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Crowdsourcing LUCAS: Citizens Generating Reference Land Cover and Land Use Data with a Mobile App

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Abstract: There are many new land use and land cover (LULC) products emerging yet there is still a lack of in-situ data for training, validation, and change detection purposes. The LUCAS (Land Use Cover Area frame Sample) survey is one of the few authoritative in-situ field campaigns, which takes place every three years in European Union member countries. More recently, a study has considered whether citizen science and crowdsourcing could complement LUCAS survey data, e.g., through the FotoQuest Austria mobile app and crowdsourcing campaign. Although the data obtained from the campaign were promising when compared with authoritative LUCAS survey data, there were classes that were not well classified by the citizens, and the photographs submitted through the app were not always of sufficient quality. For this reason, in the latest FotoQuest Go Europe 2018 campaign, several improvements were made to the app to facilitate interaction with the citizens contributing and to improve their accuracy in LULC identification. In addition to extending the locations from Austria to Europe, a change detection component (comparing land cover in 2018 to the 2015 LUCAS photographs) was added, as well as an improved LC decision tree and a near real-time quality assurance system to provide feedback on the distance to the target location, the LULC classes chosen and the quality of the photographs. Another modification was the implementation of a monetary incentive scheme in which users received between 1 to 3 Euros for each successfully completed quest of sufficient quality. The purpose of this paper is to present these new features and to compare the results obtained by the citizens with authoritative LUCAS data from 2018 in terms of LULC and change in LC. We also compared the results between the FotoQuest campaigns in 2015 and 2018 and found a significant improvement in 2018, i.e., a much higher match of LC between FotoQuest Go Europe and LUCAS. Finally, we present the results from a user survey to discuss challenges encountered during the campaign and what further improvements could be made in the future, including better in-app navigation and offline maps, making FotoQuest a model for enabling the collection of large amounts of land cover data at a low cost.

Keywords: land cover; land use; citizen science; mobile apps; in-situ data collection; LUCAS

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1. Introduction

Land cover (LC) is defined as the biophysical surface cover of the Earth, e.g., water, forest, grassland, etc., while land use (LU) is the way in which the land is used by humans or the functional aspect of the land, e.g., commercial or residential areas, grazing lands, or the types of crops grown in an area [1]. Satellite remote sensing and photo-interpretation have been used to create numerous LULC maps in the past [2], which are used as inputs to climate, LU, and ecological models [3–5], and for

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calculating policy-relevant indicators, including some related to the United Nations Sustainable Development Goals (SDGs) [6].

At the European level, there are a series of LULC products that have been created as part of the Copernicus Land Monitoring Service (CLMS). The CORINE (Coordination of Information on the Environment) land cover (CLC) data set is produced every 6 years by the European Environment Agency [7]. Produced in both vector and raster format at resolutions of 100m and 250m, CLC has been used for a diverse range of applications such as population mapping, environmental protection and landscape planning [8–10]. The Urban Atlas contains LU data for more than 700 urban areas, i.e., cities with greater than 50K inhabitants for 2012 and more than 300 cities with greater than 100K inhabitants in 2006 [11]. By using the same LULC nomenclature, the Urban Atlas allows cities across the EU to be compared, and applications such as LU modeling and the calculation of various spatial metrics [12,13] are also possible. Another product of the CLMS is the High Resolution Layers (HRL) for Europe, which includes the degree of soil sealing or imperviousness, the tree cover density and forest type, grasslands, permanent water bodies and wetness, and small woody features. Some products were produced for 2012 while others have been added for the reference year 2015 [14].

Complementing these products is the LUCAS (Land Use Cover Area frame Sample) survey [15], which takes place every 3 years and is implemented by Eurostat. The results from this systematic survey are used for LULC change detection in European Union (EU) member countries as well as many other applications [16]. A harmonized LUCAS database with survey data and images from 2006, 2009, 2012, 2015, and 2018 has recently been published [17]. In 2015, there were 273,401 samples surveyed by 750 professional surveyors, who follow a published set of protocols for data collection at each sample point [15] and a further 67K points photo-interpreted. In 2018, the number visited by field surveyors was 238,077 with a further 100K points photo-interpreted [18]. The field protocol involves the surveyor travelling to the location, noting down the LU and LC using a specific nomenclature [19], and taking photographs at the point, as well as in the four cardinal directions away from the point. There are additional modules such as travelling along a transect eastward while observing any LULC changes, collecting soil samples at specific locations, as well as the Copernicus module [20], specifically tailored for remote sensing purposes. More details can be found in the technical guides for surveyors [15,21].

It is important to note that LUCAS is the only authoritative in-situ data set available for EU wide validation purposes, which contributes towards the accuracy assessment of the CLC data set and the HRLs [22–24]. Yet in-situ data on LULC could easily be collected by citizens using GPS-enabled smartphones. There are many examples of the involvement of citizens in scientific research, referred to as citizen science [25], where observations of species, phenology, weather phenomenon or other environmental parameters have been collected by citizens in the field [26–29]. For instance, the eBird project is one of the most successful examples of citizen science in which more than 360 million bird observations have been collected by amateur enthusiasts and made available through GBIF (Global Biodiversity Information Facility) [30].

With many citizen science projects, there are often rigorous protocols that must be adhered to, which requires training as well as commitment on the part of the citizen. There are definite tradeoffs between how complex the protocol is and keeping citizens engaged [31]. However, technology can be used to help simplify protocols, and gamification can add an element of competition that can incentivize participation [32]. This combination of technology and competition was implemented in the summer of 2015 in a crowdsourcing campaign called FotoQuest Austria [33]. This campaign was specifically geared towards in-situ data collection of LU and LC, which adopted a simplified LUCAS protocol as the basis and included locations of LUCAS survey points against which the crowd could be compared, particularly since a LUCAS survey was taking place during the same time period.

The FotoQuest Austria mobile app [33] was designed in such a way as to help the users in fulfilling the protocol as much as possible, e.g., the phone would only allow users to take photographs once the point had been reached and when the compass directions indicated the correct direction. Simple dropdown menus were also provided for choosing LU and LC. During that campaign, which ran until the end of September 2015, 2,234 quests were completed at 1,699 unique locations. The gamification element involved a leaderboard with users competing for prizes, which were awarded at the end of the competition and included a smartphone and tablets. When compared with the authoritative data from LUCAS, the results showed agreement of 80% in homogeneous areas for the top-level LU and LC classes, where the LUCAS nomenclature consists of a detailed hierarchy of types that spans 3 levels of detail. When the more detailed classification of LC and LU is considered, i.e., levels 2 and 3, the agreement between the crowd and LUCAS data was much lower.

The 2015 campaign provided no training in LULC recognition and relied only on the knowledge of the individuals taking part in the game. The main reason was to minimize the burden on users as much as possible, given that each quest involved collecting data according to a protocol, and there is a tradeoff between how much you can ask individuals to do and the number of users who will participate [31]. Yet, it became clear that some training was required to improve the ability of citizens to more accurately classify LULC. The purpose of this paper is to describe the new set of features implemented in the 2018 FotoQuest Go Europe campaign, which helped citizens improve their classification of LULC. This includes an assessment of citizen performance in identifying the LC when compared to the authoritative LUCAS data for 2018 as well as an accuracy comparison between the 2015 and 2018 FotoQuest campaigns. One of the innovations of the FotoQuest Go Europe campaign was the introduction of a near real-time quality assurance system, which was designed to provide feedback to users within 24 hours of a completed quest. This was linked to a second new feature, i.e., the payment of 1 to 3 Euros for each quest, which was awarded to the users if the data submitted were of sufficiently high quality. In situations where the quality was not adequate, feedback was provided to the users in a timely fashion to help them improve. The system was first piloted in a FotoQuest campaign undertaken in 2017 in Austria, and then used in the FotoQuest Go Europe campaign undertaken in 2018.

A change detection element was also added since the 2015 and 2018 FotoQuest campaigns took place during the 2015 and 2018 LUCAS campaigns so a comparison was possible. Once at a location, participants in the FotoQuest Go Europe 2018 campaign were first asked to look at the photographs taken by surveyors in the 2015 LUCAS campaign and then asked to compare these to what they saw during the campaign in 2018. If a change was observed, users were asked to select the current LC type.

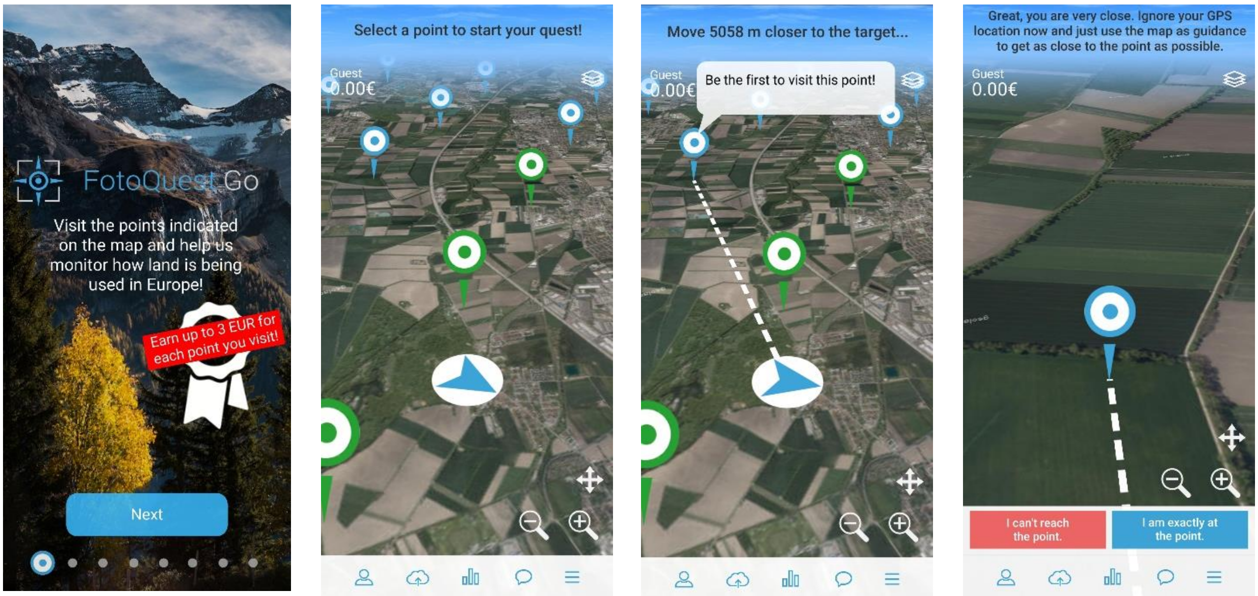
2. FotoQuest Go Europe

As outlined above, FotoQuest Go Europe represents a further development to FotoQuest Austria, which was the first mobile app developed to examine whether citizens could classify LC and LU of points on the ground. This section outlines the next generation of this app, referred to as FotoQuest Go Europe as well as the campaign that was undertaken. We also describe how the near real-time quality assurance system operates.

2.1. The mobile app

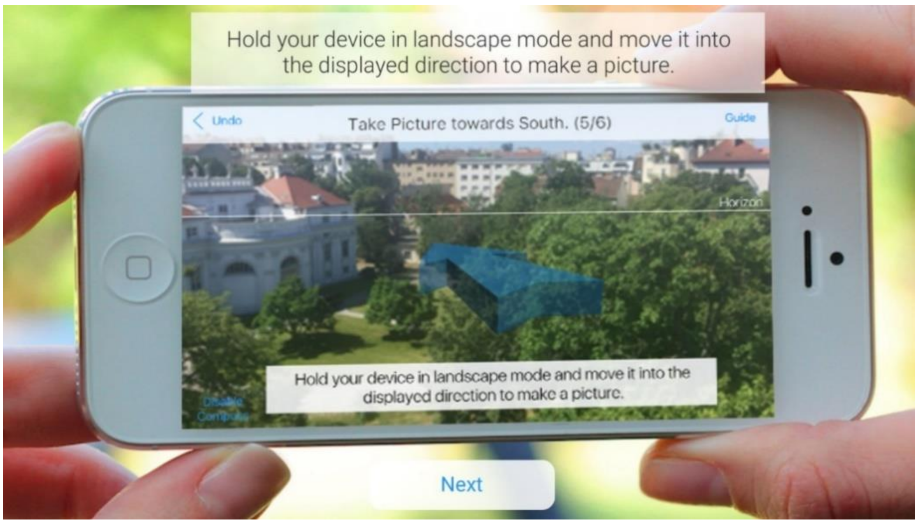
The FotoQuest Go Europe mobile app (Figure 1a) was developed in Unity, which is a game development environment that allows gamification features to be added easily to the app, e.g., a leaderboard as well as 3D objects. The basic idea is that users view quests on a map interface (Figure 1b). They then choose a quest and navigate towards the location on the map, where the app provides information about how far you are from the location (Figure 1c). The locations were a sample selected from LUCAS 2015 points. Once the user comes close to the point, the app asks the user whether they can reach the point or not. If they can, it advises them to stop using the GPS and use the map to reach the point (Figure 1d).

Once the user is at the point, they can begin the quest. The quests in the FotoQuest Go Europe 2018 campaign started by displaying on-site pictures from the LUCAS 2015 campaign. Users were then asked if the LC they observed was different to the one displayed in the app. If the LC was not different, they were then requested to take photographs in the four cardinal directions away from the point and then a downward looking oblique fifth picture of the location. This is the same as in the regular LUCAS protocol. The mobile app is designed to help the users take the pictures with the compass feature of the phone, only allowing photographs to be taken when the user is facing N, S, W and E. A line drawn across the screen also helps users take photographs so that two-thirds of the photograph is land and one-third is sky as shown in Figure 2a. Additional advice about taking the photographs is also provided within the app (Figure 2b).



(a) (b) (c) (d)

Figure 1. Screenshots from the FotoQuest Go Europe app showing (a) the starting screen of the app; (b) the map interface showing the location of quests; (c) a message helping the user to reach the location; and (d) reaching near the point.



(a)

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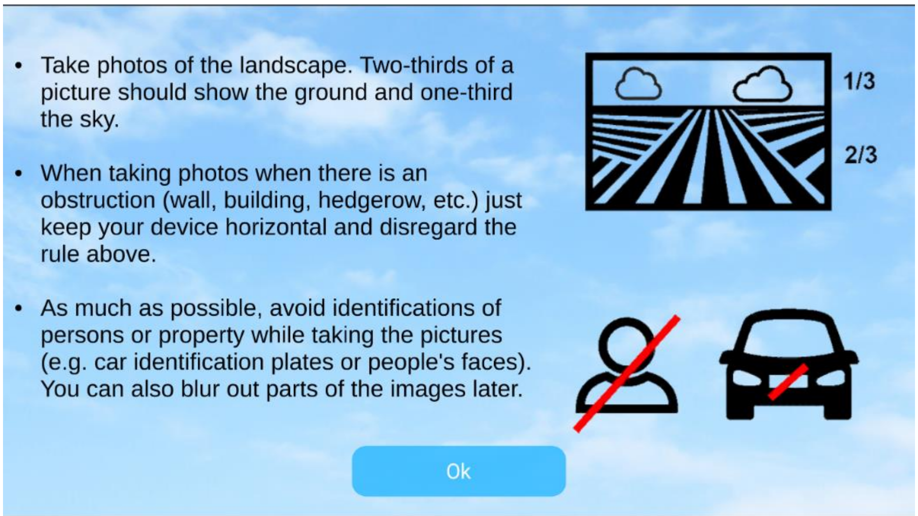
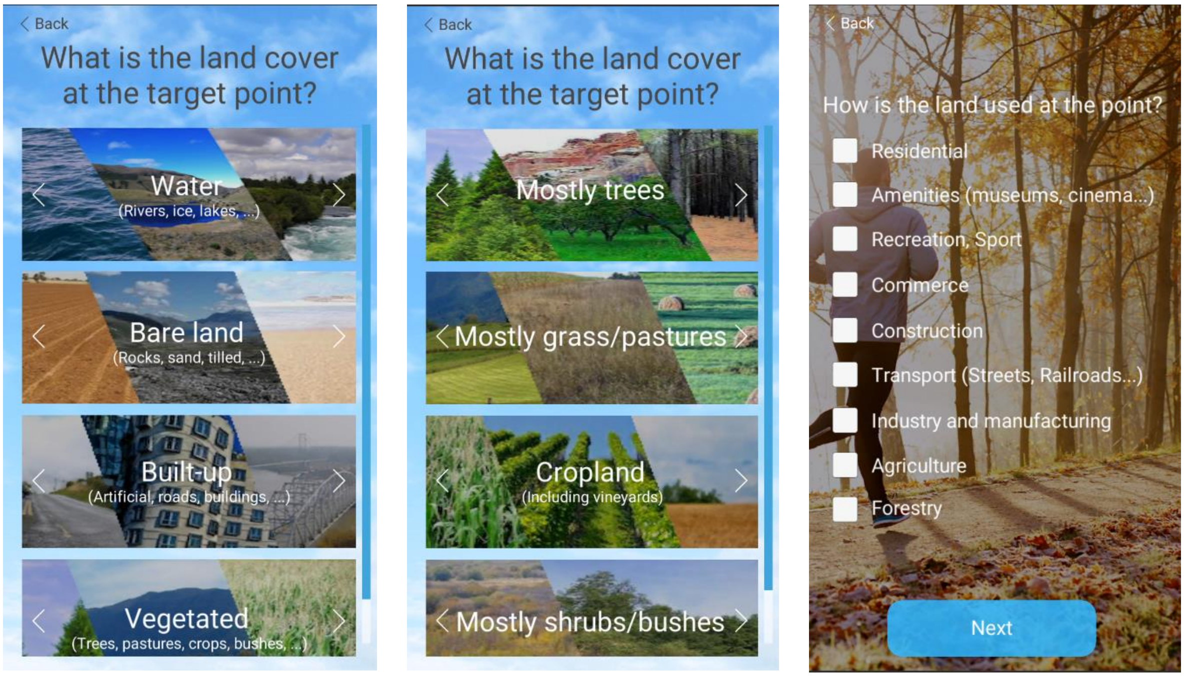


(b)

Figure 2. Screenshots from the FotoQuest Go Europe app showing (a) an example of a built-in feature in the mobile app that guides the user to take a photograph in one of the cardinal directions and (b) advice in the app about taking photographs.

Once the photographs are taken, the user is asked to classify the LC and LU using a series of screens with photographs. Figure 3a shows the first set of choices available in choosing the LC type, which are presented in a hierarchical system. For example, if the user chooses Vegetation in Figure 3a, they will be shown a further set of LC classes to choose from as shown in Figure 3b. After LC, the user is asked to choose the LU (Figure 3c).

Once these choices are made, the quest is completed, and the user is told that they will receive feedback on their quest within 24 hours.



(a) (b) (c)

Figure 3. Screenshots from the FotoQuest Go Europe app showing (a, b) the hierarchical LC classification and (c) the LU classification.

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2.2. The FotoQuest Go Europe campaign

The official FotoQuest Go Europe campaign ran between 8 June and 30 September 2018, although contributions were still being received afterwards. Several differences between this campaign and the FotoQuest Austria campaign included the wider reach of the campaign, i.e., points were made available across Europe as LUCAS is a European wide exercise, the improved user-interface and decision tree selection of LC classes (Figures 1-3), the use of monetary incentives to stimulate participation, feedback sent to users in near real-time, and change detection between 2018 and 2015. In the 2015 campaign, prizes were awarded to the individuals that undertook the highest number of quests. In contrast, this campaign awarded 1 to 3 Euros to each successfully completed quest. Success was defined by the quality of the answers submitted, which was determined through the near-real-time quality assurance system described in section 2.3. If the points were located away from a road or more inaccessible areas, they were awarded 2 to 3 euros (depending on the difficulty). Moreover, there were weekly challenges where the first person reaching the "challenge point" and providing an answer that passed the quality assurance process would receive a one-off €30 reward. These locations were not explicitly shown but a puzzle or riddle was announced on our social media pages, so users had to determine the location. This was added to provide a gaming element to the campaign. The challenge locations were also sites that were relatively far or not very accessible. Additionally, a FotoQuest Go Europe point could only be visited once, which was not the case in the 2015 campaign, where the same location could be visited by different users.

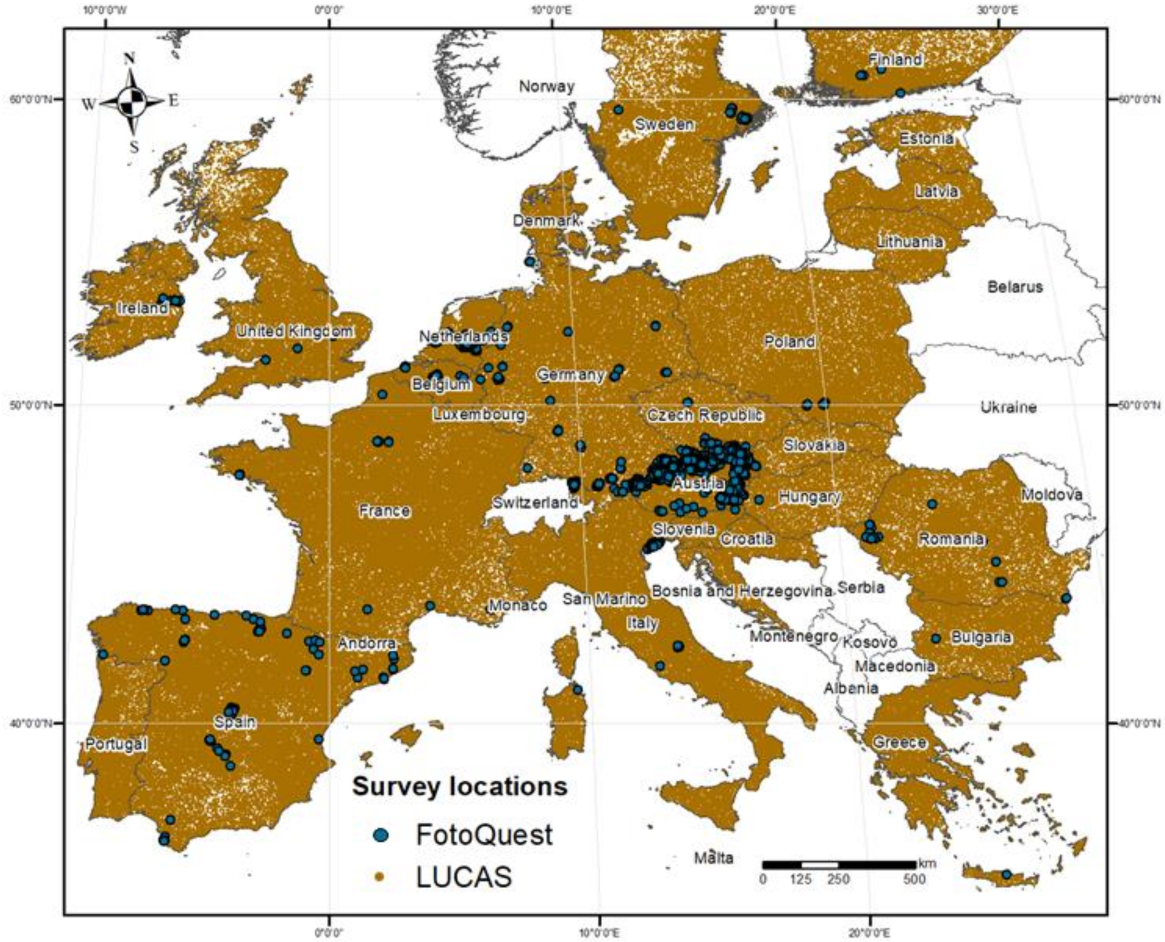

Figure 4. LUCAS survey locations, showing those that were visited in the FotoQuest Go Europe campaign in dark blue (Base maps: GADM)

In total, 140 users undertook quests covering 1612 different locations. Figure 4 shows the locations of LUCAS points across Europe as well as those completed as quests by the users. From these, a total of 71% of quests showed no change in the LC (1076 locations), 21% showed change (310 locations) and 8% were marked as not sure (118 locations).

Out of the total locations visited, 637 were declared as unreachable (or skipped in the app, which was approximately 40%) although in only 108 locations was it stated that the point was not visible. Reasons given included: Point on private property (50%), an obstacle was in the way (14%), or the point was inside a field with crops (10%). Other non-visibility reasons included: Point is on military areas (5%), point is on water (4%), point is in a nature area (with no access - 4%), bad GPS/cell coverage (4%), point is close to a highway (3%) or in heavy vegetation (3%), and various other miscellaneous reasons (3%).

Regarding LUCAS, the number of matching locations in the FotoQuest Go Europe campaign and LUCAS 2018 was 811. Since the campaign sample points were selected based on the 2015 LUCAS locations (since the 2018 LUCAS locations were not yet available at the time of the FotoQuest Go Austria campaign), the LUCAS 2018 campaign did not include all of these locations [18].

High quality quests

Once the campaign had started, the IIASA team received a suggestion to flag high quality quests, i.e., quests where the quality of the pictures, the proximity to the target and the description of the LC observed were very high. Therefore, from 2 July 2018 onwards (date shortly after which the suggestion was received), quests that fulfilled these characteristics were flagged as high quality. The idea behind this characterization was to understand whether these selected quests could have significantly better agreement with LUCAS.

2.3. The near real-time quality assurance system

The near real-time quality assurance system was built as one branch within the Geo-Wiki application [34] called FotoQuest Quality Check. The interface is shown in Figure 5. On the right hand side of Figure 5 is a map interface that shows three points for each quest made: the *Target* is the location of the LUCAS survey point; *Lucas* is the actual location where the LUCAS surveyor did their survey, which already provides a good visual impression of the small discrepancy between the two locations; and *FotoQuest* is the location of the person who made the quest during the campaign. In the example provided in Figure 5, one can see that the FotoQuest Go Europe user was on the edge of the field. Users were told to get as close to the point as possible but not to enter private properties or agricultural fields unless they had permission. After comparing the 2015 LUCAS pictures displayed in the app with the current location, the user then decided if there was a change compared to the LC present. The first level of LU chosen by the user matched the LUCAS point, i.e., Agriculture, but the type of agriculture has changed, i.e., instead of maize, the field is now being used to grow sunflowers, which the user has determined from the decision tree built into the app showing the photographs.

The objective of the near real-time feedback system was to provide advice to each user within 24 hours of receiving a completed quest. Feedback was always personalized and included four main types as outlined in Table 1. The first three types of message were issued when the user successfully completed the quest and earned 1 to 3 Euros but with increasing feedback in the form of suggestions for making improvements in future quests. For example, the second type of agreement message provides minor suggestions such as urging the user to get closer to the point in future quests if possible, while the third type provides stronger advice about future improvements. The final type of message issued was in situations where the quest was unsuccessful along with the reasons why, such as being too far from a point or the poor quality of the photographs. In this way, the users could learn from their mistakes, make better quests and ultimately earn 1 to 3 Euros for each point. In general, feedback could be qualified as: 1) Motivational, when there were some encouraging words in the message sent; 2) Neutral, when the quest was accepted and the corresponding reward was stated; and 3) Recommendations, when there was additional feedback text that contained specific indications to improve the quest. These additional recommendations were roughly classified into three groups including: 1) recommendations to improve the quality of the pictures taken; 2) encouragement to get as close to the point location as possible; and 3) recommendations on how to describe the LC at the actual location.

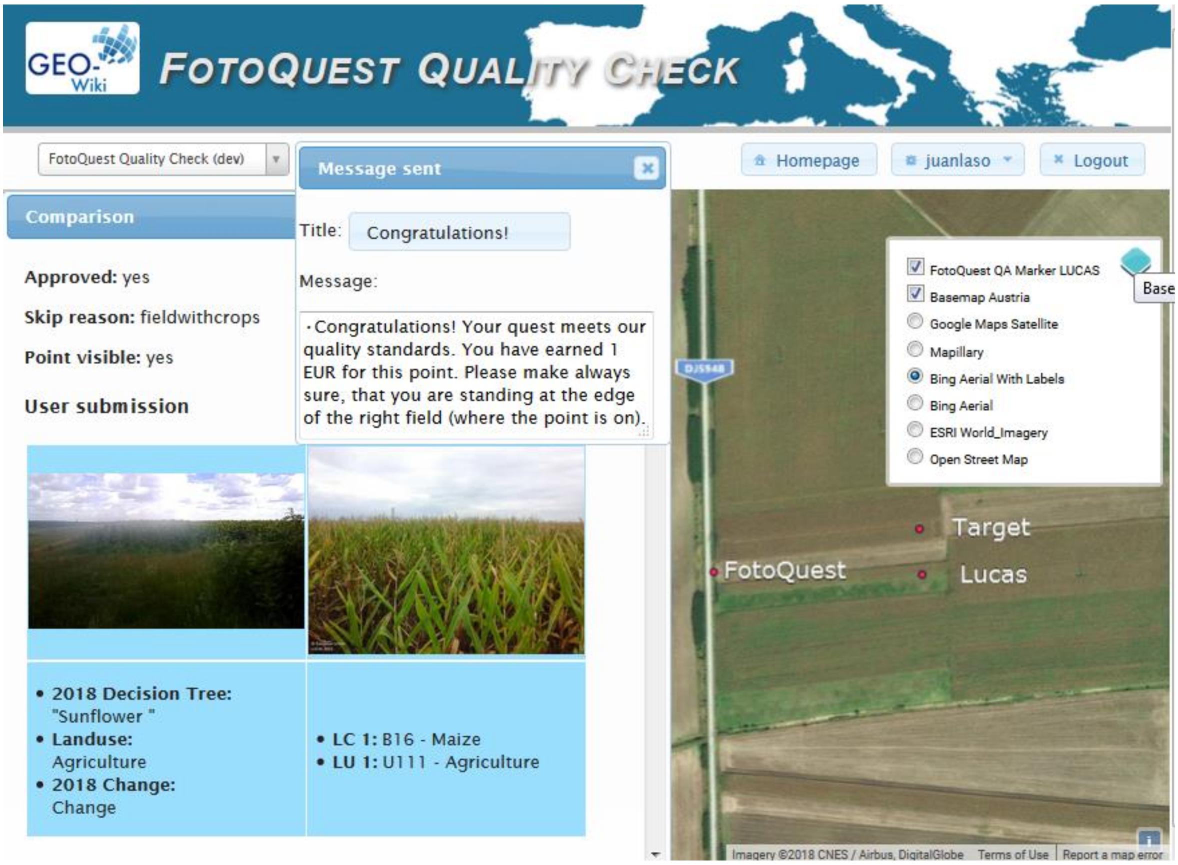

Figure 5. The FotoQuest quality branch in the Geo-Wiki platform showing the actual LUCAS point (Target), the location where the LUCAS surveyor did their survey in 2015 (Lucas) and the location of the FotoQuest Go Europe user (FotoQuest). Pictures from the LUCAS 2015 survey are displayed along with those submitted by the user. A messaging system allows the FotoQuest team to deliver feedback directly to the user in almost real-time as shown in the 'Message sent' box.

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Table 1. Types of feedback provided to the users from the near real-time quality assurance system.

Type of feedback provided	Total quests	Subtype	Example messages
Motivational	622 (39%)	Standard	Congratulations! Your quest meets our quality standards. You have earned 1 EUR for this point. Keep up the good work!
		High quality	Perfect! Your quest meets our quality standards. You have earned 1 EUR for this point.
Recommendations	326 (20%)	Distance to the point	Congratulations! You have earned 1 EUR for this point. However, you marked the point as unreachable, although we can see from the map that you could have gotten closer. Next time, please go to the exact point. If the point is unreachable, please get as close to the point as possible.
		LC / LU accuracy	Congratulations! Your quest meets our quality standards. You have earned 1 EUR for this point. When answering the questions for land use, always describe the point itself and not its surroundings. This time you chose residential, but since it is directly on the street, you should have chosen transport. Keep up the good work!
		Picture quality	Congratulations on your first quest! Your quest meets our quality standards. You have earned 1 EUR for this point! For your next quest, please keep in mind that when taking the photo, there should be one third sky and two thirds of land/ground in the picture! Have fun!
Neutral	662 (41%)		Congratulations! Your quest meets our quality standards. You have earned 1 EUR for this point.

A total of 94 users received recommendations as feedback. Table 2 summarizes the types of recommendations sent as feedback and how these were distributed. Recommendations regarding the quality of the picture was the most common type of feedback provided, which also had the highest number of most useful recommendations.

Table 2. Recommendations sent as feedback disaggregated by type of feedback.

Type	Number of users that received at least one recommendation	Total # of quests with most useful* recommendations	Percentage of quests with recommendations Mean (min-max)	Range of recommendations per user
Distance to target	31 (22%)	31	3 (0-33)	0 to 5
Quality of picture	48 (34%)	56	6 (0-66)	0 to 12
Quality of answer (LC)	27 (19%)	23	3 (0-50)	0 to 5

*Recommendation sent before the user proceeded to complete another quest, i.e., at least one day before

3. Materials and Methods

The data from the 2018 LUCAS campaign were used to calculate the agreement with data collected from FotoQuest Go Europe at three different levels of LC, e.g., level 1: Cropland, level 2: Cereals, level 3: Maize. We also separated agreement by high quality points as well as in points marked as change or

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no change. A confusion matrix between the 2018 LUCAS data and FotoQuest Go Europe was tabulated to understand which classes had the most disagreement at level 1. Tables were then generated with agreement disaggregated at different levels for the main LC classes but also to understand crop type agreement and LU agreement. The frequency of agreement/disagreement for each year (2015 and 2018) at each level was compared using a group comparison test (chi square) where the likelihood of agreement was obtained through the Cochran-Mantel-Haenszel test.

Additionally, multivariate generalized linear mixed models were employed to understand the factors influencing agreement between the LUCAS and FotoQuest Go Europe for 2018 for each LC level. Quests selected in the models included only those where the distance between the user and the point coordinates was less than 300 m, where no feedback with a recommendation was sent (i.e., the quest was deemed correctly undertaken), and when points were skipped but still visible. The models were run as binomial logistic regressions where agreement between the LUCAS and FotoQuest Go Europe was coded as 1 and disagreement as 0. These models were run in a generalized mixed model framework with a binomial distribution. Since each user provided several quests, a random effect with the user ID (UID) was included to account for lack of independence between observations coming from the same user. The models used the following as explanatory variables: Distance from the quest to the actual point coordinates (DFQ), skipping (i.e., not being able to reach the point) (SKIP), LC homogeneity (radius, 4 categories: <1.5, 1.5 - 10, 10 – 50, >50 meters) (HOM), whether the point was a high quality point or not (HQ), and the number of quests a given user had sent (QpU). A general representation of the model is:

$$\text{Agreement} = f\,(\text{DFQ, SKIP, HOM, HQ, OpU} :: \text{UID} \qquad (1)$$

where Agreement is the binomial response indicating overall agreement of FotoQuest Go Europe and LUCAS 2018 (yes = 1, no = 0). The double colon separates fixed and random effects.

The Laplace estimation method was employed to fit the models in SAS (version 9.4), using Proc Glimmix. This procedure allows binomial responses but also the use of random effects, which were needed, in this case, to acknowledge repeated observations by the same user. The random effects were evaluated using statistical inference for the covariance parameters, with a significance test based on the ratio of residual likelihoods, using a "covtest glm" statement. Additionally, we compared the relative goodness of fit of the models with and without random effects. Initial correlation tests were run across all predictors to detect and avoid multicollinearity.

Finally, at the end of the campaign, two voluntary surveys (one in English and one in German) were administered to users to share their experiences and recommendations about the campaign.

4. Results

4.1 Results from the FotoQuest Go 2018 campaign

Out of a total of 1021 approved quests that were submitted between 2 July 2018 and the end of the campaign, 521 were marked as high quality. Of these, 74% were at locations where no LC change was reported, 20% at locations with change reported, and 6% at locations where users were not sure if change had occurred or not. Most high-quality quests (56%) were submitted during the last month of the campaign (September, 293 points) with a total of 21% in August (111) and 23% in July (120).

Focusing now on LUCAS, the total number of locations in FotoQuest Go Europe that matched LUCAS 2018 was 811. At 729 of these locations, the participants were sure of whether there was either a LC change or no change. At 22% of these locations, the participants of FotoQuest Go Europe reported a change in LC, i.e., when people saw differences between the LUCAS 2015 pictures and the current LC; at these same locations, LUCAS reported 31% change between LUCAS 2015 and 2018, indicating that the participants underreported the change.

The overall agreement between LUCAS 2018 and FotoQuest Go Europe for levels 1 to 3, considering all and only high-quality points, is presented in Table 3. As expected, the highest accuracies are for level

1 although accuracies are still above 74% for level 3. Moreover, high-quality points do have a slightly higher agreement than all points together.

Table 3. LC agreement at different levels for all points and points flagged as high-quality.

Level	Overall % (n)	High quality points % (n)
3	74 (429)	79 (139)
2	82 (673)	86 (223)
1	90 (704)	91 (241)

Table 4 further disaggregates the agreement into cropland and other classes. Similar patterns can be seen except for the cropland class, where the overall accuracy is lower for levels 2 and 3 when considering all points, reflecting the difficulty in identifying crop types. However, there are notable improvements when considering high-quality cropland points. In contrast, the pattern is somewhat different for the other classes (excluding cropland). First, the overall accuracies are much higher for levels 2 and 3, and there is little difference in the accuracies between the different levels overall as well as when considering only high-quality points. This may reflect the fact that the other classes are easier to identify than cropland, even when quite detailed.

Table 4. LC agreement at different levels for all points and points flagged as high-quality, contrasting cropland and non-cropland locations.

Level	Overall % (n)		High-quality points % (n)	
	In cropland	In other classes	In cropland	In other classes
3	49 (174)	91 (255)	56 (41)	89 (98)
2	69 (180)	86 (493)	79 (43)	88 (180)
1	92 (200)	89 (504)	94 (52)	90 (189)

Table 5 provides the accuracies for the three levels when considering locations that were reported as change or no change compared to 2015. In general, as the level increases (requiring a more detailed class description), the accuracies decrease. The exception is in high-quality points with no change where levels 1 and 3 are similar in accuracy, and an observed decrease in accuracy for level 2. The accuracy of points with no change is also higher than those with change. Finally, there are small increases in the accuracy of high-quality points with no change while the results are mixed for locations with change. In particular, for level 3, the accuracy of locations with change at level 3 are considerably higher than those when considering all points while there is a slight decrease when considering level 1.

Table 5. LC agreement at different levels for all points and points flagged as high-quality, contrasting locations where change and no change was reported.

Level	Overall % (n)		High quality points % (n)	
	In change	In no change	In change	In no change
3	55 (95)	79 (334)	74 (19)	80 (120)
2	58 (125)	87 (548)	63 (27)	90 (196)
1	78 (156)	93 (548)	73 (45)	95 (196)

Table 6 displays agreement levels between FotoQuest Go Europe 2018 and LUCAS 2018 for the main LC classes. These agreement levels do not represent exact agreement for individual sub-classes, e.g., maize had higher agreement than wheat, but they give a general idea of how the participants performed. The results show that both Artificial land and Woodland have high accuracies at all three levels while accuracy decreases for Cropland and Grassland as the level increases. As these classes are amongst the most difficult to identify, this is an unsurprising result.

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Table 6. LC agreement between FotoQuest Go 2018 and LUCAS 2018 for the main LC types by level. The data are sorted by the coverage of these areas in the FotoQuest Go Europe 2018 campaign in descending order.

LC type	Coverage in FQ Go Europe (%)	Level 1		Level 2		Level 3	
		n	Ag (%)	n	Ag (%)	n	Ag (%)
Cropland	28	200	92	180	69	174	49
Artificial land	23	165	94	164	90	153	93
Grassland	22	154	81	151	77	0	-
Woodland	22	153	97	149	95	90	90
Others	5	35	43-80	32	43-80	13	75.89*

*Wetlands and Water, respectively. No observations for the Shrubland or Bareland classes.

The LC confusion matrix (Table 7) shows that the most common confusion was between Grassland and Cropland where Cropland in LUCAS 2018 is, at times, confused with Grassland (Table 7). Compared to the 2015 FotoQuest Austria result (Table 4, [33]), the user accuracy increased in the 2018 campaign, especially for Artificial land class (94% compared to 54% in 2015) and Shrubland (71% compared to 14% in 2015).

Table 7. Confusion matrix showing level 1 LC classifications from FotoQuest Go Europe and LUCAS 2018.

FotoQuest Go Europe	Artificial	Cropland	Woodland	Shrubland	Grassland	Bareland	Water	Wetland	User Acc. (%)
Artificial	157	1	6	0	3	0	0	0	94
Cropland	3	184	1	0	8	6	0	0	91
Woodland	0	0	149	2	1	2	0	0	97
Shrubland	1	0	1	10	2	0	0	0	71
Grassland	8	14	9	2	121	0	0	0	79
Bare land	0	4	0	0	0	3	0	0	43
Water	0	0	0	0	1	0	8	0	89
Wetland	1	0	0	0	0	0	0	3	75
Prod. Acc. (%)	92	92	86	94	82	0	100	100	

Overall agreement between the FotoQuest Go 2018 results and LUCAS 2018 for the main crop types is shown in Table 8. The highest agreement is for Maize, which is a relatively easy crop to identify followed by Soya. Common wheat had less than 50% agreement, but this may be due to confusion with other cereals that look similar, e.g. barley,

Table 8. Agreement in the main LC class Cropland by crop type. The data are sorted according to percentage agreement in descending order.

Crop type at level 3, Cropland	n	Agreement (%)
Maize	49	80
Soya	11	64
Common wheat	32	47
Sugar beet	7	43
Temporary grasslands	13	38
Barley	10	20
Dry pulses	9	0
Durum wheat	5	0
Others	1-5	0-100*

*One observation on "Other root crops": 100% agreement.

In terms of LU, the overall agreement was 65%. Table 9 shows the agreement by the main LU types. As FotoQuest Go Europe 2018 had a multiple-choice selection of potential LU, and each user could choose up to 3 different LU types, agreement, in this case, was considered when any of the choices matched the LUCAS 2018 data. LU choices were not split by levels as was the case for the 2015 campaign to simplify the capturing of these data. Some LU types have high agreement, in particular, Agriculture, Forestry and Construction, while Commerce had just over 50% agreement. Interestingly, Road transport had 0 agreement. This may be due to the fact that participants were on a road but they may have looked beyond the point to capture the general LU in the surrounding area (indicated by feedback provided to users in the near-real time system – Table 1) or they did not reach the point with sufficient accuracy since the coverage of this LU type is quite small in area compared to other LU types.

Table 9. Agreement by the main LU types. The data are sorted by the coverage of these areas in the FotoQuest Go Europe 2018 campaign in descending order.

LU type	Coverage in FotoQuest Go Europe (%)	N	Ag (%)
Agriculture	40	309	93
Forestry	18	135	89
Road transport	12	91	0
Construction	12	78	87
Semi-natural and natural areas not in use	5	33	0
Amenities; museums; leisure	4	33	6
Commerce	2	15	53
Others	6	48	0

4.1 Agreement between the FotoQuest 2015 and 2018 campaigns

When comparing the 2015 and 2018 campaigns, the results of the Cochran-Mantel-Haenszel test showed significant differences at all levels (1-3) (Figure 6), with higher levels of agreement found in 2018. Moreover, in the 2018 campaign, citizens were 2.9 times more likely to agree with the corresponding LUCAS campaign at level 3 ($p<0.001$, $n=696$), 3.5 times at level 2 ($p<0.001$, $n=955$), and 3.1 times at level 1 ($p<0.001$, $n=1006$). Hence, there were considerable improvements in the 2018 FotoQuest campaign compared to 2015.

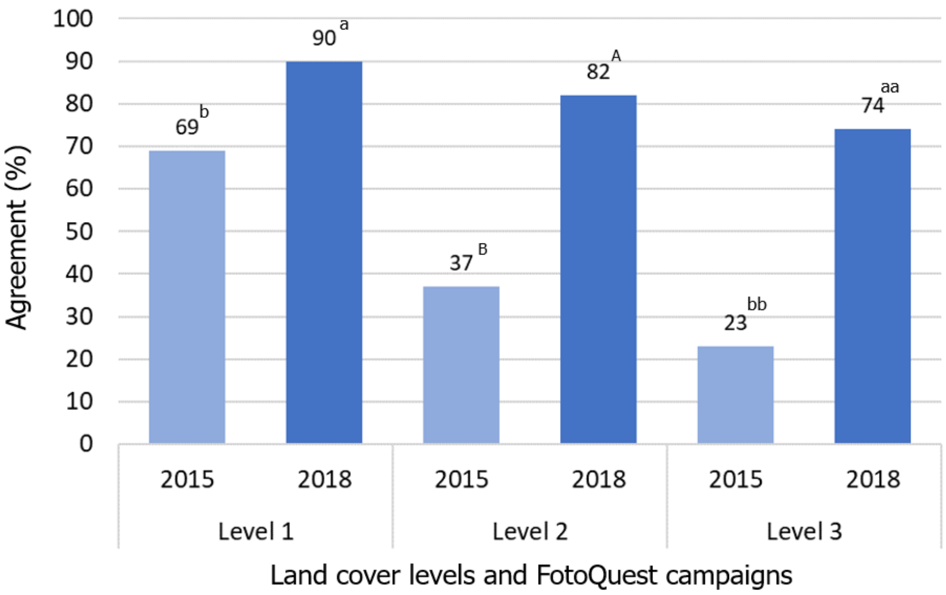

Figure 6. Comparison of agreement between LUCAS and FotoQuest for the 2015 and 2018 campaigns. Different letters show significantly different likelihoods of agreement per level (chi square test).

4.2 Multivariate analysis of LC agreement

At LC level 1, the binomial linear mixed models showed that there were no significant factors influencing the agreement between LUCAS 2018 and FotoQuest Go Europe (p>0.05, n=583). However, in the model run at LC level 2, the land cover homogeneity (HOM), which is identified by the radius around the point, significantly increased the odds of agreement between LUCAS 2018 and FotoQuest Go Europe (p=0.0244, n=530). A quest with a radius greater than 50 m increased the odds of agreeing with LUCAS 2018 by a factor of 2.3 to 2.5 times when compared to one with a homogeneity radius of between 1.5 and 10 m (p=0.02) or less than 1.5 m (p=0.01), respectively. Other comparisons were not significantly different (p>0.05), and all other variables were not significant (p>0.05).

Finally, at LC level 3, distance to the point (DFQ) was the only significant predictor of agreement between LUCAS 2018 and FotoQuest Go Europe (p=0.023, n=261). This means that for every 10 m closer to the point, the odds of such a quest agreeing with LUCAS increased by a factor of roughly 1.1. All other variables were not significant (p>0.05).

4.3 Results from the user surveys

A total of 87 users participated in the survey, with 56 users filling in the German language survey and 31 the English language one. Of the German language respondents, 60% had not participated in FotoQuest campaigns before, whereas this was 90% in the English language survey. Almost 90% of the German language respondents had not participated in any citizen science project before whereas that number was 70% for the English language respondents.

Table 10 shows the main innovations and characteristics of the FotoQuest Go Europe 2018 campaign liked by the respondents of the German and English language surveys. Regarding the motivations that drove the users of FotoQuest Go Europe, enjoying being outdoors was the highest ranked motivation in both surveys (4.7-EN and 4.3-GE out of 5 stars). Additionally, "helping science", "interest in the project", "improve knowledge" and "discover new landscapes" were also well ranked. Furthermore, some users also commented that the gaming or competing-against-others element of the game was quite an incentive for them, although this was not a pre-selected motivation in the surveys.

Table 10. Results from the survey regarding which features of the FotoQuest Go Europe 2018 campaign were liked by the users. An intense green color means a higher number of respondents, whereas pale blue colors represent the lowest number of respondents.

App feature	Number of respondents (%)	
	German survey	English survey
Points located across the whole of Europe	24 (43%)	17 (55%)
Rewards	21 (38%)	16 (52%)
Landcover specific pictures and information	21 (38%)	15 (48%)
App design	11 (20%)	18 (58%)
Feedback	14 (25%)	1 (3%)
Time period (summer)	14 (25%)	1 (3%)
Challenge points	4 (7%)	7 (23%)
Expert information (on a point)	7 (13%)	2 (7%)
Other	2 (4%)	1 (3%)

When the users were asked to rate some characteristics of the app itself, the user-friendliness of the app (8.8/10), and the LC specific pictures with links to identify LC at the point (8.7/10) were the highest features rated by the respondents of the English language survey, whereas the feedback and the reward systems (8.1/10 each) as well as the user-friendliness of the app (8.1/10) were the highest for the German language respondents. One recurring recommendation was to provide better navigation by linking to an existing map application such as Google Maps. Another request was to provide offline maps, especially for points that are difficult to reach, e.g., in the mountains, where the mobile signal is not available or intermittent. The lowest rated feature of the campaign was the weekly €30 challenge (7.8-EN and 5.3-GE /10). The reasons cited included that the point made little sense because it was too far away to reach or that the information about the challenge was simply missed, because, e.g., it was only advertised in Facebook and did not appear as a push notification in the app.

Recommendations made to the team to improve future campaigns are shown in Table 11. In the category "Others", it was often recommended to create a version with offline maps and to improve the navigation as mentioned above. It was also suggested that the project could be better described, and to show the results more openly so that people who have participated in the project as well as new potential users could better understand the aims of the project. Although some participants found the time period a positive feature (i.e., running of the campaign during the summer), others found this an aspect that could be improved, possibly because this is also a holiday period for many.

Table 11. User-recommended improvements for future FotoQuest Go Europe campaigns. An intense green color means a higher number of respondents, whereas pale blue colors represent the lowest number of respondents.

Recommendations for improvement	Number of respondents (%)	
	German survey	English survey
Information about the project	25 (45%)	13 (42%)
Time period (summer)	22 (38%)	10 (33%)
Social Media	6 (11%)	11 (36%)
Rewards	14 (23%)	4 (13%)
App design	11 (20%)	6 (19%)
Others	10 (18%)	2 (7%)
Feedback	4 (7%)	5 (16%)
Website	5 (9%)	2 (7%)

5. Discussion, Conclusions and Outlook

One of the most important conclusions from the overall FotoQuest experience is that the increased user-guidance provided in the FotoQuest Go Europe app (in 2018) compared to the FotoQuest Austria app (in 2015) has made a considerable difference to the accuracy of LULC identification by citizens. The significant differences found between the agreement with LUCAS achieved across the two campaigns (2015 and 2018) are a clear indication of the potential of citizen science when mobile technology is used in a positive, well-designed way. Various landscape related topics (e.g., landscape features, carbon storage) could benefit from the high-quality in-situ data that FotoQuest could generate, but it could also become a reliable technology for increasing the amount of training data for the production of European land cover monitoring products such as Corine +, the high resolution layers, and the local components (e.g., the Urban Atlas) at a lower cost than LUCAS. For example, the total FotoQuest field data collection and quality control costs are around €2.60 per point whereas, based on the 2015 LUCAS field work tender costs [35] and the amount of points collected (339,697) [36], LUCAS costs are around €32.40 per point, which is an order of magnitude higher than FotoQuest. Additionally, FotoQuest could connect citizens to Earth Observation in general but also more specifically to the Copernicus program through raising awareness. The user survey also confirmed the findings that the app's user-friendliness as well as the additional pictures to aid LC identification and the guiding links were useful. Moreover, the request by many users to implement additional features such as in-app navigation and offline access to maps indicates that there is a potential for continuing to improve and use the FotoQuest technology in the future.

From the results of the binomial linear mixed models, the significant effect of distance to the point (DFQ) on agreement with LUCAS for level 3 LC confirms the need to improve the navigation features. The significant effect of the homogeneity of the point (HOM) for level 2 LC, where users had better agreement in homogeneous points compared to less homogeneous points, indicates that we could further improve the in-app support for users to identify different LC types. This is especially true for cropland, which had the lowest agreement amongst all classes and where a virtual reality AI-enhanced system, combined with additional information delivered in an easy-to-understand way, could help to improve identification of this difficult LC type.

In terms of LU, one important difference between the 2015 FotoQuest campaign and the FotoQuest Go Europe 2018 campaign was that the LU choice was simplified, i.e., users no longer selected different levels of LU. LU options were shown as a list of 9 choices (see Figure 3c), where users could select up to three different options. This was done on purpose so that we could focus on LC and not overload the user with a long decision process per quest. From a user experience point of view, the process had to be simple and not take too long. Moreover, while taking pictures and identifying the LC, users were simultaneously considering the LU, which could then be filled in at the end of the quest. Finally, in-app improvements to identify the Road transport LU type (currently poorly identified) could be added in the future.

The improvements made to the app, including the user-friendly interface, guidance for taking the pictures, a visually-enhanced decision support system for identifying the LC, and the near-real-time feedback system, resulted in users getting closer to the target point and obtaining higher quality pictures although there were still a number of users that were quite far from the location or submitted poor quality photographs. Additional AI systems, which can provide alerts and suggestions for how to improve the quality of the picture taken, could be easily implemented in the app. The quality assurance service being developed in the LandSense project already addresses some of these issues [37]. IIASA is also currently experimenting with augmented reality games, where the photograph taken by the phone can be enhanced with additional measurements and information that can result in a professional picture and a high-quality quest.

Although no effect was observed from the feedback system in terms of improved agreement with LUCAS, the main benefit of such a system is that it facilitates a strong interaction between the team at IIASA and the users. The results of the user survey administered at the end of the campaign indicated that people reacted better when they felt involved, with some of the users criticizing the "default" messages, i.e., they would have liked even more personalized guidance. This finding is clearly aligned with the fact that good feedback and communication have been previously recognized to be of high importance in citizen science projects [38].

A common issue mentioned by the users was that push notifications of challenge points or other better methods of advertisement could have driven up the number of users and increased the gaming effect. This campaign (2018) as well as the 2015 campaign had some media coverage via television and advertisement through the Geo-Wiki newsletter, a regular publication from the Center for Earth Observation and Citizen Science at IIASA, as well as limited promotion via social media. Citizen engagement and retention are recurring issues for citizen science projects in general [39] and FotoQuest in particular, and one we believe would benefit from further support from higher level organizations, e.g., the European Commission or the European Environment Agency, given the potential of the technology to achieve very high quality results while involving citizens across Europe.

FotoQuest is a LULC monitoring activity complementary to LUCAS. Following the detailed assessment provided here, we have shown that high quality in-situ data can be gathered, and that citizens may more easily monitor certain LC types. FotoQuest type activities can be carried out each year, or in those years that LUCAS is not planned. Furthermore, FotoQuest campaigns may be tailored to specific validation tasks, e.g., related to specific HRLs. The FotoQuest Go Europe data presented here is open and freely available, thus contributing – as LUCAS – to much needed common sets of reference data across the EU to benchmark a variety of commercial LULC products.

Additionally, since one of the aims of FotoQuest Go Europe was to engage citizens in tracking LULC change over time, it can contribute to the monitoring of the SDGs, which is considered to be a key priority at the EU level [40]. From a recent detailed mapping of citizen science projects to SDG indicators [41], FotoQuest was highlighted as a citizen science project that could potentially contribute to six SDG indicators, i.e., 2.4.1 Proportion of agricultural area under productive and sustainable agriculture, 6.6.1 Change in the extent of water-related ecosystems over time, 15.1.1 Forest area as a proportion of total land area, 15.2.1 Progress towards sustainable forest management, 11.3.1 Ratio of land consumption rate to population growth rate and 15.4.2 Mountain Green Cover Index. Hence, FotoQuest technology could be used for a variety of EU monitoring activities.

The data collected in FotoQuest campaigns includes the description and classification of LC and LU at various locations but FotoQuest users also produced a vast library of in-situ photographs. Analysis of the quality and usability of these photographs and their potential use as reference data is already being undertaken at IIASA, especially since the pictures taken combined with the information provided by reliable users can be of massive importance. We are also investigating whether payments per point or to top validators (as done in the 2015 campaign - [33]) produce different effects, e.g., change the type of location being visited (far/close to roads). Moreover, we can obtain multiple observations at the same location (demonstrated in the 2015 campaign although not used in the 2018 one), which can be used to ensure higher quality via consensus methods or other ways of combining observations. The benefits of a funded, ongoing FotoQuest campaign driven by citizens, who, amongst other reasons, enjoy being outdoors and contributing to science, could be harnessed as a steady and reliable provision of reference data to ground truth the ever increasing amount of remote sensing big data now available and the new generation of LULC products that they will spawn.

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