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A review of public opinion on liquid biofuels in the EU: Current knowledge and future challenges

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ABSTRACT

Biofuels are regarded as a key element in order to reach the EU renewable energy targets. However the implementation of biofuel technologies, depending on the type of feedstock utilised, may have significant drawbacks, such as indirect land use change (entailing deforestation and considerable greenhouse gases emissions) and competition with food production (entailing higher food prices). Considering these controversial aspects, it is crucial to understand public opinion towards biofuels. This article therefore reviews the literature on public opinion on liquid biofuels with a focus on EU member states, with consideration of insights from North American studies.

The public is in general found to be supportive of biofuels, although public knowledge is found to be limited. However, the perception of risk redistribution implied by biofuels implementation is found to be important in understanding public opinion, and may determine public support. In addition, aspects influencing public opinion, such as media, discourses and knowledge, are identified and discussed. Due to limited knowledge regarding biofuels, we find that public opinion may be vulnerable to dominant discourses, media and social media frames — increased public knowledge may help mitigate such vulnerability. Furthermore, the study indicates increased likelihood of support by an informed and educated public when the implementation of biofuels is considered to be fair. We conclude that there is a need for further research regarding public support and resistance towards biofuels, (i) focusing on policies for biofuel implementation, and (ii) using qualitative prospective assessment methods inspired by participatory technology assessment.

1. Introduction

Renewable energy is a key lever to reduce greenhouse gases (GHG) emissions and mitigate climate change. As such, the European Union promotes renewable energy development and defines goals both at the EU level and at the individual country level [1]. Bioenergy, including biofuels, is one of these supported renewable energies. Although most of the global primary energy demand is supplied by fossil fuels (81% in 2017), global energy is supplied to a significant extent by bioenergy, which accounts for 10% of global primary energy supply [2, page 38]. Conversely, biofuels currently supply less than 1% of global final energy consumption and around 3% in the transportation sector. However, there is a clear increase in the use of biofuels, as its consumption has increased eightfold since 2000 [[2], page 91]. This significant increase in biofuels use has been to a great extent driven by incentives and favourable legislation in both the US and the EU.

However, it was shortly realised that an extensive implementation of biofuels came with significant drawbacks, and biofuels turned out to be more controversial than firstly thought. First, the advantages of biofuels in terms of climate change mitigation were called into question as the indirect land use change (iLUC) effect was pointed and quantified [3–6]. Since then, numerous studies on the quantification of iLUC induced GHG emissions, often using a Life Cycle Analysis (LCA) approach, have been published [7–10]. However, there is significant academic debate on how to account for iLUC induced emissions [11,12], as very different methodologies and models can be used [13], and these can lead to significant differences in results, thereby making these highly uncertain [14]. However, the iLUC issue is currently recognised in the EU legislation [1] and is regarded as a crucial criterion to the sustainability of biofuels; consistently with the EU's precautionary principle.

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Second, produced from grown-on-purpose biomass require land, and therefore increase worldwide competition for arable land [[15], Chapter 7]. Therefore, an increase in biofuel production may lead to an increase in food and land prices, which may affect food security, and successively increase demand for productive land leading to land transformation and intensification of production [16]. This indirect effect of biofuel production on food prices has triggered the food versus fuel debate. Particularly, it has been shown how the dramatic development of biofuels in the period 2004–2008 contributed to the significant rise in global markets food prices [17–19]. Such increases in food prices affects mainly low living standard populations [20,21], i.e. different populations than those benefiting from biofuels, hence raising serious ethical and distributional issues.

Thus, even though biofuels are seen as a key element for reaching the EU renewable energy targets, there is evidence that the development of first generation biofuels (i.e. biofuels produced from grown-on-purpose biomass) would lead to negative impacts in terms of GHG emissions (due to iLUC), and in terms of competition with food production, particularly in developing countries. Recent awareness about these negative impacts have led to a heated public controversy. Therefore, if biofuels are to be developed in an industrial scale in the EU, public opinion needs to be seriously taken into consideration. Although there have been a few studies on public opinion on biofuels in specific countries, and some of these have included reviews of the current literature [22–24], there is currently no comprehensive literature review available in the field. This study undertakes the first comprehensive literature review of public opinion on biofuels in the EU. Particularly, it addresses the following research questions:

i. What is the public opinion of biofuels in the EU context?
ii. How does the perception of biofuels relate to the public understanding of the related risk redistribution?
iii. Which factors shape public opinion on biofuels in the EU?

The rest of the article is structured as follows: Section 2 presents the methodology and theoretical framework used, Section 3 presents an overview of the reviewed literature, Section 4 reviews public opinions towards biofuels, and Section 5 discusses the findings. Finally, Section 6 concludes and provides recommendations for further research.

2. Scope, methodology and framework

2.1. Scope

This literature review comprises all the articles dealing with public opinion towards liquid biofuels in the EU. Articles dealing with other types of bioenergy are not covered, as the two main issues that have been raising concern recently — iLUC and the food versus fuel issue (see Section 1) — are mostly specific to liquid biofuels. Likewise, the different technologies and fuel generations [25] are specific to biofuels and not easily applicable to the whole bioenergy literature. These characteristics of liquid biofuels make them fundamentally different from other types of bioenergy, hence the scope limitation adopted here. However, this review does stand on the shoulders of previous discussions of bioenergy and the risk framework presented below is complimentary to the post-normal approach to environmental risk and uncertainty related to biomass as introduced by Upham et al. [26].

As the literature on public opinion on biofuels within the EU is limited, it was found relevant to complement the review with a few studies from North America, as further insights could be gained from these. Indeed, the biofuel controversy has taken an important place in both the EU and North America, as in both contexts a legislation supporting the development of biofuels was implemented [1,27,28]. Studies located in other geographical areas were excluded from the review.

The objective of this article is to provide a comprehensive review of public opinion towards biofuels in the EU, of the main determinants of public opinion (knowledge, media, discourses, …), as well as the perception of risk redistribution implied by biofuel implementation. As such, Section 4 presents the overview of public opinion towards biofuels in the EU, including the perception of risk redistribution, Section 5 discusses the influence of limited knowledge, of media frames and discourses, and the opinion towards specific policies for biofuel implementation. Finally, Section 6 concludes and presents recommendations for further research based on findings.

2.2. Methodology for articles selection

As the literature on public opinion on biofuels within the EU is limited, it was found relevant to complement the review with a few studies from North America, as further insights could be gained from these. Indeed, the biofuel controversy has taken an important place in both the EU and North America, as in both contexts a legislation supporting the development of biofuels was implemented [1,27,28]. Studies located in other geographical areas were excluded from the review.

We followed a three step process in order to select articles. First, we searched for articles using Google Scholar and Scopus, using the following keywords: (("public opinion" OR "public attitude" OR "public acceptance" OR "willingness to pay") AND biofuels). Second, we supplemented the first search looking into each article's bibliography. Then, we screened all the obtained articles and kept only those for which the scope was relevant to this review, i.e. with a focus on biofuels either in the EU or in North America, and with collection of empirical data (e.g. individual and focus group interviews, surveys, text analysis of news media and internet resources). For articles in the EU context, we stopped collecting articles when we could not identify any additional article, hence the EU literature is comprehensive. For the North American literature, we stopped collecting articles when the information contained in articles was deemed redundant in the screening phase. Thus, the articles reviewed in the North American context do not constitute the whole available literature, but they are still a comprehensive and representative sample of the literature. The search period ended in September 2020.

The collected articles were thereafter analysed following a two step process. Firstly, for each article, the data collection methodology and the main themes covered were identified. This first step enabled to analyse the main focus of data collection methodologies in the reviewed literature, and to compare the EU and North American literature with respect to these aspects. Thus, we conducted a review of the scope, range and extensiveness of the literature related to public opinion on biofuels, which is described by Paré and Kitsiou [29] as a *scoping* literature review. Secondly, the data contained in each article was categorised following themes identified, i.e. "knowledge", "food versus fuel", "political affiliation", "media", "language and framing" and "risks." This helped establishing a general overview of the different statements and findings for each of these main themes in the literature, as well as identifying geographical differences in the findings, and eventual contradictions amongst the studies. This second step therefore relates to a *mapping*, or *descriptive* literature review, as described in Paré and Kitsiou [29]. Selected articles, alongside their data collection methodology and main focus, are presented in Table 2 (EU, 15 articles) and Table 3 (North

Table 1
Different types of risks, classified by population and risk. The basic idea is that when one technology is replaced by a new technology — i.e. substituting a fossil fuel with a first generation bioethanol — then the risks from the original technology. i.e. global warming, will be replaced with same risk type *or new risk type*, targeting the same population *or a new population*. The result is four generic risk types. Inspired from Ref. [30].

	Same risk type	Different risk type
Same population	a1: Risk offset	b1: Risk substitution
Different population	a2: Risk transfer	b2: Risk transformation

Table 2
Selected articles for the literature review - EU. Number of participants in survey or focus group written in parenthesis when available. Data presented in No 3 is also reported in Refs. [39,40] with modified willingness to pay perspectives.

No	Article	Author(s)	Year	Country	Data collection	Key focus
1	Perceived importance of fuel characteristics and its match with consumer beliefs about biofuels in Belgium	Van de Velde, Verbeke, Popp, Buysse, Huylenbroeck	2009	Belgium	Survey (363)	General opinion
2	Public acceptance of biofuels	Savvanidou, Zervas & Tsagarakis	2010	Greece	Survey (571)	General opinion & willingness to pay
3	Willingness to pay for biodiesel in Spain: a pilot study for diesel consumers	Giraldo, Gracia & do Amaral	2010	Spain	Survey (121)	Willingness to pay
4	Biofuels: a contested response to climate change	Jensen & Andersen	2013	Denmark	Qualitative interviews and focus-group (17)	General opinion, Risks and uncertainties
5	Technoscientific promotion and biofuel policy: How the press and search engines stage the biofuel controversy	Eklöf & Mager	2013	Sweden	Press releases and search engines results	Role of media
6	Transport and low-carbon fuel: A study of public preferences in Spain	Loureiro, Labandeira & Hanemann	2013	Spain	Survey (750)	General opinion and willingness to pay
7	Will consumers use biodiesel Assessing the potential for reducing CO2 emissions from private transport in Spain	Gracia, Barreiro-Hurlé & Pérez	2014	Spain	Survey (400)	Intention to use biodiesel
8	Bio-, Agro- or even Social Fuels: Discourse Dynamics on Biofuels in Germany	Selbmann	2015	Germany	Literature review	Public discourses evolution
9	Do the Spanish want biodiesel? A case study in the Catalan	Kallas & Gil	2015	Spain	Survey (300)	willingness to pay
10	Internet-orientated Hungarian car drivers' knowledge and attitudes towards biofuels	Balogh, Popp, Huzsvai & Jobbágy	2015	Hungary	Survey (404 respondents)	General opinion, awareness and knowledge
11	Public acceptance of biofuels in the transport sector in Finland	Moula, Nyari & Bartel	2017	Finland	Survey (90)	General opinion
12	The attitudes of UK tourists to the use of biofuels in civil aviation: An exploratory study	Filimonau & Högström	2017	UK	Mini Interviews (102)	General opinion
13	Public attitudes to biofuel use in aviation: Evidence from an emerging tourist market	Filimonau, Mika & Pawlusinski	2018	Poland	Survey (306)	General opinion
14	Public acceptance of emerging energy technologies in context of the German energy transition	Emmerich et al.	2020	Germany	Survey (416)	Technology acceptance
15	Acceptability iof genetically engineered algae biofuels in Europe: opinions of experts and stakeholders	Villarreal, Burgués & Rösch	2020	Europe	Survey (130)	Biofuel production plant acceptance

Table 3
Selected articles for the literature review - North America. Number of participants in survey/focus group written in parenthesis when available.

No	Article	Author(s)	Year	Country	Data collection	Key focus
16	Public attitudes toward political and technological options for biofuels	Delshad, Raymond, Sawicki & Wegener	2010	USA	In-depth focus group (119)	General opinion on biofuels and related policies
17	Willingness to pay for E85 from corn, switchgrass, and wood residues	Jensen et al.	2010	USA	Survey (914)	Willingness to pay
18	Labelling renewable energies: How the language surrounding biofuels can influence its public acceptance	Cacciatore, Scheufele & Shaw	2012	USA	Survey (556)	Language, political polarisation
19	Public attitudes toward biofuels. Effects of knowledge, political partisanship, and media use	Cacciatore, Scheufele & Shaw	2012	USA	Survey (593)	Knowledge, political polarisation
20	Media Framing and Public Attitudes Toward Biofuels	Delshad & Raymond	2013	USA	Newspaper review & Survey (1000)	Media frames
21	The polarisation of public opinion on biofuels in North America: key drivers and future trends	Dragojlovic & Einsiedel	2014	USA & Canada	Survey (1302)	Political polarisation
22	Public opinion about biofuels: The interplay between party identification and risk/benefit perception	Fung et al.	2014	USA	Survey (593)	Political polarisation
23	Public perceptions of bioenergy and land use change: Comparing narrative frames of agriculture and forestry	Spartz, Rickenbach, Shaw	2015	USA	Survey (644)	Language
24	What drives public acceptance of second generation biofuels? Evidence from Canada	Dragojlovic & Einsiedel	2015	Canada	Survey (1302)	Awareness and knowledge
25	Public perception of bioenergy in North Carolina and Tennesse	Radics, Dasmohapatra & Kelley	2016	USA	Survey (586)	General opinion

America, 10 articles).

2.3. Analytical framework for risk redistribution

We analyse the relationship between the public perception of biofuels and the public understanding of the risk redistribution related to biofuels using a framework inspired from risk management [30]. The perception of risk redistribution associated to biofuels is of particular interest, as (i) perceived risks represent main hurdles to a large scale implementation of new technologies, including alternative energy systems [31], and (ii) biofuels are fundamentally being introduced to mitigate risks related to climate change. Consequently, the implementation of biofuels fundamentally implies the possibility of trade-offs and risk redistribution.

The presented framework enables comparing the baseline risk associated with the reference situation (i.e. a situation of damaging climate change induced by high fossil fuel consumption) with the countervailing risks that may appear when corrective action (i.e. biofuels implementation) is undertaken in order to mitigate the baseline risk. The classification of the countervailing risks that may appear is presented in Table 1, depending on whether the type of the new risk is different than the baseline risk (i.e. climate change damage) or not, and depending on whether the affected population is the same that undertakes corrective action (i.e. biofuel users) or not. This framework therefore underlines the different risk trade-offs and redistribution that appear when undertaking corrective action, which can be classified

according to four typologies:

- A *risk offset* occurs when the action undertaken does not modify the risk that a specific population is facing.
- A *risk substitution* refers to a situation in which one the risk that a particular population faces is substituted by another risk that affects the same population.
- A *risk transfer* occurs when a same risk moves from a population to another population.
- A *risk transformation* occurs if the undertaken action modifies both the type of risk and the affected population.

Classifying the perceived risks related to biofuel implementation according to this framework enables analysing which risk typology is particularly perceived by citizens (as presented by the studies included here), and how the risk typology interacts with the public opinion. Beyond the categorisation of the aspects identified in the review, the typology enables identifying possible risk problems that are not being covered by the reviewed studies, which either are aspects that have not yet entered citizens awareness, or aspect that for methodological reasons have not been covered by the reviewed studies.

These, lesser or not at all covered, types of risks are likely to be associated with varying degrees of uncertainty corresponding to the uncertainty framework as suggested by Bryan Wynne [32] building on but also deviating from the work of Ravetz and Funtowicz [33], and which since has been adapted to biofuels [26,34,35]. The uncertainty-framework is basically a criticism of the dominant risk-framework for representing a rationalistic and reductionist understanding of reality, which brings along the risk of ignoring potential problems where current scientific knowledge is limited, debated or controversial, or where the language of science does not meet the language of people. This framework has, arguably, been integrated in contemporary European policy via the precautionary principle which enables overcoming the limitations of a pure risk approach [32,36–38], and it will, in the discussion of the risk types, be identified according to Table 1. The focus is the relationship between the identified risk types and four uncertainty types: (i) "outcome-uncertainty", (ii) "parameter-uncertainty", (iii) "model-uncertainty", or (iv) "indeterminacy-uncertainty". We leave out the fifth level of complete uncertainty, as the basic condition, that we never will know everything, in this context is banal. The most abstract types are the two latter (iii and iv), where model-uncertainty also can be understood as ignorance based on assuming a wrong or incomplete model, and indeterminacy — or uncertainty about implicit assumptions as Upham et al. denotes it — is the aspects of the risk that cannot be described by "more science" [32]. A relevant example of level (iii) is the argument that indirect land use change is impossible to model and therefore is omitted from assessments of emission of consequences, where level (iv) underpin that uncertainty not only comes from "pure uncertainty", wrongly used models or faulty scientific paradigms, but also exists as something that cannot be reconciled by more or better science and expert knowledge, as science inevitably will be pervaded by tacit social judgement which cover indeterminacies in that knowledge itself [32]. Wynne further argue that the lack of recognizing this, distorts the understanding of the relationship between expert knowledge and public value-choices related to technology policy, and thereby also may distort public debate.

3. Literature overview

It can be firstly said that the literature available on public opinion on biofuels is limited, as only 15 relevant articles examining European conditions have been identified. The North American coverage of the theme has a similar volume, of which we have selected a representative sample.

3.1. Analytical approaches in the literature

Most of the selected studies are empirical and do not link the findings with socio-economic theoretical frameworks, although noteworthy exceptions are Selbmann [41], which uses Discourse Theory, Gracia et al. [42], which links beliefs and behaviours through the "Theory of Planned Behaviour", and Emmerich et al. [43], that employs an adapted version of the so-called Technology Acceptance Framework (TAF) [44].

Tables 2 and 3 show that the main way of gathering data in the reviewed articles is through surveys, which have limited questions and enable to reach a wide audience [45]. Conversely, qualitative interviews and focus group interviews, which enable to explore more thoroughly people's perception, have been used in a limited number of cases [46,47].

Using these in-depth approaches, Delshad et al. [46] and Jensen and Andersen [47] are able to exlore complex and important aspects of public opinion, which are most of the time left unexplored by other studies. Delshad et al. [46] is currently the only study that explores in-depth public opinion regarding policies for implementing biofuels, which is a crucial aspect — although complex — of public perception. Regarding Jensen and Andersen [47], it thoroughly explores how the perception of risks and uncertainties modifies public opinion and how public support decreases when specific problems are introduced to respondents. Jensen and Andersen [47] notes the uncertainty surrounding public opinion on technologies which are at such early stages of technological development and that are so unfamiliar to the public, and as such, deems "necessary to provide respondents with a presentation of biofuel technologies and the questions and arguments raised in the deliberations over biofuels" in order to explore the complexity of respondents' opinions. This approach has been defended for investigating public perception of other emerging technologies, for instance, hydrogen [48], but Jensen and Andersen [47] is the only study of the present review that emphasises the need for this approach. Hence, qualitative interviews, which enable to fluidly explore different aspects of people's opinions, as well as to provide context, enable to obtain very valuable data on public perception, instead of limiting themselves to *a priori* perceptions, which are for instance obtained when a survey is conducted with uninformed participants. However, as noted in other studies [49,50], the provision of context also introduces a risk of creating a respondent bias depending on how the context is presented. An alternative is to explore experts' opinions, as Varela Villarreal et al. [51] does in the case of emerging genetically engineered micro-algae for third generation type biofuels. The study finds that the insights into expert opinions can be used as a first step towards designing socio-technical systems that increases the likely hood for a higher acceptability.

Three studies explore exclusively the willingness to pay indicator [22,52,53], while the focus is also on the willingness to pay indicator in Loureiro et al. [54] and Savvanidou et al. [55]. Hence, five studies out of the selection (i.e. almost one quarter of the literature reviewed) are focused on end users' willingness to pay, which is a very limited indicator of public opinion. Indeed, Jensen and Andersen [47] argue, following Ricci et al. [48], that in such a context, a simple quantitative measure — in that case, the willingness to pay indicator — is unable to capture the complexity of public perception of emerging technologies.

Two other studies take a radically different approach reviewing the dominant representations of biofuels in society analysing articles, press releases, statements, public media, and internet search engines results (Google) [41,56]. Their approach enables studying dominant discourses, actors and narratives surrounding biofuels.

In general, it can be noted that the literature on public opinion on biofuels suffers from a lack of diversity regarding the methods applied, and often relies on methodologies (e.g. surveys) that do not enable to explore in-depth particular aspects such as perceived risk redistribution, issues of fairness or influence of knowledge on opinions — which are all particularly relevant for biofuels.

3.2. Differences with North American literature

Differences between the literature focusing on EU countries and on North American countries can also be identified. Particularly, quite a few North American studies focus on the political polarisation of the biofuel debate, i.e. on how public opinion differ, depending on the political inclination of the respondents [49,57–59], while this is not an explored subject in the EU literature. Likewise, two North American articles explored the role of the language surrounding biofuels, while this is not a subject in the EU literature. Other topics present in the North American literature and not discussed in the EU literature are issues around energy and national security as well as civic duties [46,53,60].

4. Reported opinions

4.1. Overview of public opinion

Most of the articles examining EU countries find an overall supportive public attitude towards biofuels. Indeed, Moula et al. [61] find that 60% of the respondents are willing to switch to biofuels; Balogh et al. [24] also finds a generally positive attitude, although this study focuses on particularly well informed drivers. In addition, Loureiro et al. [54] and Giraldo et al. [52] find a positive willingness to pay, meaning that end users are rather supportive towards the technology. Regarding the use in the aviation sector, it is found that biofuels are regarded as a good mean in order to make aviation more environmentally friendly, and is therefore a welcome development [23,62].

However, this overall positive attitude is challenged by the findings of some articles. Particularly, Kallas and Gil [22] find that Spanish end users are not willing to pay additionally for biodiesel, while Gracia et al. [42] concludes that even if biodiesel were widely spread in the fuelling network and available at the same price than conventional fuels, less than 50% of drivers would use it. Finally, Jensen and Andersen [47] presents a rather supportive public attitude towards biofuels, which is however conditioned by the implementation of mitigation measures when the potential for adverse unintended impacts are introduced to respondents:

> "An important conclusion of this work is that there is ambivalent and conditional acceptance among the Danish public about developing biofuel technologies for transportation […]. This means that there is no simple answer to the question of whether the public (or individual members) are "for" or "against" the development of biofuels."

For instance, the feedstock source, from which the biofuel is produced, is of importance when it comes to public opinion. A Eurostat investigation showed already in 2010 that the support of first generation types of feedstocks had a lower support compared to non-food feedstock [63].

4.2. Ambiguous assertions of public willingness to pay for biofuels

The literature is not always consistent in its conclusions on public opinion, analysed as willingness to pay for biofuels, even when the geographical area studied is similar. This is exemplified by four Spanish studies [22,42,52,54]. While the three first studies focus on the public opinion towards biofuels in Spain using the same indicator, namely the willingness to pay, these studies lead to different conclusions. Loureiro et al. and [52] both finds a positive willingness to pay, indicating that consumers are willing to pay more for biofuels, while Kallas and Gil find that consumers are not willing to pay extra money for biofuels. Furthermore, Gracia et al. assess that even with abundant supply of biofuels available at the same price as conventional fuels, less than 50% of motorists would use biofuels. Reasons explaining such differences may be due to the size of the sample of observed people, to the social background of the interviewees, to the framing of the research or the different years the research have been conducted. Finally, the actual presentation of biofuel in the studies may, together with implicit understandings amongst the researchers performing the investigations, be an important variable shaping the recorded opinion, as shown by Cacciatore et al. [49] and Spartz et al. [50] — particularly when knowledge is weak, as further discussed below.

4.3. Perceptions, opinions and risk redistribution

Table 4 presents the risk redistribution identified by respondents in the reviewed articles, comparing the countervailing risks of switching towards biofuels against the baseline risk entailed by fossil fuel consumption (climate change damage due to GHG emissions), as presented in Section 2.3. Next, we present each type of risk redistribution identified and how it relates to public perception of biofuels.

Risk Offset (a1). The first countervailing risk, i.e. GHG emissions from iLUC, relates primarily to the production of first generation biofuels, for which dedicated land is needed for growing feedstocks. Even though this risk is a main topic in the academic sphere, and one of the main caveats for biofuel development [see e.g. 64; 65; 66; 67; 68; 69; 70], this risk was only directly addressed in one of the reviewed articles, namely Selbmann [41]. Beyond this, reference is only made to iLUC in connection to the RED II requirements to limit the use of food crops as feedstocks was identified implicitly, as "deforestation" (classified as risk transformation) [55,56], but none of the included studies investigates the understanding of the link between indirect GHG emissions and biofuel production.

Risk Transfer (a2). Almost no investigations relate to the risk transfer. This is not surprising, as the transferal of the same type risks to a different population due to a shift in fuel type is unlikely; the main risk in focus, global warming, is a global impact type, and hence, *where* the emission takes place have no importance to the impact on climate change. Risk transfer may potentially become a relevant aspect with respect to the location of production, and Emmerich et al. [43] assess the public opinion related to biofuel production plants as being supportive and related to a high level of trust in local (planning) authorities.

Risk Substitution (b1). A first risk substitution perceived by the public is related to the engine performance and safety in transportation. Uninformed respondents are in some cases found to be fearful that switching towards alternative fuels may decrease security in the vehicle, because of for instance compatibility with the engine [62]. A second risk substitution perceived by the public is related to fuel availability at the pump, as some people fear that if they choose a vehicle using biofuels they may not be able to purchase as easily than with conventional fuels [71]. A third perceived risk is related to potential increases in fuel prices, as people fear that biofuels would be more expensive than conventional fuels. Some studies find that this is acceptable to the public if it enables to bring down GHG emissions or to reduce pollution [52,54]. Conversely, some people are reluctant to pay higher prices for fuels, as they may be fearing other adverse effects such as engine failures [22].

Risk Transformation (b2). One of the main risks associated with biofuel development is the potential increase in food prices due to an increasing competition and demand for land, which mostly impacts the population in developing countries [21]. When respondents perceive the "food versus fuel" issue, they are more reluctant to switch towards biofuels [42,47,61]. However respondents are not always able to identify the link between food prices and biofuel production and development [23,52,61,62]. Increase of deforestation, and related loss of biodiversity, also stemming from increased demand and competition for land, is only discussed by a few cases [47,55,72]. However, it is systematically found that public support decreases when deforestation is understood as a consequence of biofuel development. The reported types of risk transformations are all connected to indirect land use change.

Table 4
Different risk redistributions identified by the public in the reviewed articles, classified as described in Section 2. The baseline risk is the climate change damage induced by greenhouse gases emissions, and the baseline population refers to the population undertaking corrective action (i.e. biofuel users). Article numbers refer to article numbers displayed in Tables 2 and 3 Note: there is no judgement here on whether the risks perceived by the public are realistic and sensible, or not.

	Same risk type (a)			Different risk type (b)		
	Risk	Explanation	Articles	Risk	Explanation	Articles
Same population (1)	**- iLUC related GHG emission**	- iLUC may induce GHG emissions (same risk as baseline risk) that will affect the population switching to biofuels, as well as other populations.	Explicitly: 8. Implicitly: 2, 5.	**- Engine performance and safety in transportation**	- Issues related to less safety in transportation are a different risk type that may be encounter by biofuel users.	9, 12, 13.
				- Pump availability	- Fuel being not available at the pump is an issue that may affect biofuel users.	1
				- Increase in fuel prices	- Increases in fuel prices may affect biofuel users.	3, 6, 9.
Different population (2)	**- Siting of production**	- Issues related to the location of biofuel production (e.g. noise, local pollution…) may affect the population living nearby new biofuel production facilities, wherever these are located.	14	**- Increase in food prices**	- Increases in food prices may affect a different population than biofuel users, chiefly in developping countries.	4, 11, 12, 13.
				- Deforestation	- Deforestation induced by biofuel production may affect a different population than biofuel users, chiefly population of rural areas nearby tropical forests.	2, 4, 24.

4.4. Influence of knowledge

These representations of public perception of liquid biofuels related to the four different types of risk change relates strongly to the level of knowledge within the public. It is worth noting that public's level of knowledge is usually referred as a key lever in order to improve public acceptance of biofuels. Filimonau et al. [23] argues that the success of adopting biofuel technology will depend on the public knowledge, societal acceptance and consumer perception of safety, and that:

> "[…] poor public knowledge on a new technological advancement alongside the advantages it has set to deliver can hamper its rapid market penetration; it can further confuse customers and detrimentally affect their purchasing decisions […]."

A high level of knowledge can contribute to reduce specific concerns, related for instance to airplanes safety [23,62], or to the compatibility of engines with biofuels [22]. Likewise, high levels of knowledge can drive public acceptance when advantages of a technology compared to the baseline situation — i.e. fossil fuels consumption — are well understood. As such, some authors defend that end users need to be provided with more information and knowledge in order to support the implementation of biofuels [61,62].

However, there are limitations in considering knowledge as a universal lever for a broader acceptance of biofuels. Indeed, public support may also vanish, or be conditioned by the implementation of mitigation measures, as public knowledge regarding the drawbacks associated to biofuel implementation is gained [47]. This view is also supported by Cacciatore et al. [49], who finds that more knowledgeable respondents find fewer benefits relative to risks in the case of first generation biofuels. Therefore, assuming that a better public knowledge lead to support of biofuel implementation, per se, is a too simplified reasoning, as the perceived risk redistribution and fairness also will determine the extent of support.

5. Discussion

The current assessments of public opinion in the EU faces a number of challenges which we will discuss in the following. The assessments mainly target aspects of transition to biofuels that are close to the citizens everyday practises in terms of neighbouring plants, use of fuel including pump availability and fuel prices, covering risk transfer and risk substitution. On the contrary, risk transformations and risk offsets related to land use change, and the following indirect impacts, are underrepresented. This links closely to influence of knowledge on the shaping of opinions and to the need for supplementing the existing approaches for assessing public opinions with more formative strategies combining building stronger understandings and building stronger engagement and dialogue. This is furthermore stressed when applying the uncertainty framework to the risk-types covered in the investigated studies. The studies does not per see investigate the public opinion of risks related to biofuel, but rather the public opinion of different potential consequences related to biofuels. The dominant representation of the consequences focus therefore on aspects related to a low level of uncertainty, and does thereby indirectly neglect risk aspects related to higher levels of uncertainty.

5.1. Limited knowledge on biofuels

A crucial element, underlining the uncertainty related to the assertions of public opinion, is the limited knowledge in the public about biofuels [23,42,47,52,55,61,62]. In terms of public opinion, this lack of knowledge results in highly uncertain estimates about future public support, as noted by Jensen and Andersen [47], who underline how unpredictable such opinions are. Indeed, new information and knowledge can easily modify people's perception and opinion. It has been shown that public support for biofuels decreases when unintended negative consequences of biofuels are becoming apparent to respondents [47,72]. Indeed, Dragojlovic and Einsiedel [72] show how respondents's support decreased when they were informed of potential impacts on rising food prices and increased commercial logging. Likewise, Cacciatore et al. [59] shows how respondents' reaction varied depending on the chosen terminology (i.e. higher public support for "biofuel" than for "ethanol", although pointing to the same fuel). Spartz et al. [50] also shows how local respondents support varied depending on the linguistic frames that were used to introduce land use change associated with bioenergy production. Consequently, the opinion of people with limited knowledge are complex to know, as it may vary with the knowledge people are provided, as well as with the employed terminology. In terms of uncertainty, there seem to be a need for the public to get access to not only what experts deems certain knowledge, but also access to knowledge and delibarations of the full span from outcome-, paramenter-, model-, and indeterminacy-uncertainty.

A lack of knowledge therefore contributes to a large uncertainty when assessing public opinion and support towards biofuels, as opinions may easily change as additional knowledge and insights are gained. Indeed, Wegener and Kelly [73] points out that:

> "Past research in social psychology has demonstrated that attitudes based on higher levels of knowledge are more resistant to future

attempts at change […] and are more likely to predict future behavior […]"

Likewise, the language used when framing the research also has a considerable impact on the public opinion found, particularly in a situation limited knowledge amongst respondents. This may explain to some extent the discrepancies between results in different studies. Thus, it can be said that public opinion on biofuels, at least up until this point in time, may be regarded as highly variable and easily swayed. The policy implication is that public support related to biofuels policies may change quickly and significantly depending for instance on biofuels related events, communication, and information. Improved levels of science based public knowledge and transparency of positive as well as negative consequences are likely to decrease this uncertainty.

5.2. Influence of media and discourse

Mass media has been scholarly studied as a main element actively shaping people's perception of controversies [74]. Particularly, it has been discussed that mass media, including Internet-based media [75,76], may support the creation of "hegemonic discourses", thereby undermining the public debate [77,78]. Indeed, Delshad and Raymond [79] find that the influence of media is key in understanding the dynamics of public opinion on biofuels, as changes in the dominant media narratives and frames are found to have a notable impact on people's opinion. This concurs with Selbmann [41], who uses discourse analysis in order to describe the dynamics of dominant discourses in Germany and how these relate to policy measures.

Eklöf and Mager [56] explores the characteristics of the media publications surrounding biofuels in the Swedish context, and finds that some actors — i.e. policy institutions, universities and industries — are considerably more represented in the media space than other actors, such as NGOs and individual views — e.g. in blogs. Consequently, marginal standpoints and counter voices are less represented. In Sweden, the view supported by the Swedish policy-industry-academia nexus, emphasises environmental benefits of biofuels, and was found to be dominant in the national press and national representations on the Internet. These dominant actors are able to mobilise larger resources, such as networks and funds for gaining visibility online and to form alliances in order to gain visibility [56], which explains in part the unbalance in the weight of actors. Furthermore, Kangas et al. [80] has, in a Finnish case study of media representations of the sustainability of tree stump extraction for energy production, shown a polarisation enhanced in the media, where stakeholder perspectives became less nuanced and more sharp in the media representations. Based on these findings they recommend a "versatile utilisation of knowledge brokerage" [80] to enhance more 'unfiltered' science based public discussions, and the call for transparency is supported as a central theme by a number of authors [26,34,35,81,82].

The limited public knowledge regarding biofuels, combined with the influence of media in shaping opinion, and the unbalanced position that some actors may have in the media, underlines the risk that public opinion may be easily swayed.

5.3. Policies for biofuels implementation

One crucial subject, only scantly covered in the literature reviewed, is the public support towards particular policy options for the implementation of biofuels. Indeed, Delshad et al. [46] is the only study that thoroughly covers public support towards different policy options. It is however key to explore public opinion towards biofuel policies as these are a major element influencing the public support of biofuels. Indeed, even though there is an overall positive public opinion about biofuels, depending on the way these are scaled up, the implementation may entail further support or bring about resistance. Indeed, Delshad et al. [46] showcases that respondents often framed their opinions about policies for developing biofuels in terms of fairness and equity, while this strand was not usually mentioned when considering biofuel technologies. Thus, different parameters are deemed relevant by the public depending on whether one is assessing biofuels technologies or policies. Likewise, Jensen and Andersen [47] identify that fairness is a key concern for the implementation of biofuels:

> "Another issue concerning reduction in consumption was about equality. A female respondent expressed her opposition to abandoning either travel or anything else in favor of climate or environment if all did not sacrifice equitably. She would not be the only one who did "the right thing," and even if she were convinced that a reduction in consumption was necessary to address climate-change problems, she underlined that in her opinion any restrictions to mobility (or other consumption goods) must be equal to be regarded as fair and acceptable." [47].

Regarding policies, Jensen and Andersen [47] also showcases that there is a demand for democratic decision-making processes. Both the demand for fair policies and democratic policy-making processes are particularly relevant elements when considering the shaping of public opinion. A neglect of these dimensions may be part of what brings about complex movements such as the French riots — les gilets jaunes — that stemmed from a carbon tax perceived as unfair by politically diverse groupings of people [83,84].

Although such policy implementation aspects are paramount, most research is directed towards public perception of biofuels per se, and does not consider public perception towards different options for biofuel implementation, which is explicit in Balogh et al.:

> "Our research has undoubtedly proven that the attitude of tested segment of Hungarian car drivers towards the biofuels is essentially positive, thus, resistance is very unlikely in the further implementation of biofuels policy in Hungary." [24].

Such simplification may prove misleading, as people may also care about how biofuels will be implemented, i.e., about the specific policies enabling biofuel implementation.

A few recent studies add to the understanding of the relationship between public engagement, public opinion and policies. Shortall et al. [85] investigate main stakeholder's perspectives on the utilisation of "marginal land" for energy crops production in Denmark. They conclude that decisions need to reflect a balanced approach that includes "questions of equity, access and practicality", and that the deployment of marginal land therefore needs to be based on public deliberation and democratic discussions [85]. This has recently been coined with the "social license to operate" [86,87] — a term originally developed in the mining industry as a response to the opposition to extraction activities. The term conceptualise the trust relationship between a local community and a business [86], which is parallel to the trust in local authorities that may lead to support for biofuel production plants [43]. In line with the present study, Baumber concludes that the aspect of trust is underrepresented in studies of the social dimensions of cellulosic energy cropping. In a more general study of biofuel policies in Germany and Brazil [88], Takaes Santos concludes that broader deliberation on biofuel policies and large-scale biomass implementation, can be important in supporting public understanding and reflexivity towards the related risks and the way in which implementation affects environmental efficiency and social equity.

6. Conclusion and recommendations

6.1. Conclusion

This paper has investigated the literature on public opinion of liquid biofuels in the EU, with a special focus on (i) the influence of knowledge, (ii) the influence of the perceived risk redistribution implied by biofuels

development, classified as risk offsetting, risk transfer, risk substitution, and risk transformation. Adopting the risk redistribution approach enhances the identification of aspects potentially not covered in assessments of public opinion, and supplements the risk and uncertainty framework [26]. Overall, we can conclude that qualitative assessments (for instance Refs. [46,47]) are more appropriate to capture wider aspects of public opinion regarding biofuels than simpler approaches focusing on a single indicator, such as the willingness-to-pay, which appear more limited.

The public perception of liquid biofuel is predominantly reported as positive in the EU [23,24,54,62], and such positive attitude increases when technologies are based on feedstocks which do not compete with food production [42,47,61]. However, the study also reveals that the reported levels of public understanding of biofuel technologies, as well as potential negative impacts of biofuels, are limited [23,47,55,61]. The low level of public understanding embeds the risk of public opinion being swayed [41,56,79], for instance due to dominant discourses in public media, to singular events, or to social media and search engine created "echo chamber" and "filter bubble" phenomena [89,90]. Finally, the perception of policies for biofuels implementations, particularly in terms of fairness, is identified as a key element by the few studies that consider policies [46,47]. As such, the future of biofuels may very well depend on the increased likelihood of support from an informed and educated public, not only towards technologies as such, but also towards policies for biofuel implementation, and envisioned futures.

6.2. Recommendations

The considerable influence of media and discourses on public opinion, partly due to insufficient public knowledge, poses a major challenge on how to prepare the public to take qualified part in the democratic debate related to biofuel technologies and policies, especially regarding the sourcing of feedstocks. As McKay et al. [90] note, the best defence against these phenomena is to design the information flow to support reflection and understanding of diversified perspectives:

> "[…] rather than designing to change views, we suggest designing to support people in becoming and staying informed. This should be achieved in ways that encourage reflection".

This perspective stands in contrast to a strategy where the aim is to persuade to citizens e.g. to accept (or reject) biofuels.

Grasping the complexity of prospected public opinion requires dialogue and reflection. In line with this, we recommend using more qualitative methods, as well as seeking inspiration in participatory technology assessment methods and more generally deliberation as a mean to reflexivity that underline an explicit agenda of democratising the technology-debate and development [82,91–94]. As such, we recommend that the investigations of public opinion needs to be widened so that (i) public support towards specific policies for biofuel implementation is assessed; and (ii) qualitative prospective assessment methods inspired by participatory technology assessment are used. Specifically we recommend that the risk-framework and the uncertainty framework explicitly is covered in these assessments. The explicit acknowledgement of the integrate risks and uncertainties related to technological transformation and the use of this in prospective assessment is an important prerequisite for a science based realisation of the precautionary principle which is at the heart of European science and technology policy. This prospective approach may then be supplemented by the "snapshots" of contemporary perceptions that dominates the current types of assessments of public opinion in the field of liquid biofuels.

Author contributions

Søren Løkke conceived and designed the analysis, contributed to data collection, performed the analysis and wrote the paper. Emmanuel Aramendia collected majority of the data, performed the analysis and wrote the paper. Jonas Malskær collected a large part of the data, performed part of data analysis, and contributed to early phases of the writing of the paper.

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