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Linking Sustainable Mobility Criteria to Policymaking: Results of Multi-Criteria Analysis

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Abstract

With increasing emissions from the transport sector, the need to reduce emissions is becoming increasingly acute. The EC's Climate Law aims to re-duce emissions by 55% by 2030, while the growing transport sector is the slowest to meet these targets. Only a few European Union (EU) countries met the 2020 renewable energy source target in the transport sector, which indicates that major changes are needed to meet the new EU requirements. As each country has limited financial resources, it is necessary to assess the impact of the policy before its implementation. In this study, a survey of 19 industry experts was conducted to identify the most promising policy in-struments for reducing emissions in the road transport sector, as well as to identify the most promising fuels for which more resources should be devoted. In this publication, data analysis was performed by the combined Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methodology. The obtained data can be further used for in-depth analysis such as cost-benefit analysis or complex system dynamics analysis for later use in sustainable policy formulation.

Keywords: Transport, policy, survey, TOPSIS.

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1. Introduction

The transport sector is one of the most important sectors, which in 2018 was the second-largest source of greenhouse gas (GHG) emissions in Latvia and generated 28.5% of the total annual emissions [1]. Statistical data on GHG emissions also shows that emissions in the transport sector continue to increase, reaching 1.096 Mt CO2ekv in 2018 [2]. The data also show that actual GHG emissions exceed projected levels [2]. In the transport sector, the European Green Deal aims to cut emissions by 90% by 2050 by delivering a smart, competitive, safe, accessible, and affordable transport system, while the European Climate Law sets the intermediate target of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels [3], [4]. To reduce emissions in the transport sector, the European Union is-sued the revised renewable energy directive 2018/2001/EU (RED II) which entered force in December 2018 [5]. According to RED II, Latvia, like the other Member States, is entitled to determine its contribution within the framework of integrated national energy and climate plans [5]. Latvia's goals for renewable energy source (RES) integration in the energy sector are defined in the Latvian National Energy and Climate Plan 2021–2030. (NECP) [6]. Latvia's NECP sets the following main objectives in the transport sector [6]:

- to ensure at least a 14% share of RES in Latvia's final transport energy consumption by 2030;
- to ensure at least 3.5% of the share of modern biofuels in the final transport energy consumption of Latvia by 2030;
- to reduce the share of first-generation biofuels below 7% in RES by 2030;
- the share of first-generation or biofuels produced from food and feed crops may not exceed the share of such biofuels in Latvia by more than 1% in 2020 by 2030;
- Between 2023 and 2030, the use of biofuels with a high risk of indirect land-use change, the cultivation of which is associated with a significant expansion of production areas on high-carbon land, and the level of consumption of such biofuels must be completely abandoned and shall not be higher than in 2019 by 2030.

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Latvia's NECP identifies three main issues in the Latvian transport sector: An old car fleet dominated by diesel and petrol vehicles; Insignificant RES and electricity consumption in transport; and increasing the use of private vehicles and declining public transport [6].

To achieve the goals set by the NECP, Latvia needs to introduce policy instruments that would address the issues set by the NECP: to reduce the average age of vehicles in the country, which was 12.6 years in 2018; to increase the share of RES in the transport sector, which in 2019 amounted to only about 4%; to increase the use of electric vehicles (EV) in transport, which in 2019 accounted for only 0.07% of the total number of registered vehicles in technical order; as well as to reduce the use of private vehicles and to increase the popularity of public transport and active transport modes.

Before investing in the implementation of policy instruments, it is necessary to evaluate different policy instruments to determine the most effective ones. This publication offers a methodology based on expert surveys and data analysis with the combined Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

2. Literature analysis

2.1. Identification of policy instruments

To determine which policy instruments should be evaluated, an analysis of the policy instruments used in other European Union countries was performed. The countries which were chosen for the analysis were Sweden, Norway, Finland, the Netherlands, and Austria because these countries have the biggest share of the RES in the transport sector which in 2019 was 30.3%, 27.3%, 21.3%, 12.5%, and 9.8% respectfully. [7] The policy of the Baltic States (Lithuania and Estonia) was also analyzed, as they are closer to Latvia, as well as the adopted policy decisions in Latvia were examined.

A tax system based on CO_2 emissions has been introduced in three leading countries (Sweden, Norway and Finland) at the beginning of the 21st century as well as other initiatives that support environmentally friendly vehicles. For example, in Norway, EV has been exempting from VAT since 2001. Other countries have similar policy instruments in place that were introduced later, such as incentives to purchase low-emission vehicles, countries set operating tax costs based on emissions, and low-emission or zero-emission vehicles receive tax exemptions. For example, such vehicles are exempt from registration tax in the Netherlands, Austria, Lithuania and Latvia, and electric cars receive registration tax relief in Norway and Finland.

Other financial benefits for owners of more environmentally friendly cars include subsidies for low-emission cars. In Lithuania, for example, a newly introduced bonus of EUR 1,000 is available for scrapping an old polluting vehicle.

Alternative fuel vehicles also require new infrastructure, which is also subsidized in all these countries. Another policy instrument implemented in all these countries is green public procurement. To increase the share of RES with the existing fleet of internal combustion engines, countries set a mandatory share of biofuel blends.

The table below summarizes the application of the considered policy instruments in the different countries.

Table 1. Application of policy instruments in selected countries.

	Sweden	Norway	Finland	Netherlands	Austria	Estonia	Lithuania	Latvia
Exemption from registration tax		X	X	X	X		X	X
Exemption from operating tax		X		X			X	X
VAT relief		X						
Company tax relief	X				X	X	X	X
Subsidizing the purchase of vehicles	X	X	X	X	X	X	X	X
Green public procurement	X	X	X	X	X	X	X	X

States, where the number of EVs is not that high, also offer local bonuses such as the abolition of parking fees in cities, as well as the possibility of using bus lanes for electric vehicles.

2.2. Use of TOPSIS methodology in decision making

Mankind has long been interested in decision-making methods, as we often encounter the description of complicated problems, where the best option is often not obvious. The multicriteria approach makes it possible to identify a wide range of views to structure the decision-making process in terms of stakeholder preferences and a huge range of criteria, taking into account several aspects - economic, social, environmental, quality, ethical, etc. [8]. Multiple-criteria decision analysis (MCDA) is a general term for all the methods that exist to help people make decisions, even if the problem is complex or there are several conflicting criteria [8]. The application of the MCDA allows to make an informed decision, even if the criteria are contradictory [8].

The MCDA provides an opportunity to add weight to individual criteria that give different criteria different relative importance. This makes it possible to differentiate the contribution of different criteria in choosing the optimal alternative [8]. However, the weighting given to the criteria is to some extent subjective. One of the possible steps in the MCDA is to carry out a survey of specialists, which considers both the required criteria and their compliance with the final decision. Using a group of experts instead of one allows for a more objective assessment [8]. In this case, the risk of personal error is reduced. This makes it possible to differentiate the contribution of different criteria in choosing the optimal alternative [8].

One of the popular MCDA methods is TOPSIS, which was first used by Yoon and Hwang in his work “Multiple Attribute Decision-Making Methods and Applications. A State-of-the-Art Survey” [9]. The TOPSIS method is based on determining the shortest distance to the ideal solution from the geometric point of view (in the Euclidean space). The TOPSIS was used to analyze survey data and the TOPSIS algorithm will be described in more detail in section 3.2.

The TOPSIS method has several advantages that make it suitable for finding different solutions [10]:

- TOPSIS allows explicit trade-offs and interactions among attributes.
- The result can be a preferential assessment of alternatives with a numerical value that provides a better understanding of the differences and similarities between the alternatives.
- Pair comparisons are not allowed
- Unlimited range of criteria and performance attributes
- It can include a set of weighting coefficients for different attributes.
- Relatively simple calculation process,
- No special program required
- The method is perfectly suitable for connection to computer databases dealing with material selection.

The following TOPSIS features allow this method to be used in a variety of fields [11]. For example, Elzbieta Broniewicz and Karolina Ogrodnik identified the TOPSIS method, alongside the AHP method, as the most common decision-making process for The Strategic Environmental Assessment and Environmental Impact Assessment, which are important legal instruments for EU environmental policy which allows the identification, prediction, prevention and mitigation of the negative effects on the environment [12]. For example, Roman Vavrek and Jana Chovancová used TOPSIS to evaluate the energy economic and environmental performance of the EU countries where the breakdowns of energy indicators for sustainable development were separated into 3 dimensions – social, economical and environmental [13]. Xiuxia Zhang et.al. used the structural entropy-TOPSIS model for the evaluation of urban public transport priority performance in the city of Wuhan from 2006 to 2015 [14]. TOPSIS methodology was also used in the assessment of 2nd generation biofuels by Martina Haase et.al. and to determine barriers for sustainable development of renewable energy in Pakistan by Yasir Ahmed Solangi [15], [16]. The TOPSIS methodology was used to evaluate the efficiency of rail sections [17]. In Farhad Samaie et.al. study fuzzy TOPSIS methodology was used in evaluating various policies affecting the development of EVs in Tehran [18]. Gustavo Piresda Ponte et. al. used TOPSIS in their study where eighteen criteria were assessed, and ten specialists were interviewed to determine suggestions of public policies to stimulate the use of environmentally friendly energy sources at off-grid places in Brazil [19].

3. Methodology

3.1. Survey structure

The proposed methodology involves surveying experts to obtain their assessment of various policy instruments. 19 experts from different sectors (public administration, research or industry) were surveyed. Before the survey, respondents must provide information on the sector represented - public administration, research or industry.

In the first part of the survey, respondents had to evaluate each of the policy instruments according to the given criteria on a scale from 1 to 10. Policy instruments are evaluated according to 4 criteria: (i) required investments (P1), where 1 - the implementation of the measure does not require financial investment, and 10 - the implementation of the measure requires significant financial investments.; (ii) a monitoring mechanism (P2), where 1 - the implementation and monitoring of the measure is simple, and 10 - the implementation and monitoring of the measure is difficult; (iii) RES promotion potential (P3), where 1 - the measure has minimal or no effect on the increase of the share of RES, and 10 - the measure significantly affects the increase of the share of RES, and (IV) public support (P4), where 1 - the measure has no support or there is (is expected) minimal support in society, and 10 - the event has (is expected) high public support.

The following policy instruments were put forward, selected according to examples of good practice from the NECP and other countries:

1A. Exemption from registration tax for zero-emission and low-emission vehicles.
1B. Increase in registration tax for fossil fuel vehicles.
2A. Exemption from operating tax for zero-emission and low-emission vehicles.
2B. Increasing the operating tax on fossil fuel vehicles.
3A. Reduction of excise duty on alternative fuels.
3B. Increase in excise duty on fossil fuels.
4. Tax incentives for zero-emission and low-emission vehicles owned by companies.

5A. Aid for the purchase of new zero-emission and low-emission vehicles.
5B. Aid for the purchase of used (up to 8 years) zero-emission and low-emission vehicles.
5C. Aid for the purchase of low-emission and zero-emission vehicles in public procurement.
6. Establishment of alternative fuel filling/charging station infrastructure.
7. Support for the technical adaptation of vehicles to use alternative fuels.
8. Development of bicycle infrastructure.
9. Increasing the mandatory biofuel blend.
10A. Subsidization of biofuel production, including biomethane.
10B. Subsidizing the capital costs of biofuel plants, including biomethane.
10C. Facilitated conditions for biomethane injection into the natural gas grid.
10D. Proofs of origin for biomethane.
11A. Free parking for zero-emission and low-emission vehicles.
11B. Permitting the use of public transport lanes for zero-emission and low-emission vehicles.
11C. Increasing parking fees for vehicles using conventional fuels.
12. Introduction of low-emission zones in cities to reduce car traffic.
13. Electrification of the railway network.
14A. Renewal of the public transport fleet
14B. Reduction of the public transport ticket price

In the second part of the survey, respondents were invited to evaluate the potential of electric vehicles (EV), natural gas vehicles (CNG), biomethane vehicles (CBG), biofuel vehicles (BIO-F) and hydrogen (H2) vehicles in Latvia. The evaluation of the potential was given on a scale from 1 to 5, considering the relevant aspects:

- Social aspect (F1), where 1- support for the given technology will not promote the creation of social new jobs, 5 - the support of the identified RES will promote the creation of many jobs.
- Environmental aspect (F2), where 1- the identified RES support will contribute to a small negative impact on the environment, 5 - the identified RES support will promote a large negative impact on the environment.
- Technological aspect (F3), where 1- certain RES technologies are not developed, 5 - certain RES technologies are highly developed.
- Economical aspect (F4), where 1- certain RES technologies will not cost much, 5 - certain RES technologies have high costs.

In the last section of the survey, respondents assess the weight of the criteria mentioned in the first part (required investments; a monitoring mechanism; RES promotion potential and public support) and the aspects mentioned in the second part (social, environmental, and technological).

The higher the weight, the more important the indicator. The sum of the weights is equal to 1. Weighing is required for further data processing.

3.2. TOPSIS methodology

According to A. Shanian, O. Savadogo and Yoon and Hwang, the TOPSIS solution method consists of the following steps [10], [11]:

1. Normalize the decision matrix. The normalization of the decision matrix is done using the following transformation:

$$n_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r^2{}_{ij}}}; j = 1,2, \dots, n; i = 1,2, \dots, m \quad (1)$$

2. Multiply the columns of the normalized decision matrix by the associated weights. The weighted and normalized decision matrix is obtained as:

$$V_{ij} = n_{ij} w'_j; j = 1,2, \dots, n; i = 1,2, \dots, m \quad (2)$$

Where w'_j represents the weight of the jth attribute.

3. Determine the ideal and nadir ideal solutions. The ideal and the nadir value sets are determined, respectively, as follows:

$$\{V_1{}^+, V_2{}^+, \dots, V_n{}^+\} = \left\{\left(\max_i V_{ij}\, Ij \in K\right), \left(\min_i V_{ij}\, Ij \in K'\right) Ii = 1,2, \dots, m\right\} \quad (3\text{-}1)$$

$$\{V_1{}^-, V_2{}^-, \dots, V_n{}^-\} = \left\{\left(\min_i V_{ij}\, Ij \in K\right), \left(\max_i V_{ij}\, Ij \in K'\right) Ii = 1,2, \dots, m\right\} \quad (3\text{-}2)$$

where K is the index set of benefit criteria and K' is the index set of cost criteria.

4. Measure distances from the ideal and nadir solutions. The two Euclidean distances for each alternative are, respectively, calculated as:

$$S_i^+ = \left\{\sum_{j=1}^{n} \left(V_{ij} - V_j^+\right)^2\right\}^{0,5}; j = 1,2, \dots, n; i = 1,2, \dots, m \quad (4\text{-}1)$$

$$S_i^- = \left\{\sum_{j=1}^{n} \left(V_{ij} - V_j^-\right)^2\right\}^{0,5}; j = 1,2, \dots, n; i = 1,2, \dots, m \quad (4\text{-}2)$$

Remark: In the so-called ‘block TOPSIS’ method, the two distances are obtained as:

$$S_i^+ = \sum_{j=1}^{n} V_{ij} \quad (4\text{-}3)$$

5. Calculate the relative closeness to the ideal solution. The relative closeness to the ideal solution can be defined as:

$$C_i = \frac{S_i}{S_i^+ + S_i^-}; i = 1,2, \dots, m; 0 \le C_i \le 1 \quad (5)$$

The higher the closeness means the better the rank. The methods for assessing the relative importance of criteria must be well defined. In the proposed methodology, the relative importance of criteria is clarified in an expert survey.

4. Results

4.1. Identifying the most effective policy instruments

Summarizing the obtained results, the following criteria weights were determined: required investments - 0.33, a monitoring mechanism - 0.19, RES promotion potential - 0.25, public support - 0.23. Table 2 shows the five highest-rated policy instruments for each criterion.

Table 1. The five highest-rated policy instruments by each criterion

Criteria (criterion weight)	Political instrument	Score	Criteria (criterion weight)	Political instrument	Score
P1 - required investments * (0.33)	11B 1A 1B 2A 10D	1.95 2.68 3.00 3.42 3.42	P2 - RES promotion potential (0.25)	5A 6 5C 5B 13	7.42 7.42 7.11 7.14 6.63
P3 - a monitoring mechanism (0.19)	10A 10B 10C 13 7	7.05 6.79 6.57 6.57 5.84	P4 - public support (0.23)	5A 5B 5C 14A 14B	9.16 8.95 1.89 7.89 7.89

** As the most favourable case is when costs approach 0, the table shows the lowest or cheapest rated policy instruments, while the inverse values were used in the calculations.*

The results show that there is no single policy instrument that is valued equally high for all 4 criteria and that the instruments rated higher for each criterion are different, apart from vehicle purchase support policies (5A, 5B, 5C), which were rated higher in the RES promotion potential and public support, as well as in the electrification of the railway network (13), which were rated higher in the RES promotion potential and monitoring mechanism. The TOPSIS method was used to summarize the results of the first part of the survey with the previously determined weights. The results of the TOPSIS method are summarized in Fig.1.

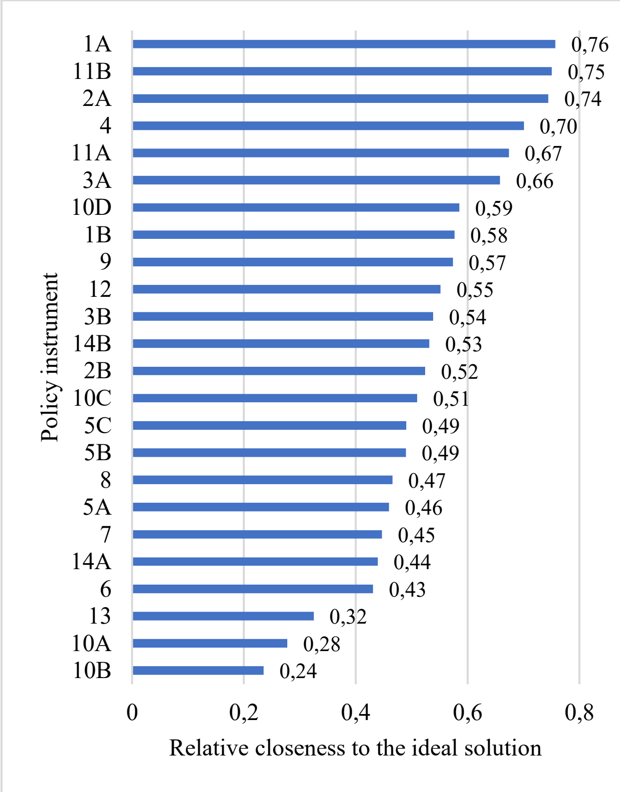

Figure 1. Relative closeness to the ideal solution of political instruments

Results show that the most influential political instruments are exemption from registration tax for zero-emission and low-emission vehicles (1A), permitting the use of public transport lanes for zero-emission and low-emission vehicles (11B) and exemption from operating tax for zero-emission and low-emission vehicles (2A) followed by tax incentives for zero-emission and low-emission vehicles owned by companies (4), free parking for zero-emission and low-emission vehicles(11A) and reduction of excise duty on alternative fuels (3A).

The results indicate that those policy instruments that require less cost were rated higher, which can be explained by the high weight given to the required investment criteria.

4.2. Identifying the most promising type of fuel

In the second part of the survey, respondents had to assess the potential of multi-fuel vehicles on four criteria. During the survey, the following weights were determined for each criterion: social aspects (impact on employment, welfare, health) - 0.22; total costs - 0.31; environmental impact - 0.25; technology development potential - 0.21.

The evaluation of each fuel type according to each criterion is shown in Fig. 2.

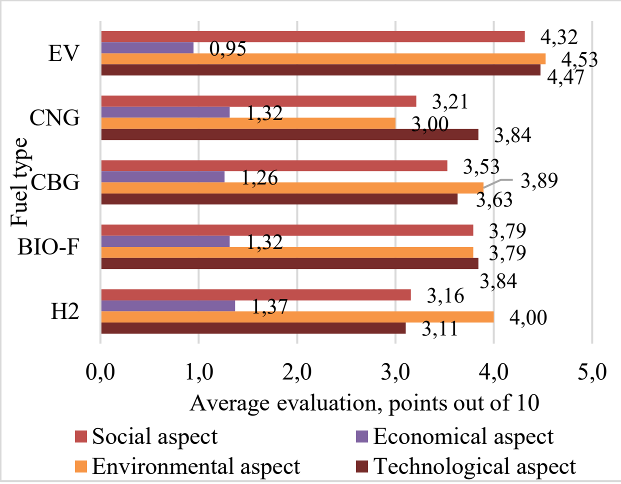

Figure 2. Evaluation of each fuel type according to given criteria.

Figure 2 shows that, according to experts, EV has the lowest costs, and EV has a greater positive impact in other respects as well. In terms of environmental impact, hydrogen-powered vehicles were assessed immediately after EV, which were also assessed as the most expensive fuel. In turn, according to the technological potential, natural gas took second place immediately after EV. The second place in social terms was the wider use of biofuel vehicles. The relative proximity of each fuel type to the ideal result is shown in Figure 3.

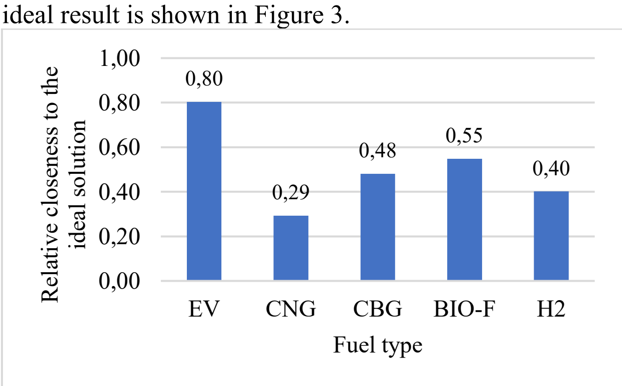

Figure 3. Relative closeness to the ideal solution of each selected fuel type

The results indicate that, according to experts, the biggest benefit in the country could be achieved by developing EV. Biofuels, biomethane and hydrogen were rated lower, while natural gas was rated the lowest, mostly due to the negative impact on the environment.

4.3. Sensitivity analysis

As the expert survey is subjective, a sensitivity analysis was performed to assess the significance of the weights identified in the expert survey. To check the effect of attribute distribution on the results of the TOPSIS method for evaluation of the fuels, the significance of attributes of the same size is selected. The chosen unitary variation ratio was 0.01, 0.5, 1.0, 1.5, 2.0, 3.0. Table 3 shows how the evaluation of policy instruments changes as the weight of the criterion increases. The results show how the assessment of policy instruments changes as the weight of each criterion increases.

Table 2. Changes in policy instruments' rank as the weight of each criterion increases.

Criteria	P1 Required investments	P2 A monitoring mechanism	P3 RES promotion potential	P4 Public support
1A	I	I	D	I
1B	I	I	D	D
2A	I	I	D	I
2B	I	I	D	D
3A	I	I	D	I
3B	I	I	D	D
4	I	D	D	I
5A	D	D	I	I
5B	D	D	I	I
5C	D	I	I	I
6	D	D	I	I
7	D	D	I	I
8	D	D	D	I
9	I	D	I	D
10A	I	D	I	D
10B	D	D	I	I
10C	I	D	D	D
10D	I	D	D	D
11A	I	I	D	I
11B	I	I	D	D
12	I	D	D	D
13	D	D	I	I
14A	D	D	I	I
14B	D	D	D	I

**Increases – I; Decreases – D*

The data in the table show that most policy instruments (20 out of 24 policy instruments) show opposite results for the "P1" and "P3" criteria. In other words, policy instruments that decrease with increasing "P1" criteria, increase with increasing "P3" criterion and, conversely, increase with increasing "P1" criterion and decrease with increasing "P3" criterion. Similarly, the trend in the evaluation of policy instruments was the opposite of criteria "P2" and "P3" for 17 of the 24 trends in policy

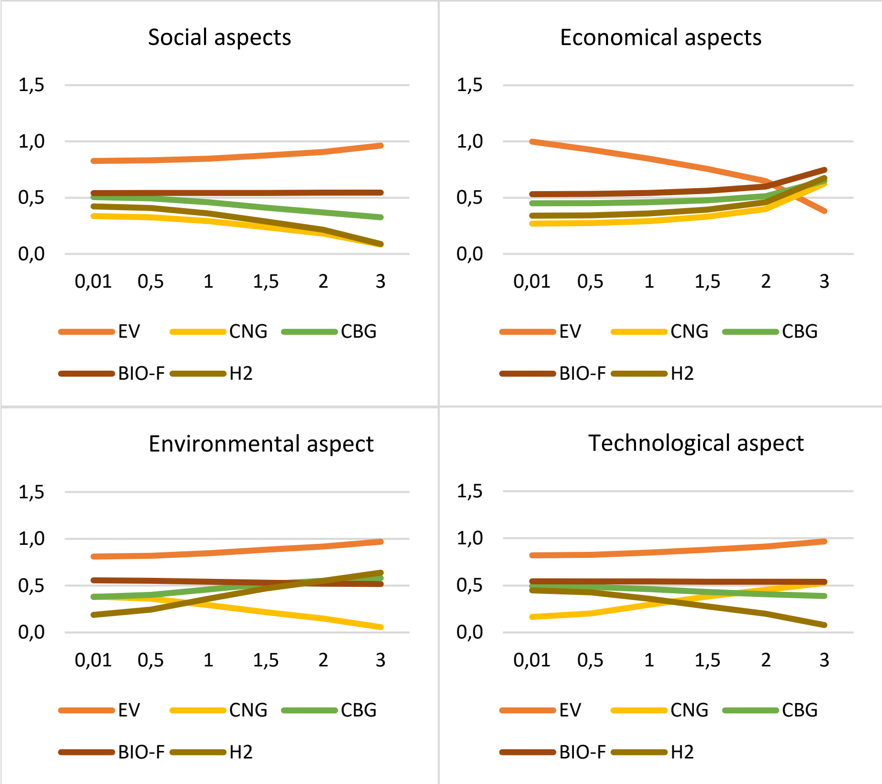

Figure 4. Sensitivity analysis for fuel evaluation

instrument change. In turn, the tendency of evaluation of policy instruments coincided with the criteria "P1" and "P2" (coincided with 17 out of 24 trends in changes in policy instruments), as well as with the criteria "P3" and "P4" (coincided with 15 out of 24 trends in changes in policy instruments).

This shows that 1) the most effective policy instruments in terms of RES promotion usually are the priciest, 2) instruments, which require less investments are easier to monitor and 3) policies that are effective in terms of RES promotion are more likely to be accepted by the public. Figure 4 shows how the evaluation of policy instruments changes as the weight of the criterion changes.

From the graphs, it can be concluded that EV receives the highest ratings in all cases, except when the importance of economic aspects increases, then the rating of other fuels increases with biofuels in the lead. The rating of biofuels does not change so drastically as the importance of other aspects changes. The rating of hydrogen fuel also increases with increasing environmental aspect role but decreases with increasing social and technological aspects. The rating of natural gas fuels also increases with the increasing role of the technological aspect but decreases with the increasing social and environmental aspects.

It should be noted that the opinions of experts were very volatile. The relative error, which was calculated with a probability of 95% for the weights of the evaluation criteria and fuel evaluation aspects of the policy instruments, is shown in Table 4.

Table 3. Relative error of determined weights of evaluation criteria/aspects.

Name of criteria/aspect		Weight of criteria/aspect	Relative error, %
Criteria for evaluating policy instruments	P1 - required investments	0.33 ±0.09	26.72%
	P2 - RES promotion potential	0.19 ±0.08	42.94%
	P3 - a monitoring mechanism	0.25 ±0.09	35.77%
	P4 - public support	0.23 ±0.08	33.59%
Aspects for fuel type evaluation	F1 - social aspect	0.22 ±0.09	41.08%
	F2 - economical aspect	0.31 ±0.07	22.38%
	F3 - environmental aspect	0.25 ±0.09	35.49%
	F4 - technological aspect	0.21 ±0.09	41.08%

Such a large relative error indicates an uncertainty characterized by differences of opinion between different experts. To obtain more accurate data, more industry experts from different representations should be interviewed.

5. Discussion

The study obtained results on the evaluation of policy instruments, as well as on the potential of different fuels in Latvia. An in-depth analysis of the highest-rated instruments is needed. This could be economic (cost-benefit analysis) or complex system dynamics analysis. For example, these data can be used further in modeling system dynamics in the transport sector, where the impact of different policy instruments is assessed.

6. Conclusions

Using the proposed methodology, several policy instruments were evaluated, which aim to increase the share of RES, not only in terms of RES promotion potential, but also in terms of necessary investments, monitoring mechanism, and public support, taking into account expert evaluation. According to the experts, the most promising political instruments are exemption from registration tax for zero-emission and low-emission vehicles, permitting the use of public transport lanes for zero-emission and low-emission vehicles and exemption from operating tax for zero-emission and low-emission vehicles;

The second part of the survey allows legislators and researchers to assess which fuel vehicles need more support. The results showed greater priority should be given to the development of electric transport, followed by biofuels and biomethane.

Sensitivity analysis showed that most policy instruments have a proportional link between the P1 and P2 criteria and between the P3 and P4 criteria, as well as an inversely proportional link between the P1 and P2 criteria.

The described methodology can be used in researches to identify the most promising support mechanisms that could be introduced by legislators to reduce the negative impact of the transport sector on the environment. The results obtained with this method can be used as a basis for further research, for example, in forecasting scenarios for the transport sector.

The disadvantage of the method is its possible subjectivity. Expert assessments varied widely, as indicated by the calculation of the relative error, which averaged around 35% in weighting. The influence of subjectivity can be avoided by interviewing more industry experts of various sectors, such as public administration representatives, researchers and entrepreneurs related to the transport sector. It is also important to address representatives of various associations, such as road transport, biogas, electric transport, fuel, and other associations' representatives as well as supporters of different types of alternative fuel vehicles (electricity, hydrogen biofuels, natural gas and bio-methane) have to be interviewed to get a broader view of the problem under study.

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