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A Digital Support Platform for Community Energy: One-Stop-Shop Architecture, Development and Evaluation

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Abstract: In the European energy market, the community energy sector is earmarked to make a significant contribution to the transition from fossil fuels to sustainable sources. Based on the diffusion of innovation model, large-scale development of community energy requires that the concept and the success of existing energy communities be widely communicated to potential participants and that user confidence be developed over time. In this paper, we present the architecture, design, prototyping, and testing of a digital support platform, co-designed with EU-wide energy communities, to support this process. The platform has been designed to engage early-stage or ongoing groups to progress projects and to connect and share experiences with other communities. This "community of communities" creates the necessary communication channel defined in the Diffusion of Innovation model. A transactional architecture for such a platform is outlined with clear links to all community energy actors. Based on this architecture, a prototype one-stop-shop (OSS) implementation is presented. Feedback gathered and lessons learned from beta testing with a representative group of end-users are outlined. The OSS architecture shows potential as a communications channel to expand the community energy concept and as a monitoring tool to track the progress of the energy community sector.

Keywords: community energy; renewable energy community; one-stop-shop; innovation; digital platform

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1. Introduction

The European Green Deal [1] and the European Climate Pact [2] highlight the urgent need for emissions mitigation. European and national authorities aim to engage the general public in climate action as this civic activation is required to reach the Paris Agreement international emissions targets to limit warming to 1.5 degrees centigrade above pre-industrial times [3]. Additional targets addressing climate action and other associated opportunities, including access to affordable, clean energy and reduced inequalities, are outlined in the United Nations (UN) Sustainable Development Goals (SDGs) [3–6]. Extensive policy measures promote actionable change as part of the "energy transition", which describes the move towards renewable and sustainable energy sources in place of traditional fossil fuels and requires significant efforts to adopt renewable energy and energy efficiency measures [7]. The energy transition involves migration to a more decentralised energy supply model enabling citizens to become "prosumers", acting as both producers and consumers [8]. Prosumers can form part of an "energy community" collectively generating and managing local renewable energy supply [9,10].

The European Union (EU) promotes community energy as a key part of its climate change response, and policies are designed to enable citizen engagement in the energy transition. Community energy is specifically referenced, with the definitions of Renewable Energy Community (REC) and Citizen Energy Community (CEC) disseminated in the Recast Electricity Directive (EU) 2019/944 [11] and the Recast Renewable Energy Directive

(EU) 2018/2001 [12] in the Clean Energy Package. These community energy projects involve citizens, local authorities, and businesses, and are financially and managerially controlled by the local community members [13,14]. It is estimated that more than 50 GW of wind and 50 GW of solar generation assets could be under community ownership by 2030 (17% and 21% of installed capacity, respectively) [15]. Half of all European Union citizens could be producing their own electricity by 2050 and meeting 45% of the EU's energy demand [16]. The recast directive also supports the development of an "enabling framework" to support prosumers and facilitate the growth of locally owned energy projects [17]. As the energy market is switching from fossil fuels and nuclear to renewable energy, it is also shifting from a decentralised market dominated by large utilities to one in which people produce their own energy and help manage demand. Without these "energy citizens", the transition to a renewable energy system will not be possible [9,16].

Energy communities have many benefits, ranging from building citizen awareness around the energy transition to improved energy use behaviour [10,17]. Involving citizens in community renewable energy generation projects can overcome resistance to infrastructure development, such as the installation of PV panels or wind turbines, known as "NIMBYism" (not in my back yard) [10,13]. Transitioning towards a renewable energy model with opportunities for local generation may also result in roles and opportunities for citizens to get involved, reducing social isolation and enabling a just transition [9,14,16,18]. Ecopower, a Belgian Energy Community Cooperative, supplies roughly 1.64% of household electricity in Flanders, with 23 wind turbines, 3 small hydropower installations, 1 co-generation installation, and 322 decentralised solar PV installations on the roofs of schools and houses. Ecopower also helps its members save energy, with members halving their electricity consumption over the past years [19]. With sufficient policy measures in place, projects can generate revenue for the local area if excess energy is fed back onto the grid with a feed-in tariff (FiT), enabling profits to be channelled into the community. A just transition can be realised with community groups having a social objective of reducing energy poverty [17,20]. Additionally, local energy generation can enable communities' self-sufficiency and energy independence [21,22], which is particularly valuable where energy security is a concern. The full potential of energy communities can only be unlocked at scale. This scalability requires data-driven solutions that promote user behaviour to take maximum advantage of renewable resources and demand management and local grid conditions as part of a community energy plan [23,24]. Groups also require ongoing connections with policy makers and state actors during project development from a top-down and bottom-up perspective [25].

For "niche" community energy developments described above to achieve widespread deployment, the Diffusion of Innovation (DOI) theory can be applied. Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system. The four key elements are innovation, communication channels, time, and the social system [26]. Existing community energy projects can have a multiplier effect, with other communities inspired to form new groups when they see and understand similar communities that have developed successful projects [10].

There are many challenges to the development of energy communities as significant actors in the energy transition [27,28]. These challenges include organisational issues, legal framework, planning requirements, market barriers, and lack of institutional/policy support and resources. The key research questions addressed in this paper are the specification of the requirements of a digital platform to assist energy communities in their development and identification of a general architecture and the design principles for such an OSS. Working with diverse stakeholders in the community energy sector, the system requirements were determined, and following a review of previous work, a suitable system architecture to meet those requirements was designed. With this architecture, a beta version of the OSS was developed and user evaluation results of this OSS are presented. These results are discussed to assess the development process and the potential of such an OSS approach.

The paper first outlines a review of innovation diffusion theory and previous work on one-stop-shops and architectural frameworks to specify the structure of a digital platform to mediate and support the stakeholders in community energy development are presented. The design process and user-led requirements for the platform are then outlined and a digital architecture to meet those requirements is developed. A prototype implementation of this one-stop-shop is presented with user feedback from a platform beta test and used to draw conclusions and plot a roadmap for the future development of such platforms.

2. Materials and Methods

The emergence of community energy groups demands system-wide transformations in sociotechnical systems of provision [22]. The energy transition faces locked-in dominant "solutions" (and the sociotechnical systems that deliver these) when novel experiments offering more sustainable alternatives need to originate in "niches". In community energy development, civil society acts as an agent of change and can form niche spaces where new ideas and practices can be developed. For this work, a niche is described as a protected space where sub-optimally performing experiments with longer-term sustainability benefits can develop. Niches comprise intermediary organisations and actors, which serve as beacons of best practice, standards, institutionalised learning, and other intermediating resources such as networking and lobbying, which are informed by, and in turn inform, concrete local projects [29–31]. Successful niches facilitate the diffusion of innovative socio-technical practices and systems. Transition theory suggests three ways by which niches can influence the regime: by enabling replication of projects within the niche, bringing about aggregative changes through many small initiatives; by enabling constituent projects to grow in scale and attract more participants; and by facilitating translation of niche ideas into mainstream settings [22]. The latter is the goal of community energy development.

For the innovation of community energy to be widely diffused, the diffusion on innovation model proposes that the concept and its operation must be widely communicated to potential participants on an interpersonal basis over a period of time as the objective is to create or change long-established attitudes held by individuals. The social system is defined as "a set of interrelated units engaged in joint problem solving to accomplish a common goal" [26,31]. The theory proposes that a target population can be broken down into five different groups, based on their propensity to adopt a specific innovation: innovators, early adopters, early majorities, late majorities, and laggards [31]. For the most part, community energy is currently at the innovator and early adopter stages in different regions and faces the challenge of engaging the rest of the population that sees higher risks in change and therefore requires assurance from trusted peers that such innovation is doable and provides genuine benefits. Previous work from transition studies identifies and groups the challenges faced into four domains: directionality, experimentation, demand articulation, and policy coordination and learning. These challenges must be overcome by taking account of the three generic features of innovation systems: interests and capabilities of actors, networks, and institutions [32]. Applying this analytical framework to community energy development, four challenge groups are articulated [27]:

- Directionality: Transition requires not only innovation but also a particular direction of transformative change. Directionality is established through policies and goals to deliver an agreed vision such as reducing greenhouse gas emissions.
- Experimentation is about testing new technologies and the societal arrangements required for their uptake. For community energy, development can be accelerated by supporting communities to act as beacon early adopters.
- Demand articulation encompasses policies that help products enter and establish themselves in markets. One example of how to support the uptake of RE technology is the awarding of higher feed-in tariffs for community energy projects.
- Policy learning and coordination highlight that transitions require coherence and consistency between policy levels. Simultaneously, transitions require room for modification and transformation of existing policies according to learning and experiences.

Community energy policy requires an iterative process of policy development driven by accurate measured data on policy impacts.

Based on this analysis, the expansion of the community energy sector could be supported by the use of peer communication networks with a commonly articulated goal, maximising the ease and simplicity of participation and experimentation for innovators and early adopters, providing strong support for early and late majorities, and providing data to policy makers to develop evidence-based policy interventions. We propose that these methods could be implemented with an integrated digital platform focused on enabling and supporting groups and projects involved in local energy generation.

Research on energy retrofits in existing commercial and residential buildings has identified many similar barriers to development as encountered in the community energy sector, including a lack of knowledge and know-how, lack of national and/or local commitment to energy efficiency, financing challenges, and market failures and inefficiencies [33]. One-stop-shops are advocated to accelerate building retrofits by the Directive 2018/844/EU on the energy performance of buildings (EPBD) and Directive 2012/27/EU on energy efficiency (EED). These one-stop-shops are transparent and accessible advisory tools from the client perspective and new, innovative business models from the supplier perspective [34]. The objective of these supports is to reduce the barriers encountered by potential retrofit customers by mapping the typical renovation journey, including marketing, preliminary proposal, building inspections and energy analysis, quotation and financing planning, quality insurance, renovation works, financing, commissioning, and follow-up [35,36]. A one-stop-shop concept for building retrofit has been proposed where the homeowner is guided through the whole renovation process of their house, with a single contact person helping them [36]. This concept means moving toward a customer-centred service model, with a single customer interface and point of contact who takes responsibility for project management [37]. This bridges the gap between the fragmented supply chain and demand sides and reduces the need for homeowners to manage various building professionals otherwise involved in the retrofit process [34]. A review of existing literature and existing studies highlighted different levels of homeowner willingness to engage with OSS models, with an effective OSS model being designed to be attractive and inclusive to a broad range of users [37]. OSS support platforms to assist with project development in home renovation found that while the OSS was informative to the end-users, it was time-consuming and overwhelming. To avoid this, the authors suggested using checklists and tools to guide projects along the development process [36].

We propose a one-stop-shop digital platform for community energy. The term "one-stop-shop" has had many meanings in the reviewed literature, ranging from a network of SMEs in a similar industry sector [38] to a process for managing user access to electronic library resources [39]. In this work, a "one-stop-shop" describes a business or organisation that offers a range of services or products all in one place. This definition is applied to community energy projects where a digital OSS is a place where the stakeholders can benefit from services offered by the OSS.

Many groups have worked on digital support platforms across multiple application domains and the approaches taken, outputs, and success of these previous works are reviewed here as a guide to understanding how existing digital platforms were developed and the purpose they served. The emergence of digital platforms as a replacement for traditional "monolithic" strategies has been analysed [40]. The platforms mediate different groups of users, such as buyers and sellers, and can be described as multisided denoting arrangements where multiple groups interact. As these platforms bring together multiple user groups, and a technology's usefulness often increases as its installed base of users increases. To remain relevant and valuable, digital platforms must provide flexible growth of expanding features while remaining stable and reliable for end-users [41]. Community energy projects can be considered multisided as they are unavoidably entangled with community, state, and private sector actors and with institutions operating at and across multiple scales. Trans-scalar assemblages of these overlapping actors enable community energy, which demands multi-sectoral participation and coordination [25]. The concept of developing a "smart community-integrated platform" has been discussed [42]. The proposed platform integrates community services such as transport infrastructure, medical access, and the Internet of Things (IoT) with communities as the core element of smart city planning. The system incorporates all the key actors and activities of a future smart city, and its functional requirements are separated by theme to allow easy access for users looking for a specific topic or item. The authors mention paying specific attention to information flow between functions on the site, which is critical to ensuring a satisfactory user experience [42].

A study of the utilisation of digital platforms for development and innovation defines a digital platform as that which is mediated via technology, enables interactions between participants or user groups, and allows users to complete tasks. This infers that digital platforms are distinct types of information technology (IT), with specified properties and purposes dependent on the user's needs, and platforms are divided into innovation and transaction categories (50). Transaction platforms can be useful for community energy development, as they provide access to content to all users without simultaneous use by others affecting the process. Thus, transactional platforms' processing power enables rapid information exchanges, removing the traditional delays associated with the non-digital dissemination of information [43].

The results of the literature review indicate that there is not a lot of directly relevant guidance on the architecture or design of an OSS suited to supporting energy community development. The OSS design and development should consider the following:

- The OSS will be multisided (multiple groups interacting) and the design must engage all stakeholders, with the OSS usefulness increasing as its installed base of users increases;
- All users have a shared purpose, which is the development of community energy projects;
- The OSS will be a transactional digital platform for knowledge exchange, which reduces the frictions in developing energy communities;
- The objective of the ECCO OSS (Supplementary Materials) is to support innovators and early adopters, who will seed the innovation required to underpin widespread adoption;
- A key function is matchmaking OSS users to provide networking opportunities and create a community of communities;
- Data responsibility and adherence to regulations and legislation will be essential to user trust when developing the digital platform; and
- To remain relevant and valuable, digital platforms must provide flexible growth of expanding and evolving features while remaining stable and reliable for end-users.

3. Design Process

The proposed OSS will deliver an online digital platform that will connect users from various backgrounds, including the public, technology experts, and policy makers. As digital platforms are always expected to evolve, both the initial system design and its evolution involve an iterative process, and end-user involvement is necessary at all stages. To meet these requirements, an "action design research" (ADR) approach is well-suited and was adopted in this work [44]. ADR is an iterative process of simultaneously "taking action" and conducting "research" with the inseparable and inherently interwoven activities of building the IT platform, deploying with the target users, and evaluating it concurrently. The first step of the ADR approach was to engage with existing community energy groups to identify the key OSS users and the challenges they faced in the context of the Diffusion of Innovation model. After analysis of these challenges, a system architecture was defined based on the identified key transactions of the OSS. An OSS prototype was developed based on the defined architecture and deployed to a group of beta test users, who provided feedback on the usefulness of the design and implementation of the OSS.

Challenges Faced by Groups

Community energy projects face several challenges that affect the growth and success of projects. One of the difficulties groups face is organisational, as volunteers are the driving force of most groups but they struggle to find time to dedicate to the group projects that span several years from concept to realisation. Another issue experienced is a lack of technical expertise and limited guidance on the next steps for the project [21]. In addition, policies and regional organisations that support energy community projects vary significantly in each country, and a lack of policy understanding and connection to support groups can hinder project growth. This overall lack of communication and clarity on the process between groups, members, and mentors, including technical experts, can drastically impact project development [25].

A critical factor in community energy project growth is finance, as it can be challenging for groups to raise feasibility and development funds [21]. These issues can negatively influence the initial uptake of projects and the overall success rate of existing projects, delaying progression and ultimately deterring groups from taking part. These challenges must be overcome to avoid groups being excluded from the opportunities associated with local renewable energy generation [8,9].

The ECCO OSS gives users autonomy over the site, sharing helpful information between users and groups to aid project growth and removing restrictive barriers that can deter projects from progressing. It is designed as part of the "enabling framework" outlined by the EU to support community energy projects [17]. Improved supportive mechanisms offered by the OSS can level the playing field for local energy groups to get involved in the energy market and facilitate updated policy to enable this engagement [45].

4. Platform Architecture

The one-stop-shop (OSS) is designed to be a flexible, multisided, transactional platform that provides a structured support system to assist projects at each stage of development. The initial design task is to identify the users of the service, as illustrated in Figure 1. The primary users of the OSS are identified as:

- Community members who organise themselves into active community groups;
- Organisations such as regional public authorities, non-governmental organisations (NGOs), and academic research institutes that support these groups; and
- At the national and transnational levels, policy makers who must implement policy and measure its impact at the grassroots level.

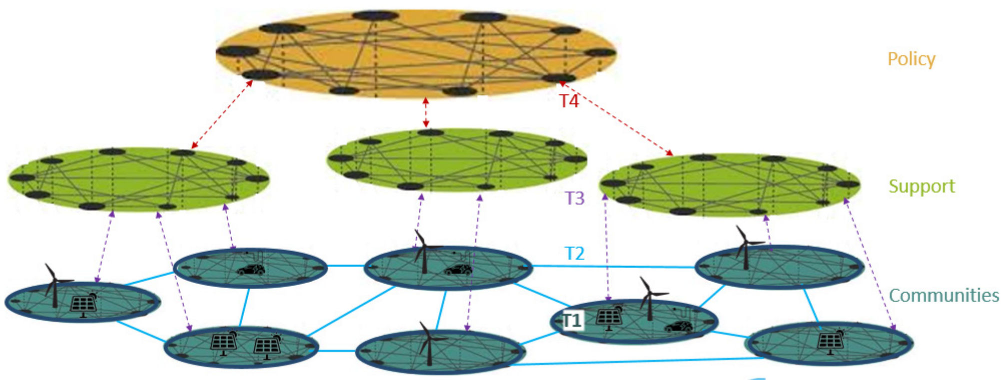

Figure 1. OSS design architecture. T1–T4 indicate the transactions between users.

For its diverse key users, the OSS can facilitate horizontal and vertical connections within the energy community sector that represent the transactions between OSS users. The definition and support of these transactions is the key element in OSS design and implementation. The four layers of transactions, labelled T1 to T4 in Figure 1, are:

- T1 Intra-Community Transactions: Within energy communities, transactions focus on specific energy projects and initiatives within the community. These transactions

involve the development and operation of projects and communications between community members.
- T2 Inter-Community Transactions: Between energy communities, transactions focus on sharing knowledge and expertise, supporting the development of other communities and building trust and confidence in the community. This is an essential element of the Diffusion of Innovation model, as previously outlined. In this paper, these transactions are referred to as a horizontal network.
- T3 Support Layer Transactions: Many stakeholders in the promotion of energy communities play a support role and wish to assist communities to progress projects and monitor the progress of the community energy sector. A two-way transaction is required, where the support groups provide resources required by energy communities and the communities provide feedback on the usefulness of those resources and data on their activities and progress. In this paper, these transactions are referred to as vertical networks.
- T4 Policy-Level Transactions: At the national and transnational levels, policy makers determine the conditions in which energy communities operate. EU and national policies must now support recent EU directives enabling community participation in the energy market. Policy makers will have transactions with grassroots communities to adopt data-driven policy plans and to communicate policy changes to end-users. These transactions may be mediated via the support layer in Figure 1, but for this paper, mediation of the transaction does not significantly affect the design process. These transactions are also classed as vertical.

T1 Intra-Community Transactions

Community energy groups face many challenges around the formation of the group, internal communication, and project development. These challenges can be divided into group, technical, and financial subsections, and transactions within the community would deal with these topics. The OSS should assist with the emergence of new community energy groups and support the continued development and success of existing groups by enabling those internal transactions required for success. Social network features offer an efficient format for sharing information amongst many people, such as community energy groups having the advantage of user familiarity with such networks and could play a useful role in the OSS.

T2 Inter-Community Transactions

A key function of the OSS is to provide networking opportunities and create a community of communities. To expand the adoption of the community energy model as modelled using the Diffusion of Innovation model, the majority of potential participants in an energy community must have assurance from trusted peers (early adopters) that community energy is doable and provides genuine benefits. The OSS can connect users across various communities and geographical locations, enabling participants to see the success of beacon projects, inspiring them to proceed with their local projects. The transactions at this level focus on the dissemination of knowledge amongst peers and match the inter-community social connections to project-specific development phases. In addition, social connections with other users can provide dedicated topic spaces in which groups can communicate. This interaction disseminates knowledge and inspires participants in emerging projects, providing an expanding network of knowledge and experience for the network. With increased user engagement, the continued interaction of users will build a large online knowledge base for future developments.

T3 Support Body Transactions

Support bodies generate knowledge, resources, and tools that enable energy communities to operate and progress their energy projects. Transactions between energy communities and these support organisations are bidirectional. The OSS enables support bodies to disseminate reliable and relevant resources and support activities to assist community groups. Information and project development support must be provided in an organised and structured manner, with the end-user experience in mind. In the reverse transaction, energy communities provide data on their progression and feedback on the impact of resources provided to the support bodies. These feedback data are critical for the optimal design and delivery of evidence-based support for the sector.

T4 Policy-Level Transactions

The Climate Action Agenda is clear and the policy objectives have been defined. The challenge for policy makers is the realisation of the energy transition goals, including the goals for energy communities. The OSS will enable tracking of the growth of energy community projects and highlight where common problems are experienced, thus indicating where additional measures are necessary. Policy makers will have transactions with grassroots communities to disseminate policies and collect data on the community energy sector. These data will allow the impact of the community energy sector to be measured, including how groups grow and perform and where there may be a need for additional policy measures.

5. OSS Prototype Implementation

Based on the findings from the literature review, the ECCO OSS should meet the requirements of a multisided platform with users, as shown in Figure 1. The transactions between those users as described above are supported with specific instances providing information and resources for community energy projects alongside social connections to other projects and community groups.

The primary goal of the OSS is to assist energy communities to develop successful energy projects that contribute to the energy transition and are of benefit to the community members. Therefore, the OSS adopted a bespoke project development timeline, developed by one of the ECCO project partners (55), that articulates each stage of a community energy project along three parallel paths: People, Technology, and Finance. The timeline, as shown in Figure 2, divides the project into six distinct phases: Awareness, Emergence, Development, Post-development, Construction, and Operation.

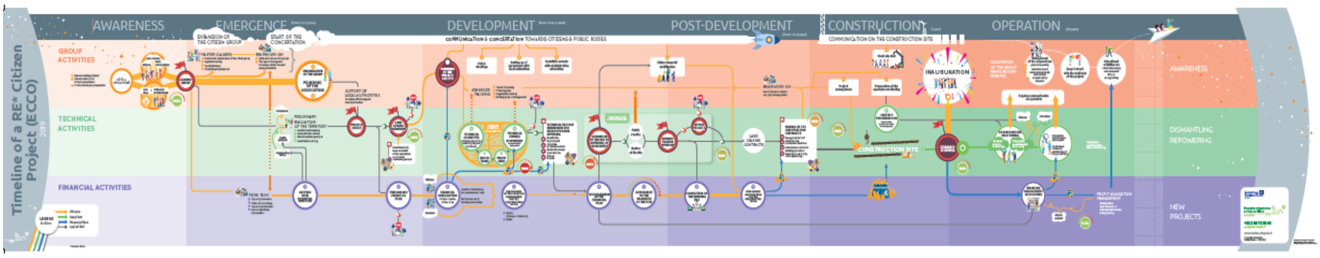

Figure 2. Community energy project timeline.

The OSS should guide and support the users along this development path with information about REC development tools and resources accessible at each step.

5.1. Rapid Prototyping

Using the ADR method for OSS development, an early implementation of the system for iterative user evaluation is essential. A Content Management System (CMS) was used to develop a rapid prototype of the site using the Joomla CMS. As an open-source tool, Joomla is a free CMS for publishing web content. It is built on a model–view–controller web application framework that can be used independently of the CMS and contains many features to deliver the OSS functionality. Additional plug-ins, such as JomSocial, enable the social media functionality that many of the Intra and Inter Community Transactions require. This includes user-created profiles, connection with other users via "friend requests", and group setup for internal communication within an energy community. A forum structure was developed using the Kunena plug-in with a structured hierarchy of topics that could be easily navigated. Implementing existing plug-ins allows an expedited development process as it avoids building features from scratch, saving valuable time in development and allowing more time for user engagement.

5.2. OSS Description

Based on the design process outlined above, the developed OSS offers a community interaction space, access to resources and tools, and a discussion forum. Each feature is included in a dedicated OSS space. The landing page of the OSS is shown in Figure 3 (https://www.ecco-oss.eu/ (accessed on 1 May 2022)).

Figure 3. The landing page of ECCO OSS.

OSS users can use the platform as a guest or as registered users. The level of OSS resources and tools available varies between guests and registered users. To gain full access to the OSS community page, users must log in and register details on their profile. While only name, username, and email address are mandatory, participants are asked to input additional information about their project(s) and topic of interest. This information is helpful to understanding the profile of the users participating on the site and may be used to facilitate user matching or filtering of relevant content.

Registered participants of the site are presented with a familiar social media interface, enabling users to connect with others on the site or groups carrying out similar projects. Users can see the activity of their friend connections, and community groups can communicate with each other. Community groups can set up projects within their group on the site, and the OSS includes a project Progress Tool that measures project development along the community energy project Timeline Tool shown in Figure 2. The Progress Tool is used as the project progresses to signpost users to relevant resources at each development stage. Groups can work on multiple projects and share updates on their work, thus assisting others on the site. The system operation from an energy community perspective is shown in Figure 4.

The operational structure, as shown in Figure 4, centres on the individual users who register on the OSS. Once registered, they can set up or request to join a community group. Within this group, members may set up one or more energy projects with different members contributing to specific projects. Group members may have private events and a private forum on their group projects to facilitate *T1* Inter-Community Transactions centred on project development.

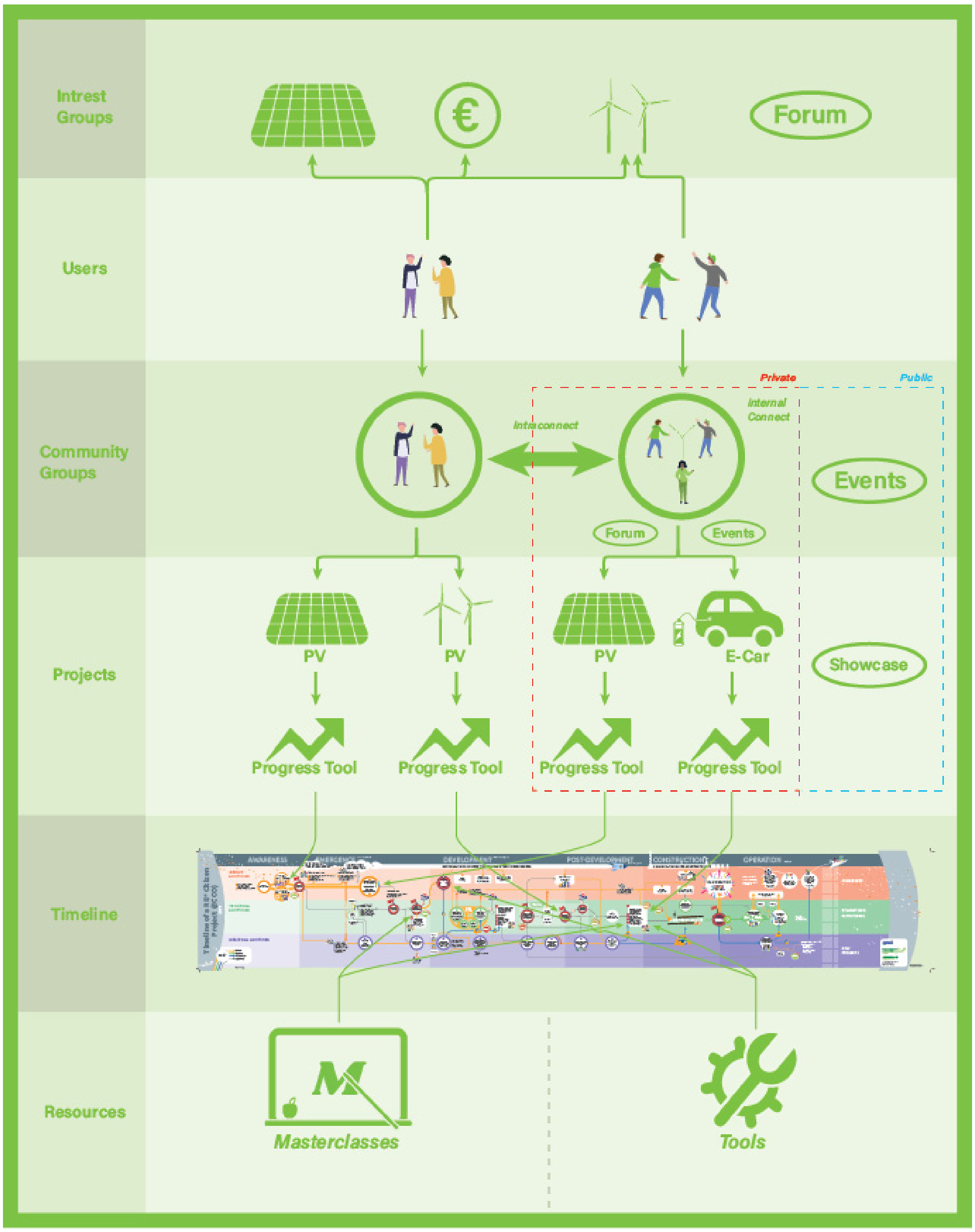

Figure 4. OSS operation overview from an energy community perspective.

The Intra-Community Transactions of the OSS, to foster connection and communication between users and across a range of projects, are supported as each community may choose to share information on their projects via public events and "showcase" pages. This shared resource demonstrates to emerging energy communities the potential for success in the sector, and consistent with the Diffusion of Innovation model, exhibits the success of innovators and early adopters to promote community energy acceptance amongst early majorities. A sample showcase page is shown in Figure 5. Interested users can request contact with the showcase group via a contact form.

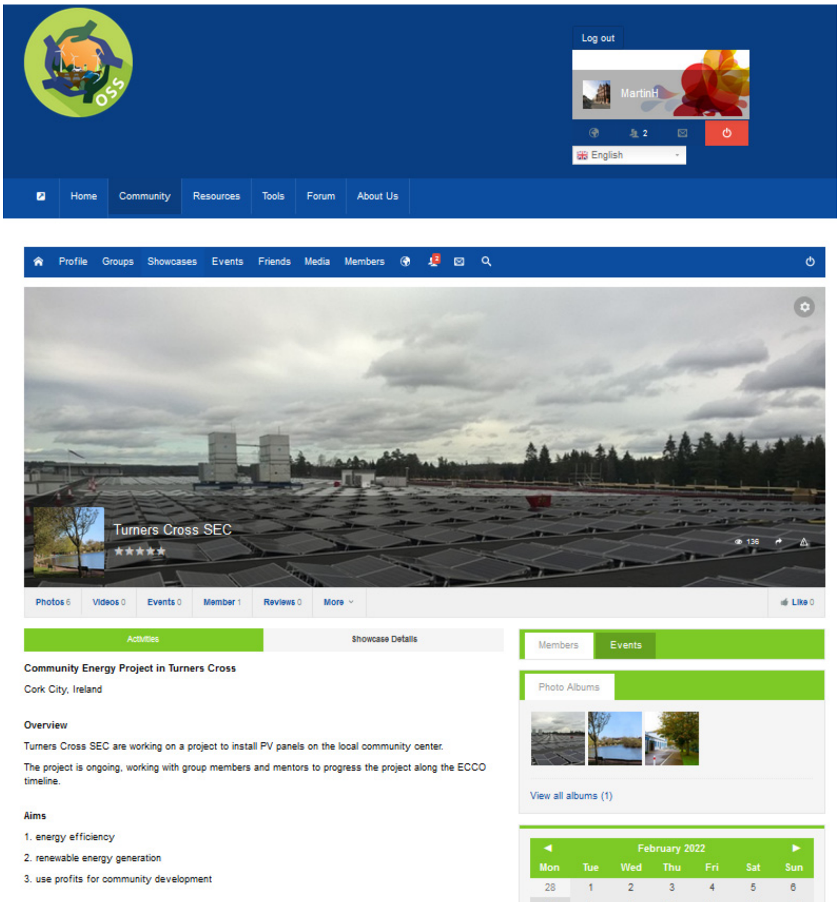

Figure 5. Project showcase sample.

Intra Community Transactions are further supported by the interest group forums shown at the top of Figure 4. Users can post queries under forum sub-topics relating to particular features of the community-driven energy transition, including various forms of renewable energy, e-car sharing, governance, and finance. Users may also contribute suggestions and comments on the OSS development. The forum page is hidden to unregistered users to encourage interested parties to sign up to the site and maintain the ability to moderate contributions. Having the ability to remove access to any parties who are not abiding by the user guidelines, including being polite and a ban on obscene images or language, is critical to maintaining relevant content on the forum. This forum moderation incurs an ongoing cost, and this is one challenge for OSS operation.

Useful resources for community energy development in the OSS, shown at the bottom of Figure 4, are found on a dedicated page that lists the items as "tiles", showing a summary of the content with an access link. The resources page contains a range of information for EU-wide community energy projects, including a financing guide and links to online third-party tools relevant to planned community energy projects.

As previously stated, the OSS includes a project Progress Tool that measures project development along the community energy project Timeline Tool, shown in Figure 4, and signposts users to relevant resources for their project development stage. The Progress Tool consists of a user-friendly survey of the community project to develop a maturity matrix that reflects a project's stage of development. Providing groups with a means to measure the progress of their project guides them through growth on all dimensions required for project success simultaneously and to visualise their progression to completion along the community energy project pathway. The Progress Tool contains a "Project Board", shown in Figure 6, where groups can see an overall snapshot of their project progress (49% completion in this case) before going into further detail on the "Metrics" tab.

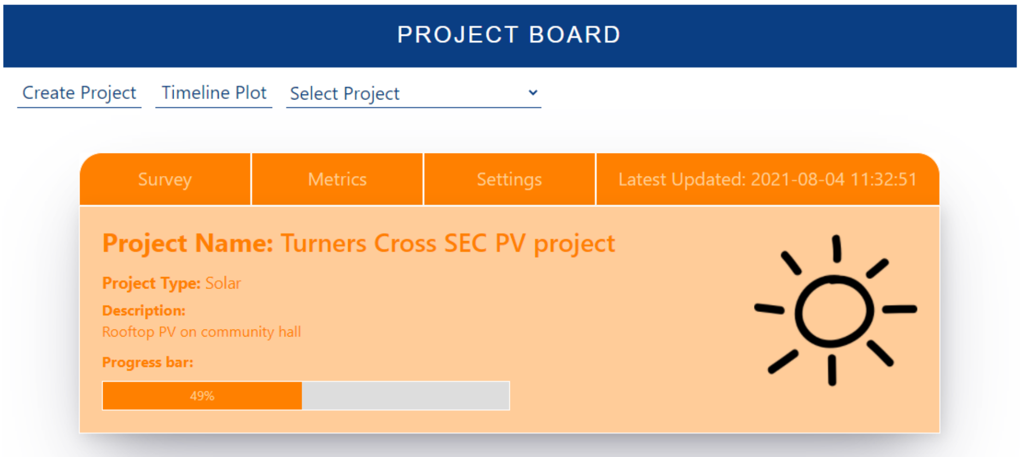

Figure 6. Progress Tool project board.

The progress of a project on the Timeline Tool for a project in the emergence phase of development is shown in Figure 7. During the project emergence phase, the key training recommended relates to administration, legal form, and suitable business models.

Figure 7. Progress Tool result for a project in the emergence phase showing relevant masterclasses and tools.

Additional tools, provided in the current OSS implementation, include:

- The greenhouse gas (GHG) calculator, an online tool capable of quantifying the carbon dioxide (CO_2) emission reduction of various forms of renewable energy compared to national and EU averages per year.
- The Technology Decision Plan (TDP) allows new or experienced users to consider their surrounding area and the natural resources available to help them select suitable renewable energy options. The TDP enables early-stage projects to kick-start their thought process around possible project ideas.

Support-Level (*T3*) and Policy-Level (*T4*) Transactions in the current OSS are currently unidirectional, with support bodies providing resources to energy communities, as shown in Figure 4. Bidirectional Support and Policy-Level Transactions in the OSS include support bodies and policy makers extracting data from the OSS to monitor community energy success and assess the impact of support actions or policy changes on the growth of that success. As a multisided digital platform, the OSS's usefulness for support bodies and policy makers to extract useful data increases as its installed base of users increases beyond the scale supported at this prototype stage. A trial data analysis for these transactions using simulated data has demonstrated this OSS function.

6. Evaluation

The ECCO OSS was tested with end-users within the ECCO project representing energy communities and support bodies, sustainable energy communities in Ireland, and with members of RESCOOP, the European Federation of Citizen Energy Cooperatives. During development and testing, the OSS was introduced to four separate community groups or projects, leading to nearly 100 users on the site, 20 registered groups, and 80 projects listed with the Progress Tool.

The users were trained in the use of the site and given tasks to complete, including setting up a project group and using the OSS to measure the project progress. Following this initial session, the groups were engaged for a second time after three weeks, which provided time to experience the platform and its features. Following feedback from the initial test users, a series of videos were added to the OSS, which can be viewed on YouTube by searching ECCO OSS, to assist users with topics including:

- A quick overview of the OSS;
- Registration and login to the OSS;
- Using the community tab to connect with likeminded people;
- Navigating the OSS so that you can easily find useful resources;
- The Progress Tool to monitor project progress; and
- How to plot the community project journey on the Timeline Tool.

The feedback from these testing sessions measures the user experience with the OSS, the perceived value and benefits of the OSS, and technical issues and opportunities observed by the users.

The reported user experience with the OSS was overwhelmingly positive, with the familiarity of the interface resulting in a short learning curve and users rapidly engaging with the tools and features of the OSS. Feedback on overview statistics and OSS metrics to promote user activity was recommended by users and was incorporated in a revised OSS. Such developments to improve user experience were regularly incorporated in the OSS in the iterative development cycles. A sample of feedback on user experience recommended that it would be beneficial if the project board showing the overall score of projects from the Progress Tool was integrated into the associated community group, allowing users to quickly have a snapshot of the project's progression from within the community page. Such user recommendations can regularly be delivered in scheduled upgrades to the OSS.

The OSS test users reacted positively to the OSS design and its potential benefits with each group, identifying a use case for the site. This reaction was reported by users at all layers of the OSS design architecture, shown in Figure 1. Community users were enthusiastic about Inter- and Intra-Community Transaction features and requested additional OSS features. To support Inter-Community Transactions involving shared documents, it is recommended that the OSS have structured file storage for documentation, much like that offered on Google Drive or Basecamp. Enabling users to share documents via the OSS would eliminate the need for a separate shared folder system and provide an "all-in-one" solution that is the goal of the OSS.

For support bodies, the OSS's ability to assess project status and provide appropriate resources was valued. Support bodies requested a dynamic library of user-rated resources for the OSS that could be supported by providing up-to-date resources. The dynamic library should respond to the user, providing pre-filtered content based on the user's saved preferences, including user location, language preferences, project type, and interests. A user rating system can help identify outdated or low-rated items and will assist in the curation of content that is critical to maintaining site traffic and user engagement.

Many security issues and development bugs were identified during user testing. These issues were passed to the OSS development team, and changes were made promptly where feasible. This prompt response is critical in the iterative development and testing cycles and shows users the value of their feedback.

7. Discussion

The presented work seeks to address a key research goal of developing a framework for the development of digital tools to support the engagement and participation of citizens in the community energy sector. Large public or private utility companies that manage energy production, distribution, and consumption currently dominate the energy market. To meet energy transition goals, citizens can play a much larger role in the sector through distributed energy production, energy trading, and demand-side management. The change required to engage and facilitate citizens to contribute to the sector requires innovation in the social, legal, financial, and technical environment in the sector. Dissemination and education of citizens of the potential of community energy and support to enable them to participate are also required.

In this work, the Diffusion of Innovation theory is applied to this community energy emergence innovation. This theory outlines the key requirements and mechanisms for innovations to emerge from niche activities to mainstream adoption. In this work, early adopters, beacon community energy groups, and support agencies contributed to the development of a set of key user requirements for innovation diffusion. This work identified a digital platform as a scalable model for meeting those requirements and prioritised the key features that such a platform might offer to the key stakeholders. The key features were access to relevant tools and educational information and contact with other community groups for sharing experiences and lessons learnt. The structure of the platform was chosen to be project-based within communities, as the successful implementation from idea to operational energy project is central to community development and success.

After initial prototype development, the benefit of defining an abstract architecture for the digital platform was clear. This abstraction focuses the development on the function of the platform and its user requirements and prevents the final system from being constrained or directed by technology selection choices. In this work, the abstract architecture has facilitated a change in underlying technology, with a clear focus on the system's functionality and users. The developed prototypes following this system architecture have been well received by all stakeholder groups and form the basis for a digital energy community platform as part of a long-term accelerator network. In addition to serving the needs of communities, the proposed architecture can scale with the growth of community energy and can provide valuable insights into the sector development, allowing data-driven policies and supports to be developed, deployed, and assessed.

8. Conclusions

Working with a diverse range of stakeholders in the community energy sector, this work outlines key development requirements for sector development. The emergence of the sector can be modelled using the Diffusion of Innovation theory, and we identified the three key user layers in the sector as community members, support organisations, and policy makers. A practical OSS must support well-defined transactions between these users, categorised as Inter-Community, Intra-Community, Support-Level, and Policy-Level transactions.

The prototype OSS implements a model architecture for a one-stop-shop that is described as a multisided transactional digital platform, with users having a common goal of underpinning the diffusion of community energy projects. The platform reduces the frictions encountered in developing energy communities and supports and promotes the success of innovators and early adopters who inspire others to participate in the energy transition. More than 80 test users representing all target user groups evaluated the prototype system. The feedback from these testing sessions was positive in user experience and perceived value measurement while also identifying some key technical issues.

This work has delivered a robust architecture for a digital platform designed to meet the requirements of energy communities. The architecture and design process are models of development for future digital support development to support community energy initiatives, but could also be applied in other community-centred activities.

Supplementary Materials: The OSS can be accessed at https://www.ecco-oss.eu/. The OSS tutorial videos can be viewed at: https://www.youtube.com/channel/UCvl-oGmbWNNC-lVF2jwFmgA (accessed on 1 May 2022).

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