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Beliefs about technological and contextual features drive biofuels' social acceptance

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A R T I C L E I N F O

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A B S T R A C T

To make the transition towards renewable and sustainable energy possible, there is a need to make new relevant technologies, including biofuels more acceptable and accepted. To promote biofuels acceptance and thus adoption means to improve both their perceived technological features and the surrounding context supporting their adoption, as well as some social-psychological features of the target adopters. Achieving the ultimate goal of biofuels adoption thus requires a complex and holistic approach to foster this new energy technology's acceptability and acceptance considering several biofuels features. For this aim, the integrated Sustainable Energy Technology Adoption Model (i-SETA) was developed and tested with newly piloted tools to measure the relevant biofuels' beliefs profile. A Path Analysis tested the relationship between the investigated variables. Results revealed the importance of beliefs belonging to each one of the different considered domains (technological, contextual, and personal variables). Several of them had a direct impact on the cognitive and affective biofuels evaluation, and subsequently on biofuels acceptability and acceptance, for European Union both laypeople and expert stakeholders (total sample of 1017 participants). The main results thus revealed that very specific beliefs, across all the three beliefs classes, can be identified as either barriers or drivers with respect to the aim of boosting biofuels' acceptability and acceptance. Each one of these specific beliefs could thus be properly targeted in the audiences to cope with the barriers and capitalize on the drivers.

1. Broader context

The technical summary of the most recent Intergovernmental Panel on Climate Change climate change report [1] documents deterioration in all major elements of the climate system (e.g., atmosphere, land, and ocean), leading toward frightening changes in climate. This condition is the cause of phenomena such as decreasing ice area, sea level rise, and ocean acidification [1]. To limit global warming to 1.5 °C above pre-industrial levels, rapid, far-reaching, and unprecedented changes are needed [2]. It becomes clear that among the various possible interventions to stop climate change, consuming less energy and relying increasingly on renewable and sustainable energy technologies is one of the most important ways forward [2]. The contribution of Social Sciences and Humanities is pivotal for promoting and facilitating the widespread adoption of any renewable and sustainable energy technology. Understanding the interplay between a certain technological innovation's features, on the one side, and the human social response to such a new energy form, on the other side, is quintessential for concretely moving forward into the energy transition, as part of a broader ecological transition. The energy technology development aims to develop any specific instance – e.g., biofuels – towards its Technology Readiness Level (TRL) 9, which is the highest attainable level. However, this is not sufficient, if it is not matched by a similar development in terms of acceptability, acceptance, and adoption by people, i.e., the potential users of the new energy technology, such as biofuels. In parallel to the TRL, promoting the social acceptance of such technologies is therefore critical to fostering the global and local adoption of these technologies, buffering the effects of climate change (adaptation), and decreasing or stopping it (mitigation). The match between any single new energy technology and the population has to be optimal to foster the widest and quickest possible adoption process: this includes

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Abbreviations

i-SETA	integrated sustainable energy technology adoption model
TRL	Technology Readiness Level
GHGs	Greenhouse gasses
CO_2	Carbon Dioxide
WTP	willingness to pay
SETA	sustainable energy technology acceptance model
BBS	biofuels beliefs scale
BASA	biofuels attitude scale as acceptability
BISA	biofuels intention scale as acceptance
BOKS	biofuels objective knowledge scale
NGOs	Non-Governmental Organizations
EU	European Union
EC H2020	European Commission Horizon 2020
ABC-Salt	Advanced Biomass Catalytic Conversion to Middle Distillates in Molten Salts
CFI	comparative fit index
TLI	Tucker-Lewis index
SRMR	standardized root means square residual
RMSEA	root means square error of approximation
AIC	Akaike information criterion
PAB	positive attitude toward biofuels
BU	biofuels usability
UI	use intention
SD	standard deviation

considering people's attitudes (acceptability), intention to use (acceptance), and actual first and then habitual uses (adoption) of the target energy technology (e,g., biofuels).

2. Introduction

The significant increase in greenhouse gas (GHGs) emissions has caused a sharp rise in global temperatures in recent years. Even while present restrictions are limiting these emissions, mitigation must be increased to avoid potential future harm from the ensuing climate change.

Fossil fuels have played a significant role in the technological advancement of the last couple of centuries, unfortunately also leading to critical environmental issues including pollution and climate change, as well as difficulties with human and other forms of life health and well-being. To reduce GHGs and adapt to climate change, a shift to a low-carbon economy is thus becoming increasingly important to limit the temperature increase to 1.5 °C by 2050.

The 27th United Nations Climate Change Conference emphasized the need to replace fossil fuels, particularly coal, with sustainable energies that can immediately reduce GHGs and battle climate change (e.g. Ref. [3]). The development of these sustainable energies – such as solar, wind, and advanced biofuels – from the so-called mitigation technologies will mark the beginning of the green energy transition, which is essential for achieving the Sustainable Development Goals of the United Nations [4].

Biofuels are among the most important sustainable energy technologies for cutting back the usage of fossil fuels, achieving carbon neutrality, and minimizing adverse environmental effects. The use of biofuels in place of fossil fuels for heating, power generation, and transportation would have numerous economic and social advantages in addition to environmental ones [1,5]. In fact, in the last few decades, there has been a strong push to explore the production of biofuels, given their potential to benefit from current distribution systems and technologies, reducing CO_2 emissions [6].

Secondary biofuels are made from processed organic materials and can be used as liquid fuels, such as in vehicles and industrial processes, in contrast to primary biofuels, which are created by burning unprocessed organic materials, such as wood chips and pellets, and are primarily used for heating, cooking, or electricity production [7].

The first generation of secondary biofuels, being derived from food crops, has been criticized for using fertile land for fuel production. Even though using conventional (first-generation) biofuels in place of fossil fuels reduces the environmental impact, their use is subject to several critiques. These types of biofuels lower GHGs emissions but, regrettably, their use is also connected to events like deforestation, indirect land use change, and the removal of land from agricultural food crops (e.g., rapeseed, corn, sugarcane, palm [8]). These features represent serious barriers in terms of social acceptance. As a result, the use of biofuels as an alternative to fossil fuels has become a subject of debate and controversy [6].

Instead, the second-generation approach, which is currently the most popular, uses lignocellulosic biomass or agricultural waste (byproducts of other agricultural industries), which is thought to have a lower environmental impact [9]. The creation of a third generation, based on algae, is under development. These features represent promising drivers in terms of social acceptance.

There is a continuing transition to advanced biofuels (such as second-generation biofuels), which employ biomass from agricultural waste or non-food crops. Advanced biofuels, which primarily utilize food (waste oils and animal fats) and agricultural waste but also algae or woody waste, have the advantage of not competing with the food sector and not having a detrimental influence on land use [1].

However, more contemporary biofuels, which have many benefits for the environment and are a renewable and sustainable energy technology, may still face opposition that prevents their widespread acceptance [5,10–13]. Energy technologies, even the particularly renewable and ecological ones, are very frequently met with opposition, which hinders their widespread acceptance [14,15]. Moving into the behavioral adoption stage, the energy transition requires an understanding of the elements that encourage the acceptability (i.e., positive attitude) and acceptance (i.e., adoption intention) of these energy technologies. It is therefore imperative that these renewable and sustainable energy technologies are accepted to complete this transition in a reasonable amount of time [16]. To this end, it is important to identify those variables that may initially facilitate (or discourage) the positive attitudes toward them (acceptability) and then the full range of positive intentions toward them (acceptance), up to the social implementation and diffusion of biofuels (i.e., their adoption).

2.1. Social acceptance definitions

Although interest in sustainable and renewable energy technologies has grown rapidly in recent years, a consensual univocal definition of their acceptance is still to be acquired: such a theoretical advancing step is needed to properly understand and address the acceptability, acceptance, and adoption of biofuels. These ideas fall within the broader category of what is referred to in the literature as "social acceptance".

There is neither a common interpretation of these constructs nor a consensus-based explicit and standardized operationalization of them; moreover, there are still very few systematic theoretical-conceptual integrated reflections on these notions (for an exception [17]). It is crucial to conceptually separate these constructs because their definitions are frequently overlapping or inconsistent [18]. The term "Acceptability" can be used to label the psychologically favorable orientation towards a given energy technology (in this case, biofuels). Thus, acceptability can be compared to the social-psychological concept of an attitude, which places a person along a continuum of negative-positive perceptual and evaluative states from biofuels social-psychological refusal up to their acceptability (implying both cognitive, affective, and behavioral features [18]).“Acceptance” refers to an intended positive behavioral response towards a specific energy technology (biofuels in this case). According to Wüstenhagen et al. [19] and Dessi et al. [5], this can be conceptualized and operationalized at least as a tripartite construct made up of i) the intention to endorse social-political support for biofuels; ii) the intention to use biofuels; and, finally, iii) the intention to purchase biofuels on the market by spending money (e.g., via a willingness to pay - WTP). Lastly, “Adoption” might be seen as the actual social diffusion of energy technology, in this case, biofuels. Utilizing biofuels can be a process that starts with a choice, is followed by the purchase of the specific energy technology, and ends with its habitual use [5,20].

2.2. Social acceptance determinants

It is important to study the determinants and the outcomes of these three concepts, which can be conceived, respectively, as the main independent and dependent variables. The determinants of acceptability can be either social-psychological features of the person (the adopter), as well as her/his beliefs about the energy technology to be accepted (biofuels) and about its context of acceptance (namely, the economy, the market, and the political-administrative conditions). Once acceptability is formed, it can operate as a motivating factor for particular intentions and actions, such as the intention to act in favor of biofuels, which is their acceptance, and the actual action in favor of them, which is their adoption [5,21].

Regarding acceptability and acceptance determinants, a qualitative study on biofuels [5] revealed a variety of beliefs that, respectively, fall into three categories.

1. The first category consists of the intrinsic technological aspects of the technology to be adopted, as perceived by the adopter (technological beliefs).
2. The second category consists of contextual factors as perceived by the adopter (i.e., features of the context where the adoption process happens), which are the adopter’s beliefs about the economics and the market, as well as about politics and the administrative system.
3. The third category relates to the adopter’s personal factors (both cognitive, affective, and social), i.e., the adopter’s self-beliefs regarding her/his own social-psychological features.

Other studies concerning the social acceptance of biofuels have shown that the main predictors of the acceptability and acceptance of this technology can be traced back to the three categories that emerged from the study by Dessi et al. [5]. Specifically, three recent studies have shown how variables pertaining to each of these categories can impact the social acceptance of biofuels. The study by Mouzaidis et al. [22] showed how contextual factors, particularly economic factors, play a crucial role in the social acceptability and acceptance of biofuels. In contrast, the study by Yin et al. [23] brought out the centrality of the characteristics related to the adopting person and his/her perceptions. Finally, the study by Baur et al. [24] pointed to technology characteristics as determinants of social acceptance in addition to contextual (economic) factors. Precisely, it was found that the impacts of biofuels on the environment significantly influence their social acceptance.

2.3. Theoretical models on renewable and sustainable technologies’ social acceptance

Devine-Wright [25] highlighted the need for systematic research on social acceptance, by making use of models that are created by combining psychological theories with those from other social sciences. To gain a deeper knowledge of the mechanisms driving any technology acceptance, Gaede and Rowlands’ work [26] also made evident the necessity for an interdisciplinary approach. As a result, numerous models have been created [27]. Some of them (social-psychological models) concentrate more on the adopter’s traits (i.e., only the third category in the tripartite beliefs taxonomy), whereas more interdisciplinary models concentrate on a wider variety of factors that are thought to predict attitude (acceptability), intention (acceptance), and behavior (adoption) criteria.

Social psychological models take into account only individual social-psychological traits that may influence how people perceive renewable and sustainable energy technologies and, consequently, how they will judge them. Among these models, the most studied in the field of energy technology acceptance are, for example, the norm activation model [28], the theory of planned behavior [29,30], the value-belief-norm theory [31], the motivational model [32] and the social representation theory [33].

Among the interdisciplinary models, complementing purely psychological constructs with theoretical elements from Sociology and Economics, the technology acceptance model [34] can be considered the first model to specifically analyze the acceptance of new technology. More recently, the SETA, sustainable energy technology acceptance model [21] is the first model to explain the acceptance of hydrogen refueling facilities by combining theories from social and environmental psychology: it includes variables adopted in the technology acceptance model and adds other variables, such as trust in suppliers, knowledge, perceived risk, values and emotional reactions to technology. The SETA model is one of the most comprehensive models for studying the acceptability and acceptance of renewable and sustainable energy technologies, combining established theories in social and environmental psychology such as the theory of planned behavior [29,30] and the norm activation model [28,35]. In addition to these models, there are other interdisciplinary models used in research to investigate the social acceptance of energy technologies, such as the unified theory of acceptance and use of technology [36] or the integrated acceptance and sustainability assessment model [37].

However, the majority of these models primarily highlight the significance of the social-psychological characteristics of the adopters, and there is not a single all-inclusive model that combines perceived technological, perceived contextual, and self-perceived personal characteristics (as independent variables) to explain the acceptability and acceptance (as dependent variables) of renewable and sustainable energy technologies.

Recently, the integrated sustainable energy technology adoption model (i-SETA [18]) has been proposed by building on the existing state of the art to include a wider range of determinants of renewable and sustainable energy technologies’ acceptability, acceptance, and adoption. Fig. 1 shows the various stages of the social acceptance process.

This model considers the independent variables in accordance with the SETA model [21] as well as with the qualitative study by Dessi et al. [5], which highlighted the social acceptance significance of the three different types of adopters’ beliefs previously described. Among the independent variables of the i-SETA model, over and above the self-perceived personal features of the adopter, there are also variables such as values (biospheric values), trust components (trust in policy makers and trust in technical scientifical actors), interest, and influence which, while excluded from the SETA model, may also contribute to sustainable energy technology adoption [38–41]. Additionally - if compared with the SETA model - the i-SETA model is composed of variables about two further different categories of beliefs, added as determinants of biofuels acceptability and acceptance. Specifically, the following variables were added.

- Contextual beliefs (economic-market and political-administrative), were investigated through the variables “costs savings” (savings due to the use of biofuels), “local socio-economic sustainability” (positive impact of biofuels use on the local economy), and “policy-making legitimation” (support from politicians towards biofuels);

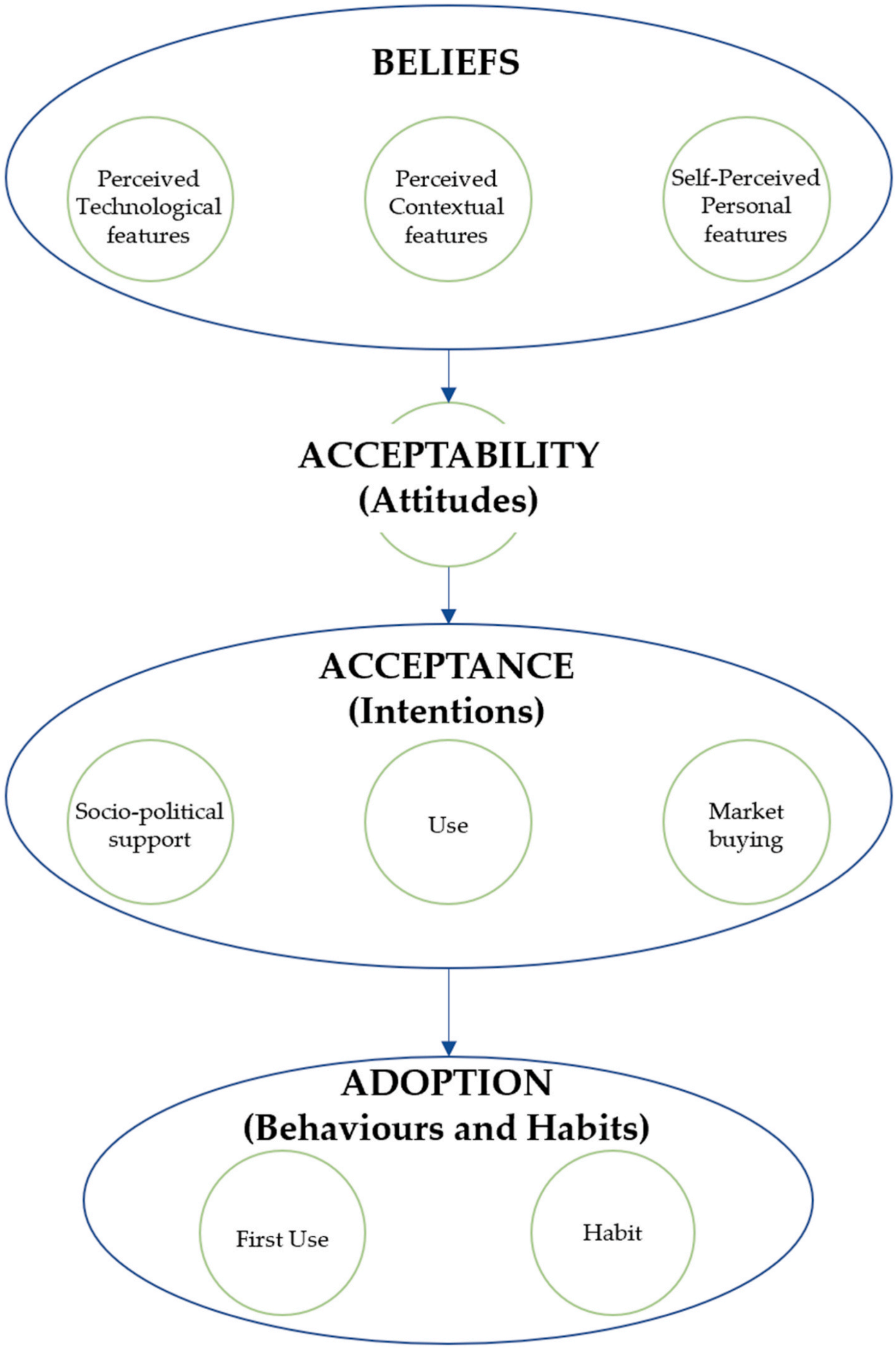

Fig. 1. The integrated sustainable energy technology adoption (i-SETA) model (adapted from Bonaiuto et al. [18]).

- Technological beliefs were investigated through the variables "emissions sustainability" (reduction of emissions through the use of biofuels), "technology compatibility" (compatibility of biofuels with present infrastructures), and "global environmental sustainability" (positive global environmental impact of biofuels).

Furthermore, following the acceptance tripartite idea proposed by Wüstenhagen et al. [19] and confirmed by Dessi et al. [5], Bonaiuto et al. [18], in an effort for theoretical alignment, relabeled the three main intentions considered as dependent variables: the intention to support as socio-political support; the intention to use as individual use across multiple domains (e.g. private car, airplanes, ships); the WTP (willingness to pay) as market buying intention. Finally, adoption encompasses both an initial, non-systematic use and a stable, habitual adoption; however, for the sake of this research, these last criteria are not estimated in the model tested, given the difficulty in empirically addressing it within a cross-sectional study.

The innovativeness of this research is therefore primarily related to the development of such a model, which aims to try to provide a tool that can be useful in explaining which social-psychological variables may have an impact on social acceptance (viewed as a tripartite construct [19]) of biofuels. This study then aims to solicit an advance in the literature on social acceptance of renewable and sustainable energy technologies. This model, indeed, should be replicated to generalize this interpretation of social acceptance to all renewable and sustainable energy technologies.

The i-SETA model will then be explained in its operational details in the following paragraphs.

3. Aims of the study

Based on the sustainable energy technology acceptance (SETA) model, this research develops a conceptual framework to investigate biofuel social acceptance within the European Union (EU), considering both the general public and the relevant expert stakeholders. The aim is to build a comprehensive model for biofuel social acceptance, to integrate not only traditional social-psychological variables referring to the adopter self-perception but also relevant perceived contextual variables and those regarding the intrinsic characteristics of the technology (e.g., from the point of view of the adopter). The integrated sustainable energy technology adoption (i-SETA) model is presented by building on the empirical outcomes of Dessi et al. [5] and Ariccio et al. [42], thus including perceived technology features, perceived contextual (both market and politics) features, and self-perceived personal features. Thus, the main objective of the study is to propose an important integration of one of the most widely used models in the context of technological innovation (SETA). Besides being the main objective of the study, this also turns out to be the main source of innovativeness of the study, which aims to propose a new, empirically tested, theoretical model.

3.1. Specific aims are as follows

1. Verifying the reliability of the ad hoc created measures specifically related to biofuels social acceptance, namely, the biofuels beliefs scale (BBS, as already tested in Ariccio et al. [42]); the biofuels attitude scale as acceptability (BASA), tested here for the first time; the biofuels intention scale as acceptance (BISA), tested here for the first time, which includes both socio-political support intention and use intention; the biofuels market buying intention simply operationalized in terms of WTP; and finally, the biofuels objective knowledge scale (BOKS) tested here for the first time.
2. Testing the i-SETA model of biofuels' social acceptance in a mixed sample of both the general public and stakeholders.
3. Detecting the impact of perceived technology characteristics and contextual factors (BBS) in the process of biofuel social acceptance in terms of both acceptability (BASA) and acceptance (BISA).
4. Comparing the i-SETA model with the SETA model, hypothesizing that the i-SETA shows a higher overall explained variance compared to the SETA.

4. Method

4.1. Participants

The sample consisted of 1017 participants (mean age = 32.49, sd = 11.50) from 8 European countries. Concerning gender, the sample consisted of 419 women (41.2 %) and 598 men (58.8 %). Regarding the participants' nationality, 100 are from Belgium, 154 are from France, 154 are from Germany, 152 are from Italy, 101 are from the Netherlands, 101 are from Sweden, 103 are from Norway, and 152 are from the United Kingdom. The sample has a high educational level and comes from a variety of fields of study ranging from Science, Technology, Engineering, and Mathematics disciplines to Social Sciences and Humanities. In addition, employed participants work in different organizations (Small and Medium Eenterprises, Large Companies, Governmental Organizations, Academies and Research Centers, and Non Governmental Organizations). Sampling covered both the general public and expert stakeholders. Expert stakeholders were selected as belonging to professional categories that are relevant to biofuels, on the basis of a previous mapping study within the same project [43]. Sampling features correspond to relevant criteria requested by the funded research project, to map different EU geographical areas, as well as different stakeholder categories (see also Ariccio et al. [42]).

4.2. Procedure

The survey instrument used in this quantitative study is a self-administered questionnaire (shown in its full version in Appendix 1). For recruiting general public participants from the eight considered countries, the English version of the questionnaire was used via the Prolific platform (https://www.prolific.co/), where users are paid to fill in surveys. Whereas for recruiting stakeholders in the biofuels sector from four different large European countries (Italy, United Kingdoms, Germany, and France), Qualtrics' Online Panel service was employed: to ease participation from stakeholders of the four selected countries, the questionnaire, originally developed in English, was translated into Italian, French, and German. Quality check questions and enforced screening criteria were used at the beginning of the survey so that respondents who did not match the target stakeholders could be excluded at an early stage. This study was submitted to the Ethics Committee of the Department of Psychology of Developmental and Socialization Processes, Sapienza University of Rome (Italy), (submitted April 28, 2021, final approval May 27, 2021, Protocol n. 742, Pos. VII/15).

4.3. Tools

A questionnaire was developed on the basis of both several tools previously used in research and the results emerging from the qualitative study of Dessi et al. [5]. Thus, the items that compose the measured dimensions were either extracted from previously published scales (and then adapted to this study object) or created ex-novo for this investigation. Specifically, the following measures were used.

Biofuels beliefs scale (BBS, Ariccio et al. [42]). The scale is composed of 26 items measuring the beliefs that may be relevant to drive people's attitudes toward biofuels (i.e., biofuels acceptability). The items were measured via a 7-point Likert response scale, from 1 = "strongly disagree" to 7 = "strongly agree". The scale includes six sub-dimensions, of which the first is about the political-administrative context, the second and third are about the economic-market context, and the last three are about the specific energy technology features. More specifically, such sub-dimensions are 1. Policy making legitimation, composed of 7 items (e.g.: "The government should provide more financial support to researchers and industries in developing biofuels"), $\alpha = 0.86$; 2. Cost savings, composed of 3 items (e.g.: "Biofuels costs could lead to an increase in transportation-related costs"), $\alpha = 0.64$; 3. Local socio-economic sustainability, composed of 3 items (e.g.: "Growing biofuel plants reduces the quality of life in local communities"), $\alpha = 0.72$; 4. Global environmental sustainability, composed of 6 items (e.g.: "Biofuels production threatens plants and wildlife"), $\alpha = 0.80$; 5. Emissions Sustainability, composed of 4 items (e.g.: "Biofuels burn cleaner than fossil fuels"), $\alpha = 0.80$, 6. Technology compatibility, composed of 3 items (e.g.: "Biofuel-based distribution system is compatible with the fossil fuel-based one"), $\alpha = 0.76$.

Biofuels objective knowledge scale (BOKS, ad hoc measure adapted from Puricelli et al. [44]). To explore subjects' objective knowledge about biofuels, some items were either extracted and adapted from the study by Puricelli et al. [44] or created *ex-novo* together with technical members of the European EC H2020 project ABC-Salt to test for their validity and complexity. The scale is composed of 10 items, with a 5-point Likert response scale, from 1 = "strongly disagree" to 5 = "strongly agree" (e.g.: "Biomethane produced from biomass is a sustainable alternative for feeding compressed natural gas vehicles"), $\alpha = 0.62$.

Fairness [21]. The scale is composed of 8 items, with a 7-point Likert response scale, from 1 = "strongly disagree" to 7 = "strongly agree" (e.g.: "In the decision-making process on biofuels, the public's views are sufficiently taken into account") and measures the evaluation of a specific technology based on the perception of fairness of the various decision-making processes involved in its implementation, $\alpha = 0.75$.

Trust in scientific actors [45]. The scale is composed of 2 items with a 7-point Likert response scale, from 1 = "strongly disagree" to 7 = "strongly agree" (e.g.: "Scientists have done a good job in biofuel development") and measures the beliefs that scientists and producers have properly worked in biofuel development, $r = 0.62$.

Trust in policy-makers [45]. The scale is composed of 2 items with a 7-point Likert response scale, from 1 = "strongly disagree" to 7 = "strongly agree" (e.g.: "Non Governative Organizations and associations have done a poor job in biofuel development") and measures the beliefs that policymakers have properly worked in biofuel development, $r = 0.49$.

Modified differential emotions scale (adapted from Conte et al. [46]). To understand the type of feelings elicited when thinking about biofuels, 22 items were adapted from Conte et al. [46] by inserting "biofuels" within each question, as the original version did not propose questions related to the topic. The items were rated on a 4-point Likert response scale, from 1 = "strongly disagree" to 4 = "strongly agree", measuring emotionality toward biofuels in terms both positive (e.g.: "How joyful, content or happy do you feel about biofuels?"), $\alpha = 0.93$, and negative emotions (e.g.: "How much disgust, aversion, or revulsion do you feel about biofuels?"), $\alpha = 0.93$.

Outcome efficacy [21]. The scale is composed of 4 items (e.g.: "Biofuels are useful"), with a 7-point Likert response scale, from 1 = "strongly disagree" to 7 = "strongly agree". Outcome efficacy refers to the extent to which solutions to a problem can be found and thus, in this specific case, it concerns both the likelihood that biofuels will reduce energy problems and the extent to which a person thinks that pro- or anti-biofuel behavior will influence their implementation, $\alpha = 0.62$.

Social norms [47]. The scale is composed of 6 items, with a 7-point Likert response scale, from 1 = "strongly disagree" to 7 = "strongly agree", and measures both descriptive (e.g.: "Most of my fellow citizens are in favor of biofuel") and injunctive norms (e.g.: "Most of the people important to me think that I should be in favor of biofuels"), $\alpha = 0.90$.

Personal norms [47]. The scale is composed of 3 items, with a 7-point Likert response scale, from 1 = "strongly disagree" to 7 = "strongly agree" and measures the moral obligation to act for biofuel implementation (e.g.: "I feel guilty if I do not act in favor of biofuel"), $\alpha = 0.83$.

Biospheric values [39]. The scale is composed of 4 items, with a 9-point Likert response scale, from 1 = "strongly disagree" to 9 = "strongly agree" and measures those values that take into account the beneficial properties of the environment, $\alpha = 0.92$.

Biofuels attitude scale as acceptability *(*BASA*,* ad hoc measure adapted from Zaunbrecher et al. [48]). A semantic differential was used to measure the Attitude towards biofuels consisting of 16 adjective pairs (e.g., "I think that biofuel technology is: alien/familiar; harmful/safe"), with a 7-step Likert response scale. A principal component analysis showed the distinctiveness of the following two factors: 1. Positive attitude toward biofuels ($\alpha = 0.94$) and biofuels usability ($\alpha = 0.68$). In this study, the total score was considered, $\alpha = 0.91$, for model parsimony reasons.

Market buying intention as WTP (ad hoc measure adapted from Lanzini et al. [49]). The willingness to pay (WTP) was measured with the following item: "Between the following options, please state the maximum premium price you would accept to pay (per liter) to purchase biofuels derived from renewable sources instead of traditional, fossil-based fuels". The response includes options from 0.00 euro to 0.20 euro, with intervals of 1 euro cent (this has been adapted from the previously existing version to match the specific context and content in terms of realistic market buying intention).

Biofuels intention scale as acceptance (BISA ad hoc measure). The scale is composed of 11 items measuring people's intentions toward biofuels, i.e., their acceptance. A principal component analysis showed the distinctiveness of the following two factors.

1. Use intention *(*ad hoc measure derived and adapted from Dessì et al. [5]). The factor is composed of 5 items (e.g., "How willing would you be to fuel your private vehicle with biofuels?"), with response options on a 7-step Likert scale, ranging from 1 = "Very unwilling" to 7 = "Very willing", with the added "Not applicable" option, $\alpha = 0.90$.
2. Socio-political support intention (derived and adapted from Huijts et al. [50]). The factor is composed of 6 items, related to the following question: "If there was a discussion in your area about whether or not to place a biofuel station, how likely would you be to take the following actions in favor or against it" (examples of actions were: Sign a petition; Make a donation). For each action, the response had to be provided on a 7-step Likert scale, from 1 = "I would certainly do not do this" to 7 = "I would certainly do this", $\alpha = 0.84$.

4.4. Data analysis

To verify the reliability of the ad hoc measures specifically related to biofuel acceptance (Aim 1), a principal components analysis with Promax rotation with Kaiser normalization was performed on the biofuels intention scale as acceptance (BISA), on the biofuels objective knowledge scale (BOKS), and the biofuels attitude scale as acceptability (BASA). Tables 1–3 show the factor loadings of individual items. Scree plots were also used to confirm the expected number of factors and the factorial loading of each item in the expected component (i.e., subscale). Then, descriptive statistics were calculated for all the variables, as shown in Table 4, to verify the normality of their distribution. Bivariate correlation analyses were performed to test the relationships between the variables (Aim 1). In Table 5 these Pearson's correlation are shown. A path analysis was then conducted to test the i-SETA model of biofuel acceptance (Aim 2). For detecting the impact of perceived technology characteristics and contextual factors in the process of biofuel social acceptance (Aim 3), the average extracted variance of the sub-factors of the BBS on the considered outcomes (BASA and BISA) was computed. Finally, the goodness of fit measures and the average explained variance of the SETA and i-SETA models were compared (Aim 4). All models were verified through the AMOS 22 software [51], using the maximum likelihood method to estimate model parameters with the calculation of standard errors based on the observed information matrix. Nationality and gender were added as covariates, controlling for their influence in the relationship between all the variables in the model. The initial model included the expected unidirectional arrows among the latent factors. To increase the models' fit during the step-by-step improvement process, non-significant parameters were eliminated, and new parameters were added, considering those modification indexes suggested by the Lagrange Multiplier Test [52] that were theoretically justifiable. The significance of the $\chi 2$ value was not considered for assessing the overall fit of the models (see Marsh et al. [53], for a detailed account of its weak reliability), whilst it was considered the more reliable ratio between $\chi 2$

Table 1
BOKS (biofuels objective knowledge scale).

Items	
In 2018, about 5–10 % of the diesel produced in the EU consisted of biodiesel	0.64
B10 is a blend of diesel with hydrotreated vegetable oils (HVO)	0.62
About 12–15 % of biofuels in the EU were produced in Spain in 2017	0.61
Scientifically, bioethanol is currently and commonly divided into three generations based on the feedstock used	0.60
The 'biomass fuels' are gaseous and solid fuels produced from biomass	0.59
Production costs for biofuels are similar for fossil fuels	0.59
Biomethane produced from biomass is a sustainable alternative for feeding compressed natural gas vehicles	0.52
Advanced biofuels are those fuels, not belonging to first-generation biofuels, that are produced from edible feedstocks	0.50
Bioethanol is blended with petrol in spark-ignition engines due to EU legislation	0.49
Biofuel can be produced from cooking oil	0.42

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Table 2
BASA (biofuels attitude scale as acceptability).

Items	Factor 1	Factor 2
	PAB	BU
I think that biofuel technology is: positive	0.88	
I think that biofuel technology is: acceptable	0.86	
I think that biofuel technology is: beneficial	0.85	
I think that biofuel technology is: morally right	0.83	
I think that biofuel technology is: necessary	0.82	
I think that biofuel technology is: effective	0.73	
I think that biofuel technology is: clean	0.73	
I think that biofuel technology is: pleasant	0.72	
I think that biofuel technology is: attractive	0.71	
I think that biofuel technology is: modern	0.66	
I think that biofuel technology is: safe	0.65	
I think that biofuel technology is: natural	0.63	
I think that biofuel technology is: simple		0.83
I think that biofuel technology is: inexpensive		0.75
I think that biofuel technology is: familiar		0.67
I think that biofuel technology is: mature		0.47

Table 3
BISA (biofuels intention scale as acceptance).

Items	Factor 1	Factor 2
	UI	SPSI
How willing would you be to take public transportation (e.g., bus, taxi) fuelled with biofuels?	0.91	
How willing would you be to travel on a cruise/ferry ship fuelled with biofuels?	0.87	
How willing would you be to fly on an aircraft fuelled with biofuels?	0.86	
How willing would you be to take a train fuelled with biofuels?	0.84	
How willing would you be to fuel a private vehicle with biofuels?	0.74	
Write a letter to a newspaper or magazine		0.87
Speak up at a public meeting		0.84
Participate in a demonstration or public event		0.81
Make a donation		0.76
Sign a petition		0.54
Vote for a party in the local elections that shares one's opinion on this topic		0.52

Note: UI: use intention, SPSI: socio-political support intention

and degrees of freedom (being under 3, the threshold acceptability according to McIver & Carmines [54]). Other indices were also considered to have a more comprehensive evaluation [55], for instance, the comparative fit index (CFI) and the Tucker-Lewis index (TLI), that compare the factor models fit of a baseline model in which all observed variables are expected to be uncorrelated. CFI and TLI >0.90 indicate an acceptable fit, while values > 0.95 indicate a good fit. The standardized root means square residual (SRMR) is a residual-based statistic for which values less than 0.10 and 0.05 are considered respectively acceptable and as a good fit. The root means square error of approximation (RMSEA) measures the difference between the model-implied covariance matrix and the population matrix to control sampling variability. RMSEA values of 0.05 or less indicate a close fit, and values up to .08 represent a reasonable error of approximation. The Akaike information criterion (AIC [56,57]) was also considered because it adjusts $\chi 2$ for the number of estimated parameters and can be used to compare competing models that are not nested, as in our case. For ease of interpretation, adjusted R^2 values were estimated for each model.

Table 4
Descriptive statistics, skewness, and kurtosis, on all the variables' model.

	Min	Max	Mean	SD	Skewness	Kurtosis
Objective knowledge	1.27	5.00	3.33	0.41	0.72	2.67
Trust in policy makers	1.00	7.00	4.20	1.11	−0.16	0.85
Trust in technical scientifical actors	1.00	7.00	4.86	1.09	−0.49	0.48
Fairness	1.00	6.88	4.13	0.87	0.09	0.65
Costs savings	1.00	7.00	3.20	1.45	0.23	−0.77
Local socio-economic sustainability	1.00	7.00	3.65	1.01	0.03	0.74
Policy-making legitimation	1.29	7.00	5.37	0.91	−0.72	0.98
Emissions sustainability	1.25	7.00	5.01	1.01	−0.55	0.51
Technology compatibility	1.00	7.00	4.51	1.05	−0.12	0.48
Global environmental sustainability	1.00	7.00	3.89	1.10	−0.01	0.09
Positive emotions	1.00	4.00	2.21	0.72	0.25	−0.69
Negative emotions	1.00	4.00	1.35	0.52	2.22	5.07
Outcome efficacy	1.25	7.00	4.95	0.85	0.09	0.37
Biospheric values	1.75	9.00	7.66	1.38	−1.23	1.41
Social norms	1.00	7.00	4.41	1.01	−0.34	0.88
Personal norm	1.00	7.00	3.91	1.39	−0.18	−0.47
Technology acceptability	1.93	7.00	5.02	0.79	−0.44	0.47
Use intention	1.00	8.00	6.68	1.09	−1.35	2.59
Socio-political support intention	1.00	5.00	2.66	0.87	0.29	−0.27
Market buying intention	0.00	23.00	12.52	6.13	−0.30	−0.59

5. Results

5.1. Verifying the reliability of the ad hoc created measures (aim 1)

5.1.1. Principal component analysis of the BOKS, the BASA, and the BISA

BOKS: The Kaiser–Meyer–Olkin sampling adequacy measure attained fairly high values (=0.81), demonstrating that commonalities were high, and the correlation matrix of the sample was appropriate for the analysis to proceed [58]. It yielded a one-factor solution explaining 31.84 % of the variance as emerged in Table 1, labeled as biofuel objective knowledge.

BASA: The Kaiser–Meyer–Olkin sampling adequacy measure attained fairly high values (=0.91). It yielded a two-factor solution explaining 58.29 % of the variance as shown in Table 2. The biofuel attitude scale as acceptability factors were provisionally labeled 1. Positive attitude toward biofuels (PAB, $\alpha = 0.94$), 2. Biofuels usability (BU, $\alpha = 0.68$). In this study, the total score was used to test a more parsimonious model, considering the large number of variables investigated.

BISA: The Kaiser–Meyer–Olkin sampling adequacy measure attained fairly high values (=0.87), demonstrating that commonalities were high, and the correlation matrix of the sample was appropriate for the analysis to proceed [58]. It yielded a two-factor solution explaining 64.7 % of the variance as highlighted by Table 3. The factors were labeled use intention (UI, $\alpha = 0.90$) and socio-political support intention (SPSI, $\alpha = 0.84$).

Tables 1–3. Factor analysis of the BOKS (1), BASA (2), and BISA (3).

5.1.2. Descriptive statistics and correlations

To analyze the normality of the distribution of the variables examined, as well as to investigate any multicollinearity among the variables present in the model, descriptive statistics were conducted and linear correlations (Pearson's r) among the variables were investigated. Results of descriptive analyses and the correlation matrix are reported respectively in Tables 4 and 5

The analyses showed that the variables assume a tendentially normal distribution and there is no multicollinearity among the variables ($r <$

Table 5
Variables' correlation matrix (Pearson's *r*).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Objective knowledge	1																			
Trust in policy makers	−.02	1																		
Trust in technical scientifical actors	.28**	.11**	1																	
Fairness	.31**	.05	.49**	1																
Costs savings	.31**	−.06*	.11**	.19**	1															
Local socio-economic sustainability	.11**	−.09**	−.13**	−.01	.16**	1														
Policy-making legitimation	.24**	−.04	.34**	.27**	.11**	.26**	1													
Emissions sustainability	.28**	−.04	.41**	.38**	.11**	.24**	.51**	1												
Technology compatibility	.37**	.01	.17**	.20**	.06*	.04	.16**	.16**	1											
Global environmental sustainability	.02	−.12**	−.24**	−.20**	.17**	.51**	−.26**	−.43**	.05	1										
Positive emotions	.38**	.02	.40**	.48**	.23**	.07*	.40**	.43**	.15**	.32**	1									
Negative emotions	.22**	−.18**	−.08*	.13**	.27**	−.40**	−.21**	−.13**	.06	−.33**	.26**	1								
Outcome efficacy	.16**	.08**	.38**	.21**	.06	.30**	.41**	.43**	.12**	.33**	.34**	−.27**	1							
Biospheric values	.07*	.05	.09**	.09**	−.05	.01	.19**	.12**	.02	.06	.20**	−.08*	.16**	1						
Social norms	.31**	−.02	.42**	.48**	.14**	.13**	.35**	.41**	.20**	.26**	.45**	.02	.32**	.07*	1					
Personal norm	.31**	−.01	.36**	.51**	.14**	.10	.37**	.41**	.14**	.27**	.54**	.10**	.28**	.19**	.49**	1				
Technology acceptability	.34**	.03	.56**	.49**	.08*	.29**	.56**	.64**	.25**	.46**	.58**	−.21**	.54**	.18**	.53**	.51**	1			
Use intention	.14**	.01	.32**	.21**	.03	.29**	.48**	.38**	.10**	.26**	.28**	−.31**	.41**	.22**	.33**	.27**	.56**	1		
Socio-political support intention	.37**	−.01	.34**	.42**	.19**	.04	.38**	.37**	.19**	.18**	.57**	.16**	.26**	.27**	.42**	.53**	.49**	.25**	1	
Market buying intention	−.03	−.03	.08**	.13**	−.04	.10**	.21**	.19**	−.06	.16**	.10**	−.08**	.09**	.16**	.05	.13**	.19**	.20**	.15**	1

Note: $^{**}p < .01$; $^{*}p < .05$.
Objective knowledge[1]; Trust in policy makers[2]; Trust in technical scientifical actors[3]; Fairness[4]; Costs savings[5]; Local socio-economic sustainability[6]; Policy-making legitimation[7]; Emissions sustainability[8]; Technology compatibility[9]; Global environmental sustainability[10]; Positive emotions[11]; Negative emotions[12]; Outcome efficacy[13]; Biospheric values[14]; Social norms[15]; Personal norm[16]; Technology acceptability[17]; Use intention[18]; Socio-political support intention[19]; Market buying Intention.[20].

0.70).

5.2. *Testing the i-SETA model of biofuels' acceptance and detecting the impact of perceived technology characteristics and contextual factors (BBS) in the process of biofuels' social acceptance in terms of acceptability (BASA) and acceptance (BISA) (aim 2 and 3)*

In testing Aim 2, the i-SETA model yielded optimal fit indices, including the $\chi 2/\text{df}$ ratio, as shown in Fig. 2. Looking at the structural coefficients, in testing Aim 3, it emerges that use intention is predicted positively by technology acceptability ($\beta = 0.39$, $p < .001$), policy making legitimation ($\beta = 0.21$, $p < .001$), and biospheric values ($\beta = 0.10$, $p < .001$), and negatively by negative emotions ($\beta = -0.17$, $p < .001$).

As concerns socio-political support intention, it is predicted positively by personal norms ($\beta = 0.23$, $p < .001$), technology acceptability ($\beta = 0.20$, $p < .001$), negative emotions ($\beta = 0.19$, $p < .001$), biospheric values ($\beta = 0.16$, $p < .001$), policy making legitimation ($\beta = 0.14$, $p < .001$), objective knowledge ($\beta = 0.11$, $p < .001$) and fairness ($\beta = 0.10$, $p < .001$).

Market buying intention is predicted positively by technology acceptability ($\beta = 0.13$, $p < .001$), biospheric values ($\beta = 0.11$, $p < .001$), and emission sustainability ($\beta = 0.11$, $p < .001$), and negatively by technology compatibility ($\beta = -0.10$, $p < .001$).

Technology acceptability is predicted positively by positive emotions ($\beta = 0.28$, $p < .001$), emissions sustainability ($\beta = 0.24$, $p < .001$), trust in technical scientific actors ($\beta = 0.14$, $p < .001$), outcome efficacy ($\beta = 0.13$, $p < .001$), social norms ($\beta = 0.12$, $p < .001$), fairness ($\beta = 0.11$, $p < .001$), objective knowledge ($\beta = 0.08$, $p < .001$) and global environmental sustainability ($\beta = 0.07$, $p < .001$), and negatively by negative emotions ($\beta = -0.23$, $p < .001$).

As regards personal norm, it is positively predicted by positive emotions ($\beta = 0.32$, $p < .001$), fairness ($\beta = 0.24$, $p < .001$), social norms ($\beta = 0.23$, $p < .001$), and biospheric values ($\beta = 0.07$, $p < .001$).

About emotions, positive emotions are positively predicted by fairness ($\beta = 0.21$, $p < .001$), policy making legitimation ($\beta = 0.14$, $p < .001$), emissions sustainability ($\beta = 0.14$, $p < .001$), objective knowledge ($\beta = 0.14$, p $< .001$), biospheric values ($\beta = 0.14$, $p < .001$), social norms ($\beta = 0.11$, $p < .001$) and costs savings ($\beta = 0.09$, $p < .001$).

Negative emotions are negatively predicted by local socio-economic sustainability ($\beta = -0.22$, $p < .001$), outcome efficacy ($\beta = -0.20$, $p < .001$), global environmental sustainability ($\beta = -0.14$, $p < .001$), and positively by cost savings ($\beta = 0.15$, $p < .001$), objective knowledge ($\beta = 0.14$, $p < .001$), trust in policy makers ($\beta = 0.13$, $p < .001$) and fairness ($\beta = 0.13$, $p < .001$).

Finally, outcome efficacy is predicted positively by policy making legitimation ($\beta = 0.21$, $p < .001$), trust in technical scientific actors ($\beta = 0.19$, $p < .001$), emissions sustainability ($\beta = 0.18$, $p < .001$), local socio-economic sustainability ($\beta = 0.13$, $p < .001$), global environmental sustainability ($\beta = 0.08$, $p < .001$), and trust in policy makers ($\beta = 0.06$, $p < .001$).

Concerning the role of the covariate nationality, it showed an impact on community use intention ($\beta = 0.06$, $p < .001$), socio-political support intention ($\beta = 0.05$, $p < .001$), and outcome efficacy ($\beta = 0.07$, $p < .001$).

Concerning the role of the covariate gender, it had an impact on positive emotions ($\beta = 0.10$, $p < .001$), technology acceptability ($\beta = 0.05$, $p < .001$), personal norm ($\beta = -0.11$, $p < .001$) and market buying intention ($\beta = -0.11$, $p < .001$).

5.3. *Model comparison (aim 4)*

The SETA model yielded good fit indices, as highlighted in Fig. 3. Looking at the structural coefficients linking the endogenous and the exogenous variables, the following paths emerged as significant.

Use intention is predicted by technology acceptability ($\beta = 0.49$, $p < .001$) and biospheric values ($\beta = 0.12$, $p < .001$) in positive terms, and by

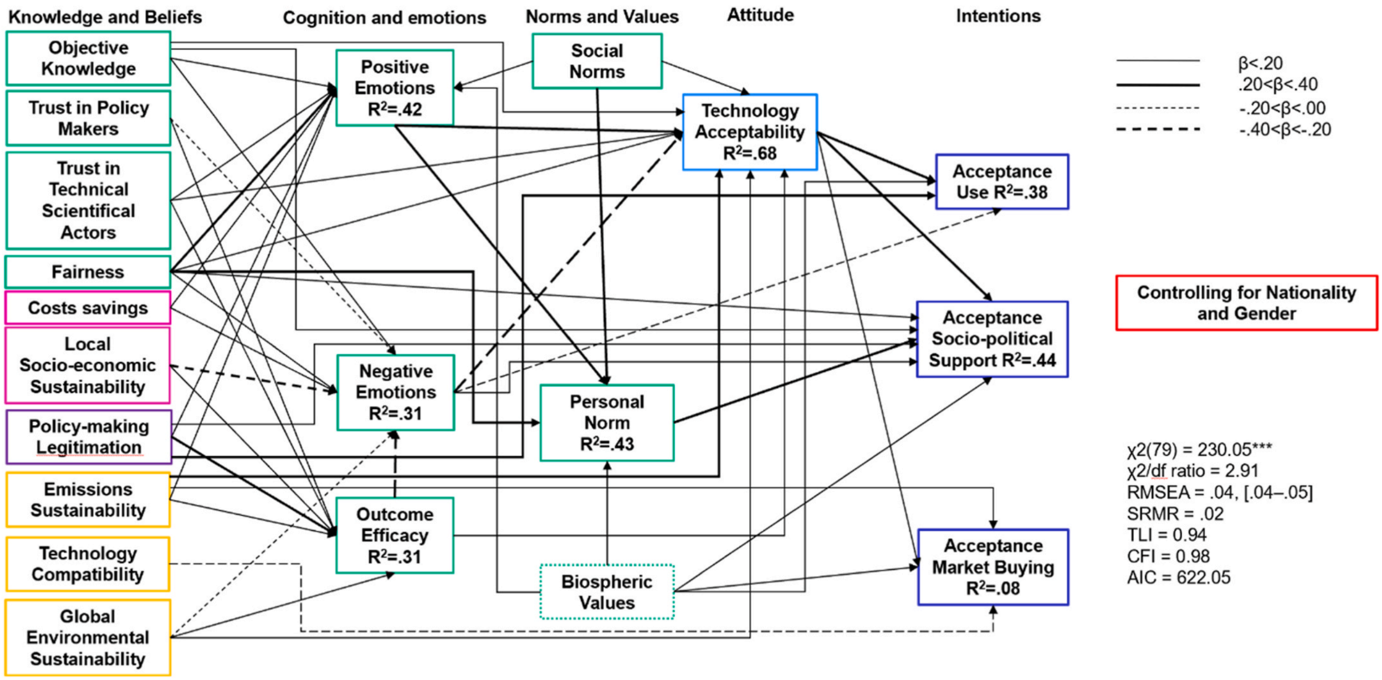

Fig. 2. Path diagram of the i-SETA (integrated sustainable energy technology adoption) model – N = 1017
Notes. Significant pathways of the i-SETA model. Statistically significant and positive relationships are indicated with a solid arrow while significant, and negative relationships are marked with a dashed arrow. Arrow size thresholds: Coefficients between 0 and 0.2 = 0.75 dpi; Coefficients between 0.2 and 0.4 = 1.5 dpi; Coefficients over 0.4 = 6.3 dpi.

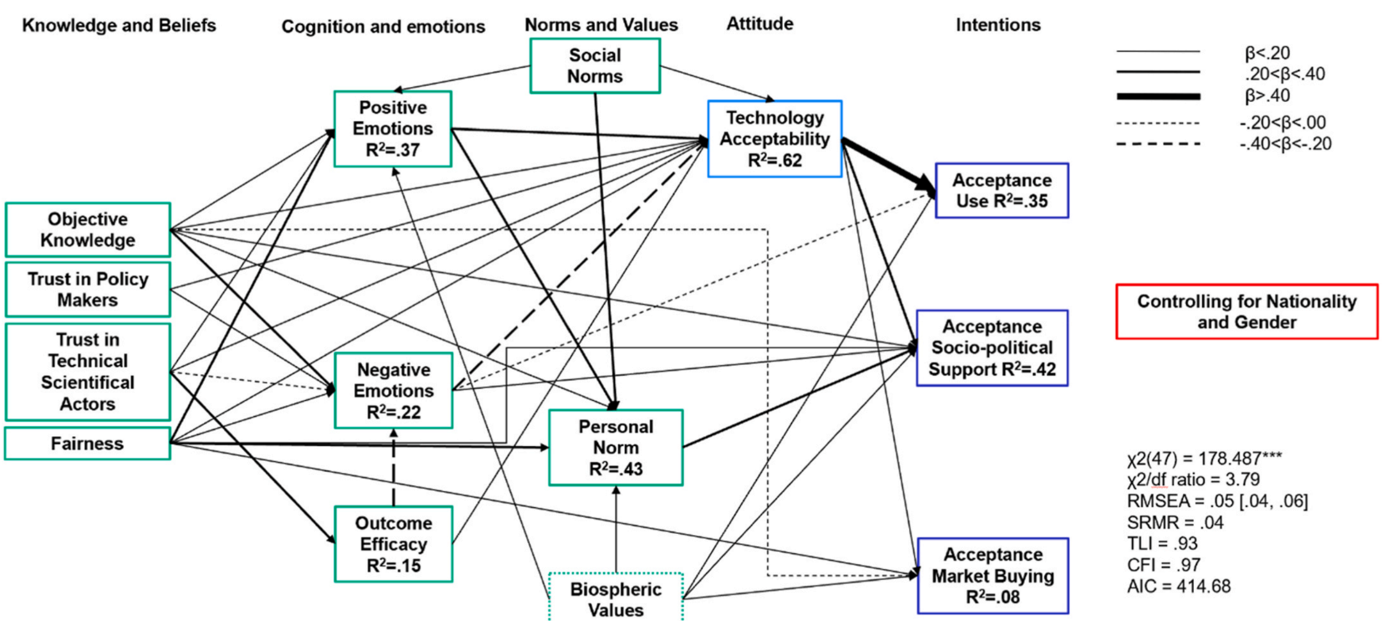

Fig. 3. Path diagram of the SETA (sustainable energy technology acceptance) model – N = 1017
Notes. Significant pathways of the SETA model. Statistically significant and positive relationships are indicated with a solid arrow while significant, and negative relationships are marked with a dashed arrow. Arrow size thresholds: Coefficients between 0 and 0.2 = 0.75 dpi; Coefficients between 0.2 and 0.4 = 1.5 dpi; Coefficients over 0.4 = 6.3 dpi.

negative emotions ($\beta = -0.19$, $p < .001$) in negative terms.

Socio-political support intention is positively predicted by personal norm ($\beta = 0.24$, $p < .001$), technology acceptability ($\beta = 0.22$, $p < .001$), biospheric values ($\beta = 0.18$, $p < .001$), objective knowledge ($\beta = 0.14$, $p < .001$) and fairness ($\beta = 0.11$, $p < .001$).

Finally, market buying intention is positively predicted by technology acceptability ($\beta = 0.17$, $p < .001$), biospheric values ($\beta = 0.12$, $p < .001$), and fairness ($\beta = 0.07$, $p < .001$), and negatively by objective knowledge ($\beta = -0.11$, $p < .001$).

Considering the antecedents of the outcomes, it can be seen that technology acceptability is positively predicted by positive emotions ($\beta = 0.37$, $p < .001$), outcome efficacy ($\beta = 0.19$, $p < .001$), trust in technical scientifical actors ($\beta = 0.17$, $p < .001$), social norms ($\beta = 0.15$, $p < .001$) and fairness ($\beta = 0.14$, $p < .001$), whereas it is negatively predicted by negative emotions ($\beta = -0.32$, $p < .001$).

As regards personal norm, it is positively predicted by positive emotions ($\beta = 0.30, p < .001$), social norms ($\beta = 0.23, p < .001$), fairness ($\beta = 0.23, p < .001$), biospheric values ($\beta = 0.07, p < .001$) and objective knowledge ($\beta = 0.06$, $p < .001$).

About emotions, positive emotions are positively predicted by fairness ($\beta = 0.25$, $p < .001$), objective knowledge ($\beta = 0.19$, $p < .001$), social norms ($\beta = 0.18, p < .001$), biospheric values ($\beta = 0.16, p < .001$) and trust in technical scientifical actors ($\beta = 0.13$, $p < .001$), whilst negative emotions are predicted by objective knowledge ($\beta = 0.25$, $p < .001$) and trust in policy makers ($\beta = 0.15$, $p < .001$) in positive terms, and by outcome efficacy ($\beta = -0.34$, $p < .001$) and trust in technical scientifical actors ($\beta = -0.09, p < .001$) in negative terms.

Finally, outcome efficacy is positively predicted only by trust in technical scientifical actors ($\beta = 0.38$, $p < .001$).

Concerning the role of the covariate nationality, it affected outcome efficacy ($\beta = 0.10$, $p < .001$) and use intention ($\beta = 0.05$, $p < .001$).

Concerning the role of the covariate gender, it had an impact on positive emotions ($\beta = 0.09$, $p < .001$), personal norm ($\beta = -0.11$, $p < .001$), and market buying intention ($\beta = -0.12$, $p < .001$).

The model comparison shows that the i-SETA has a higher overall explained variance than the SETA. Table 6 shows how the i-SETA also presents better-fit indices than the SETA.

The SETA model accounts for an acceptable proportion of variance of the three outcome variables, i.e., the biofuels acceptance intentions related to use, socio-political support, and market buying (35 %, 42 %, and 8 % of the accounted variance, respectively); and for a high proportion of variance of its main direct antecedent, i.e., technology acceptability (62 % of accounted variance). The SETA model also explains an acceptable proportion of variance of the personal norm (43 % of accounted variance), positive emotions (37 % of accounted variance), negative emotions (22 % of accounted variance), and outcome efficacy (15 % of accounted variance).

Concerning the i-SETA model, it explains a good proportion of variance of the three biofuels acceptance variables, i.e., community use, socio-political support, and market buying (38 %, 44 %, and 8 % of the accounted variance, respectively), and a high proportion of variance of its main direct antecedent, i.e., technology acceptability (68 % of accounted variance). The i-SETA model also accounts for an acceptable proportion of variance of the personal norm (43 % of accounted variance), positive emotions (42 % of accounted variance), negative emotions (31 % of accounted variance), and outcome efficacy (31 % of accounted variance).

In conclusion, it can be stated that i-SETA outperforms SETA considering the overall explained variance, with the most remarkable improvement (+100 %) in the explained variance for the perception of the outcome efficacy, and small improvements (from +2 % up to +9 %) in five of the other variables (intention to use, intention of socio-political support, technology acceptability, positive emotions, and negative emotions), with no improvements (+0 %) in only two variables (market buying intention and personal norm).

6. Discussion

Based on the integrated sustainable energy technology acceptance (i-SETA) model, this research develops a conceptual framework to investigate biofuel acceptance by the EU general public and expert stakeholders. This study, to the authors' knowledge, is the first one to propose an integrated model that encompasses all contextual, technological, and social-psychological factors for the study of biofuel acceptance.

New scales to measure acceptability, acceptance, and objective knowledge (i.e., BASA, BISA, and BOKS, respectively) were tested and most of them had optimal reliability indices (Aim 1).

The optimal psychometric properties of the ad hoc built scales allowed us to investigate their relationship via path analysis, showing the relevance of biofuels' beliefs in directly favoring both attitudes and intentions (acceptability and acceptance).

In testing Aim 2, i.e., testing the i-SETA model in a mixed sample of the general public and expert stakeholders, the model had optimal fit indices and explained a good proportion of variance of the outcome variables investigated.

Concerning social-psychological variables, analyzed in previous studies [50], great emphasis has been placed on beliefs related to the adopter's social-psychological characteristics.

Regarding the two bases of trust, namely, trust in scientific actors and trust in policy makers, it is found that the former had a positive impact on both outcome efficacy, positive emotions toward biofuels, and technology acceptability, while the latter had a negative impact on negative emotions. As the original model [21] and other studies have shown, trust in the actors responsible for the technology directly influenced positive and negative emotions as well as the perceived risks and benefits of the technology [59–62]. Trust in scientific actors also led to a perception of the effectiveness of biofuels application in decreasing the negative consequences of fossil fuel. These results are consistent with other studies [59,63–65].

Considering the knowledge aspect, objective knowledge of biofuels had a positive link with both positive and negative emotionality and technology acceptability. The significant role of biofuels objective knowledge represents a new interesting contribution: not only for its impact on the mediating variables of biofuels affective assessment (both positive and negative affective and emotions presumably due to a more complex ambivalent mindset resulting from a greater knowledge) but also for its positive direct impact in favoring biofuels technology acceptability and also one of the intention, namely, socio-political support. Having a relevant variation of knowledge, by considering both the lay general public and various kinds of stakeholders, allowed us to appreciate the important role that knowledge too can play among other variables.

Regarding the last belief toward the social-psychological characteristics of the adopter included in the model, fairness positively influenced positive emotions. This result contrasts with the findings of Huijts et al. [50] in that fairness only had a negative influence. While in the original SETA, fairness influences personal norms indirectly via positive affect and perceived effects, in the i-SETA fairness directly influences the personal norm.

Personal norm was predicted by biospheric values, social norms, positive emotions, and fairness while there was no link with technological-contextual factors. These results are in line with the study of Huijts et al. [50] according to which problem perception, in this case about procedural fairness, is a direct determinant of the personal norm. The positive relationship between biospheric values and the personal norm is also in line with other studies such as green design packaging acceptance [66] and smart meters acceptance [67,68]. Biospheric values

Table 6
Fit indices of the models tested for each theory (SETA and i-SETA) on the general sample, controlling for gender and nationality.

	$\chi 2$	*Df*	*P*	*χ2/df ratio*	CFI	TLI	RMSEA [90 % CI]	SRMR	AIC
1. SETA	178.487	47	.000	3,79	.97	.93	.05 [.04, .06]	.04	414.68
2. I-SETA	230.05	79	.000	2,91	.98	.94	.04 [.04, .05]	.02	622.05

Note. CFI = comparative fit index; TLI = Tucker-Lewis index; RMSEA [90 % CI] = root mean square error of approximation; SRMR = standardized root mean square residual; AIC = Akaike Information Criterion.

also positively influenced positive emotions. This result is consistent with the study of Contzen et al. [69] in which it was found that stronger biospheric values are related to stronger positive emotions about the adoption of heat pumps.

Concerning Aim 3, the role played by perceived technology characteristics and contextual factors in the process of biofuel acceptance was investigated using the recently developed biofuel beliefs scale [42]. Unlike the results concerning social-psychological variables, those concerning technological and contextual variables are more innovative. These variables, included in the i-SETA model, were not present in the SETA model [50]. For this reason, the results that emerged from the relationships of these variables with the others in the model are an important step forward for the existing state of the art.

For the technology features, the variable global environmental sustainability had a direct positive effect on outcome efficacy and technology acceptability and a negative effect on negative emotions, but no direct effect on acceptance outcomes. Emission sustainability, i.e., the environmental benefits that biofuels are believed to bring, such as reduced pollutant emissions, was linked with both the affective component, i.e., positive emotions, and the cognitive components, i.e., outcome efficacy; moreover, emissions sustainability had a positive impact on technology acceptability and acceptance of market buying. The other factor concerning technological aspects, i.e., technology compatibility (the degree of compatibility between fossil fuel and biofuels in terms of storage, transport, and distribution), had a negative effect on acceptance of market buying. These results are in line with several studies that have shown that technology characteristics influence the perception of technology and thus are antecedents of technology acceptance [70–72].

Regarding the economic factors, local socio-economic sustainability had a positive effect on outcome efficacy and a negative relationship with negative emotions, while cost savings had a positive relationship with both negative and positive emotionality.

Again, regarding the contextual aspects measures, policy-making legitimation had a direct positive effect on both use intention and support intention. It also had a direct positive effect on outcome efficacy and positive emotions. Having the perception that biofuels are supported by policymakers with policies that encourage their use generates positive feelings while having the perception that the use of biofuels will not be incentivized in any way generates negative feelings. Policy-making legitimation can push us to see that this energy technology is effective in solving environmental problems. These results are consistent with the study of Bastan et al. [73] which showed how government support can maximize the acceptance of building information modeling technology in Iran.

It should then be emphasized that these beliefs (technological and contextual), together with the adopter's social-psychological beliefs, have a positive impact on the tripartite acceptance of this technology, as well as on mediating variables, which in turn have impacts on outcome variables. In fact, the only mediating variable that has no relationship with technological and contextual factors is personal norm.

First of all, technology acceptability (the favorable attitude towards biofuels) has a direct positive effect on the three outcomes of acceptance: intentions of socio-political support, use, and market buying. Technology acceptability is then directly predicted by both positive and negative emotionality toward biofuels, some contextual and technological factors (global environmental sustainability and emissions sustainability), and all social-psychological factors except for personal norm, trust in policy makers and bioshperic values.

When it comes to outcome efficacy, i.e., the perceived effectiveness of biofuels application in decreasing the negative consequences of fossil fuels, it is related to multiple factors ranging from trust in the technical-scientific actors and policy makers to the political and economic contextual aspects, which may include receiving subsidies from the government such as tax credits and promotion by political institutions or creating more jobs at the local level. The positive effect of Outcome Efficacy on Technology Acceptability is consistent with Huijts et al. [50] findings.

Regarding emotions, the lack of political support for introducing incentives for biofuel use and perceiving the technology as responsible for harming the ecosystem and environment, lead to negative emotions about biofuels. On the contrary, attention to environmental issues, socially favorable judgment in adopting biofuels, having confidence in the responsible actors of the technology, and perceiving biofuels as sustainable and therefore environmentally beneficial energy technology that is supported at the policy level, all generate positive feelings. These results are in line with several pieces of evidence across contexts and different kinds of sustainable technologies such as nuclear power plants [74] carbon capture and storage [59], and hydrogen technology [63]. Emotions in turn have direct impacts on both the biofuels' acceptability and acceptance. In particular, positive emotions relate directly and positively to technology acceptability and personal norm. Negative emotions, whilst, have a direct negative impact on technology acceptability and intention to use, and a direct positive impact on intention to socio-political support.

Finally, a statistical comparison between the SETA and i-SETA models, brought out how the i-SETA produced optimal fit indices which are better than the tested SETA version. Furthermore, i-SETA outperforms SETA considering overall explained variance (Aim 4), with improvements in explaining the variance of crucial variables at various steps of the model: starting with both the affective and especially the cognitive assessment of biofuels (respectively both biofuels' triggered emotions and biofuels' perceived outcome efficacy), down to the biofuels' technology acceptability in terms of positive attitudes, and finally for two out of three intentions (i.e., to socio-politically support and to use biofuels). It should therefore be emphasized that the impact of technological and contextual variables brings a crucial increase in explaining the acceptability and acceptance of biofuels.

6.1. Practical implications

To make the energy transition possible, there is a need to make new technologies for renewable and sustainable energy more acceptable and accepted; this also applies to the case of biofuels. This can be achieved by leveraging both the perception of the features of biofuels technology, the perception of its context of adoption (economics and politics), and finally, the adopting persons considering a wide number of social-psychological features. These technologies too often present resistance from end-users due to inherent unconvincing technology characteristics or a general skepticism toward the adoption context, as well as also in some skeptical personal features of the adopters themselves. All these features need to be properly addressed to first maximize the probability of acceptability and in turn acceptance and adoption. Achieving this goal requires a holistic approach to foster appropriate beliefs towards a new energy technology, that is, first of all improving the perceived technological features of the biofuels (especially regarding environmental impacts, but also compatibility), improving the surrounding political and economic context supporting its approval, and improving some individual features of the target adopters.

The results of this study revealed the importance of beliefs within each domain, that is, about technological, contextual, and personal variables in impacting first of all on the cognitive and affective biofuels evaluation, and subsequently on biofuels acceptability and acceptance, both for laypeople and expert stakeholders.

More specifically, the adopters' features were already known to be relevant to the acceptability, acceptance, and adoption of biofuels and other renewable and sustainable energy technologies. However, these processes may require complex management and, in some cases, long-time perspectives. This research highlights an important role played by the beliefs that the potential adopter holds concerning the target renewable and sustainable energy technology to be considered (biofuels, in this case). The use of a reliable valid tool to measure all major classes of biofuels' relevant beliefs (about both the technology and the economic and political context) shows that these beliefs act both as a first step in the affective and cognitive assessment of biofuels, then on their acceptability, and finally on their acceptance. These results of the model revealed that very specific beliefs, across all the identified classes, can be identified as potential drivers, or barriers, to boost biofuels' acceptability and acceptance. Each one of these specific beliefs could thus be properly targeted in the audiences to cope with the barriers and capitalize on the drivers. In particular, some practical implications from the study's innovative findings (related to technological and contextual variables), can be envisioned to promote social acceptance of biofuels, as follows.

It will be necessary to communicate the reduced global environmental impact (lower emissions compared to fossil fuels) of biofuels and make technical information accessible and understandable to the population, leveraging emotional involvement and creating the perception of having the ability to generate change [75].

Moreover, to make local benefits salient, knowledge of positive local impacts due to biofuels' production, such as increased employment of farmers, should be promoted [5,76], and people should be reassured about the absence of risks.

Finally, as a significant impact of policy-making legitimation on the biofuels acceptance has emerged, politicians and Non-Governmental Organizations (NGOs), having a strong influence on public opinion, would have a responsibility to support biofuels and show the general public the reasons to move away from fossil fuels. In particular, the promotion of biofuels (as well as other renewable and sustainable energy technologies) by policy-makers and NGOs could accelerate the energy transition process, and with it the achievement of the United Nation's proposed sustainable development goals [4]. The energy transition process related to the use of biofuels (as well as other sustainable energy technologies) is indeed closely linked to the achievement of most of the sustainable development goals (e.g., affordable and clean energy; climate action), leading to global improved environmental and economic condition.

6.2. Limits and future developments

The main limitations of this study are its cross-sectional nature and the imbalance in the sample between expert stakeholders and the lay public. Additionally, data collected in the study refer only to self-report measures that are subject to response bias (such as social desirability), while there are no more broadly generalizable measures (such as behavioral measures). To demonstrate causality between the investigated constructs, longitudinal studies aimed at understanding the evolution of participants' social acceptance over time, and studies on more balanced samples which could allow direct statistical comparisons between lay public and expert stakeholders, could be envisioned as future studies to understand all the dynamics among the actors involved in the transition process towards renewable and sustainable energy technologies. A second source of error is related to the type of model, which considering variables as "measured" does not handle measurement error. Trying to handle these problems, latent variables models (e.g., structural equation models) can be developed. To test latent variables models however, given the large number of estimated parameters, a larger sample would be required. These sources of error may affect the interpretation of the results, especially in terms of the "strength" and/or significance of the effects examined. Variables that might have emerged in the model to strongly influence social acceptance of biofuels may weakly influence such acceptance. However, the overall interpretation of the model would not change significantly. Instead, an experimental study would need to be conducted in order to hypothesize causality between the variables.

Furthermore, although a sample of participants from several European countries was considered in this study, the differences between these countries were not analyzed in detail. Differences between European countries with multilevel analysis were considered only for the acceptance of other technologies, such as robotics [77]. Future studies could therefore focus on the differences across European countries to understand why the energy transition to renewable and sustainable energy technologies occurs at different times and speeds in different European countries, or different societal strata.

Moreover, in future developments, the i-SETA model, tested here to analyze the acceptance of biofuels, could be tested to analyze the acceptance of other renewable and sustainable technologies.

It would be important to develop *trans*-technology studies to hypothesize possible comparisons between different energy technologies, allowing comparisons between different types of technologies (e.g., mitigation and adaptation). Furthermore, the study of social acceptance of sustainable energy technologies focuses mainly on the most developed (with higher TRL) and mainstream (particularly solar and wind) energy technologies. Other types of technologies, such as tidal energy or negative emission and geoengineering technologies, are instead less studied. Increasing the number of studies that analyze the social acceptance of low TRL technologies would be crucial, as these are precisely the technologies that are most likely to face opposition from the public and the most need support to be commercialized and diffused.

Therefore, it would be useful to develop all-encompassing studies that frame the social acceptance of different energy technologies from a holistic perspective (such as systematic reviews or meta-analyses).

Finally, to get a clear picture of the process that leads people to choose a sustainable energy technology, it would also be necessary to study the last part of the process, i.e., adoption. Adoption, indeed, has been little studied by previous studies [78] and not considered by this study. Therefore, future studies could investigate what leads people to use and habitually adopt a specific technology after liking and choosing it. Experiments manipulating some of the relevant variables that emerged in the i-SETA model testing will also be welcomed to significantly advance in terms of causal evidence supporting the envisaged relations among beliefs, acceptability, and acceptance, towards adoption.

Author contributions

MB Conceptualization, Project administration, Funding acquisition, Writing - original draft, Writing - review & editing, Supervision. OM for Formal analysis, Methodology, Writing - original draft, Writing – review & editing. AM for Formal analysis, Methodology, Writing - original draft, Writing-review & editing. SA for Conceptualization, Project administration, Data curation, Methodology, Writing - original draft, Investigation, Writing – review & editing. FD for Conceptualization, Project administration, Data Curation, Methodology, Investigation, Writing - original draft, Writing – review & editing. FF for Formal analysis, Methodology, Writing - original draft, Writing – review & editing, Supervision.

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Declaration of competing interest

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Data availability

Data will be made available on request.

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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.2023.113867.

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