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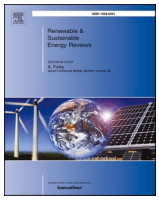

Sustainable technology acceptability: Mapping technological, contextual, and social-psychological determinants of EU stakeholders' biofuel acceptance

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ABSTRACT

The acceptance of biofuels is of paramount importance for the EU sustainable energy transition. This qualitative study identifies barriers and facilitators regarding biofuel technology acceptability. Stakeholders initially selected for their interest and influence in the EU biofuel field were asked about biofuel acceptance and four clusters of variables associated with the acceptability according to the literature on similar sustainable technologies: technology per se, economic and market-related aspects, political and administrative aspects, and social-psychological features of the person. Results from a qualitative content analysis based on 32 stakeholders interviews confirmed the presence of contents in these four clusters, highlighting specific issues linked to biofuel technology acceptability. Facilitating and inhibiting aspects of each cluster are discussed; quantitative research developments as well as applied implications are envisioned towards biofuel acceptance.

1. Introduction

Fossil fuels have been of capital importance for the technological development of the latest centuries, but at the same time they have contributed to both serious environmental problems, such as climate change and pollution, and related health and well-being problems for humans and other forms of life [1]. Even though more and more research and technology aim at the reduction of the enormous environmental and social problems caused by the still widespread use of fossil fuels, transition to de-carbonization and sustainability is of the utmost importance for contemporary society and future generations. The introduction of new sustainable energy technologies can therefore be, on the one hand, fundamental to achieve some of the UN Sustainable Development Goals (SDG #7, #11, and #13 certainly, but also #12, #14, and #15 [2]; unfortunately, on the other hand, such an innovation can also be a source of social problems. Consequently, an early understanding of the social acceptance of sustainable energy technologies becomes valuable for society, and it can be of fundamental importance for helping the implementation of policies aimed at containing climate change via the wide adoption of more sustainable fuels.

After reviewing the existing knowledge about biofuel acceptance, this contribution presents a qualitative study about antecedents of biofuel acceptance by EU expert stakeholders.

1.1. The social acceptance of sustainable technologies

First of all, it is useful to define a few relevant concepts when dealing with new technologies, since literature is not always consensual in the use of these terms.

Following Huijts et al. [3], the term "acceptability" refers to features favouring a behavioral response either in favor or against a technology. Thus, "acceptance" is a behavior that accepts and promotes the use of a technology, rather than inhibiting or criticizing it. Support can be expressed by publicly supporting the technology, or simply by buying and using it. Instead, resistance can be expressed not only through rejection of the technology, but also through real protest initiatives [4]. The "adoption"of a technology, on the other hand, is a multi-step process of selecting, purchasing, and committing to use it until achieving persistent use [5].

Overall, acceptability can thus be considered as a set of condition allowing acceptance behaviors that are eventually resulting in adoption.

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List of abbreviations

BECCS	Bioenergy with Carbon Capture and Storage
CCS	Carbon Capture and Storage
CO2	Carbon Dioxide
CSR	Corporate Social Responsibility
EU	European Union
GHG	Greenhouse Gas emissions
ILUC	Indirect Land Use Change
LCA	Life-Cycle Assessment
NGO	Non-Governmental Organization
SDG	Sustainable Development Goals
SETA	Sustainable Technology Acceptance Model
SME	Small and Medium-sized Enterprises
SWH	Solar Water Heaters
TAM	Technology Acceptance Model
TRL	Technology Readiness Level
UN	United Nations
WTP	Willingness To Pay
WtW	Well-to-Wheel

The acceptability of a sustainable energy technology and its subsequent acceptance, up to its final consequential adoption by the stakeholders and the public, can be influenced by three macro-categories of antecedents: its intrinsic technological aspects, contextual factors, and personal factors [3].

The next sections will thus present these three macro-categories of antecedents (section 1.2, 1.3., 1.4). Next, a short review of the main theoretical models proposed to combine them will be presented (1.5) and finally the current study will be introduced, highlighting why it was chosen to focus on an expert stakeholder sample (1.6).

1.2. Technology features

Sustainable technologies' intrinsic characteristics are an important factor in technology acceptability and acceptance (see Table 1), because they are able to influence people's assessments (e.g., regarding the noise generated by wind turbines [6]). In the field of biofuels, the main technical barrier to acceptance seems to be their chemical properties compared to traditional fuels [7]. There are, however, other problems related to the characteristics of biofuel technology, such as landscape changes like deforestation to accommodate agricultural crops. These landscape changes can cause concern about environmental and aesthetic features [8], and also lead to resistance from local farmers [9]. Among the positive characteristics of biofuels, there is their compatibility with conventional engines [10]: biofuel use does not require crucial modifications to traditional engines and it can also be supplied with the existing petrol facilities [11].

1.3. Contextual factors

In addition, contextual factors, namely objective characteristics determined by the context, are also able to directly or indirectly affect the acceptance of sustainable technologies [18]. In the context of sustainable technologies, it is possible to investigate different aspects: economic and market aspects; and policy and administration aspects.

1.3.1. Economic and market aspects

In the market context, the cost of biofuel is central to acceptance. Alternative fuels are mostly perceived positively, as long as they are not more expensive than conventional fuels [18]. Consumers are willing to pay more for biofuels than fossil fuels [19,20], whilst people who are familiar with biofuels are less willing to pay a higher price for these [21]. When the price of biofuel is the same as the price of fossil fuels, other factors influence the consumer choice [22], such as environmental sustainability aspects like reduced carbon emissions [23] or economic aspects like the cost of ownership [24]. Among car owners, the increase in food prices represents one of the factors that prevents from buying biofuels, along with the lack of availability at the nearest petrol station [25]. Regarding the economic aspects, the adoption of biofuels has, among the positive sides for the local economy, the increase in jobs and therefore in local income. In a study by Selfa et al. [26] in fact, the concern about the location of a biofuel refining plant has decreased in view of deriving economic benefits.

In addition to economic and market aspects (Table 2), policy and administration aspects are also to be taken into account in the process of biofuels spreading (Table 3).

1.3.2. Policy and administration aspects

An important socio-political aspect driving the acceptance of biofuels is their support by policy makers (Table 3): a study by Scarlat and Dallemand [28] showed that the use of biofuels is related to government policies and support programs. In order to ensure the implementation of sustainable technologies, it is important that decisions are made in a collaborative manner and not through hierarchical procedures [29]. A study by Terwel et al. [30] on the acceptability of decisions regarding Carbon Capture and Storage (CCS) technology showed that people were more willing to accept decisions by the political authority after knowing that environmental NGOs and industry organizations had been involved

Table 1
Literature findings concerning "Technology features" impacting sustainable technology acceptance on laypeople and/or experts.

Factor	Study	Technology	Sample	Key findings	Effect on acceptance
Chemical properties	[7]	Biofuel	Southeast Asian Laypeople	The different chemical properties such as the use of vegetable oil in fossil fuel engines represents a technical barrier to the adoption of biofuels.	−
Compatibility with conventional engines and existing petrol facilities	[10,11]	Biofuel	Global Laypeople and experts	The compatibility of biofuel with conventional engines and existing petrol facilities may influence acceptance.	+
Infrastructures	[12]	Renewable technologies	German Laypeople	New technical infrastructures such as fuel stations not always find public support with regard to local acceptance.	−
Feedstock	[13]	Biofuel	Finnish Laypeople	People prefer biofuels from agricultural wastes.	+
Change of land use	[14]	Biofuel	Malaysian Laypeople	The change of land use represents a strong barrier for the development of biofuels	−
Emissions	[14–16]	Biofuel	General Laypeople	Increased carbon emissions from land use change and increased nitrogen and particle emissions emerged as a strong barrier for biofuel development. CO2 reduction influences adoption of biofuels versus fossil fuels	+/−
Enviromental impact	[17]	Hydrogen fuel	EU Laypeople	The perception of environmental risk leads to negative assessments of alternative fuels.	−

Table 2
Literature findings concerning "Economic and market aspects" impacting sustainable technology acceptance on laypeople and/or experts.

Factor	Study	Technology	Sample	Key findings	Effect on acceptance
Price	[18, 27]	Biofuel	German Laypeople and U.S. Experts	Alternative fuels are mostly perceived positively, as long as they are not more expensive than conventional fuels. Stakeholders considered high cost to be one of the main barriers to producing biofuels from microalgae	+/−
Food prices	[25]	Biofuel	Global Laypeople	The increase in food prices represents one of the disadvantages of biofuels among car owners	−
Market availability	[25]	Biofuel	Global Laypeople	Lack of availability at the nearest petrol station is an important factor that prevents people from buying biofuels.	−
Local development	[26]	Biofuel	U·S. Laypeople	Local development and consequent economic benefits, derived from the location of a biofuel refining facility may influence acceptance.	+

Table 3
Literature findings concerning "Policy and administration aspects" impacting sustainable technology acceptance on laypeople.

Factor	Study	Technology	Sample	Key findings	Effect
Regulatory policies	[28, 29]	Biofuel	Dutch and Global Laypeople	Regulatory policies are relevant factors in the acceptance of biofuels and wind energy.	+
Support programs	[28]	Biofuel	Global Laypeople	The use of biofuels is related to support programs	+

in the decision-making process. As highlighted by Chin et al. [14], a policy in support of biofuels must have several characteristics: it needs a clear objective, it must be consistent [31], it must have government agencies able to deal with biofuel issues in a timely manner [32], and the community must be involved [33].

1.4. Social-psychological factors

Social-psychological factors include personal characteristics that can influence perceptions about new technologies and, consequently, the way people will approach them. Main psychological factors that play a key role in the acceptance of sustainable technologies, as identified and studied in the literature, are: knowledge, experience, perceived outcome efficacy, values, emotions, trust, norms, fairness, place attachment and place identity, Table 4 summarizes the state of the art regarding the relations of such social-psychological factors with sustainable technologies acceptability and acceptance.

1.5. Existing models

Literature from different disciplines provides several comprehensive models trying to combine the previous three macro-categories of features affecting sustainable technologies acceptability and acceptance. Devine-Wright [41] emphasized the need for systematic research on public acceptance by referring to models hybridized from psychological theories and other social sciences. The work of Gaede and Rowlands

Table 4
Literature findings concerning "Social-psychological factors" impacting sustainable technology acceptance on laypeople and/or experts.

Factor	Study	Technology	Sample	Key findings	Effect
Knowledge	[20, 34–40];	Renewable technologies	Dutch and UK Laypeople	People have little subjective knowledge about renewable energy such as biofuels; low level of knowledge of a specific technology is associated to a greater perception of risk; more educated people had more knowledge about biofuels; the stronger the knowledge of a renewable technology, the more it is perceived as environmentally friendly; the greater the person's subjective and objective knowledge about renewable energy, the more likely the person is to accept it.	+
Experience	[41–47]	Biofuel and renewable technologies	Dutch, EU and Global Experts	Experience is able to increase the knowledge of a given technology as well as the perception of costs, risks and benefits; direct subjective experience with a renewable technology can affect acceptance.	+
Perceived outcome efficacy	[48–50]	Biofuel and renewable technologies	UK Laypeople and Iranian Experts	Outcome efficacy influence intention to accept.	+
Values	[51,52]	Renewable technologies	Global and Dutch Laypeople	Self-transcendence values are able to influence the cost and benefit assessments of energy alternatives and can affect acceptance; biospheric values correlate with perceived energy risks while selfish values seem to correlate with perceived benefits.	+
Emotions	[49, 53–56]	Biofuel and renewable technologies	U·S., Dutch, German Laypeople and Iranian Experts	Positive affect have positively influenced evaluations of hydrogen technologies, nuclear power plants and carbon capture and storage. Negative affect have negatively influenced evaluations of hydrogen technologies, nuclear power plants and carbon capture and storage.	+/−
Trust	[54,55, 57–60]	Biofuel and renewable technologies	U·S., Dutch, Chinese Laypeople and Malaysian Experts	Trust is able to influence the perception of risks and benefits of technology. Trust based on moral integrity is more likely to influence the acceptability of the project than trust based on competence.	+
Norms	[49,61]	Biofuel and renewable technologies	Chinese Laypeople and Iranian Experts	Injuctive and descriptive social norms significantly predicts intention to use biofuels.	+
Fairness	[29,41, 62–64]	Renewable technologies	Dutch, Australian and UK Laypeople	Procedural and distributive fairness influence attitudes directly and intentions indirectly.	+
Place attachment and place identity	[8,45,65]	Renewable technologies	Dutch, EU and German Laypeople	Residents of industrialized places are more likely to accept "green" energy facilities. People who are most likely to oppose developments are those who derive a positive sense of identity from rural landscapes especially if they also live there.	+/−

[66] also made clear the need for an interdisciplinary approach to achieve a greater understanding of the processes underlying any technology acceptance. Among such models (Fig. 1) complementing purely psychological constructs with theoretical elements from Sociology and Economics, there is the TAM, i.e., Technology Acceptance Model [67], which can be considered as the first model to specifically analyze the acceptance of a new technology. More recently, the SETA, Sustainable Energy Technology Acceptance model [3] is the first one developed and used to explain the acceptance of hydrogen refueling facilities by combining theories from social and environmental psychology: it includes variables adopted in the TAM; and it adds other variables, such as trust in suppliers, knowledge, perceived risk, values and emotional reactions to technology.

However, reviewing these models, a few issues emerge.

First of all, across such models, technology acceptance can be considered at different levels, depending if the focus is on the introduction of the new technology at the policy-making and political level, if it deals with its success in the market, or if it focuses on how welcome the new technology, and the related infrastructures, are in a specific local community. Moreover, these models have been applied to a variety of new technologies, often to technological infrastructures related to renewable energy production and distribution, but rarely to biofuels. It should also be noted that most of the studies on biofuel acceptability have so far focused on its acceptance among the general public [13,14,20,46], while only very few studies have focused on expert stakeholders and this even though it is plausible that stakeholders acceptance should be the first step to biofuel diffusion and production.

A specific literature research has thus been conducted on biofuel acceptance among expert stakeholders.

1.6. Stakeholders' acceptance of biofuel among expert stakeholders in Europe: an understudied topic

Table 5 presents the few studies specifically focusing on biofuel acceptance among expert stakeholders.

Without going into the details of these specific studies, it can be noted how the studies on the acceptance of biofuels among expert stakeholders are very few, focusing on different kinds of stakeholders (universities, consulting firms, NGOs, government agencies, industries): they address only non-European samples, while biofuels are currently growing and supported by the European Union (EU) to reduce the European environmental footprint. This is why the present study chose to focus on biofuel technology and on its acceptability, acceptance, and adoption among a large and differentiated number of expert stakeholders within the EU.

Table 5
Studies investigating biofuel acceptance by expert stakeholders.

Study	Sample	Country	Key findings
[68]	13 Solar Water Heaters (SWH) companies (universities, consulting firms, NGOs and government agencies)	Mexico	The cooperation of participants from various sectors is able to raise social acceptance of renewable energy technologies
[69]	37 stakeholders (universities, NGOs, government, industries)	United States	NGO representatives perceived rural development as an opportunity and technology conversion as a weak point; academics perceived competition with other renewables as a major threat
[27]	12 stakeholders (scientists, experts from technology centers and members of companies)	United States	Main barriers to biofuel production from microalgae were high cost and high energy requirements
[60]	509 stakeholders groups in the Klang Valley	Malaysia	Perceived benefit emerged as the main predictor of public support
[49]	180 stakeholders (agricultural professionals)	Iran	The proposed model (including perceived variables such as benefits, problems, outcome efficacy, risks, costs, personal norms, behavioral intentions) is able to predict 35% of the variance in the willingness of agricultural professionals to use renewable energy, and 38% of the variance in the "personal norm" towards the use of renewable energy

Since biofuels, among the different sustainable technologies currently under development, represent an interesting perspective in the necessary conversion of the energy-productive system towards decarbonization and environmental sustainability, it is important that scientific research addresses not only the production, processing and distribution processes of biofuels, but also their social acceptance processes. To do this, it is necessary to have a clearer picture of the aspects that could facilitate or hinder their adoption, highlighting every variable that potentially intervenes in the adoption decision-making process.

1.7. Aim

The aim of this study focuses on identifying biofuel technology

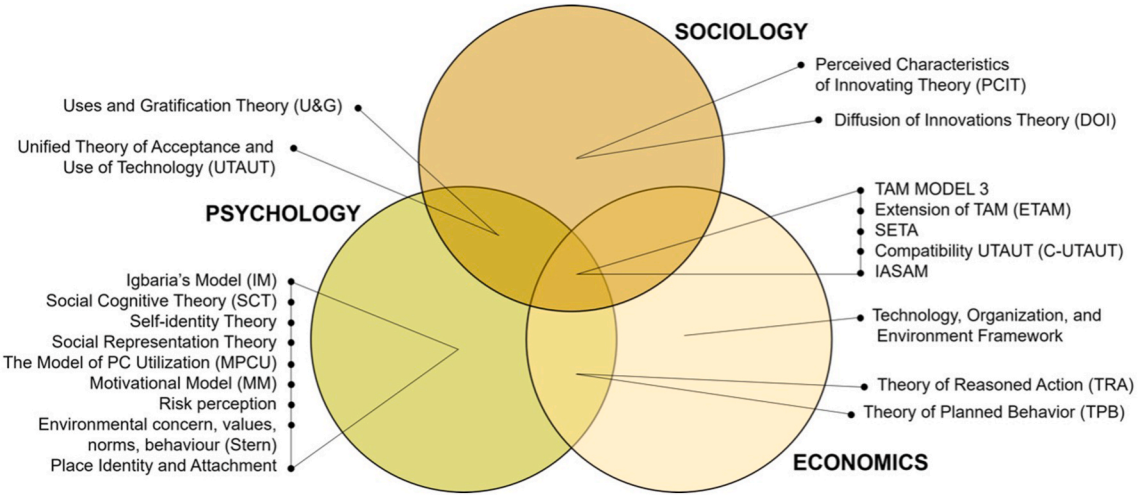

Fig. 1. The most relevant theories and models regarding the social acceptance of technology in Psychology, Sociology and Economics.

acceptance barriers and facilitators, on the basis of the textual content of the interview's responses considering the different societal perspectives provided by EU stakeholders mapped for their interest and influence degrees in the biofuel sub-area. This aim is achieved by an analytic strategy with a deductive approach: namely, a literature-based content analysis of the interviews data. The present study features an innovative theoretical and methodological approach and has relevant applied implications. Starting from the widest review of the literature known to authors, a holistic approach was employed. Variables and models from the interdisciplinary literature on sustainable technology acceptance derived from psychology, sociology and economics, has been employed to build an open-ended interview model, which aims to gather a wide range of information about the participants' knowledge, attitudes, experience, etc. regarding biofuels acceptance and adoption (specifically focusing on facilitating and resistance factors). The content analysis aims at identifying specific contents across all domains previously identified in the literature, by considering expert stakeholders which are relevant for the biofuel area, among the EU mapped ones.

More specifically, the operational aim is to confirm – within the analyzed textual material of the interviews answers – the presence of each single variable included in the list regarding the three main literature-derived areas (encompassing four clusters) of barriers and facilitating factors, namely: technology features, contextual features (with economic and market aspects, as well as policy and administration ones), and social-psychological features.

2. Material and methods

2.1. Procedure

A list of stakeholders has been extracted from the ETIP Bioenergy website, a project that has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 825179. They are listed according to each one of the target Countries where to recruit the stakeholders to be interviewed. The data gathering phase started in November 2019 with the first completed interview on November 25th, and the last interview completed on August 8th, 2020.

As a first contact, a formal e-mail was sent to each of the identified stakeholders with a brief description of the objective and the request to participate in the interview on the Qualtrics online platform. In face of a major lack of replies, a second way of stakeholders contacting was adopted: a formal e-mail was sent again to each of the identified stakeholders and immediately afterwards each contact person was approached by telephone. During the phone call, the objective of the interview was explained again, by one of the co-authors (different co-authors took care of different countries stakeholders, approaching them in English or in their native language whenever possible). In cases where the contact person was not willing to participate in the interview, s/he was asked to provide the contact of another person within the same organization – whether institution, company or NGO – who would be willing to fill out the interview.

Once a stakeholder accepted, s/he received a link via e-mail from her/his contact person, in order to fill in the interview by writing. The interviewed stakeholder knew that her/his contact person was available (by e-mail or telephone) in case s/he needed further information. Reminders were sent by the contact person to the single participant, whenever s/he was delaying her/his interview replies, until its completion.

2.2. Interview structure

The literature review on technology acceptance, and particularly the more recent integrative interdisciplinary models, served as the starting point for the design of the interview general structure and its specific questions. The facilitating or inhibiting variables can be grouped into the three macro-areas: technological factors; contextual elements, further divided into economic factors, market factors, policy factors; and social-psychological factors.

The interview consists of 30 main questions on biofuel acceptance (sometimes articulated into sub-questions, see Appendix 1) organized in eight sections disposed in a standard, non-random order (Fig. 2): background questions, background knowledge on biofuel, technology features, economic aspects, market-related aspects, policy and administrative aspects, social-psychological factors and summary questions. The summary questions section included acceptability criteria (WTP, biofuels' evaluation, personal use probability, organizational use probability and global adoption probability): this information is not considered in the present contribution due to editorial constrains. In general, some questions asked interviewees to answer according to their personal opinions and experiences. Other questions were formulated in a broader term, allowing stakeholder to either report their own opinion or to share what they thought to be other people's opinion (general public, organizations, etc.). Moreover, a 1-page text giving specific standard info about a sustainable liquid biofuel (middle distillates) from various ligno-cellulosic waste streams details was placed after the first two general sections (see Appendix 1).

The entire project of investigation, detailed in its execution modalities and participants involved, has been submitted to the Ethics Committee of the Department of Psychology of Developmental and Socialization Processes, Faculty of Medicine and Psychology, Sapienza University of Rome (Italy), receiving the approval to proceed (submitted July 01, 2019, final approval October 02, 2019, Protocol n. 1306 pos. VII/15). This research effort belongs to a wider project (EC H2020 ABC-Salt, Grant Agreement n. 764089).

2.3. Sample

A preliminary stakeholder mapping procedure was employed to define the relevant sample for this study. Each stakeholder organization has been measured in terms of overlapping interest with the wider project on biofuel and in terms of its influence within the stakeholders' network [70].

The present sample consists of thirty-two individuals belonging to different institutions, companies, NGO's (mean age: 42,56; standard deviation: 12,11; 27 men, 5 women). The unbalanced sample in favor of men is a representation of the biofuel sector and in broader terms of the renewable energy sector where women are still underrepresented.

The sample (Table 6) has a predominant technical background and belongs to eight different European countries (Italy, France, Germany, Belgium, Sweden, Norway, The Netherlands, UK), covering several organizational categories: Academy and research centers, Large companies, Small and medium-sized enterprises (SME), Non-profit & Association bodies, Governmental organizations).

Moreover, in each country the four selected stakeholders cover the four quadrants identified by the two mapping variables (low or high interest in the specific biofuel project, and low or high influence within the ETIP stakeholder network, see Fig. 3), as previously mapped [70].

2.4. Data analysis

Since data collection was conducted with an online open-ended interview and since participants were required to answer in English even when that was not their native language, the textual production was of only 1281 words. This is why it was chosen not to run any quantitative analysis, but rather a qualitative content analysis [71]. A similar approach and data analysis technique has already been used in studies on energy acceptance, such as that of Langer et al. [72]. MaxQDA Computer Assisted Qualitative Data Analysis Software [73], was employed to organize the interviews collected by the Qualtrics online platform and to allow for comparison. The textual output from the interviews were imported into the MaxQDA software and labels or codes

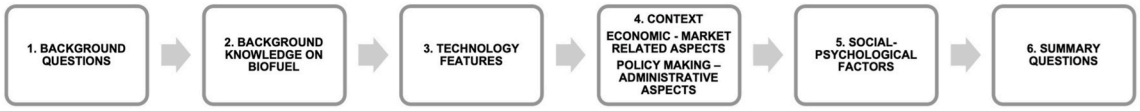

Fig. 2. Interview structure.

Table 6
Description of the sample (SH stands for Stakeholder and marks the sequential number of the interview).

Stakeholder	Age	Gender	Sector	Field	Country
SH1	43	Woman	ACADEMY & RESEARCH CENTRE	Chemistry	Italy
SH2	59	Man	LARGE COMPANY	Biology	Sweden
SH3	29	Man	NO-PROFIT & ASSOCIATION	Chemistry	France
SH4	54	Man	NO-PROFIT & ASSOCIATION	Energy Science	Sweden
SH5	35	Woman	NO-PROFIT & ASSOCIATION	Energy Science	France
SH6	55	Man	LARGE COMPANY	Chemistry	Italy
SH7	53	Man	SME	Physics	Germany
SH8	38	Man	ACADEMY & RESEARCH CENTRE	Biology	France
SH9	57	Man	GOVERNMENTAL ORGANIZATION	Physics	France
SH10	29	Man	ACADEMY & RESEARCH CENTRE	Energy Science	Norway
SH11	29	Woman	GOVERNMENTAL ORGANIZATION	Energy Science	UK
SH12	40	Man	ACADEMY & RESEARCH CENTRE	Engineering	Norway
SH13	49	Man	NO-PROFIT & ASSOCIATION	Engineering	UK
SH14	61	Man	ACADEMY & RESEARCH CENTRE	Chemistry	Netherlands
SH15	65	Man	LARGE COMPANY	Biology	Norway
SH16	31	Man	ACADEMY & RESEARCH CENTRE	Economics and SSH	Sweden
SH17	29	Man	SME	Energy Science	Netherlands
SH18	45	Man	ACADEMY & RESEARCH CENTRE	Chemistry	Germany
SH19	28	Man	NO-PROFIT & ASSOCIATION	Engineering	Belgium
SH20	38	Man	LARGE COMPANY	Engineering	Italy
SH21	50	Man	SME	Engineering	Italy
SH22	44	Man	ACADEMY & RESEARCH CENTRE	Economics	Sweden
SH23	29	Man	GOVERNMENTAL ORGANIZATION	Biology	Belgium
SH24	63	Woman	NO-PROFIT & ASSOCIATION	Economics and SSH	Norway
SH25	30	Man	NO-PROFIT & ASSOCIATION	Engineering	Germany
SH26	34	Man	ACADEMY & RESEARCH CENTRE	Chemistry	Germany
SH27	44	Man	LARGE COMPANY	Engineering	Belgium
SH28	55	Man	GOVERNMENTAL ORGANIZATION	Biology	Netherlands
SH29	31	Man	GOVERNMENTAL ORGANIZATION	Biology	UK
SH30	52	Woman	GOVERNMENTAL ORGANIZATION	Engineering	Belgium
SH31	25	Man	ACADEMY & RESEARCH CENTRE	Chemistry	Netherlands
SH32	38	Man	ACADEMY & RESEARCH CENTRE	Chemistry	UK

were assigned to highlight interesting and meaningful parts of the content. With a deductive approach, three coders analyzed the produced text identifying topics related to the four clusters of variables emerged from the sustainable energy technologies' literature review (technology characteristics, economic and market aspects, policy and administrative aspects, and social-psychological factors), which served as main content organizing categories. Following the consensual coding technique [74], each answer's textual production was categorized consensually by one of the six co-authors together with a collaborator, with the goal of assigning it to one or more category/ies and one or more relative subcategory/ies. It was then calculated Cohen's $K = 0.83$ (inter-coders agreement based on 25% of the interviews). Some answers could provide text for a single category and subcategory (i.e., typically very short answers, such as very few words): thus the answer overlaps with one single coded text item. While some other answers provide a richer textual material which is coded into different parts (various text items) by referring to different categories and/or subcategories (i.e., typically longer answers): thus here the answer does not overlap with one single coded item, rather it generates two or more text items.

For each category, subcategories (Topics) were identified (7 variables related to technology characteristics, 5 variables related to economic and market aspects, 2 variables related to administrative and policy aspects, 8 variables related to psychological factors) on the basis of the above reported literature review (see Tables 1–4). The content analysis procedure is illustrated in Fig. 4.

Anyway, each text item is always selected on the basis of the immediate context of the whole sentence in which is produced (answer), as well as on the basis of the wider context provided by the framing question which triggered that answer. The tables reported in the next Results section show only a few of the coded text items: their selection from the pool of all the coded text items belonging to a certain subcategory to be included into the relevant results' table has been consensually agreed by the same three coders on the basis of various considerations, according to the following priorities: a) representativeness of a frequently observed specific content; b) representativeness of different stakeholders in terms of sectors and countries; c) intelligibility of the written spelling.

3. Results

3.1. Technology features

Table 7 reports exemplary extracts referring to those technology features (derived from the literature) which can represent a positive and/or negative factor for biofuel acceptability and adoption.

3.1.1. Chemical properties

Considering acceptance positive aspects, the specific consumption of biofuel should be an advantage. The Well-to-Wheel (WtW) methodology that evaluates the energy impact of propulsion technologies, in particular the total energy used to allow the fuel to make the journey from the primary energy source to the refueling of the vehicle tank, would therefore highlight the energy efficiency of biofuels as favoring usage. Among the chemical and physical characteristics, however, several

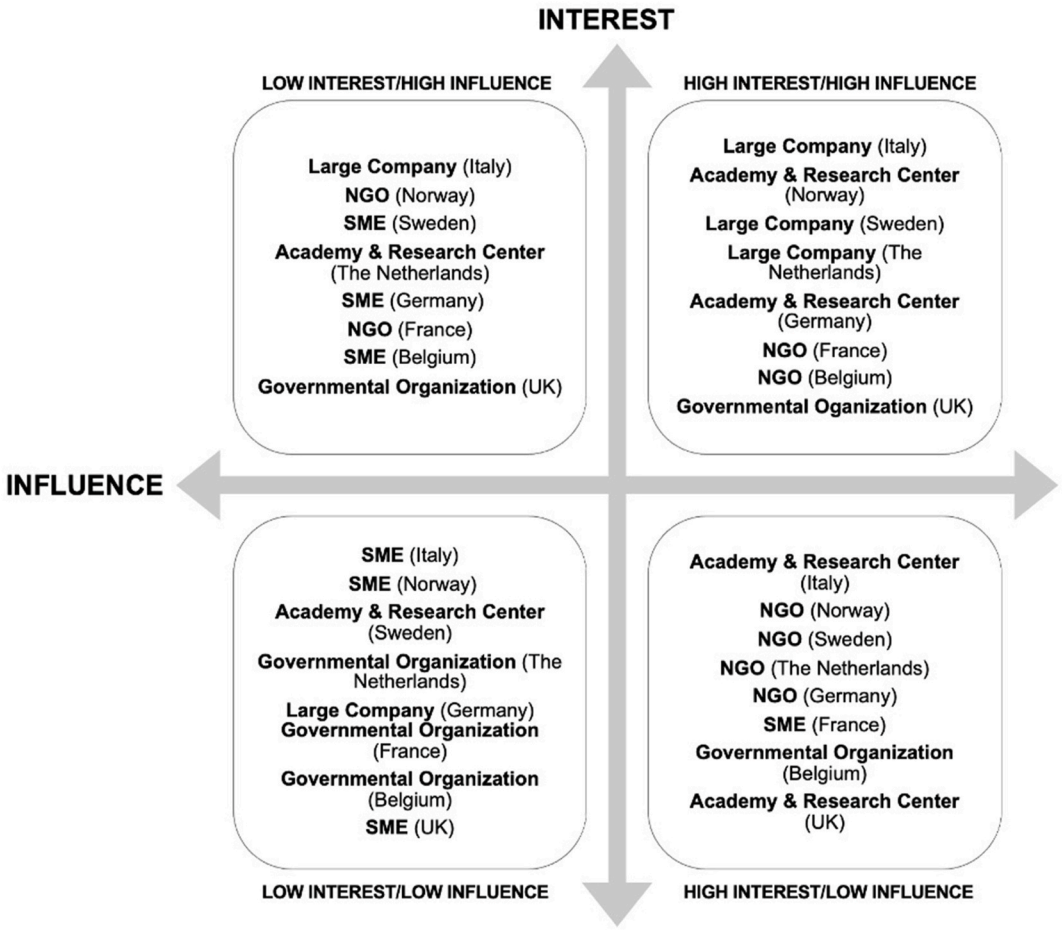

Fig. 3. The organizational categories and countries of the 32 interviewed stakeholders, as previously mapped via the four quadrants given by their low or high Interest and low or high Influence within an EU biofuel stakeholder list (ETIP).

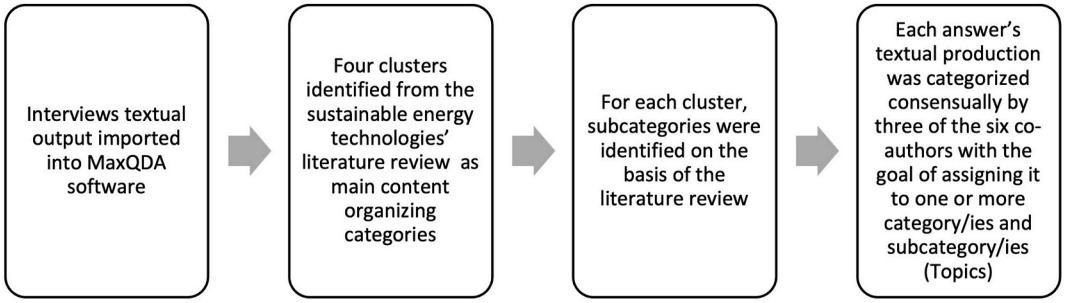

Fig. 4. Content analysis procedure.

problematic aspects emerge too. The Technology Readiness Level (TRL) scale, which is used to track the progression of the technology, would show a low maturity of biofuels compared to other sustainable technologies. Another negative aspect related to the chemical characteristics of biofuels would be biofuels lower heating value or net heating value, which assumes that the latent heat of vaporization of water in the reaction products is not recovered: this would lead to the perception of increased consumption for drivers.

3.1.2. Compatibility with conventional engines, existing facilities and infrastructures

Biofuels are essential to the green transportation sector. Sustainable mobility would therefore be possible thanks to the introduction of biofuels. The aspects of incompatibility that have emerged with current storage facilities, distribution practices, engines, and infrastructure refer to several levels: at a technical level there may be an incompatibility in rail transportation sector because power trains would require adaptation in order for biofuels to be used; while at a social, political and economic level lock-in effects could occur in transportation. It is however pretty consensual that the high compatibility of biofuels with conventional engines and existing petroleum facilities could facilitate its use.

3.1.3. Perceived feedstock sustainability

Stakeholders highlight how there is no consensus on feedstock sustainability estimation. It would seem that first-generation biofuels that are produced from food-crops are perceived as less sustainable than biofuels which are produced from wastes and agricultural residues, and which thus do not compete directly with food and feed crops. The

Table 7
Factors and topics related to "Technology features" and their representative verbatim extracts selected from the interviews. SH stands for stakeholder and the number refer to its sequential order in the interviews sample.

Technology features	Representative example quotations in expert interviews	Topics
Chemical properties	*"Positive WtW [..]".* (in relation to question: "Which are the most important arguments in favor of utilizing biofuels?") [SH6, Man, 55, Italy, Chemistry, Large Company, Quadrant 1] *" [..]High energy density. [..]"* [SH17, Man, 29, Netherlands, Energy Science, SME, Quadrant1] *" […]They are cleaner when they burn. [..]* [SH12, Man, 40, Norway, Engineering, Academy & Research Centre, Quadrant1] *"TRL (compared to other rewable options). [..]"* [SH14, Man, 61, Netherlands, Chemistry, Academy & Research Centre, Quadrant2] *"Low heating value (leading to the perception of higher fuel consumption for drivers)"* [SH8, Man, 38, France, Biology, Academy & Research Centre, Quadrant4]	Chemical properties
Compatibility with conventional engines and existing petrol facilities	*"Biofuels may use the same and existing infrastructure for transport, storage and distribution/fill as fossil based fuels, may also be blended with fossil fuels if required, thus can be easily introduced and integrated with the existing fossil based infrastructure".* [SH2, Man, 59 years, Sweden, EVP Business development and innovation, Biology, Large Company, Quadrant 1] *" […]Power trains need to be adapted for some biofuels. […]."* [SH7, Man, 53, Germany, Managing Director, Physics, SME, Quadrant3]	Compatibility with conventional engines and existing petrol facilities
Infrastructures	*"Essential to "green" transport sectors for which there (hardly) are no renewable alternatives on the short - medium term, i.e. heavy duty road transport, aviation and shipping."* (in relation to question: "Which are the most important positive properties of biofuels?")[SH14, Man, 61, Netherlands, Chemistry, Academy & Research Centre, Quadrant2] *" […]lock-in effects in transport […]"* (in relation to question: Which are the most important arguments (up to 5) against utilizing biofuels?") [SH7, Man, 53, Germany, Managing Director, Physics, SME, Quadrant3]	Infrastructures
Feedstock	*"It is a good alternative to avoid that the organic waste material end in the garbage dump."* [SH12, Man, 40, Norway, Engineering, Academy & Research Centre, Quadrant1] *"Some biofuels are really sustainable (biofuels from European feedstocks) whereas imported biofuels are suspected to be less sustainable (from palm and soy)".* [SH3, Man, 29 years, France, Project Manager, Chemistry, Non-profit & Association, Quadrant 2] *"biofuels are seen as negative when they are produced from cropped colza or other plant (first generation biofuels)[…]"* [SH30, Woman, 52, Belgium, Engineering, Governmental Organization, Quadrant2]	Perceived Feedstock sustainability
Change of land use	*"Mainly the indirect land use change, in particular from forest to cultivation) boosted by the increasing demand of biofuels. […]"* [SH20, Man, 38, Italy, Engineering, Large Company, Quadrant3]	Change of land use
Emissions reduction	*"The most important positive properties of biofuels is the contribution to GHG emissions reduction due to the natural adsorption of CO2 by renewable feedstock compared to the fossil one.[…]."* [SH20, Man, 38, Italy, Engineering, Large Company, Quadrant3] *"It seems that biofuels do not have an better impact on the quality of air (Nox emissions, ppm, …) than their fossil equivalent (bioLNG do not seem better than LNG for instance) Concerning the CO2 emissions, it depends on the way it is produced, so the impact is unknown as well"* [SH30, Woman, 52, Belgium, Engineering, Governmental Organization, Quadrant2]	Perceived Emissions
Environmental impact	*" […] the overall impact on the earth should be lower with biofuels than with fossil fuels. Biofuels may/should contribute to reduce human impact upon earth."* [SH7, Man, 53, Germany, Managing Director, Physics, SME, Quadrant3] *" […]Contribution to climate change mitigation. […]"* [SH7, Man, 53, Germany, Managing Director, Physics, SME, Quadrant3]	Environmental impact

(*continued on next page*)

Table 7 (*continued*)

Technology features	Representative example quotations in expert interviews	Topics
	"Remediation and protection of heath lands, wetlands and peoples home from flooding and soil erosion. […]" [SH11, Woman, 29, UK, Energy Science, Governmental Organization, Quadrant4] *"Deforestation. Biodiversity losses."* [SH8, Man, 38, France, Biology, Academy & Research Centre, Quadrant4] *"destruction of ecosystems by planting more production forests […]"* [SH32, Man, 38, UK, Chemistry, Academy & Research Centre, Quadrant2]	

different estimation could also depend on feedstock's geographical origin.

3.1.4. Change of land use

When the feedstock implies the use of agriculture land instead of wastes and residues, an important factor emerges that is the change of land use. The ILUC (Indirect Land Use Change) that refers to the cultivation of crops for biomass on agricultural land – and that can result in the displacement of existing food crop production, causing a change in land use elsewhere – represents a factor that could adversely affect the acceptance of biofuels.

3.1.5. Perceived emissions

Most stakeholders agree that biofuels contribute to the reduction of harmful emissions. Renewable feedstocks therefore have a positive effect on air quality. Thus, feedstock characteristics would be critical because emissions would depend on them. The combustion of biofuels, compared to fossil fuels, would produce fewer pollutants. Among the critical aspects of emissions reduction, the impact of biofuels on emissions would be uncertain because it would depend on how they are produced. In sum, if biofuels are produced from sustainable feedstock, then there will be a reduction in pollutant emissions.

3.1.6. Environmental impact

Interviewed stakeholders do not reach a consensus about overall environmental impact of biofuels. Several stakeholders describe the positive impact of biofuels on climate change mitigation.

On the contrary, other stakeholders think that biofuels have a negative impact on the environment, especially when it involves land use change and deforestation. It is clear that the environmental impact of biofuel production will depend on several factors ranging from the type of raw material, management and location of the land to be cultivated.

To sum up, among the beneficial aspects of biofuel adoption, the ability to reduce human impact on the environment and combat climate change is featured; while among the harmful effects deforestation, thereby resulting in biodiversity losses, is key.

3.2. Economic and market aspects

Table 8 reports exemplary extracts regarding how the different variables emerged from the literature as economic and market features can represent a positive and/or negative factor in view of biofuel acceptability and adoption.

Table 8
Factors and topics related to "Economic and Market aspects" and their representative verbatim extracts selected from the interviews. SH stands for stakeholder and the number refer to its sequential order in the interviews sample.

Economic and Market aspects	Representative example quotations in expert interviews	Topics
Price	*"Cost-effective (compared to other renewable options). TRL (compared to other rewable options). BECCS option. no renewable alternative"* [SH14, Man, 61, Netherlands, Chemistry, Academy & Research Centre, Quadrant2] *"if the biofuels is used in aviation, I would take the plane again from time to time biofuels for cars could be burned in our actual thermic motors, and be transported by the exisiting distribution networks, it demands less investment than the investment needed for electric cars"* [SH30, Woman, 52, Belgium, Engineering, Governmental Organization, Quadrant2] *" In the short term I think that biofuels will cost more than fossil fuels. One of the factor is the economy of scale of the already developed O&G industry. Another one is huge quantities available and concentrated,. Instead biofuels are a more distributed form of generation of fuel and they have some supply chain limitation that constitute its bottleneck in terms of production scale up."* [SH20, Man, 38, Italy, Engineering, Large Company, Quadrant3] *"I think that in the long term this gap will be reduced but still the economy of scale will play a determinant role in the cost structure.* Only a strong policy intervention could shift the steadiness of this situation, either in term of taxation of fossil fuel or incentives for biofuels." [SH20, Man, 38, Italy, Engineering, Large Company, Quadrant3]	Conversion price; Consumer price; Production price
Food and production costs	*"One negative aspect of using a biofuel in my organization may be related to the initial capital investment needed to transform the production from fossil fuel to biofuel."* [SH20, Man, 38, Italy, Engineering, Large Company, Quadrant3] *"If freight prices increase it basically increases the price of all the goods transported, including food."* [SH19, Man, 28, Belgium, Engineering, No-profit & Associations, Quadrant1]	Conversion price; Consumer price; Production price
Economic benefits/ economic support	*"Economic criteria remain the main criteria for end-users, above environmental and social benefits. Without benefits, no adoption."* [SH8, Man, France, Biology, Academy & Research Centre, Quadrant4] *"poor economics, require public subsidy; logistically challenging; provide little or no LCA benefit; can contribute to deforestation or competition within the food chain"*	Economic benefits and economic support

(*continued on next page*)

Table 8 (*continued*)

Economic and Market aspects	Representative example quotations in expert interviews	Topics
	(in relation to question: "Which are the most important negative properties of biofuels?") [SH13, Man, 49, UK, Engineering, Non-profit & Organization, Quadrant3]	
Market availability	*"Care needs to be taken to establish truely sustainable biofuel value chains - this is neither easy nor obvious (in some cases). Biofuels do have an impact on land use and resource management. Power trains need to be adapted for some biofuels. Sustainable biofuels will only be able to cover a (limited) fraction of our current fuel demand.*" [SH7, Man, 53, Germany, Managing Director, Physics, SME, Quadrant3]	Limited availability on the market
	"cost, and *in the short term lack of selling points*." [SH28, Man, 55, Netherlands, Biology, Governmental Organization, Quadrant3]	
Local development and energy independence	*"Absolutely! Biofuels production can contribute to local employment and value adding throughout a complete value chain from growing a crop/forest and through the primary and secondary processing to a fuel product ready for market. Further, the processing of the bio-feed stock may open other routes for processing and products and materials, e.g. carbon fiber, which adds further value to the production platform. As biofuels production can be integrated into existing production platforms/ infrastructure, e.g. pulp mills, the additional production of biofuels at these sites may add further value, profitability and competitiveness to the site - Additional return on site and assets.*" [SH2, Man, 59 years, Sweden, EVP Business development and innovation, Biology, Large Company, Quadrant 1]	Local development and energy independence
	"lower GHG savings, agriculture economic support, production distributed all around EU, petroleum independency" [SH27, Man, 44, Belgium, Engineering, Large Company, Quadrant4]	

3.2.1. Price

From stakeholder responses regarding biofuel's price, it is possible to identify three key factors influencing the adoption of biofuels: conversion prices, consumer prices, and production prices.

As regards to the positive aspects related to the conversion price of biofuels, the interviews revealed their price competitiveness in relation to other sustainable technologies. Compared to another sustainable technology such as electric cars, the use of biofuels would furthermore require less economic commitment and would be more beneficial.

As regards the biofuel price for the consumer, differences are expected in the short term and in the long term. In the short term biofuels will cost more than fossil fuels. However, in the long term this gap will be reduced.

As regards to the biofuels production costs, interviewed expert stakeholders consider them as a barrier to acceptance. From an organizational point of view, the transformation of production from fossil fuels to biofuels encounters an important economic barrier as the initial process requires a relevant capital investment and would therefore be disadvantageous for production companies.

The high biofuels costs could lead to an increase in transportation-related costs resulting in an increase of food raw materials costs.

3.2.2. Economic benefits and economic support

If users would perceive biofuels has providing economic benefits, this could encourage their acceptance. However, some stakeholders, highlight that people might not consider biofuels to provide economic benefits. End-users would consider only the economic side rather than the environmental and social benefits in the adoption of biofuels. Similarly, when addressing biofuels' negative properties, as found in many other stakeholder responses, lack of economic benefits results, thus emphasizing the importance of some economic support for biofuel acceptance. Thus, economic benefits are needed and economic support favors acceptability and adoption.

3.2.3. Limited availability on the market

An important factor that prevents people from buying biofuels is the limited market availability compared to fossil fuels. Compared to the demand for biofuels, there is currently a shortage of availability that would therefore allow only a limited supply. Among the negative aspects related to the use of biofuels versus fossil fuels, there is their market scarcity, which includes not only production aspects but also sales aspects. In fact, in the short term, one factor that will inhibit end-users' adoption of biofuels will be the lack of pump stations.

3.2.4. Local development and energy independence

Stakeholders consider biofuel production to have positive effects at the local scales, especially favoring local economic development and local energy independence. Among the economic aspects, the adoption of biofuels has several positive sides for the local economy like the increase in jobs and increase in local income. Another positive aspect related to local development would be petroleum independency. In sum, biofuel production would take place among all EU countries which, in this way, would be able to spur local development and to obtain independence from fossil fuels.

3.3. Policy and administration aspects

Table 9 reports exemplary extracts regarding how the different variables emerged from the literature as administrative and policy features can represent a positive and/or negative factor in view of biofuel acceptability and adoption.

3.3.1. Regulatory policies

Regarding biofuels introduction, most of the stakeholders interviewed agreed that policies are crucial for adoption by the end-users. Policies would be needed to accelerate the transition from fossil fuels to biofuels and the ultimate goal would be to reduce pollutant emissions. To this end, there is the need to achieve a common political will to work towards solving climate change challenges. To sum up, regulatory policies, would favor the adoption of biofuels because their introduction would make them convenient and would also reduce polluting emissions, according to a cascade effect.

3.3.2. Support programs and information actions

Programs in support of biofuels have been found to be relevant by most experienced stakeholders for acceptance. Programs to support and promote biofuels need the involvement of several figures. Politicians would then have the task not only to support research in the field of biofuels, but also to show to laypeople the reasons behind the desire to move from fossil fuels to renewable energy. In addition to politicians, other important figures could be useful to convey information messages

Table 9
Factors and topics related to "Policy and Administration aspects" and their representative verbatim extracts selected from the interviews. SH stands for stakeholder and the number refer to its sequential order in the interviews sample.

Policy and Administration aspects	Representative example quotations in expert interviews	Topics
Regulatory policies	*"Regulation may help to speed up change from fossil to biofuels, a good example of driving demand for biofuels can be found in Sweden now, i.e. the reduction quota "reduktionsplikten" driving demand towards those fuels with the least carbon footprint."* [SH2, Man, 59, Sweden, EVP Business development and innovation, Biology, Large Company, Quadrant 1] *"More policy would be needed to secure adoption from the end-users"* [SH10, Man, 29, Norway, Energy Science, Academy & Research Centre, Quadrant2] *"Because I strongly believe that an intervention is important to contribute to climate change challenge we are facing. However it is necessary to build a common political willingness with the support of specific policies to make the reduction to the emission at world-level significant.* [SH20, Man, 38, Italy, Engineering, Large Company, Quadrant3]	Regulatory policies
Support programs and information actions	*"Yes, politicians have to be involve. They should support the research on biofuels and show to the public why we need that change in the next years."* [SH12, Man, 40, Norway, Engineering, Academy & Research Centre, Quadrant1] *"Yes, promotion will need to be done on many levels."* [SH7, Man, 53, Germany, Managing Director, Physics, SME, Quadrant3] *"There needs to be careful messaging and it is best promoted through the NGO's that have massive impact on public opinion; without them onside it will be a very difficult task"* [SH13, Man, 49, UK, Engineering, Non-profit & Organization, Quadrant3]	Support programs and information actions

capable of promoting the acceptance and adoption of biofuels. NGOs would be able to effectively promote information in favor of biofuels as they have strong influence on public opinion. Therefore, biofuels support programs span across multiple levels and incorporate multiple sources: Institutional level support promotes research in the field, while non-institutional level support promotes adoption by conveying informational messages.

3.4. Social-psychological features

Table 10 reports exemplary extracts regarding how the different variables emerged from the literature as social-psychological features of the person can represent a positive and/or negative factor in view of biofuel acceptability and adoption. Variables are listed from the more cognitive to the more affective up to the social ones.

3.4.1. Knowledge

Knowledge is able to influence the acceptance of renewable technologies. What emerges from the stakeholders' responses are the consequences related to lack of knowledge about biofuels and the

Table 10
Factors and topics related to "Social psychological features" and their representative verbatim extracts selected from the interviews. SH stands for stakeholder and the number refer to its sequential order in the interviews sample.

Social-psychological features	Representative example quotations in expert interviews	Topics
Knowledge	*"Information would be helpful to overcome doubts of its use among consumers and enhance demand".* [SH2, Man, 59 years, Sweden, EVP Business development and innovation, Biology, Large Company, Quadrant 1] *"Due to lack of knowledge of people on biofuels they have often stereotypes. But as soon as you explain them that you will not starve the world and you play a positive role for national agriculture and protein and economic sovereingty they can easily be convinced".* [SH3, Man, 29 years, France, Project Manger, Chemistry, Non-profit & Association, Quadrant 2] *"I think that stakeholders information and engagement is essential for the penetration of biofuels into the market. The information campaign should be as simple and essential as possible, in order to bring a clear message about the role of biofuels."* [SH20, Man, 38, Italy, Engineering, Large Company, Quadrant3] *"the end user do not know how the fuel is produced and which is the impact on the environment"* [SH30, Woman, 52, Belgium, Engineering, Governmental Organization, Quadrant2]	Lack of knowledge and consequence; Information, high knowledge and acceptance
Experience	*"With positive experience, I would try to convince other people."* [SH18, Man, 45, Germany, Chemistry, Academy & Research Centre, Quadrant1]	Experience
Perceived outcome efficacy	"*Most end users are mainly interested in the "performance" and ease of fuels.* " [SH7, Man, 53, Germany, Managing Director, Physics, SME, Quadrant3] *"People will choose the cheapest option, because in short term, the private economy is more important than the climate"* [SH16, Man, 31, Sweden, Economics & SSH, Academy & Research Centre, Quadrant3]	Perceived outcome efficacy bases
Values	*"More about the values that I want to teach to the next generation about the use and preservation of the natural resources"* [SH12, Man, 40, Norway, Engineering, Academy & Research Centre, Quadrant1] *"My green values."* [SH15, Man, 65, Norway, Biology, Large Company, Quadrant3] *"Sustainability values"* [SH29, Man, 31, UK, Biology,	Values

(*continued on next page*)

Table 10 (*continued*)

Social-psychological features	Representative example quotations in expert interviews	Topics
	Governmental Organization, Quadrant1]	
Emotions	*"I am worried about the removal of agricultural land and the reduction of food raw materials and their higher cost"* [SH1, Woman, 43 years, Italy, Post-doc in environmental catalysis, Chemistry, Academy & Research Centre, Quadrant 2] *"yes, proud of contributing decarbonizing our city and company"* [SH27, Man, 44, Belgium, Engineering, Large Company, Quadrant4] *"It would make me feel better, but that is about it"* [SH32, Man, 38, UK, Chemistry, Academy & Research Centre, Quadrant2]	Negative emotions for the process; Positive emotions for the outcome
Trust	*"both are needed" "For me, as a politician, it's about moral integrity. The end users (professionals!!) will focus on competence and moral integrity as the second place within the boundaries that will be given." "For a biofuel developer: competence […]. For an end user: moral integrity. Because information in the media will be based more on these aspects than on questions of competence. For a policymaker: moral integrity. Because in the end, you will need consumer support."*	Competence-based trust and integrity-based trust; Competence-based trust and integrity-based trust relevance depending on stakeholders' categories
Norms	*"Yes, because there are social judgements, linked to certain organizations."* [SH23, Man, 29, Belgium, Biology, Governmental Organization, Quadrant3] *"I think People will judge me as a well oriented person who promotes a green change"* [SH24, Woman, 63, Norway, Economics & SSH, No-profit & Association, Quadrant4]	Norms
Fairness	*"Improved public relations and corporate social responsibility. Leading by example."* [SH11, Woman, 29, UK, Energy Science, Governmental Organization, Quadrant4] *"At organization level, I think that an effective and social responsible application and development of biofuels can be a beneficial on the company image and other social aspects."* [SH20, Man, 38, Italy, Engineering, Large Company, Quadrant3] *"Investment in bio-based solutions must keep Fair Trade, antislavery and environmental/ climate/animal stewardship issues in mind but otherwise, end-users should not perceive any difference."* [SH11, Woman, 29, UK, Energy Science, Governmental Organization, Quadrant4]	Fairness

importance of information campaigns for biofuel deployment. The interviewed expert stakeholders highlight a lack of end-user knowledge regarding biofuels. Not being aware of the biofuel's production processes can lead to misperceptions about the challenges and opportunities related as well as about the potential applications and the kind of impact they will have on the environment. The lack of knowledge of people who do not have a technical background about biofuels can also lead to stereotypes. Explaining to end-users what the benefits could be for national agriculture and economic sovereignty, for example, could be a winning strategy to break down stereotypes about biofuels. In sum, biofuel knowledge would be a factor favoring biofuel acceptance and adoption. Stakeholders highlight the need of diffusing information about biofuels especially among end-users and they also highlight how this is directly link to biofuel acceptance. Particularly, clear and comprehensive information campaigns are needed. Therefore, information too would favor biofuel acceptance and adoption.

3.4.2. Experience

No specific questions were asked about experience, thus the topic was not often mentioned by stakeholders. However, one stakeholder highlights how positive experience with biofuels is able to influence acceptance because people who already have experience with a sustainable technology tends to be more favorable in this regard.

3.4.3. Perceived outcome efficacy bases

The perceived outcome efficacy, in this specific context, refers to the effectiveness of the biofuel application for the expert stakeholders. Different stakeholders might judge perceived outcome efficacy with reference to different desired outcomes. According to one stakeholder, the ease of use and the high performance are key biofuel's properties which are capable of driving users' preference for biofuels over fossil fuels. For another stakeholder, the bottom line of biofuels adoption lies in their low cost for the consumer, because they are driven by the economics rather than sustainability argument.

On the whole, therefore, similarly to the trust bases dichotomy, there are here two criteria for perceived outcome efficacy bases: performance-based efficacy and price-based efficacy.

3.4.4. Values

Among psychological factors, several values are capable of influencing attitude, beliefs, and behaviors. Some answers to the question regarding the criteria for regulating choices and behaviors regarding the use of biofuels, have highlighted the role of biospheric values namely those linked to concern for the environment. Another aspect related to values is the importance of pushing future generations to take pro-environmental actions to safeguard natural resources.

3.4.5. Emotions

Both positive and negative emotions are able to influence acceptance of renewable technologies. Emotions emerging from stakeholder responses point in both directions: negative emotions related to the adoption process and positive emotions for the adoption outcome.

Negative emotions appeared to be triggered by some features of the production process – i.e., worry for land use removal, food-raw materials reduction, biofuel high price – and they would hinder adoption.

Anticipated positive emotions elicited by biofuels adoption – i.e., feeling better, feeling proud for decarbonizing the environment – encourage biofuel's adoption.

3.4.6. Trust

Trust in the actors responsible for the technology plays a key role for sustainable technologies acceptance such as biofuels. To investigate stakeholder trust in detail, two dimensions of trust were considered, namely trust based on competence and trust based on moral integrity. A specific question was asked about which of the two dimensions of trust was more important for the stakeholders. The majority of the expert

stakeholders interviewed agreed that, for biofuel acceptance, both trust based on competence of the actors responsible for the biofuel and trust based on their moral integrity are equally needed. Among stakeholders who gave a more detailed responses on this topic, different opinions emerged about the role of the two dimensions of trust. The relevance of one type of trust over the other one results to depend on the stakeholder category. According to one stakeholder, for biofuel adoption, trust in the actors responsible for the technology based on moral integrity is therefore preferred by policymakers like him, while the preference of professionals is less distinct. According to another stakeholder, for biofuel adoption, trust in the actors responsible for the technology based on moral integrity is preferred by policymakers, as also reported by the previous stakeholders including end user; while trust based on competence appears more relevant to professional biofuel promotors.

3.4.7. Norms

Subjective norms, i.e., a person's perceptions of the need to behave in a certain way due to social pressure, influences the adoption of a sustainable technology, as emerged from stakeholders' responses. Social pressure, or more specifically, injunctive social norms that relate to what most people approve or disapprove of, would thus seem to drive the adoption of biofuels. Consistently, adopting a biofuel would lead to a socially favorable judgment. In sum, social influence processes triggered by social norms favor biofuel acceptance and adoption.

3.4.8. Fairness

Stakeholder responses regarding their perception of the fairness of the processes involved in the implementation of the biofuel revealed the relevance of Corporate Social Responsibility. Biofuel adoption can contribute to the social responsibility strategies of companies thus helping to improve the image and reputation of the company by building strong relationships among stakeholders: this can work as a positive factor for biofuel acceptance and adoption.

4. Discussion

The present work aims to describe the factors that promote or inhibit biofuels acceptance according to a sample of expert European stakeholders interviewed as relevant actors in the field of biofuels. The paper outlines a number of factors which are derived from multidisciplinary models, and which have been previously investigated in relation to many different sustainable technologies, mostly from the laypeople perspective rather than from the expert stakeholders one. Factors belonging to all four clusters – addressing the intrinsic characteristics of the technology, its economic and market features, its administrative and policy aspects, and its social-psychological factors – emerged in this qualitative study on thirty-two expert EU stakeholders. In their responses, stakeholders sometimes respond on their behalf as subject matter experts, sometimes by referring to the organization in which they work, and sometimes by referring to the facilitating and inhibiting aspects of biofuel acceptance for end-users in general: in each cluster it is possible to find the different levels.

4.1. Technology characteristics

Interviewed stakeholders highlight a number of positive and negative technology characteristics, especially linked to the chemical and physical features of biofuels. Among the positive aspects of biofuels that would encourage their acceptance, there is better energy efficiency with reduced greenhouse gas emissions. With regard to compatibility with conventional engines and infrastructures, the expert stakeholders' considerations show that biofuel can be used directly in conventional engines and can be supplied with the existing petrol facility, thus facilitating their adoption. These results are in line with the evidence of the studies of Milazzo et al. [10] on rape biodiesel production and Van den Hoed [11] on fuel cell technology adoption. Emerged incompatibility aspects, on the contrary, could inhibit its adoption: they are of a technical nature, and refer to incompatibility such as in the rail transport sector because electric trains would require adaptation to use biofuels; or of a broader nature such as at the social, political and economic level (e.g., lock-in effects in the transport sector). Several other aspects emerged that would undermine acceptance such as a low TRL indicative of technological immaturity and lower performance than fossil fuels. It should be noted that specific knowledge and competences are required for understanding and evaluating these issues so, while these topics were raised and discussed in the present expert stakeholder sample, it is less clear how they are known and interpreted among laypeople: state of the art literature did not address such an issue yet.

Feedstock seems to be a particularly controversial issue, which could play a relevant role in evaluating overall biofuel environmental impact. According to the stakeholders, when locally produced feedstocks are composed of agricultural wastes and residues and do not compete directly with food and feed crops, when they contribute to local development, to valorization of waste, to have a lower environmental impact with a reduction in CO2 emissions, then they are more easily accepted (as in other biofuels' studies [13,16]). In contrast, when feedstocks are produced from food crops, as with the first generation of biofuels, they are considered by stakeholder as less sustainable and therefore less easy to accept. Consistently, stakeholders highlight, among the aspects inhibiting acceptance, the phenomenon of ILUC (Indirect Land Use Change) which is a result of unsustainable feedstocks and has negative environmental impacts such as deforestation with biodiversity losses. These results are in line with previous studies by Upham et al. [75] on carbon emissions in relation to land use change, and Houghton et al. [76] on agricultural expansion as one of the causes contributing to the deforestation. The environmental impact of biofuels is therefore linked to the management of the land to be cultivated and its location and the type of raw materials used for production.

With respect to this cluster, the facilitating factors that emerged from the interviews with stakeholders are energy efficiency, compatibility with conventional engines and infrastructures, sustainable feedstock; while among the emerged inhibiting factors there are: low TRL, and indirect land use change as a result of non-sustainable feedstock.

4.2. Economic and market aspects

A distinction can be made here between conversion prices, consumer prices, and production prices. The stakeholder highlights that price of biofuels for consumers is expected to be higher than for fossil fuels at least in the period following their market introduction and this would not facilitate their adoption, while the price gap between biofuels and fossil fuels in the long run could decrease. This result is in line with the study by Oltra [27] on US stakeholders who show that stakeholders considered high cost to be one of the main barriers to producing biofuels from microalgae. In terms of conversion price, biofuels would appear for stakeholders to require less economic commitment than other sustainable technologies, thus facilitating acceptance. On the contrary, a barrier to acceptance that emerged from stakeholders would occur at the production level due to the high initial capital investment. Given the high price of biofuels compared to fossil fuels, stakeholders highlight the need for economic benefits through the introduction of public incentives in order for end users to prefer biofuels.

Consistently with a study on biofuels acceptance by laypeople in general [25], present results show that the limited market availability in terms of production aspects and sales aspects compared to fossil fuels is another factor that will inhibit end-users from buying biofuels.

Finally, at a macro-economic level, the local development will facilitate biofuels acceptance because it would bring a number of benefits to the local economy such as the creation of new jobs as well as energy independence, as also shown in a study on biofuel refining facility on U.S. laypeople [26].

Within this cluster, the facilitating factors that emerged are

economic incentives and local development induced by biofuel production (and conversion prices compared to other sustainable technologies); while among the inhibiting aspects there are the biofuel high price for the consumer and for biofuel production; and the biofuel limited market availability.

4.3. Policy and administration aspects

As reported by a number of stakeholders, the introduction of pro-biofuel policies in several European countries, such as the Netherlands and Sweden, has encouraged personal adoption in everyday life.

The adoption of biofuels for stakeholders is linked not only to favorable regulatory policies, but also to support programs. This was also highlighted in the study by Scarlat and Dallemand [28] on biofuel certification in the European Union, in the United States and in other countries worldwide on laypeople.

Programs supporting biofuels span multiple levels and incorporate multiple sources. The results show that, since it is a technology that has yet to be introduced, on the one hand, policy makers need to promote biofuels research and development at an institutional level, while NGOs can promote adoption by conveying informational messages at a non-institutional level using their strong influence on public opinion. As seen in the literature indeed, informational messages regarding the positive aspects of biofuels conveyed through the media are able to shape the U.S. public perception [77].

To sum up, administrative and policy factors that facilitate adoption are introduction of pro-biofuel policies and both institutional and non-institutional support programs.

4.4. Social-psychological factors

In relation to social-psychological factors, both cognitive, affective and social variables emerged. As for more cognitive factors are concerned, most stakeholders highlight that trust based on competence and trust based on moral integrity are both needed equally in biofuel acceptance. This result differs from previous studies [58] where for example public acceptability of renewable energy projects in China and the Netherlands was based more on integrity-based trust as being more likely to influence project acceptability (compared to competence-based trust). It is thus possible that while previous studies highlighting relevance of integrity-based trust were focused on laypersons when expert stakeholders are considered both integrity- and competence-based trust become equally relevant for promoting sustainable technology acceptance and adoption. Further quantitative research is needed to corroborate this provisional conclusion.

Responses from stakeholders oriented to ecological behaviors highlight the presence of biospheric and self-transcendence values that would lead to biofuels acceptance. This result is in line with the literature showing that people endorsing these values are more favorable towards sustainable technologies acceptance in general such as nuclear energy by Dutch laypeople [51].

Laypeople's general lack of knowledge about biofuels highlighted by expert stakeholders is in accordance with several studies cited in previous paragraphs [20,34,35]. As reported in the literature, there is a positive correlation between the knowledge of renewable energy technology and acceptance [39,40]. Present results on biofuels from expert stakeholders' opinions stress that the lack of knowledge would often lead to stereotypes towards a given sustainable technology, inhibiting its acceptance. In this scenario, expert stakeholders, acting as educational advisors in information campaigns to end users can serve as gatekeepers thereby facilitating biofuel acceptance [49,78,79].

In addition to knowledge, also direct experience with a sustainable technology, as highlighted by the stakeholders who have several years working with biofuels in various sectors, would promote the acceptance of this technology as also reported in the study by Devine-Wright [41] who summaries existing social research on the acceptance of renewable energy technologies.

Regarding perceived outcome efficacy bases, two criteria seem to emerge: a performance-based criterion in that end-users will only prefer biofuels over fossil fuels if the former are easy to use and have high performance; and a price-based criterion according to which people will always favor the cheaper alternative. Outcome efficacy has proven to be an important factor in the acceptance of biofuels by Iranian stakeholders [49] and the main determinant of support for the development of renewable energy sources by UK laypeople [50].

In relation to the more affective type of variables, stakeholders express negative emotions if they consider the negative aspects that the production process may have on the environment, while other ones show positive emotions considering the beneficial effects of the adoption of biofuels on the environment. This result is in line with several evidences across contexts and different kinds of sustainable technologies: nuclear power plants on U.S. laypeople [53] carbon capture and storage on Dutch laypeople [55] and hydrogen technology [54] on Dutch laypeople.

When it comes to social variables, as studies on biofuel acceptance by Iranian stakeholders [49] and on Chinese gas operators [80] report, social approval drives people acceptance actions. In this case, social influence, or more specifically, injunctive social norms drive biofuel adoption as it would lead to socially favorable judgment. Another social variable emerged from stakeholders is fairness in terms of Corporate Social Responsibility: adopting biofuels and creating socially responsible business strategies and practices would help organizations to improve their reputation and image as also reported in a study on three gas operators in China [80].

5. Conclusions

This contribution explored the perceptions of EU expert stakeholders about the acceptance drivers and barriers that biofuels will face in global rollout (Table 11): they refer either directly to the new sustainable technology under acceptance, i.e., the to be accepted item's intrinsic features (in this case, biofuel); or to the acceptance process' contextual features which surround and accompany the new sustainable technology introduction; or finally to the acceptor subject's personal features (in this case, the full range of biofuel expert EU stakeholders).

The topics that emerged from this qualitative study on the whole consist in the variables of the SETA model [3], which presents a technology acceptance framework specifically proposed for sustainable energy technologies such as wind mills and hydrogen technology. However, the SETA model is limited to psychological factors. In this study in addition to social-psychological factors, other factors, either intrinsic or situational, are considered as potentially capable to influence the acceptance of the technology (specifically biofuels): namely, features of the technology, economic and market aspects, and policy and administration aspects. Moreover, compared to the SETA model which is tested on the general public, this study specifically refers to a range of expert EU stakeholders who may have a broader and more complex view being representative of stakeholders with low or high interest towards a specific biofuel project topic, as well as of stakeholders with low or high influence in the relevant stakeholders network (across sectors such as academia, large companies, SMEs, NGOs, governmental bodies).

This study allows to identify some trends that could be further studied in the near future.

An aspect needing exploration pertains those variables that the stakeholders have highlighted as both a facilitating factor and a barrier to acceptance. Among these, for example, the use of sustainable or non-sustainable feedstock, which has positive repercussions in the first case and negative repercussions in the second case in terms of environmental impact: such a factor would thus be double-edged and ambivalence could arise in terms of its effects on biofuel acceptance and adoption. There could be other factors having similar complex effects on acceptance (such as, knowledge and emotions).

Table 11
Favoring and inhibiting factors (i.e., facilitators and barriers) of biofuels acceptance from EU stakeholders ($N = 32$).

Areas	Factor cluster	Facilitators	Barriers
Technology	Technology	• Energy efficiency • Compatibility with conventional engines and infrastructures • Use of sustainable feedstock to reduce harmful emissions	• Low TRL • ILUC as a result of unsustainable feedstock • Use of unsustainable feedstock leading to more harmful emissions
Context	Economy and Market	• Economic incentives • Local development induced by biofuel production	• Biofuel high price for the consumer and for biofuel production • Limited market availability
	Policy and Administration	• Introduction of pro-biofuel policies • Both institutional and non-institutional support programs	//
Person	Social-Psychology	• Knowledge and direct experience with a sustainable technology • Biospheric and self-trascendence values • Positive emotions related to the beneficial effects of the adoption of biofuels on the environment • Injunctive social norms • Need for both integrity- and competence-based trust • Fairness (CSR)	• Lack of knowledge towards the sustainable technology • Negative emotions considering the negative aspects that the production process may have on the environment

Besides the factors that were directly addressed in the interview, some stakeholders, most from the academic and research sector, spontaneously mentioned the role of some social-psychological variables, especially values and emotions. Responses regarding the fairness of processes, instead, were provided mostly by stakeholders belonging to Government Organizations. The importance of knowledge is found mostly for stakeholders of Large Companies and NGOs. Such associations among a specific stakeholders category and specific facilitating or hindering factors can be tested in future larger surveys.

Results from this study can be used to theoretically derive an updated model to be tested using multivariate statistical techniques in order to establish the relative contributions of the four clusters factors in explaining biofuel acceptance. Such future quantitative developments can more properly help in targeting different stakeholders' sub-groups in terms of their different features favoring or hindering biofuels acceptance. The stakeholder segmentation could finally help in designing differentiated specific communication strategies and initiatives in favor of biofuel acceptance (and possibly adoption too).

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Credit author statement

F D: Writing – original draft, Writing – review & editing, Visualization, Formal analysis, Investigation, Data curation, Methodology, Validation S Ar: Writing – review & editing, Investigation, Methodology, Validation T A: Investigation S Al: Investigation N L: Methodology, Validation M B: Conceptualization, Supervision, Project administration, Funding acquisition, Writing – review & editing, Resources, Methodology, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2022.112114.

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