuania and Slovakia show a low degree of policy intervention, whereas Croatian and Czech stakeholders have the opposite approach. Concerning *decarbonization*, experts from Slovenia and Hungary show the lowest level of intervention, versus Slovakian and Polish experts' preferences. Concerning the criterion *national market*, Bulgarian and, again, Estonian experts' preferences show the lowest level versus Slovakia, among others. Finally, by criterion, *land use* related alternatives seem to be the least prone to be addressed by free market mechanisms, whereas *national market* development seems to be the most, reflecting the different approaches and policy tools taken for different criteria even within the same overall goal of promoting biofuel alternatives.

Conclusions

The methodology presented is suitable to investigate whether there is a consensus in outlining the common biofuel policy in the BioEast macro-region. The experts' preferences concerning criteria related to land use, decarbonization and development of a national market are raked with similar importance, with a slight preference for the latter. At the same time, the results demonstrate that in terms of biofuels' contribution in the RES-T, there is a great variation in the criteria to be considered for forming and implementing biofuel policies, with large between-country disparities related to each national reality (e.g. available land for biofuel production and target fulfilment).

Countries delaying in reaching mandated biofuel targets seem targeting policies focused on biofuel demand, while less prioritizing other criteria related to land use issues and domestic feedstock sources. There are differences in the degree of intervention regarding biofuel policy expressed in the preferences, which in this case do not seem to be correlated to the degree of reaching targets for renewable energy in transport. Adaptation of dedicated biofuel policies at an early stage plays a more important role to achieve renewable energy in transport goals, which will allow a realistic start of transition to the sustainable and circular bioeconomy in the macro-region.

Author contributions

Conceptualization. B.K, B.M., I.D.; methodology. B.K., B.M.; software. B.M.; formal analysis. B.K., B.M.; investigation. B.K., B.M.; data curation. B.K.; writing—original draft preparation. B.K., B.M., I.D.; writing—review and editing. B.K., B.M., I.D.; visualization. B.M., B.K.; supervision. B.M., B.K.; project administration. I.D.; funding acquisition. B.K., I.D., B.M.

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