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Creating a social license to operate? Exploring social perceptions of seaweed farming for biofuels in Scotland, Northern Ireland and Ireland

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ABSTRACT

Seaweed aquaculture is a growing industry due to the multiple uses of macroalgae. One such use is bioenergy, which raises uncertainties concerning economic feasibility and social implications. Most industries likely to have an impact on the environment and people are subjected to resistance from communities of interest and local communities. People are now empowered to communicate their expectations and influence industrial activities by granting or withholding their social license to operate (SLO). For new industries like seaweed cultivation for bioenergy, it is crucial to understand and meet societal expectations, and as such, SLO has become a major consideration. This mixed methods study aims to investigate perception of seaweed cultivation for biofuels in potential areas of developments (Scotland, Northern Ireland and Ireland) in order to determine critical considerations for future SLO. As respondents were mostly unfamiliar with the activity, we found that their perceptions are constructed through comparisons and analogies to familiar industries following the social representations theory. While the survey revealed a general positive perception for biofuels from seaweeds, potential SLO for future projects appears to be subject to several conditions: environmental impact, respect of local population's lifeworld and a truthful relationship with the developer. We showed that scale of exploitation is pivotal in terms of perception for seaweed cultivation and is likely to greatly influence SLO. The scale of exploitation along with its effects on communities and environment, as well as dialogue adapted to local context, will require serious consideration by companies looking to farm macroalgae for biofuels.

1. Introduction

1.1. Background

The world is facing an unprecedented environmental challenge that requires a drastic shift in the way we consume and produce energy [1]. Developing effective and efficient energy technologies while minimizing the effect on the environment is critical to limiting global warming to 1.5 °C. However, industrial activities, including those in the renewable energy sector, have to achieve acceptance and approval from the general public and the local communities in which they operate [2,3]. It is recognised that local communities and communities of interest, including stakeholders beyond the local area, can be empowered to communicate their expectations of industrial activity and may object to developments resulting in projects being impaired or failing [4,5]. The importance of community support for a specific project has been termed Social License/License to Operate (SLO). There are many projects worldwide for which SLO have not been gained, for example: the Enbridge pipeline in Canada [6], wild seaweed harvesting in Scotland [7] or Seafish, Tasmania's super trawler [8]. These cases demonstrate that public support can be withdrawn by the community due to various factors, such as environmental concerns or inappropriate engagement strategies, with significant impacts for the industries involved [6,7,9].

For any new or developing sector and project, the question of building SLO at an early stage is of great importance to avoid conflict and fully integrate within the local community. In this study, we investigate how future SLO can be envisioned through understanding public perceptions prior to an industry development. To do this, we identify the themes that emerge from perceptions study of seaweed farming for bioenergy production in Scotland, Northern Ireland, and Ireland and connect them to the pillars of SLO.

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1.2. Principles of social license to operate

The SLO framework emerged from the mining industry in the 1990's when developers realised that meeting legal requirements could not fully guarantee to successfully operate an activity within communities [10–12]. SLO has been criticized for being coined by industry to operate with less difficulty within their host communities, yet, it has become a tool that enable communities to voice their opinions and be heard by companies [6]. Issues relating to the social acceptability and social acceptance literature are relevant to SLO. However, SLO attempts to go beyond acceptance and empower communities by proposing a framework that characterizes the relationship between projects and communities of interests at different levels [11]. The different levels of SLO start from the absence of SLO (withdrawal), to acceptance, approval and finally psychological identification or co-ownership, which is indicative of profound integration of the project within its community [5,9,13].

According to Boutilier and Thomson's [9] model, the different levels of SLO are linked to four factors or pillars:

(1) Economic Legitimacy - the perception that the activity will bring an economic benefit to the community of interest,
(2) Socio-political Legitimacy - implies that the company 'acts according to stakeholders' views of fairness', 'including the notion that the project should contribute to, and respect the local way of life by meeting expectations about its role for society',
(3) Interpersonal Trust - the perception that the developer 'listens, responds, keeps promises, engages in mutual dialogue and exhibits reciprocity in its interactions' with the community of interest,
(4) Interorganizational Trust - which implies that 'relations between the stakeholder's institution and the project are based on an enduring regard for each other's interests' [9].

SLO has been studied across many already operating marine sectors such as: aquaculture [5,14,15] and marine renewable energy [16–19]. In the marine renewables sector, especially for wind energy, conflicts and lack of SLO can be due to visual impacts, environmental impacts, location as well as poor communication and engagement with local communities [16,20]. Similarly, in the aquaculture sector, fish farming in particular can suffer from a poor reputation due to perceived damage to the environment [21,22]. On land, the first generation biofuels sector also suffers from a lack of SLO due to the deforestation, water contamination and depletion, and the competition with food production [23]. It is not yet clear if and how SLO could be predicted for future industries such as seaweed cultivation for biofuels with which the public is still unfamiliar.

1.3. Perceptions and social license to operate

Hall et al., [17] highlighted the importance of researching factors that may influence SLO, such as public perception of an activity. This has been exemplified by a study on the finfish industry in Scotland demonstrating that poor public perception of the industry negatively influences SLO [14]. In the case of the whole aquaculture sector Mather and Fanning [5] showed the diversity of qualitative and quantitative methods that can be used to study public perceptions, bringing insight on how to overcome potential difficulties for future projects and enhance SLO. Likewise, there is a large number of studies exploring acceptance mechanisms and SLO after the development of industrial activities. However, recent research in the marine renewables sector has acknowledged the need for investigation on social acceptance before the industry and project develop as it may impacts operational phases of the activities [24,25]. For Devine-Wright and Wiersma [25], this type of research represents the opportunity to facilitate the transition towards low carbon energy by providing insights into preferences for future technologies and developments.

For emerging industries, social acceptability research prior to development has value as it involves investigating preconceived opinion formed through deduction rather than experience and familiarity with the technology. For example, for the adoption of novel aquaculture practices for which there are low levels of public awareness, it was found that education via improved communication is needed in order to gain support [26]. Evidence from carbon capture and storage showed that considering a lack of general awareness among the public, the framing of the information may greatly influence perceptions of the activity [27]. Perceptions are extremely variable and not only shaped by direct communication but also by the context such as culture, geography and other social factors [27,28]. As more host communities are likely to be affected by new technologies, studying preconceived opinions that could influence SLO prior to development should help define how to better communicate and allow a better fit for these industries within communities and society [27,28]. Bidwell [29] demonstrated that beliefs and attitudes towards wind energy are positively influenced by altruistic personal values, while traditionalist values negatively influence these attitudes. Russell and Firestone [30] found that there were differences in opinions on wind energy between those who lived in an area prior to construction and those who moved in post-construction, with the latter generally having more positive attitudes towards the technology. Research in other sectors such as aquaculture and bioenergy with carbon capture and storage (BECCS) have also established that attitudes towards these industries can be influenced by contextual elements which are, at first glance, unrelated to the activity in question [7,14,26,27]. Serge Moscovici's social representations theory is a useful framework that helps to draw a deeper understanding of drivers of these social perceptions. It established that that individual views are shaped by social norms, culture, beliefs, knowledge and language in order to make the unfamiliar, familiar [31,32]. Beyond the perception of the activity itself, this underlines the importance of the context in which the activity is taking place as it may have positive or negative effects on perceptions of the activity.

1.4. Context of seaweed farming for biofuels

In Europe, seaweed farming or cultivation is of increasing interest for multiple purposes such as food production as well as higher value products used in the food industry, pharmaceuticals or cosmetics [33]. To this day China and Indonesia are the largest producers of seaweed biomass from farming mostly for the food market [34–36]. Seaweed farming is the process of human introduction and cultivation of macroalgae on various artificial substrates either in the sea or on land in tanks and is considered an aquaculture practice [37]. The production of seedling material typically takes place in a hatchery and the young seaweeds are deposited on lines or nets suspended in the water from moorings [33,38]. Mature seaweeds are harvested, which means removed from their artificial substrate, by hand or mechanically. This process differs from the activity of wild harvesting which relies on wild seaweed material [7]. Seaweed can also be farmed in association with other aquaculture species through integrated multi-trophic aquaculture (IMTA) [39,40] or integrated with offshore marine renewable sites [41].

Since the 1970's, research and industry have been interested in the potential of seaweed for the production of third generation biofuels, including bioethanol, biodiesel or biogas to use as transport fuels or to produce heat and electricity [42–44]. In comparison to first and second generations of biofuels, seaweeds as a feedstock for bioenergy could represent numerous advantages including their high growth rate and the absence of competition with land food crops [38,45]. In 2019, the MacroFuels project successfully tested seaweed biofuels mixed with E10 in a car engine concluding satisfactory performance and emissions when compared with traditional fuels. However, obstacles remain concerning the economic viability due to the high cost of seaweed production and variability in seaweed composition [46,47]. It is increasingly suggested that combining biofuel production with high value compounds such as

proteins, fatty acids, pigments used for cosmetics, nutraceutical and pharmaceutical application, could compensate for production cost and reduce waste production through biorefinery approaches [46,48].

The upscaling of seaweed farming remains of major interest, but also raises issues and challenges [33,49]. Large-scale seaweed cultivation in developed nations would require significant technical improvement, especially if the biomass is farmed offshore [38]. Mechanisation could be an appropriate solution for harvesting in order to compensate for the workforce needs [33,45,50]. Finally, finding appropriate sites that meet biological requirements without conflicting with other users of the environment brings another constraint [47,50]. Seaweed cultivation is a fairly recent aquaculture practice in Europe where regulation and licensing frameworks are still based on more established types of aquaculture, especially shellfish farming [34]. Literature from Ireland and the UK emphasized the need for adaptations in policies in order to ease licensing processes [34,51,52]. Conceptually, we envision farming seaweed for bioenergy production as crossing the borders of three different industries, bioenergy, marine renewables, and aquaculture; this may increase the complexity of future social interactions and SLO.

1.5. Knowledge and gaps on attitudes towards seaweed cultivation and bioenergy

Evidence from France and Scotland already shows that the scale of the farms can generate disputes between farmers and communities [7]. The authors note that more research is needed on how perceptions of seaweed farming in the communities most likely to be impacted by growth of the industry is linked to SLO for down-stream value-chains (i.e. the products that the farms are producing) [7]. In 2012, Roberts and Upham [53] published a study on management issues for macroalgae fuels touching upon public perception from the point of view of expert stakeholders. Their results showed that expected public perception could be negatively affected by visual impacts but more importantly by the competition for space at sea. In spite of these challenges, factors such as the provision of job opportunities for local communities may influence positively, the public perception of the activity [53]. Two recent studies have attempted to look at the public and community vision, rather than experts vision in the UK [52,54]. From the consumer perspective, the first study suggests a willingness from members of the public to make a trade-off between the space occupied by seaweed cultivation and powering more households with seaweed biogas [54]. Gegg and Wells [52] have also investigated questions on drivers of public perception of biofuel production from seaweed in the UK through focus group discussions with the public and stakeholders. Their results highlighted that the public respondents were mostly positive regarding the potential energy benefits but were not convinced of the overall legitimacy of the activity. They concluded their study by emphasizing the need of larger sample quantitative studies, including the variables of knowledge and awareness of the respondents [52].

At this stage, there are no ways to measure the different levels of SLO as it would require the existence of seaweed biofuels projects. For this reason, we propose to expand current knowledge on perceptions of seaweed farming for biofuels in three case study areas (Ireland, Northern Ireland and Scotland) where seaweed farming is already occurring at a small scale, where the biophysical conditions are suitable for large-scale operations, and/or there is governmental support for seaweed farming. By exploring perceptions in potential future communities of interest, using a bottom-up approach we aim to determine factors that may affect future SLO.

In order to do so; we use a mixed-method approach intending to sample a larger population than past perception studies expecting to complement previous research. We also investigate survey comments to highlight where themes coincide with the different aspect of legitimacy and trust as potential indicators for future SLO.

We address the following questions:

- What are the factors influencing the perception of seaweed farming for biofuels?
- How can perception of the industry prior to development inform on its legitimacy and trust requirements for future projects?

2. Materials and methods

2.1. Study area

Three locations were chosen, based on their traditional use of wild harvested seaweed, their biophysical potential to host the scale of seaweed farm required for seaweed derived biofuels, and the funding mechanism for the study (Interreg VA: Northern Ireland, Ireland, Scotland) as part of the Bryden Centre for Renewable Energy (https://www.brydencentre.com/). Local species of seaweeds such as Dulse (*Palmaria palmata*) have been traditionally hand harvested by the local population and used for food consumption or larger kelp species have been used as fertilisers across Scotland, Northern Ireland and Ireland. However, seaweed farming is not a traditional activity in these three areas and is at a nascent stage of development for small scale farms and research and development sites [55,56]. There are currently no sites dedicated to seaweed farming for feedstock for bioenergy, which means it was not possible to concretely target a specific community that would be more likely to face such a development than others would. However, as mentioned above, these areas are biophysically suitable for seaweed cultivation and there are a few small sites already present. Therefore, these areas include communities that are likely to interact with seaweed cultivation developments in the future.

2.2. Survey design

In order to understand the public perception of seaweed farming for biofuels and any potential links to SLO, we designed a mixed method survey with dichotomous items, Likert-type items, multiple choices items and space for qualitative comments following the Tailored Design Method from Dillman et al., 2014 [57]. A literature review of social acceptance and SLO for marine activities especially marine renewables and aquaculture papers, guided the questionnaire content. Considering the objective to explore the preconceived opinions of seaweed cultivation for biofuels, we decided that a quantitative structured questionnaire based only on findings from other marine industry activities would have constituted too stringent a frame for the survey. The quantitative questions were designed to assess the first impressions that participants had about this activity, taking into consideration their potential lack of knowledge. Scale items were designed to assess reported knowledge and levels of trust towards information providers (unipolar). Likert-type items were used for attitudes towards the industry (bipolar). The dichotomous items were designed to address questions about awareness. Open ended questions and space for comments were added to the survey in order to strengthen understanding of drivers of these attitudes [19,58]. These qualitative questions provided respondents with the freedom to express their opinions beyond the restricted frame of the quantitative options. This aimed to highlight other emerging variables as well as providing a reflection on the mechanisms that construct opinions prior to industry development [57,59]. Following Bryman's 2006 and 2016 [60,61] work on qualitative and quantitative research, this mixed method was designed for two main objectives: (1) explanation and development of the quantitative responses by the qualitative comments allowing a better completeness of the responses; (2) initiating new ideas and seeking new perspectives by exploring the themes emerging from the comments. In addition, we hypothesized that most participants would have little or no knowledge of the activity and this involved several design considerations. Firstly, specific attention was drawn to the wording of the questions in order to make it as simple as possible. The introduction statement was written in order to provide adequate information so the participant could understand sufficiently to

answer the questions, but avoiding introducing positive or negative bias. Secondly, we chose not to include neutral options in the questions in order to assess the likelihood of positive or negative responses and avoid the potential mid-point choice coming from an inclination to please the interviewer, as discussed by Garland, 1991 [62] and Croasmun and Ostrom [63]. It was expected that, if unfamiliar with the activity, a majority of respondents would rather pick the neutral option than to give uninformed opinions, thus creating a misuse of the neutral option [64]. Participants were encouraged to pick one side and reassured by explaining the questions were about their perception and not about their knowledge. The survey can be found in Appendix 2 along with questions objectives and the information sheet provided with the survey Appendix 1.

The design was also adapted to a mixed-mode administration, including online and in the street. We acknowledge that that the survey would reach participants outside of the coastal area, so included the variables *'housing distance from the coast'* and *'frequency of visits to the coast'* (Table 2) in order to account for the potential influence of this distance in the responses [65,66]. The use of a mixed mode (online and in the street) distribution of survey is justified to lower the costs of the fieldwork and improve timeliness. It is also a way for reducing measurement errors, increasing the response rate and reducing the coverage error in the sample [57,67]. However, it reduces the representativeness of the sample [57,67]. In order to accommodate in-person and online modes of survey implementation, specific attention was given to the design of the survey to adapt it to both modes. All the questions and information statements were worded in a way that they were identical and understandable when they were answered online or face to face in the street, to minimize potential errors due to administration mode. However, due to technical constraints the visual format (e.g. font, colour scheme) could not be applied in exactly the same manner.

2.3. Pilot and pre-testing

The survey was pretested with experts to strengthen the objectives and validity of the questions as well as the formatting of the survey. A breakdown of the questions and objectives is available in Appendix 2. Two pilots were conducted, online and in the street in order to test and adjust the wording of the questions and limit measurement errors. The online pilot was conducted with PhD students at the Scottish Association for Marine Science. This allowed adjusting the online survey interface and visualizing the data output in order to create a similar format for both sets of survey data. The second pilot was conducted with members of the public on the street in Oban and highlighted a need for a better adaptation of the introduction statement, reordering certain questions and the inclusion of a final space for qualitative comment as certain respondent needed to expand on certain ideas and questions.

2.4. Survey distribution

The survey was distributed in person in the street and online, through nonprobability convenience sampling. The street surveys were conducted over a period of 4 weeks in Northern Ireland and Ireland and over a period of 3 weeks in Scotland between April and September 2019. The survey was distributed throughout the week and weekends to improve the likelihood of sampling a large portion of demographics (e.g. retired people, workers, students). The online survey was distributed via email through Universities present in the local areas (University of Highlands and Islands (Scotland), Queen's University Belfast (Northern Ireland) and the Letterkenny Institute of Technology (Republic of Ireland) and through local towns Facebook groups. A GDPR compliant web survey platform, www.onlinesurveys.ac.uk, was used. For the in person surveys, participants were sampled in the streets of local towns along the coast (Fig. 1). For the street survey, towns were chosen in order to cover a broad range of the coastline in the three areas and to maximize the response rate. The three areas are important locations of interest for tourism and leisure, these places are frequently visited by non-residents during weekends and holidays, especially during the spring/summer season [68–71]. As SLO is granted or withdrawn by members of local communities, as well as people outside of what is considered as the local area but who might be part of a community of interest, we chose to expand the sample beyond the local residents. Considering our choice of sampling strategy and the mixed-mode administration, we have to underline that the study is not

Fig. 1. Map of the 16 towns chosen as street survey sites during the summer 2019, along the coast of Northern Ireland ($N = 145$), Ireland ($N = 110$) and Scotland ($N = 89$).

representative of the general public at a national scale. It rather focuses on people living, working, studying and also visiting these areas. A total of 767 participants were surveyed: 344 in the street and 423 online. The locations of the street survey and the number of responses per location can be found in Fig. 1. A full breakdown of the response rates can be found in Table 1.

2.5. Analyses

Data collected in the street were entered into an Excel spreadsheet by the first author. This process was done on a daily basis in order to avoid fatigue and reduce errors. Online data were first downloaded to Excel and stored on the Scottish Association from Marine Science network drive.

The survey data included 767 respondents to the survey of which 442 responded to at least one of the qualitative questions (Table 1). The responses from the online and street survey were analysed separately and compared. All of the quantitative questions were analysed statistically using the software RStudio 1.1.463 [72]. The statistical approaches used are described in the results section. The qualitative responses were thematically coded by the first author with Excel following a similar approach to Billing, 2018 [14], described as follow: responses were separated according to the answer to the previous question (e.g.: negative or positive). They were also separated according to the administration mode and the residency of the respondent to identify any differences that might be due to these parameters. The first step was an initial exploratory coding comment by comment, allowing identification of emerging themes in the responses [14,59]. Through the initial process, memos were written to highlight recurring themes for each question. Codes were then organised according to these themes and initial comments were reviewed in order to verify their effective link with the themes. This iterative process allowed at each stage to generate new and clearer themes and improve coding accuracy [73]. In order to link perceptions to SLO we used a matrix mapping the emerging themes from the comments within the components of legitimacy and trust [9].

3. Results

3.1. Descriptive statistics

Survey work resulted in a total of 767 responses, the descriptive statistics for each administration mode are presented in Table 2. The online sample over-represents younger respondents (18 to 24 and 25 to 44 years old) while the street sample is closer to the demographics for the three different areas with a slight over-representation of the 65 to 74 years old category [70,74,75]. In order to account for variations between the two samples, the results are presented separately in the two administration modes. We consider that the two administration modes did not lead to significant errors of measurements, as this was supported

Table 1
Response rates for the street survey per sampling area. Response rate for the online survey calculated from the number of respondents who completed the survey divided by the number of people who opened the survey but did not complete it. Rate of qualitative responses: number of respondents who responded to at least one of the qualitative questions out of the total number of responses (N).

	Online	Street		
	N = 423	Northern Ireland N = 145	Ireland N = 110	Scotland N = 89
Total rate for survey responses	0.51	0.37	0.37	0.56
Rate of qualitative responses	0.73	0.31	0.37	0.5

Table 2
Descriptive variables online, in the street and combined.

		Online %	Street %	Street and online
	Categories	N = 423	N = 344	N = 767
Reported level of knowledge about marine industries	None	14.6	20.1	17.1
	Very moderate	29.3	26.7	28.1
	Moderate	31.4	41.9	36.1
	High	17.5	8.7	13.6
	Very high	7.1	2.6	5.1
Reported level of knowledge about biofuels	None	15.1	19.8	17.2
	Very moderate	38.8	31.7	35.6
	Moderate	32.6	37.5	34.8
	High	10.2	10.5	10.3
	Very high	3.3	0.6	2.1
Reported awareness about seaweed farming	Yes	80.2	62.5	72.3
	No	19.6	37.5	27.6
Reported awareness about seaweed biofuels	Yes	55.3	36.7	47.0
	No	44.7	63.4	53.1
Housing distance from the coast in km	0 to 5	64.5	60.2	62.6
	6 to 10	13	9.3	11.3
	11 to 20	8.3	10.5	9.3
	>20	14.2	20	16.8
Frequency of visit to the coast per week	<once	40.7	29.4	35.6
	1 to 2 times	15.4	22	18.4
	3 to 5 times	11.6	8.1	10.0
	>5 times	32.2	40.7	36.0
Living country	Scotland	54.4	21.2	39.5
	Northern Ireland	31.4	48.5	39.1
	Ireland	14.2	30.2	21.4
Age range	18–24 years old	18.9	6.7	13.4
	25–44 years old	41.1	17.4	30.5
	45–64 years old	34.9	41.6	37.9
	65–74 years old	3.3	25.9	13.4
	75+ years old	0	7.8	3.5
	Prefer not to say	1.7	0.6	1.2
Formal education	No schooling	0.5	6.1	3.0
	Secondary school	19.1	45.3	30.9
	Bachelors	34.5	22.9	29.3
	Masters	25.5	6.1	16.8
	Doctorate	10.2	1.7	6.4
	Professional degree	6.4	11.3	8.6
	Prefer not to say	3.8	6.4	5.0
Employment situation	Retired	5.0	41.0	21.1
	Employed	57.8	46.8	52.9
	Unemployed	0.9	6.1	3.2
	Student	36.1	4.6	22.0
	Prefer not to say	0.2	1.4	0.8
Employment	Accountancy, banking, finance, business & insurance activity	4.5	4.4	4.4
	Arts and Entertainment	7.3	1.5	4.7
	Charity and voluntary work	0.5	1.7	1.0
	Education	25.4	11.6	19.2
	Environment, agriculture, forestry & fishing	3.6	3.8	3.7
	Human Health and Social Work Activities	11.6	16.6	13.8
	Informatics	2.8	0.9	2.0
	Information and Communication	1.7	1.7	1.7
	Leisure, sport and tourism	2.4	4.1	3.1
	Manufacturing and Construction	1.2	10.5	5.3
	Mining, energy and water supply	1.2	2.3	1.7
	Other	4.0	4.1	4.0
	Public admin, law & defence, social security, Military	3.3	10.8	6.7

(continued on next page)

Table 2 (*continued*)

	Categories	Online % N = 423	Street % N = 344	Street and online N = 767
	Religious	0.7	0.3	0.5
	Sale, Accommodation & food services	3.6	18.0	10.0
	Scientific and Technical	25.1	4.9	16.1
	Transportation and Storage	1.2	2.9	2.0
Gender	Female	56.5	49.1	53.2
	Male	42.6	50.9	46.3
	Other	0.9	0.6	0.8

by the strong similarity in the content of qualitative responses. However, the majority of the very negative responses were given in the online sample, as expected due to more upfront and frank behaviour, while the responses in the street tended to be less negative as they were directly addressed to the researcher [57]. When respondents refused to respond to certain questions, '*NAs*' were attributed.

Sprearman's rho (ρ) correlations and Kruskal-Wallis tests were performed to explore potential links between variables. Spearman's ρ correlation were used and interpreted according to the thresholds ρ < 0.3 = weak correlation, ρ |0.3:0.6| = medium correlation [76]. Statistical results are complemented through each section with the qualitative results in order to describe underlying reasons of their responses and enhance completeness of the data [61]. In the online sample, the confusion that appeared between seaweed farming and seaweed harvesting was the only major qualitative difference between the two samples. In some cases, the term farming was interpreted as the activity of seaweed harvesting while certain participants had doubts about the definitions or what it meant in terms of techniques.

'It all depends on how it will be farmed. Dredging will not be beneficial, more information required on seaweed farming to allow an informed choice.' (R145 – Online, Scotland)

Participants responding positively to the quantitative questions often stated worries and concerns in their comments. These worries and concerns converged towards the themes highlighted in the negative comments.

3.2. Perceptions of seaweed farming

The four perception questions presented in Fig. 2 were gathered to generate a single measure of perception using the Cronbach's α to insure the internal reliability (Cronbach's α of Perception: online = 0.83; street = 0.71). The same process was used to create the variable *Reported knowledge* (reported knowledge about marine industries and reported knowledge about biofuels: Cronbach's α: online = 0.71; street = 0.74) and *Link to the coast* (Living distance and frequency of visit: Cronbach's α: online = 0.63; street = 0.57). The perception of seaweed farming for biofuels (General perception Fig. 2a), and the perception of the effect on environment, local community and local economy (Fig. 2b, c, d) present similar pattern of responses mainly towards the two positive choices. For the three locally focused cases/variables (Fig. 2b, c, d), the choices were mostly in favour of 'beneficial' rather than the extreme positive response 'very beneficial'. As mentioned above most of the very negative responses stating the perception of very damaging effect of the activity were given online. Even though the pattern of responses were the same in the three locations (Scotland, Northern Ireland and Ireland), perceptions were significantly less positive for Scottish residents, as shown by the Kruskal-Wallis and Dunn post-hoc tests (Table 3). It is worth remembering the confusion between seaweed harvesting and farming that occurred in a number of responses in the online sample, which may have led to the larger number of negative comments. Seaweed farming may have evoked the image of kelp dredging and its associated impacts on the marine environment, such as destruction of the wild seaweed forests. These negative comments were mostly given by Scottish respondents, which may explain the significant difference with the two other locations.

The perception of the activity is negatively correlated with the level of education. This means that less formally educated respondents have demonstrated a more positive preconceived perception of the activity. Respondents with higher levels of formal education have given more negative responses. However, perception did not vary significantly according to reported awareness or reported knowledge (Table 3).

The qualitative analysis revealed that given perceptions were based on comparisons to other industries. For participants with positive perceptions, comparisons were generally expressed following the pattern that seaweed farming for biofuels would be positive in comparison to fossil fuels, first generation biofuels, fish farming or wild seaweed harvesting. Similarly, negative responses also related to other activities such as negative analogies to land farming, especially for biofuels, the fossil fuel industry, fish farming or negative comparisons to other marine renewable technologies. The production of biofuels from seaweed was also considered as not beneficial enough in comparison to other renewables, such as wave and wind energy. Likewise, certain respondents stated seaweed farming would be positive but only for food and other high value products, not for biofuels.

'We shouldn't farm seaweeds for biofuels. Other renewables are better. It should only be used for food.' (R356 – Street, Scotland)

Throughout the comments, environmental concerns were numerous and were highlighted in different ways, such as worries about pollution and various negative effect on biodiversity.

'The local wildlife is my biggest concern, so if seaweed farming impacted on the local wildlife, then I would change my mind about it.' (R183 – Online, Scotland)

These environmental concerns were dominant in comparison with socio-economic concerns and this was supported by quantitative responses see Fig. 3. For both, the environmental effects remain the main issue to be addressed, before economic and social concerns. Nevertheless, it appears that seaweeds currently benefit from a green image and are perceived as a source of environmentally friendly and sustainable products.

'It is a green option, better for the environment.' (R115 – Online, Northern Ireland)

'Seaweeds are organic, it is different than coal or oil' (R345 – Street, Scotland)

Respondents expect the farming activity to be as sustainable as possible and beneficial to the environment by creating a carbon sink and reducing hydrocarbon demand. However, participants were also concerned that farming might be environmentally damaging at a local scale. In addition, some respondents suggested that monoculture could be detrimental. The 'other' category in Fig. 3, a. and b. mostly contains respondents who were not willing to prioritize only one aspect and considered that the three should be of equal importance. Even though social and economic concerns were not the main priority in the quantitative responses, it was mentioned that the three parameters should coexist to make the industry prosper and sustainable. Many comments were linked to price, value, employment as well as technical consideration both positively and negatively.

3.3. Seaweed farming in the local community: potential support and dialogue

The majority of participants responded that they would be supportive of a seaweed farm project close to their home (Fig. 4). The pairwise comparisons of the support, using Dunn's post-hoc test, showed that scores were significantly different between each country indicating that the level of support varies significantly between the three locations (Table 3). Level of support was highest in Northern Ireland and lowest in

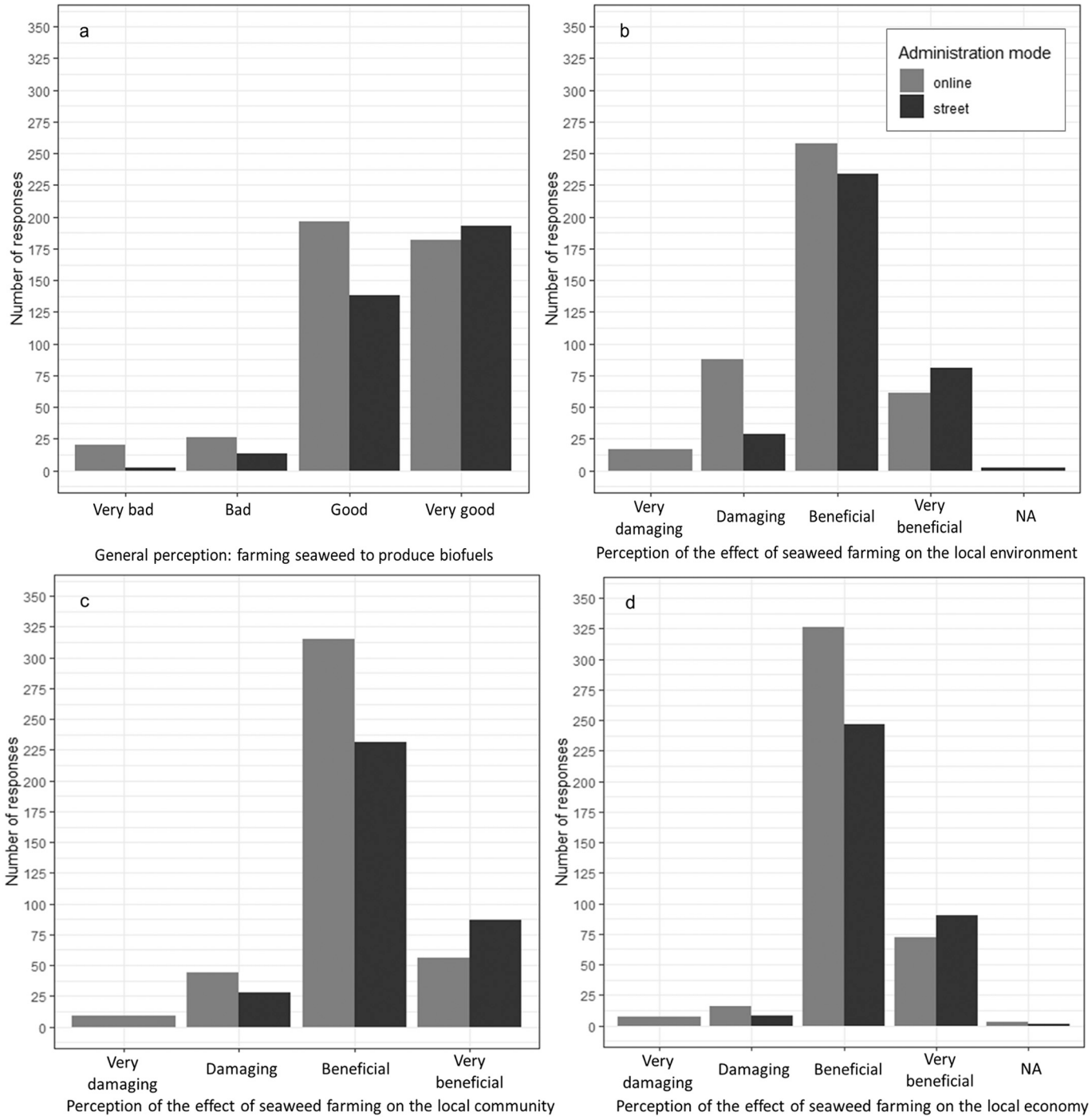

Fig. 2. Perception variables online and in the street: General perception (a.); Perceived effect on the local environment (b.); Perceived effect on the community (c.); Perceived effect on the local economy (d.).

the Republic of Ireland. The level of support appears negatively correlated with age, implying that younger respondents generally gave more support than older respondents. We also observed a weak positive correlation with the level of reported knowledge (Table 3).

When compared to the perception questions, we noticed in the comments the content of the concerns on environmental impacts are similar. However, in the context of a local development, responses were dominated with local social and economic topics such as employment or potential negative effects on the operation of activities like tourism or fisheries. For this question, comments tended to identify potential personal effects on the respondent's lifeworld by the operation and relationship with the developer. Many respondents stated that they would not be willing to give full support before being entirely informed about the project, which linked with the majority of responses being in favour of dialogue with the company (Fig. 4). 93% of the respondents would be open to dialogue with the company (91% in the street and 95% online). The willingness to engage in dialogue is positively correlated with the reported knowledge and the formal education of the respondent and, similarly the level of support is negatively correlated with the age. It was also significantly higher for respondents who had heard about seaweed farming before (Table 3). However, there was no significant difference between the three countries. This willingness to be engaged in

Table 3
Spearman's rho correlation and Kruskal-Wallis test between descriptive variables and perception, support, dialogue and acceptable size. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

	Perception	Support	Dialogue	Acceptable size
Spearman's rho correlations ρ < 0.3 = weak, ρ |0.3:0.6| = medium correlation, ρ > 0.6 = high				
Reported knowledge	−0.01	0.10 **	0.12***	0.14***
Link to the coast	0.02	0.04	0.06	−0.09*
Age range	0.02	−0.16***	−0.11**	−0.12***
Formal education	−0.21***	0.05	0.11**	0.06
Kruskal-Wallis				
Reported awareness of seaweed farming	X^2 1.5, df = 1	X^2 1.9, df = 1	X^2 16.0, df = 1, ***	X^2 1.0, df = 1
Reported awareness of seaweed biofuels	X^2 0.13, df = 1	X^2 3.5, df = 1	X^2 4.2, df = 1	X^2 1.9, df = 1
Living country	X^2 23.1, df = 2, ***	X^2 27.4, df = 2, ***	X^2 1.4, df = 2,	X^2 2.9, df = 2,
Dunn's post-hoc living country				
Scotland/Northern Ireland	3.8***	3.1**		
Scotland/Republic of Ireland	4.2***	−2.6*		
Republic of Ireland/ Northern Ireland	−1.0	5.1***		

dialogue was justified in the comments by the need for information on the technical details, potential impacts and benefits of the development highlighting that respondents were willing to make informed decisions either positive or negative.

'I can't support before I know more about it, is there a smell?' (R238 street – Republic of Ireland)

Beyond receiving transparent information, dialogue was seen as an opportunity to give their opinion, be heard, be involved and be able to influence decision-making. They also expected transparency and to build trust with the developers. In this process of trust building some participants stated the importance of the source of information.

'Open dialogue creates the most transparency possible, providing a dynamic conversation between public and company. Issues, concerns, and critique may be addressed when they arise, rather than when they erupt in a mass public outcry' (R152 online – Scotland)

This result contrasts with the responses on the willingness to receive general information about seaweed farming for biofuels. Only 51% stated they would happily receive general information on the activity when it doesn't concern a development close to their home. Following this question, participants were asked for their level of trust towards companies, government, media and scientists to provide them with transparent information. Scientists appeared to be the most trusted source to provide general information, followed by the developers themselves, the media and lastly government sources. Several respondents indicated the importance of the science role in providing evidence for new industry development. Multiple comments insisted on the need of neutrality and independence of the scientists, which could influence the level of trust attributed to them.

'I trust scientists if they are independent. It is good in principles, but we need to know more about the science and all the potential consequences' (R305 Street – Scotland)

3.4. Acceptable seaweed farm size

The importance of the variable scale of the farming was highlighted by the literature and was a clear concern to many respondents in their comments, even before the question came up in the survey. The maximum acceptable size of a seaweed farm chosen was generally the smallest possible (1 to 5 football pitches) (Fig. 5). The responses do not vary significantly according to country or formal level of education. The maximum acceptable size of a farm is negatively correlated to the age of the respondent, similarly, to support and dialogue (Table 3). A slight

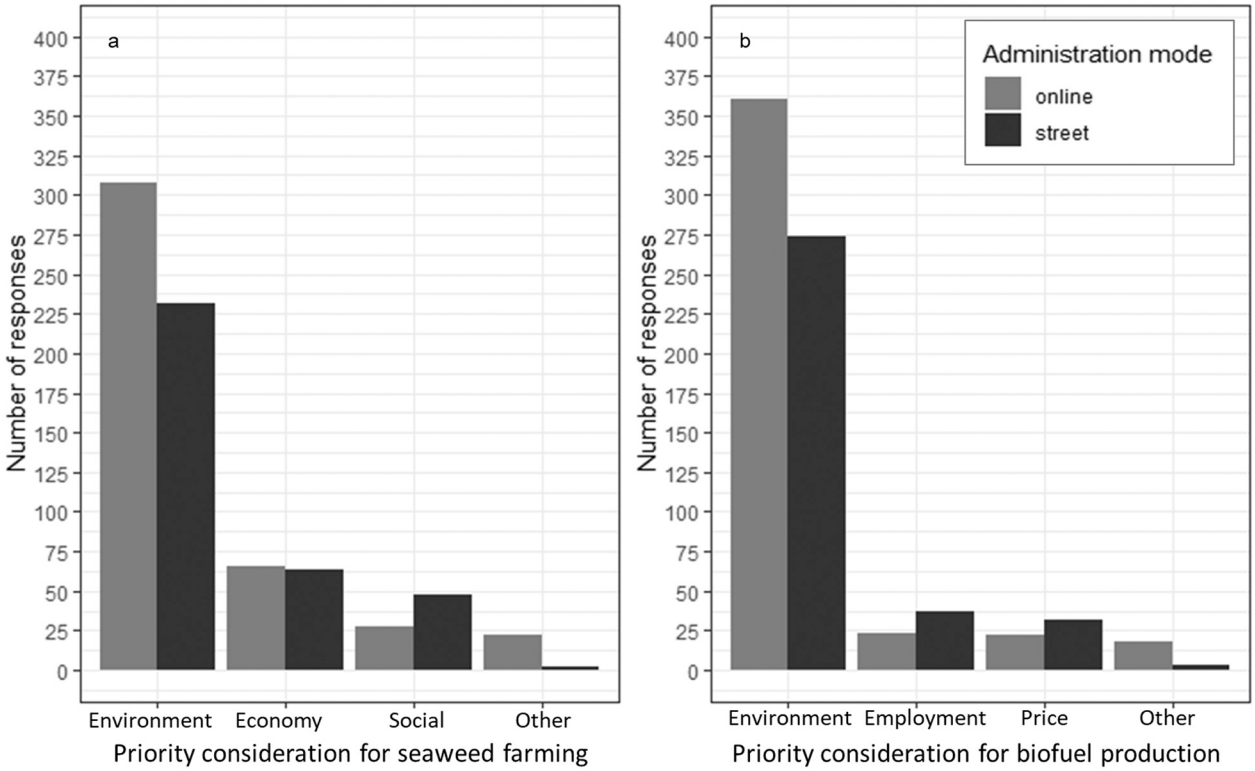

Fig. 3. Considerations of priority concern for seaweed farming (a.) and biofuels production (b.) according to online and street respondents in the three locations.

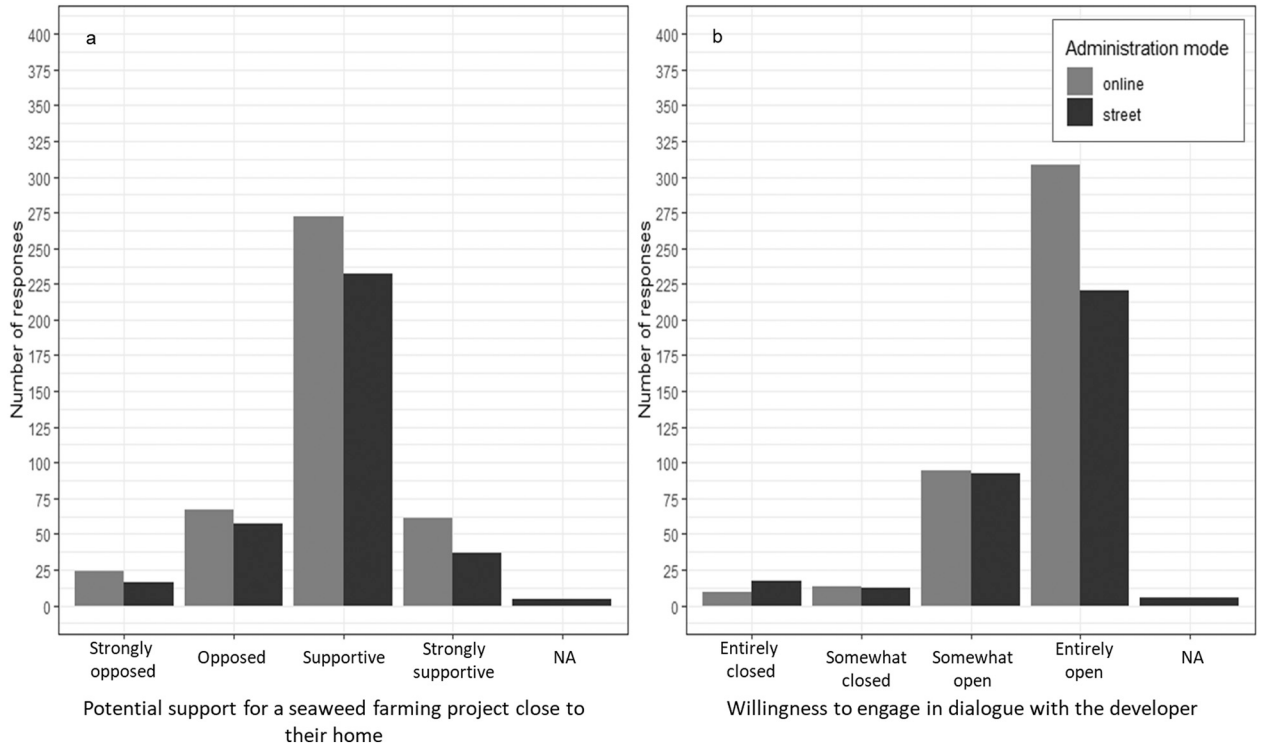

Fig. 4. Potential support (a.) and willingness to engage in dialogue (b.) in the case of a project in their backyard.

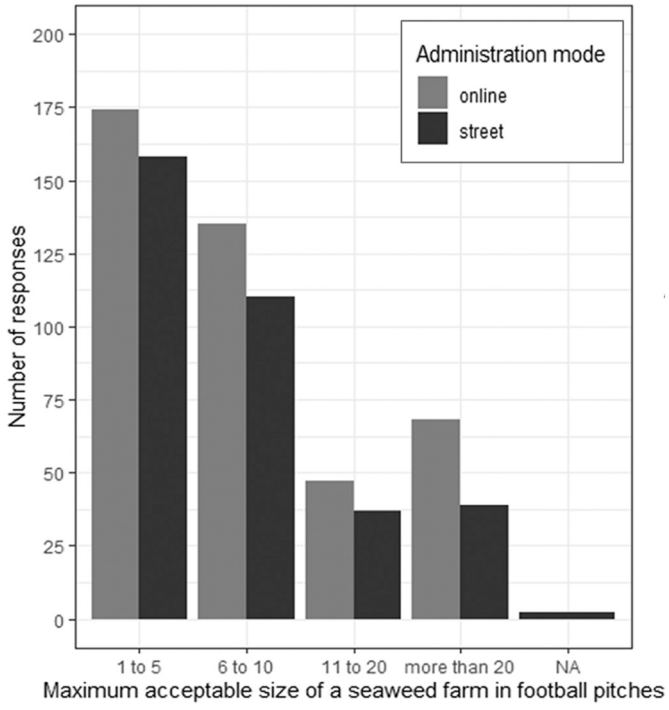

Fig. 5. Acceptable surface of a seaweed farm online and in the street in football pitches.

negative correlation also appears with the respondent's link to the coast (living distance and frequency of visits) meaning that respondents with a closer link to the coast had a slight preference for smaller farms. As mentioned above, comments about the size of the farm were abundant among all the qualitative responses and they combine the majority of the themes mentioned in the perception and support questions concerning environmental, social and economic concerns. Throughout this survey, scale has become the cornerstone variable that links all the aspects of the activity: environmental effects, community effects, ownership models, location, technical issues. While this is not exclusive, the positives comments were often associated with the idea of smaller scale farms and the negatives with large-scale.

'I would like to see farm allocation based around the concept of crofting or small holdings. If it was too large, corporate would probably ignore any environmental concerns against profit. It could be an opportunity to the small fishermen who have lost out to the factory fishing ships for example.' (R295 online – Scotland)

The only aspect that appeared more beneficial in a large-scale farm context would be the viability: several respondents adopted a "the bigger the better" attitude for economic viability.

'the bigger the better for economic viability and to have enough production for biofuels.'(R290, Street – Republic of Ireland).

3.5. From public perceptions to social license to operate

The qualitative responses to this survey gave insight on the potential focus for SLO. The themes emerging from the perception comments that link to SLO through legitimacy and trust are summarized in 4. The comments on the general perception of the industry related to the different aspects of legitimacy, with participants advising that the industry must develop in a fair way for society and local population and be economically viable. However, concerns about environmental issues were abundant in participant's perceptions and they constituted the major factors able to influence the legitimacy of the activity.

'Seaweed farming would help clean the ocean' (R271 Street – Republic of Ireland)

'It could be like a reserve for wildlife.' (R341 Street – Scotland)

'It will contribute towards CO2 reduction and lessen hydrocarbon demand.' (R396 Online – Republic of Ireland)

Responses on the perception of the activity in general did not give much insight into the variable of trust on a general level. However, the concept of trust became more evident as soon as respondents were

placed in the hypothetical position of a local community member when we asked them their potential level of support for a project near their home and their willingness to engage with the developer. These questions led to comments that were more personal, often relating to elements of lifeworld.

'Biofuels are good for the environment. But yes, maybe I would be concerned about the views from my house, property value etc.' (R309 Online – Scotland)

Most of the legitimacy themes highlighted in the general perceptions were also present in the local section of the questionnaire, where socio-economic matters were more frequent than environmental concerns. These themes related to employment, impact on the value of their home, competition with other industries, and road traffic. Finally, there were a large number of comments on the importance of the quality of the relationship with the developer, emphasizing the necessity of appropriate dialogue to develop trust and ultimately SLO.

'It would be beneficial for Island's communities but could be disturbing sometimes. It all depends on the communication from the company.' (R341 Street – Scotland)

4. Discussion

We studied the perception of seaweed farming for biofuels in order to assess preconceived opinions among the public and evaluate what factors may be involved in the activity's social license to operate (SLO). Based on our survey results, we discuss the key findings and critically reflect on how perceptions of the industry are created. In particular, we highlight that, support is conditional, engagement is a powerful factor in developing trust, and the keystone finding, that scale is a significant factor in forming opinions on seaweed farming.

4.1. Where do perceptions come from?

Respondents to our study have demonstrated, in quantitative terms, a general positive perception of the idea of cultivating seaweeds for bioenergy. However, in the qualitative results there was a running narrative of participants justifying negative opinions based on comparisons with other activities such as renewable energy technologies, fossil fuels, land biofuels and aquaculture. This process of association to other contexts and phenomena that are already familiar to respondents can be linked to the social representations theory, originally formulated by Serge Moscovici [32,77]. Several studies in the renewable energy sector have applied this theory [31,77,78] and it underlies the importance of the social context in shaping individual views through social norms, elements of culture, beliefs, knowledge and language.

This phenomenon is even more remarkable for new technologies where public literacy/ information provision is low. Social representations become crucial in rendering unfamiliar objects more familiar: this is what Moscovici called *anchoring* [32]. In the review on public perception of new energy technology, Boudet [78] describes this as the use of mental shortcuts using cultural views, media information or cultural values in order to construct opinions on a new topic. This study also noted that *"preconceived attitudes often determine how new information is processed*" [78], while Devine-Wright explains it as a way to "*make sense of complexity"* [79].

A second aspect of the social representation theory is the phenomenon of objectification, which implies the production of an iconic meaning or image that is then associated to an imprecise concept or unknown object [32]. Nowadays, mainstream media and social media communications have a strong role in shaping these images [80–82]. In the case of climate change or environmental related issues due to industrial activities, negative reports are abundant [83,84]. Narratives in the media and associated images aiming to facilitate the process of understanding on climate topics lead to anchoring through objectification [83,85]. Furthermore, media content that has the potential to trigger emotions has more impact on objectification and is more likely to be shared [83,86,87]. This process of objectification is perceptible throughout our study as most of the comments explaining negative views were based on highly newsworthy examples, such as deforestation for first generation biofuels, or the environmental damage of fish farming. The most striking example in this study is that certain respondents directly associated the term *seaweed farming* with the activity of mechanical harvesting of wild seaweed, which lead to occasional emotive comments.

'It is ripping out and using exiting kelp beds which are a vital and unique habitat and ecosystems!' (R96 – Online, Northern Ireland)

We can assume that the then recent (2018) and intense protest against a scoping proposal for mechanical seaweed harvesting in the West Coast of Scotland and the Islands might have had an influence on these responses. This was widely broadcasted in the media and resulted in a ban of mechanical harvesting of five species of kelp, for the purposes of *'commercial use'* [88]. In our study, the association with mechanical harvesting was often the result of a misunderstanding of terms. However, this argument does not intend to demonstrate that all associations to other activities are misunderstandings. Rather, it is an illustration of the role of previous knowledge and negative experiences on perceptions of risk, and how this can influence representations of new industrial activities in the marine environment. Further, these representations might be interacting with what we term 'cautiousness' of attitudes observed in negative responses to questions asking about levels of support for the industry. This cautious approach related to the impacts of other marine activities that participants would not find acceptable, but drew on to inform their opinions on seaweed farming. This means that negative representations of other activities or events create a perception of risk from seaweed farming:

'It would most likely lead to the same intensive production as for example agricultural biofuel production, and monocultures to satisfy an energy demand which is not sustainable in the longer term' (R291, Online – Scotland)

To give another example, the seaweed cultivation industry in France faced this cautiousness and perception of risk due to experience of toxic macroalgae blooms on beaches in Brittany causing the death of two dogs, a horse and affecting human health [89]. Social representations are not exclusively present in negative reactions. Within the positive responses, cautiousness was also dominant, with worries often relating to the same issues as found among negative responses. As the boundary between positive and negative responses appears to be narrow, we postulate that it is due to the high uncertainty of the respondents. Undeniably, it is difficult to expect strongly polarized opinions on the hypothetical production of biofuels from seaweed on which very little information is currently available. However, this reveals that social representations may affect perceptions on various aspects of the legitimacy of the activity such as negative effects on the environment (Table 4).

4.2. Cautious support for local developments

When we moved the focus of the questions to a more local-scale and asked about the potential support for a project in their local area, the majority of the respondents stated they would receive it in a supportive way. Similarly, people with negative perspectives on this future activity stated that they were open to changing their minds under certain conditions, such as a transparent dialogue with the company and reassurance of the preservation of their lifeworld. Admittedly, there is no obvious way to confirm that this would be the case for an actual project. Such confirmation would require upstream (before the project) and downstream (once the project develops and after) studies. Besides, all the requirements brought up by the respondents are anchored in a local context. They related to the preservation of an individual lifeworld [24,90]. On the one hand, it appears that environmental features represent high emotional value relating to place attachment and deserve to be preserved. In a study on wind farms Devine Wright [91] highlighted that high level of place attachment correlate with high

Table 4
Factors emerging from the perception comments that may influence SLO by enhancing or reducing legitimacy and trust.

	Perception that may enhance	Perception that may reduce
Economic and socio-political legitimacy	Positive effects of biofuel production on the global climate through provision of an alternative source of energy, reduction of greenhouse gas emissions and dependence on fossil fuels.	Risks of pollution and damages to local environments.
	Positive effects of seaweed farming on global and local environments through carbon absorption, reduction of pollution, creation of habitats.	Large scale of farming that is associated with higher risk of environmental damages and competition with other users of the sea.
	Perception of efficiency and low cost of production.	Use of an edible resource as energy source.
	Potential for local community benefits such as job creation, positive effect on local economy and production of local energy.	Perception of lack of efficiency and economic viability in comparison to other renewable energy technologies.
	Raising awareness by providing general information on the development of the activity.	Lack of available information for the public increasing cautiousness.
Interpersonal and interorganizational trust	Provision of transparent information at early stages of project development.	Lack of transparency and publicity of new project development.
	Opportunities for discussions between local communities and developer.	Rushed, low-effort engagement processes and lack of community empowerment throughout the development of the project.
	Taking into account local requests.	
	Activity developed by local community members.	Activity developed by large-scale corporation or company with poor reputation.
	Company willing to preserve existing local livelihood and lifeworld.	Uncertainty on environmental effects and lack of scientific evidence.

cautiousness about new development due to a higher sense of threat. It is argued that improving knowledge on place attachment, place identity and social representations constitutes better roots for understanding public attitudes towards renewable energy project rather than using the oversimplified 'Not in my backyard' justification [91–94]. Economic factors also play an important role in people's SLO requirements for developments in their local area, such as the value of their houses and the effects of the activity on other local sectors [9,95]. These different features are highly place-dependent as well as personal, and need to be specifically determined for each project location via qualitative research. Furthermore, the presence of elements of place attachment, the strong environmental concerns and economic considerations throughout the survey reveal them as factors likely to influence the legitimacy of the future activity (Table 4). Nevertheless, this inclination to preserve the local features is not pushed to the extreme requirement of keeping the place completely untouched. In many ways, respondents were not entirely conservative and showed their willingness to accept a certain level of sacrifice if the benefits outweighed the disadvantages.

'I have concerns regarding environmental damage. If these concerns could be allayed I feel this could benefit the local community and economy.' (R194, Online – Scotland)

This idea of benefit/impact balance is present in Boutilier and Thomson's [9] SLO framework through the monetary aspect of economic legitimacy but also by providing non-monetary benefits to the community through an effort of reciprocity. To build a good relationship between companies and communities it has been shown that the perceived balance between cost and benefits (monetary and non-monetary) play a crucial role for perception of new activity and SLO [95,96]. However, when the potential impact on the environment is high (e.g. in the mining sector), it appears that there is a limit in the willingness to compromise [95] and the activity might lose its legitimacy. A strong parallel with our results can be observed here, which highlights the importance of environmental concerns for legitimacy (Table 4). In the context of our study, aspects of place attachment and environmental concerns constitute elements to be taken into account by future project leaders in their relationship building with local communities and communities of interest. In order to improve trust and the perception of fairness between the two parties, SLO could be employed by valuing local knowledge and empowering local communities by acknowledging their 'social licensing authority'.

4.3. The power of engagement for trust

During this survey, respondents were often concerned about giving uninformed opinions. However, only half of the total respondents (both online and in-street) wanted to receive general information on seaweed farming and seaweed farming for biofuels. Besides, when put in the position of providing an opinion on seaweed farming in their local area, respondents expressed a preference for exhaustive and transparent information about the project. The reluctance of participants to give full support before being fully informed emphasises the necessity of providing members of the community with comprehensive information, as has been demonstrated for other innovative industries such as wind farming and carbon capture and storage [81,96]. Respondents perceived dialogue with the developer as a way to receive information, an opportunity to voice concerns and to be involved in the decision-making processes (Table 4). It has been established that when there is high uncertainty about environmental and social risk, people will make judgements based on personal values, referring once again to social representations and to the aspect of cautiousness evoked in the first two sections of this discussion [97].

Engagement with local communities is considered crucial for earning trust [98]. However, Soma and Haggett [20] demonstrated that using engagement strategies aiming only to inform and raise awareness was not an efficient way to improve the relationships with local communities and other stakeholders. These processes should include, with equal importance, listening to and acting on feedback from the community [16]. This should be a way to empower the community by enabling them to have a say in the project direction and enriching the project by sharing their local knowledge [99,100]. Relational reciprocity should be an ongoing process as it constitutes the basis of trust building and can strengthen the social capital of the company [9,99,101,102]. When these processes are not genuinely inclusive, it can result in difficulties fostering SLO. For example, in France members of certain local communities feel unheard by the regulators, industry, and scientists about the seaweed farming licensing process, despite extensive public consultations. This results in a tendency for communities and other stakeholders to mistrust the consultation process, and weakens the SLO for seaweed cultivation [7,89]. In our study, the position of prudent support rather than very supportive' or 'opposed before I know more' revealed once more the spirit of cautiousness of certain respondents, while demonstrating the need for trust building. Providing transparent information about the project proposal should thereby be the first step within the engagement process, as it would allow members of the community to trust their own ability to make an informed decision. The second essential step for trust building would be to develop and maintain the reciprocity of the dialogue by providing definite opportunities of involvement for the community in the project, and demonstrating a

willingness of adaptation to local demands. We see here how investigation of opinions and requirements from communities of interest could enrich projects and guide developers towards building activities that are more embedded within their communities. And, it is equally important for communities to be given opportunities of engagement to feel empowered through developments [99,100].

4.4. Scale as a keystone for potential SLO

It is still uncertain whether, where and when seaweed farming could scale up for the production of bioenergy. It is also uncertain at which scale this could happen. Experts are well aware of the technical and economic challenges this represents [33,38,103]. Today being commercially viable and technically feasible do not constitute sufficient basis for the success of an industry. SLO considerations remain central and may affect drastically the operations [7]. We have found through the survey that the issue of the scale was the most dominant concern for participants and often related to environmental interactions. Seaweed farming at a small scale was perceived as not damaging to the environment and even beneficial in some cases. Even though the idea of biofuel production from seaweed seemed appealing as an alternative source of energy, the scale of cultivation worried many participants. To produce third generation biofuels from seaweeds, the required biomass and consequently the scale of seaweed farming would need to be significantly increased [45], as many respondents highlighted. Beyond the risk of competition with other users, in more developed nations the increase in scale will require technical improvements and mechanisation [104]. Larger scale operations, as well as monoculture and ownership by large corporations, were often associated with a perception of industrialisation of the environment. These representations of scale and concerns formed a large part of the negative perceptions towards seaweed farming. This potential resistance towards new industrialisation of the sea by farming seaweed for bioenergy was mentioned in the MacroFuels project outcomes [105]. Conversely, respondents demonstrated a preference for locally owned businesses that were seen as more accessible and trustworthy in comparison to large companies or multinationals. This is paralleled in other renewable energy activities; Baxter et al., [24] found a higher acceptance for community owned projects in the wind sector. The preference for small-scale farming was also coupled with the end-use preference for food and high-value products rather than bioenergy. Many scholars consider that the production of bioenergy from seaweed has no direct competition with food production [50,106,107]. However, for certain respondents to our survey, food production from seaweeds should take priority over bioenergy. This could raise a myriad of questions about public perception of food and energy needs both currently and for the future.

As an intermediate between the positives and negatives of scale, the notion of biorefinery could become a reasonable and possibly more acceptable way to develop the future industry and is already a substantial research focus. Biorefinery approaches integrate the generation of energy from seaweed with the production of sustainable food and high value chemicals within a circular economy model without necessarily requiring significant biomass [49,55,108]. Developing circularity for seaweed production could allow a change of perception that appears polarized at the moment: from small-scale, locally owned farms for food production that oppose large-scale and significant biomass production for biofuels, to a more nuanced vision of this new industry.

4.5. Limitations and future work

This is the first mixed methods study looking at perceptions of seaweed farming for biofuels to better understand SLO requirements. For this reason, it has a certain number of limitations. Firstly, representation of the activity of seaweed farming for bioenergy are still in construction, which means that perceptions are likely to change greatly as familiarity increases. With increased media communication on new projects that seek to develop seaweed farming such as the Jeff Bezos and WWF Earth fund [109], public perception might be influenced either in positive or negative ways. If our study gives some indications - not predictions - on the factors that may have negative influence on perceptions, it is important to take into account the dynamic aspects of public perceptions in a changing world. Secondly, as the study is based on perceptions on potential developments, there is no certitude that these perceptions will be translated into SLO for future projects. There is a need for further research on local implications of such developments and in-depth study of the local context to strengthen these findings. Finally, our sample focuses on the public in coastal areas of three locations that might be closely affected by future seaweed farming developments. In spite of the large number of responses to the survey, the sampling strategy used for this study did not allow us to obtain a representative sample. This, added to the rapidly changing perceptions on seaweed farming, should bring caution to any attempt to generalize these results.

From a perception perspective, members of the public highlighted several key factors that may influence positively or negatively SLO for seaweed biofuels (4). This study has raised broad-scale considerations for the industry to examine and address as it develops. The use of a mixed methods approach aimed to mitigate limitations of individual qualitative and quantitative approaches, providing a more nuanced understanding of perceptions [110]. We would advise considering this study as a starting point for further investigations directed at a framework of local community investigations in order to determine key factors of SLO for future projects in specific locations. Future research would benefit from taking into account local context through social representations of the activity itself and other industries, as well as place attachment mechanisms. In agreement with Gegg and Wells [52], longitudinal research would improve investigation of changing perceptions as the industry develops. Another avenue for future research would be to investigate the vision for the development of the seaweed farming industry from expert stakeholders in order to determine potential dissonance between public and expert visions and expectations, and potentially improve communication.

5. Conclusion

We have studied the perception of seaweed farming for biofuels in an attempt to determine what expectations, questions and worries could emerge from the public who is the most likely to grant or withdraw a SLO. Being able to understand the key social concerns that a nascent activity may encounter as it develops could prove valuable for both communities and industries that aim to develop in the context of a just transition as it may improve reciprocity and fairness.

Our results demonstrated a general positive perception of seaweed farming for biofuels in Scotland, Northern Ireland and the Republic of Ireland at this stage. This might constitute a strong starting point for the industry in terms of earning future SLO. However, positive attitudes should not be taken for granted or generalized. Differences are likely to appear for projects in specific locations and communities, demonstrating the need for investigation of the social requirements where projects expect to develop. As perceptions may constitute relevant indicators for future SLO it is important to understand how they can be influenced. Perceptions of other industries such as fossil fuels, first generation biofuels, marine renewables and fish farming play a role in building the perception of seaweed farming through social representations. Negative attitudes towards other industries may constitute the root of negative perception of seaweed farming for biofuels. Provision of good quality and transparent information about this new activity could reduce the influence of social representation as well as potential misconceptions.

Comparable to other industries, aspects of community engagement are also vital from the public point of view to build trust with the developer. Preservation of the community's lifeworld, jobs, other economic considerations and especially protection of the environment are

the main requirements for building the legitimacy of the activity. The size of the farm is a pivotal factor for perceptions of seaweed farming and may constitute the central difference between operations resulting in SLO being granted or not. It is therefore advisable that developers carefully consider both the scale of their operations as well as the end-use, in addition to the more subtle features of perceptions, as they influence SLO.

CRediT authorship contribution statement

Julie Rostan: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft - review & editing.

Suzannah-Lynn Billing: Supervision, Conceptualization, Methodology, Writing - review & editing.

Adam Hughes: Supervision, Conceptualization, Writing - review & editing. Investigation, Writing - review & editing.

John Doran: Supervision, Writing - review & editing.

Declaration of competing interest

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

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The project was conducted after ethical approval No OLETHSHE490 from the University of the Highlands and Islands.

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Appendix 1. Information sheet provided to respondents

Public opinion on the production of biofuels from seaweeds

Introduction for participants

Macroalgae or seaweed are valuable marine resources because they are rich in a variety of chemical components that can be used for food, to produce bioplastics and as a source of energy. This is what we call **biofuels**. There are different types of seaweed biofuels that can provide energy for transport, gas, electricity... But they are not yet in use.

Small-scale **seaweed farms** already exist, generally to produce food. However, to produce energy, the quantity of seaweed needed would be greater. Building new seaweed farms would be necessary to cultivate enough seaweed for the production of energy.

What exactly this is about

This questionnaire is designed to last 5 minutes. It aims to assess:

- *Public perception about seaweed farming and producing energy from seaweeds.*
- *Awareness about marine activities and biofuels.*
- *Willingness to be informed and engaged.*

Privacy Notice

Participation in this survey as well as the data collected will remain entirely anonymous and confidential. Personal data or data that may allow any identification of you will not be collected during this project. The data gathered will only be used by the PhD researcher for this project. The data will be used in scientific articles, and reports. The data will be kept for five years on the Scottish Association for Marine Science server before being destroyed.

You can withdraw from the survey at anytime.

Data controller: Julie Rostan at the Scottish Association for Marine Science

This data will not be sent out of the EU. The processing will not involve automated decision-making. The legal basis for collection and processing of this data is consent.

Your rights

- The right to access your data.
- The right to rectification if the data we hold about you is incorrect.
- The right to restrict processing of your data.
- The right to request erasure (deletion) of your data.
- The right to data portability.

If you have any request or question please email 18022217@uhi.ac.uk ; Julie.Rostan@sams.ac.uk or Suzi.Billing@sams.ac.uk.

Scottish Association for Marine Science, Scottish Marine Institute, Oban, Argyll, PA37 1QA.

You also have the right to lodge a complaint with the Information Commissioner's Office about our handling of your data by sending an email to data.controller@inverness.uhi.ac.uk

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Appendix 2. Survey questions and objectives

	Data question code	Questions	Reponses	Question type	Objectives
1	Reported knowledge marine industries	You would say that your level of knowledge about marine industries (e.g: fisheries, aquaculture…) is:	Very High; High; Moderate; Very moderate; None	Scale	Own estimation of knowledge about marine industries
2	Reported knowledge biofuels	You would say that your level of knowledge about biofuels is:	Very High; High; Moderate; Very moderate; None	Scale	Own estimation of knowledge about biofuels in general
3	Reported awareness seaweed farming	Have you ever heard about seaweed farming before today?	Yes/no	Dichotomous	Awareness of the existence of seaweed farming - Have they heard of it before?
4	Reported awareness biofuels from seaweeds	Did you know that it is possible to produce biofuels (for transport, electricity, gas…) from seaweeds before today?	Yes/no	Dichotomous	Awareness of the existence of seaweed biofuels - Have they heard of it before?
5	Information	Would you be interested in receiving more information about these topics? What is your preferred option for receiving information about seaweed farming?	Yes/no	Dichotomous	Willingness to be informed and how.
6	Trust	The 4 following actors intend to share information with you about the production of biofuels from seaweed in your region: The company producing biofuels from seaweeds, Media/ journalists, Scientist, and Government. Could you tell me what level of trust you would give to each one of them to deliver transparent information?	Low level of trust; Medium level of trust; High level of trust	Ranking	Assessing level of trust depending on the sources of information.
7	General opinion	Developing seaweed farming to produce biofuels would be:	Very positive; Positive; Negative; Very negative	Likert type	Measures general opinion on the idea of the production of biofuels from seaweeds.
8		Qualitative: Why?		Open-ended	This question is place here to avoid bias potentially cause by the following questions (eg: thinking about environmental, economic and social effects).
9	Priority seaweed farming	For the production of biofuel from seaweeds, what do you think is the most important?	Seaweed farming should have a positive effect on the local economy. Seaweed farming should preserve the local environment. Seaweed farming should contribute to social benefit for the local residents. Other	Multiple choices	Assessing which is the priority aspect between social economic and environment for seaweed biofuels. Open to other choices to provide a broader the opportunity of answer.
10	Priority biofuels	For the production of seaweeds from farming what is the most important for you?	The production of biofuels should create jobs. The price of biofuels should be low. Using biofuels should have a positive effect on the environment. Other	Multiple choices	Assessing which is the priority aspect of concern between social economic and environment for seaweed farming. Open to other choices to provide a broader the opportunity of answer.
11	Perception environment	In your opinion, the effect of a seaweed farm on the environment is:	Very positive; positive; negative; Very negative	Likert type	Assessing perceptions on potential economic social and environmental effect of seaweed farming.
12	Perception economy	In your opinion, the effect of a seaweed farm on the local economy is:	Very positive; positive; negative; Very negative	Likert type	
13	Perception community	In your opinion, the social effect of a seaweed farm on the local community is:	Very positive; positive; negative; Very negative	Likert type	
14	Size	In your opinion, what is the maximum acceptable size of the seaweed farm in football pitches?	1 to 5–6 to 10 - 11to 20 - More than 20	Scale	Determining what size would be acceptable. Place before introducing the questions on potential development close to their home.
15	Support	Hypothetically, a new company would like to develop a seaweed farm near your house you would feel: Support	Very Supportive; Supportive; Opposed; Strongly opposed	Likert type	Hypothetical support for a project close to their home. Respondent are placed in the position on a member of a local community. This changes from the questions before which were general. Determine if there is a significant shift in attitudes.
16	Dialogue	Hypothetically, a new company would like to develop a seaweed farm near your house you would be: Dialogue	Entirely open to dialogue; Somewhat open dialogue; Somewhat closed to dialogue; Entirely closed to dialogue	Likert type	Assessing the level of willingness to be engaged by the company in the case of a project close to them. This could be compared to the willingness to receive general information.
17		Qualitative: Why?		Open-ended	
18	Housing distance from the coast in km	How far do you live from the coast?	0–5 km; 6–10 km; 11–20 km; 20 km+	Scale	Living distance from the coast to assess geographical link to the coast.
19		How often do you visit the coast?		Scale	

(*continued on next page*)

(*continued*)

	Data question code	Questions	Reponses	Question type	Objectives
	Frequency of visit to the coast per week		<1 per week; 1–2 per week; 3–5 per week; >5 per week		Frequency of visit to assess geographical link to the coast.
20		Qualitative: Open final comment		Open-ended	
21		Country of residence			
22		Age range	<18; 18–24; 25–44; 45–64; 65–74; 75 years or older; Prefer not to say		
23		Formal education	No schooling completed; High school graduate; Bachelor's degree - Master's degree; Professional degree; Doctorate degree; Prefer not to say		
24		Employment situation	Retired; Employed; Unemployed; Student; Prefer not to say		
	Demographics				
25		Employment sector	Accountancy, banking, finance, business & insurance activity; Arts and Entertainment; Charity and voluntary work; Education; Environment, agriculture, forestry & fishing; Human Health and Social Work Activities; Informatics; Information and Communication; Leisure, sport and tourism; Manufacturing and Construction; Mining, energy and water supply; Other; Public admin, law & defence; social security, Military; Religious; Sale, Accommodation & food services; Scientific and Technical; Transportation and Storage		
26		Gender	Male; Female; Other; Prefer not to say		

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