Crowdsourcing Energy Data for Participatory Renewable Energy Planning and Modeling

Günther Sagl*,**, Bernd Resch*,**, Anja Summa*, Christoph Mayer*, Sen Sun*, Maria Minji Lee*

* Chair of Geoinformatics, Heidelberg University, Germany
** Department of Geoinformatics – Z_GIS, University of Salzburg, Austria

Abstract. As renewable energy is increasingly fed into regional energy networks, they face significant additional spatial and temporal load fluctuations, making a reliable energy supply more difficult. This is particularly true in the context of varying weather conditions. Thus, diverse energy data on a building or household-level are essential for sustainable renewable energy planning and modeling. However, such data are hardly accessible – if existing at all – because they are mostly owned by private companies like energy providers or network operators. In this paper we tackle this challenge and propose a crowdsourcing approach to acquire fine-grained building and household-specific energy data. Further, we present a technical infrastructure which is based on (mobile) location-aware technologies. We focus on two complementary user interfaces for data acquisition, namely a web application and a smartphone app. The results demonstrate that crowdsourced building and household-specific energy data can support renewable energy planning and modeling processes.

Keywords. Mobile energy data acquisition, location-aware technologies, public participation, VGI, solar thermal systems

1. Introduction

Within the broad and long-lasting political debate about an energy transition to renewable sources, three main trends are clearly identifiable, especially when considering the dependence on the weather: The energy production shifts, firstly, from planned to fluctuating and, secondly, from centralized to decentralized. Thirdly, expensive and nonrenewable energy carriers are increasingly replaced by cost-free and renewable ones (Appelrath

Published in "Proceedings of the 11th International Symposium on Location-Based Services", edited by Georg Gartner and Haosheng Huang, LBS 2014, 26–28 November 2014, Vienna, Austria.

et al. 2012). Thus, the increasing integration of renewable energy sources into existing energy infrastructure necessitates extensions and modifications of power and heat networks, as well as the construction of additional power plants and storage facilities (SRU 2011).

From a more general perspective, the increasing use of renewable energy sources causes significant additional spatial and temporal load fluctuations in regional energy networks due to the dependence on weather conditions. These fluctuations present novel challenges for planning new energy infrastructures and optimizing existing ones (Törnros et al. 2014). The sources that cause such fluctuations include industrial as well as private wind parks, photovoltaic systems, solar heating systems etc. This diversity of renewable sources and the manifoldness of owners make it difficult to establish a common data base that enables GIS based modeling and planning for renewable energy.

A best possible estimate of overall energy supply and demand, especially when considering renewable energy sources, requires detailed and fine-grained energy-relevant data (Resch et al. 2014). Such data can support renewable energy providers, energy infrastructure companies, or city planners in modeling and planning reliable energy supply. Besides the demand of electrical energy, the demand of heat energy can vary considerably if buildings or households are using private solar thermal systems since this decreases the need for external heat energy, e.g., from a district heating network.

However, in contrast to private photovoltaic systems, which are subsidized by the government, and for which at least some technical facts are publicly available due to legal obligations, private solar thermal systems are typically not registered at all. So, in order to tackle the challenge of filling the gaps of energy-relevant data on a building or household-level, specifically with respect to heat demand and heat supply, new data acquisition approaches are needed.

Within the context of renewable energy data acquisition, we derive the following research question: how can mobile and location-aware technologies facilitate crowdsourcing energy-relevant data, thereby supporting renewable energy planning and modeling? In addition to several technical challenges, this research question also addresses aspects of the users' small but valuable contributions, as well as the potentially increasing awareness of the public about the complexity of sustainable renewable energy planning and modeling.

In this paper we describe a crowdsourcing approach for acquiring fine-grained building and household-specific data relevant for renewable energy planning and modeling. We focus on the underlying location-aware technical infrastructure, particularly on complementary user interfaces. The basic idea is to spread simple tasks such as taking a picture of solar panels to many collaborators rather than single experts – in other words, many people are available that can do a simple job, but few people are available who can do an expert job. Therefore, we rely on the knowledge and the willingness of the broad public to contribute to the overarching goal of a successful energy transition to renewable sources.

The paper is structured as follows: the next section, section 2, is dedicated to related work. In section 3, we describe the concept of the system architecture, which is the technical basis of our crowdsourcing approach. Then, in section 4, we elaborate on prototypical implementation aspects, particularly on the complementary user interaction interfaces for energy data acquisition. In section 5, we discuss the results achieved as well as the limitations of our crowdsourcing approach. Finally, in section 6, we present our main conclusions and close with some future research needs.

2. Related Work

Within the last years, governments, governmental-related organizations, as well as private companies have recognized the value of GIS-based public participation platforms as an effective instrument to increase both the awareness and acceptance of the broader public with respect to renewable energy planning and energy infrastructure projects. Since the public acceptance strongly influences planning and investment dependability, it is of vital importance for the project initiators, project sponsors, and project executives. Otherwise, an effect called the NIMBY phenomenon (Not In My BackYard), can potentially cause an enormous public outcry against such projects, can lead to severe (and expensive) delays and even to a cancelation of the entire project (cf. Devine-Wright 2011). One successful strategy to tackle the NIMBY phenomenon is providing participation opportunities for citizens and people interested in planning processes in order to increase transparency and to improve access to information about a specific project. For this, modern web-based concepts such as Public Participation GIS (PPGIS), Government 2.0 and Web 2.0 have been found useful. For instance, in a recent empirical study related to renewable energy planning, Kropp (2013) shows that more than 90% of the study's participants (n=377) believe that conventional public participation methods (disclosure of project plans in the city hall, open councils, etc.) should be extended by map-based applications on the Internet.

However, public participation applications have been typically developed for specific projects or for single use. Concrete concepts and implementation for crowdsourcing energy data are rarely documented in scientific literature. One promising approach by Karnouskos (2011) proposes the use of smartphones for energy data acquisition. Although the paper shows a comprehensive vision of using modern Internet and Communication Technologies (ICT) to enable communication between "prosumers" and the energy system, however, a concrete practical implementation is missing.

Bazilian et al. (2012) present the idea of open energy analysis tools in combination with energy-relevant open data. However, apart from the overall concept described, concrete technical implementations as well as potential practical issues imposed by a real-world context are missing.

Furthermore, Volunteered Geographic Information (VGI) (Goodchild 2007) has been proven to be a valuable additional data source for diverse research areas, e.g. for assessing building footprints (Fan et al. 2014). However, the potential of VGI need to be evaluated in the context of renewable energy, specifically with respect to energy production facilities, private small-scale power plants, energy consumption data, measurements from private weather stations, or citizen science oriented approaches for acquiring additional energy-relevant data.

3. System Architecture Concept

The goal of our approach is the establishment of a location-aware system architecture that enables the acquisition and management of locations and properties of renewable energy systems, as well as detailed household data relevant for heat demand estimation. Herein we focus on the solar thermal systems case.

3.1. Overall Modular System Architecture

The overall system design follows the loose coupling approach, which allows for separating content, style and logic. As illustrated in Figure 1, the core of our location-aware infrastructure is a Django-based web framework. Simply speaking, Django as a middleware application mediates the communication between the data management and the web and mobile interface, where the data is entered, edited and displayed.

The back end is a conglomerate of Open Source software: we use an Apache webserver with Django's Web Server Gateway Interface (WSGI) module, which is a requirement for Apache to serve Python applications. Django also provides an out-of-the-box Create, Read, Update and Delete (CRUD) interface, which allows direct data exchange to the database (Figure 1). In order to turn Django into a geographic web framework, we added the extension Geo-Django. Geo-Django in turn requires PostGIS, the geographic extension of the open source database management system PostgreSQL. PostGIS offers geospatial data types, which enables the integration of the collected geodata into Geographic Information Systems for further spatial analyses.

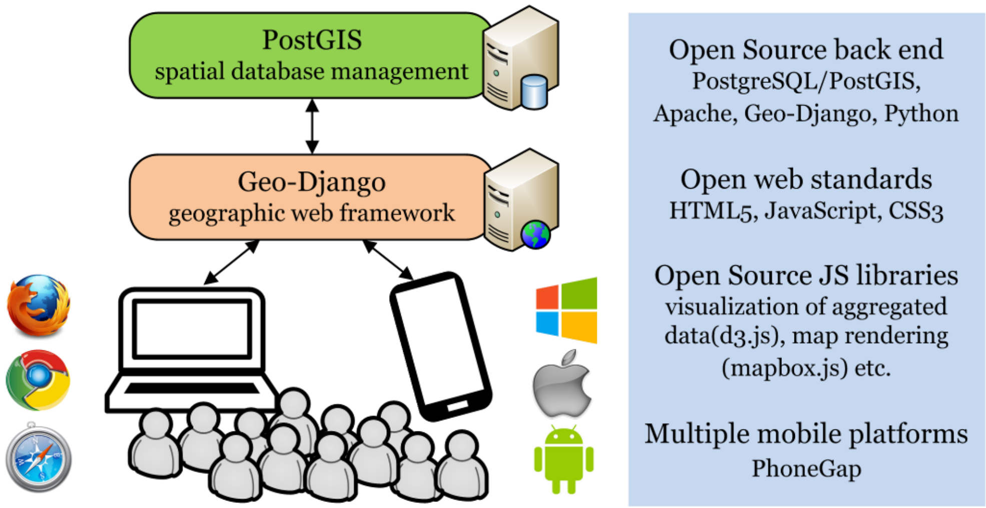

Figure 1: Schematic overview of the location-aware technical infrastructure

On client side, we focus on easy and intuitive data acquisition and data editing regarding solar panels and households. The solar panel data acquisition process comprises panel detection and panel information collection. Herein, panel detection involves the acquisition of a picture of a solar-panel and its corresponding location. The panel information collection requires more detailed knowledge of solar panels and, moreover, information about the panel's corresponding household. In order to support an optimal solar panel data acquisition we offer two complementary web-based tools with graphical interfaces: a fully-fledged web application and a light-weight mobile app.

3.2. Web Application

The web application is designed for easy data acquisition, data editing and data visualization on different screen sizes. Therefore, „responsive web design" ensures the intuitive use of the web app on diverse (mobile) devices such as standard desktop computers, laptops, tablets, smartphones etc. In order to minimize technical barriers for contribution, the user interface of a crowdsourcing application should not contain any technical, logical, legal or intellectual barriers (Nelsen 2006). Adhering to this principle, we provide a set of predefined attribute values for solar-panels in a simple Hyper Text Markup Language (HTML) form. Furthermore, since the user's current location is of crucial importance for further spatial analysis, a correct and accurate location input is supported through a combination of different location mechanisms such as HTML 5 GeoLocation, as well as standard base maps including satellite imaginary and street map.

The web application is intended for comprehensive data manipulation tasks, specifically enriching already existing data sets with more details like type of solar collectors or the orientation of the solar panel. In order to provide a clear overview and make these tasks highly intuitive and straightforward for the user, the web application is designed for devices with larger displays (desktop computers, laptops, tablets, etc.). Nonetheless, due to the use of responsive web design methods, e.g. Cascaded Style Sheets (CSS) media queries, the web application can also be accessed via a standard web browser from small-display devices such as smartphones. For data acquisition and data manipulation via the web application, we follow a two purpose strategy:

- *Intended Use:* the web interface is intended for devices with a larger screen, e.g., laptops or desktop computers, thus providing a convenient way for advanced but easy typing, filling in forms and data fields.
- *Intended User:* the web interface is designed for experts or trained people who are able to assess a solar panel on a picture, as well as the owners of solar panels who add household-specific data.

3.3. Mobile App

In addition to the web application, the mobile app serves as an intuitive and easy-to-use tool that is specifically designed for on-site energy data acquisition, e.g. solar panel image acquisition. As for the web application (refer to section 3.2 for details), we follow a two purpose strategy.

- *Intended Use:* The mobile app primarily serves the purpose of on-site solar panel detection, comprising four simple steps: (1) determine current position and time (automatically), (2) taking picture(s) of the solar panel, (3) entering basic attributes of that solar panel, and (4) submitting these data to the central server instance.
- *Intended User:* The mobile app is designed as a mobile, on-site data acquisition tool for everyone with a smartphone or tablet willing to contribute to the energy transition in the broader sense, even without any previous knowledge on the subject.

Following these two criteria we designed a mobile app that is easy to use and exactly fulfills the purpose of crowdsourcing energy data for renewable energy planning and modeling. The app has four main characteristics: first, a clearly structured interface that guides the user through the process of entering a new solar panel; second, an intuitive way for correcting input data such as re-taking a picture, or canceling the entire data acquisition process; third, a location-based, semi-automated cross-check mechanism should avoid multiple database entries about the very same solar panel; fourth, transparency of the data acquisition workflow, i.e., the user should know which data is collected when. Further aspects regarding data privacy are discussed in section 5.

4. Validation: Prototypical Implementation

The prototypical implementation follows the system architecture design explained in section 3. Since both the web application and the mobile app exchange data with the database via Django, a RESTful[1] web service that serializes the existing data set is implemented. The data format used is JSON[2] due to its light-weighted structure as compared to, e.g., XML-based alternatives. The base maps used are part of the open source mapping platform "mapbox", an open source mapping platform, and provide an unobtrusive style for easy geographic orientation.

From a thematic point of view, this prototypical implementation is tailored to crowdsourcing location specific data in the context of solar thermal energy systems. We therefore term this specific implementation instance Solar Thermal Energy Locator Applications, in short "STELA". So far, the standard language for the web application and the mobile app is German due to the test region of Heidelberg, Germany.

4.1. Web Application

The Graphical User Interface (GUI) of the web app "STELAweb" comprises the main menu bar at the top, a sliding data entry form on the left side, and a map container (Figure 2). The main menu bar combines the functionality of user management and data creation. A user registration is not mandatory for adding solar panel data, but it is for household data to enhance data privacy. Within the main menu on the top left, a user can add data for "solar

---

[1] Representational state transfer (REST), a specific architectural abstraction style within distributed systems

[2] JavaScript Object Notation (JSON), an open standard as an alternative to XML

panel" or "household" via the corresponding data entry form – Figure 2 on the left shows the example of the data entry form for solar panels, a similar form is available for household data. For visualization purposes, individual solar panels available in the database are aggregated using spatial clustering and rendered as markers on a base map, thereby balancing information density across spatial scales while zooming. Only data about solar panels are shown, household data are not available via that interface.

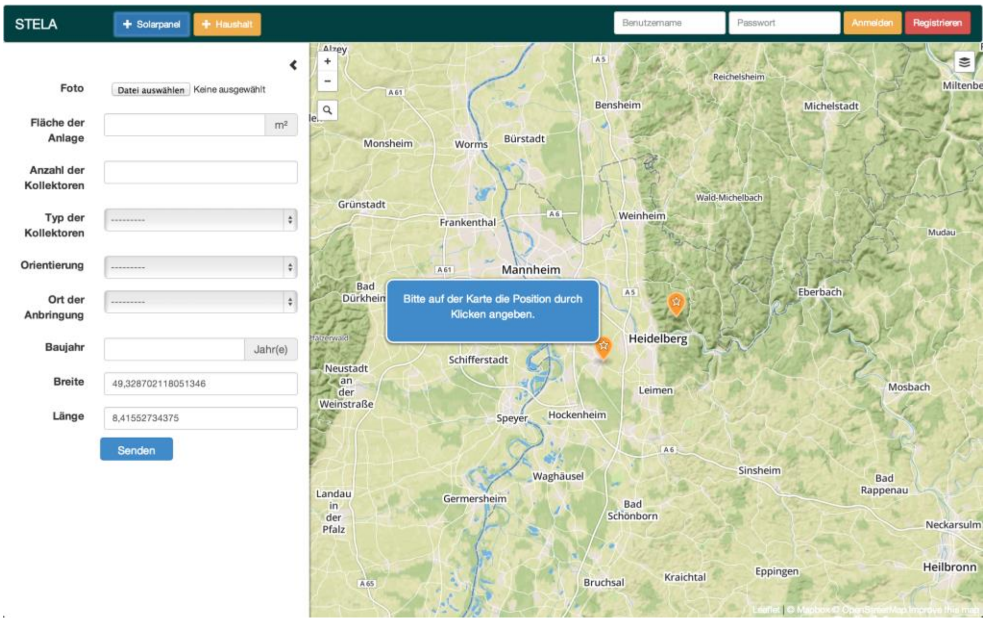

Figure 2: "STELAweb" – Graphical User Interface of the web application; forms on the left allows for adding solar panel data and household data

Entering new data or revise existing data consist of five steps:

1. When starting the web app the map is centered at the user's current position or, if current location data are not available, the map is centered to the bounding box of Germany. Alternatively, the user can use the address query function to center the map at the desired location.
2. New entries for solar panels or households are added by clicking the corresponding buttons in the navigation bar and filling in the respective HTML form appearing in the side bar.
3. Submission of the data to the server. The user receives a short feedback whether the data are successfully submitted and entered into the database on the server.

4. A successful submission about solar panel data is immediately available and visualized at the client.
5. Available solar panel data can be edited or deleted; household data can be added to each solar panel data set.

Besides creation and visualization, other operations of the solar panel data such as update and delete are supported as well (Figure 3, at the bottom of the pop-up window).

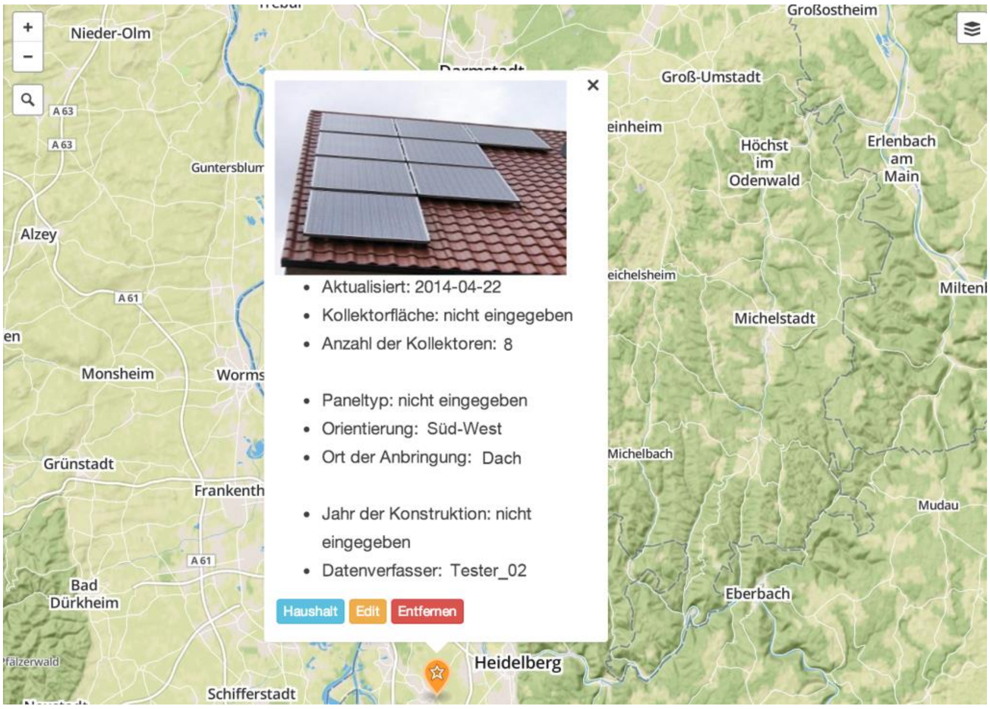

Figure 3: "STELAweb" – example of a popup window comprising solar panel data;

4.2. Mobile App

The mobile app "STELAapp" consists of six screens, which cover the four-step sequence of data acquisition. These four steps relate to "position", "picture", "details", and "submit" and are displayed as a progress bar within the app. As shown in Figure 4, the first four screens refer to "position" and "picture".

The first screen shows a map with the locations of solar panels already captured. The initial map is centered at the user's location, which is visualized using a position symbol. If automatic geo-localization is not possible, the user can enter an address. Further, the solar panel locations are visualized as individual locations or as clusters, depending on the zoom level and the number of solar panels. This visualization provides the user an overview of existing solar panels nearby. Moreover, it enables the user to check whether a solar panel data entry already exists in the database and, if so, to validate it. On the second screen, the user can add a new solar panel location while the user's current location is updated in case the user moved from the initial location (step 1).

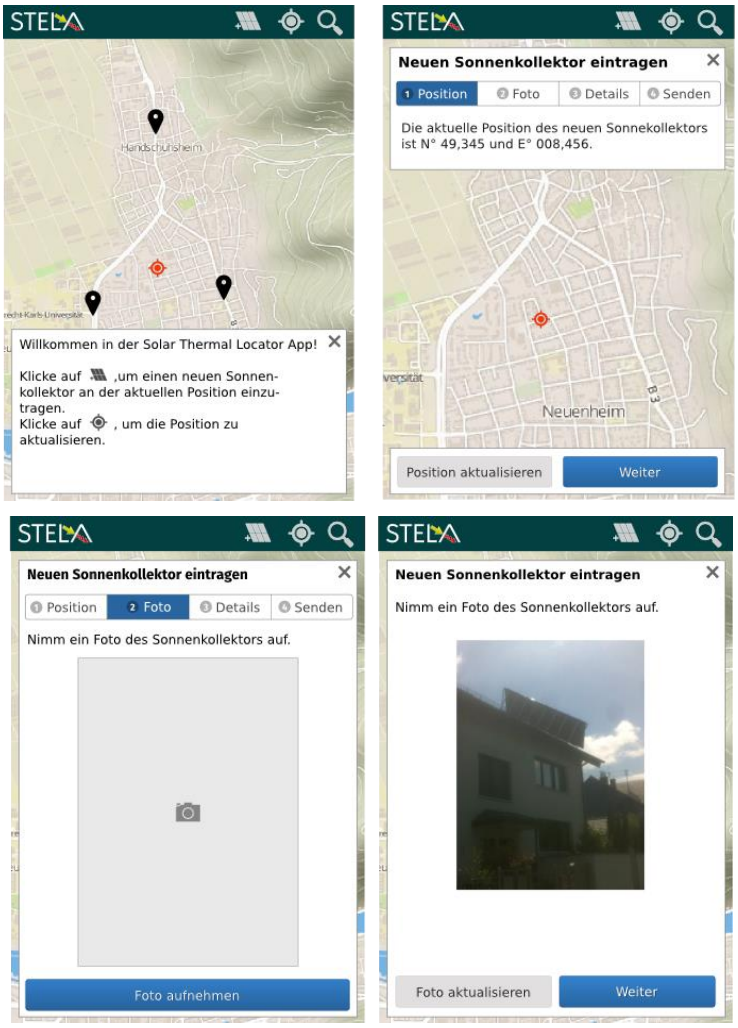

Figure 4: "STELAapp" – four screens of mobile energy data acquisition

The third screen is used for taking a picture of the solar panel, which is then displayed on the fourth screen. Here, the user can decide to keep or retake the picture. The fifth and sixth screens are not illustrated herein. The fifth screen is very similar to the corresponding form of the web app (Figure 2, left); it allows the user to insert additional information about the solar panel. This part is optional, because not all app users may have detailed knowledge about a specific solar panel. In the sixth and final screen the user can check the data entered and submit it to the central server instance.

Throughout the data acquisition process the user can navigate back and forth among the screens by clicking on the steps on the progress bar. As a result of the overall user interface design and the progress bar in particular, the user can control every single step within the data acquisition workflow and get informed which data are send when.

From an implementation point of view, the mobile app was created using state-of-the-art open web standards (HTML5, CSS3, and JavaScript JS). Exemplarily, the app was then ported to Android via Apache Cordova, a freely available platform for building native mobile applications using aforementioned web standards. The six screens are encapsulated in one single HTML document with objects, which are dynamically manipulated via the Document Object Model (DOM) using JS. This also improves the performance of the app by avoiding (re)loading entire HTML pages, thereby providing a more native app-like feeling.

5. Discussion and Limitations

Within the crowdsourcing approach for energy data acquisition presented herein, two complementary user interfaces are designed and implemented. First, the web application STELAweb is the main user interface for entering rather comprehensive details of solar panels or households (Figure 2 and Figure 3). Furthermore, the web application is particularly useful for manipulating and editing already existing data sets on devices with a larger screen (e.g., laptops or tablets). Second, the mobile app STELAapp is specifically designed for acquiring data about solar thermal systems on site, e.g., in the form of geo-referenced pictures of solar panels. Although the mobile app comprises less functionality than the web application, it nevertheless allows for crowdsourcing objective data in form of pictures. Such pictures can then be examined by experts or trained persons in order to get the most information out of a picture. Thus, STELAweb and STELAapp are complementary applications that facilitate the crowdsourcing of fine-grained energy data on the level of households or buildings, thereby supporting renewable energy planning and modeling. We demonstrated this on the example of solar thermal systems.

However, several limitations and constraints need to be addressed. As described in the introduction, not only information on the solar panels is valuable for renewable energy planning and modeling, but also data about the household, such as number of people living in the house, energy consumption, the house's age etc. Such data could therefore be considered private and, therefore, a clear privacy policy needs is inevitable (cf. Damiani 2014). Consequently, the mobile app should include optional log-in functionality – like the web application. Such an authorization mechanism could help to build trust with inhabitants that can provide valuable energy-related information.

Furthermore, in terms of user encouragement and motivation, the authorization functionality mentioned before could be used to provide anonymized activity summaries or "score-sheets", thereby offering location-aware feedback in a gamming manner (e.g., who are the most active contributors, where are the latest entries from, what is the degree of completeness of those data, has an data entry been cross-checked on site, etc. Potentially, highly active user could be rewarded by energy-related institutions. Following this idea of "gamification", STELA could turn into a community-driven project, like Open Street Map (OSM 2014), that supports a successful energy transition using the local knowledge of the crowd.

Another issue refers to data quality in the context of crowdsourcing. The approach described herein is designed for crowdsourcing renewable energy data, exemplarily demonstrated for the solar thermal system case, and also bringing together energy experts and laymen. In any case, the extraction of specific energy-related information from a picture would require certain "quality standards" with respect to both the picture and the person that took that picture. For instance, a minimum picture resolution, the object's exposure to light, the ascertainment of relevant details such as orientation of the solar panel should follow a minimum standard. However, such aspects can hardly be standardized in order to keep a certain data quality level high. The approach of crowdsourcing energy provides nonetheless an additional opportunity of data acquisition for participatory renewable energy planning and modeling.

6. Conclusion and Outlook

In this paper we presented an approach for crowdsourcing energy data for participatory renewable energy planning and modeling and focused on the underlying location-aware infrastructure: we allow people to contribute energy data by means of web-based crowdsourcing and public participation platforms using both a mobile and a standard web application. Mobile technologies such as smartphones are used for on-site data acquisition in the form of geo-referenced images of solar panels and solar thermal systems in combination with supplementary input – this was demonstrated on the example of the mobile app STELAapp. The web application STELAweb provides a more convenient way for adding or editing detailed data of solar panels. Additionally, STELAweb is used to acquire and edit household data.

Hence, referring to the research question stated in the introduction, the overall location-aware infrastructure described herein enables an innovative and complementary way (web application plus mobile app) to collect relevant and fine-grained energy data on a building or household-level. Since such data can hardly be acquired otherwise, they are potentially valuable for renewable energy planning and modeling. Furthermore, such a crowdsourcing approach (e.g., using a mobile app) in combination with an online participation and information platform (e.g., a responsive web application) potentially induce high public visibility and, therefore, increase the awareness of the complex topic of a sustainable energy transition.

The scientific contribution of the research outcomes presented in this paper is twofold. First, the crowdsourcing approach described is an efficient and complementary way for acquiring energy data, thereby supporting the establishment of a more complete energy data base. So far, data attributes include the size and orientation of solar panels, the number of people living in a household, the number of households in a building, the size of heated rooms and areas. Second, the location-aware infrastructure combines the advantages of efficient on-site data acquisition (mobile app) and advanced off-site data entering and data manipulation (web application). The fine-grained building and household-specific energy data gained that way can support renewable energy planning and modeling. We validated the approach and the location-aware infrastructure on the example of solar thermal systems in the context of heat energy supply and demand.

Furthermore, due to the modularity and the loose coupling, the system architecture can easily be extended and applied to several other crowdsourcing and data acquisition needs. Such application domains include, for instance, urban flora and fauna monitoring, or urban infrastructure damage registration and assessment.

In a next step we will focus on the enhancement of the location-aware component for data quality improvement. For instance, when a user is nearby a location with already captured solar panel data or household data, the user might be asked to confirm that data. Another challenge is the preparation of energy data acquisition guidelines in order to maximize the information content in the data acquired.

References

Appelrath H-J, Kagermann H, Mayer C (2012) Eds Future Energy Grid-Migration to the Internet of Energy; Acatech: Munich, Germany

Bazilian M, Rice A, Rotich J, Howells M, DeCarolis J, Macmillan S, Brooks C, Bauer F, Liebreich M (2012) Open source software and crowdsourcing for energy analysis. Energy Policy, 49:149-153

Damiani M (2014) Location privacy models in mobile applications: conceptual view and research directions. Geoinformatica, 18:819-842

Devine-Wright P (2011) Renewable Energy and the Public: From NIMBY to Participation. Earthscan: London, UK

Fan H, Zipf A, Fu Q, Neis P (2014) Quality assessment for building footprints data on OpenStreetMap. International Journal of Geographical Information Science, 28:700–719

Goodchild MF (2007) Citizens as sensors: The world of volunteered geography. GeoJournal, 69, 211–221

Karnouskos S (2011) Crowdsourcing information via mobile devices as a migration enabler towards the smartgrid. In Smart Grid Communications (SmartGridComm), 2011 IEEE International Conference on, 67-72

Kropp, C. (2013) GIS-Gestützte Online-Bürgerbeteiligung im Kontext der Planung und Genehmigung von Energieinfrastrukturvorhaben: Eine Anforderungsanalyse. Master Thesis, Heidelberg University, Heidelberg, Germany

OpenStreetMap OSM Community http://www.openstreetmap.org. Accessed 23 May 2014

Resch B, Sagl G, Törnros T, Bachmaier A, Eggers JB, Herkel S, Narmsara S, Gündra H (2014) GIS-Based Planning and Modeling for Renewable Energy: Challenges and Future Research Avenues. ISPRS International Journal of Geo-Information. 3(2): 662-692

Sachverständigen Rat für Umweltfragen SRU (2011) Wege zur 100% Erneuerbaren Stromversorgung; Erich Schmidt Verlag: Berlin, Germany

Schnelle K, Voigt M (2012) Energiewende und Bürgerbeteiligung: Öffentliche Akzeptanz von Infrastrukturprojekten am Beispiel der Thüringer Strombrücke; Heinrich-Böll-Stiftung: Thüringen, Germany

Törnros T, Sagl G, Resch B (2014) Ein GIS-basierter Ansatz zur optimalen Standortfindung für dezentrale Speicher in Energienetzen, in Angewandte Geoinformatik AGIT 2014, J. Strobl, et al., Editors, Wichmann/VDE Verlag: Heidelberg, Germany. 169-174