Participatory development of digital support tools for local-scale energy transitions: Lessons from two European case studies

Richard J. Hewitt *, Cheryl de Boer, Johannes Flacke

ABSTRACT

Spatial planning systems at local and regional levels are often not well-adapted to the growth of small-scale and local social innovations in renewable energy. Participatory decision support tools have been developed to support the implementation of many areas of environmental policy, but are less common in energy contexts. In response to this knowledge gap, we discuss, compare and contrast the participatory development of two different types of digital support tools for the cases of Spain and the Netherlands, leading to insights into the characteristics that local-level stakeholders find particularly desirable. We adopt an integrative approach, hybridizing implementation theory and action research for, respectively, analysis of implementation characteristics of key actors, and knowledge co-construction with participant stakeholders. The tools developed represent two extremes of the spatial decision support tool spectrum, a simple touchscreen application on the one hand (COLLAGE) and a more complicated spatial model on the other (APoLUS). COLLAGE was used and well-liked by stakeholders, whereas APoLUS was not adopted by the participant group, who nevertheless contributed much essential information to its development. We identify eight key differences between the two tools which shed light on the nature of bottom-up energy transition processes: 1: Target users; 2: Target scale of action; 3: Relevance to users’ needs; 4: Interactive quality; 5: Key emphasis; 6: Level of complexity; 7: Ease of communication of tool rationale; 8: Cost. The differences between these tools also relate to a recognized dichotomy in sustainability transition research, with complex spatial support systems like APoLUS tending towards descriptive-analytical modes of sustainability science and simpler tools like COLLAGE being more clearly related to transformational modes. Approaches to supporting local-scale energy transitions that are able to span both modes are likely to become increasingly relevant as the climate crisis evolves. We also identify a research gap between support tools for implementation of established policy and support tools for transformative actions at local scales, and suggest the study of digital “transition support tools” as a promising avenue for future research.

© 2020 The Authors. Production and hosting by Elsevier B.V. on behalf of KeAi Communications Co., Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

The growth of small-scale and local renewable energies (SLRE) is a recognizable social innovation [1] which calls for additional support for spatial planning at the community level. In particular SLRE projects typically need to facilitate sharing and synthesis of different types of complex information, concerning, e.g. local planning policies, siting, and compatibility with existing land use in individual localities. Participatory research approaches [2–4] offer a means to synthesize bottom-up knowledge held by stakeholder communities and facilitate their decision-making through digital decision support tools of various kinds. However, the development of such tools is not always straightforward or quick, and it is clear that some kinds of tools are likely to be more useful than others. In this paper we summarize the results of two recent participatory support tool development processes that were carried out concurrently in two different European countries. We describe what key lessons were learnt from these experiences and offer some general recommendations to help researchers support local-scale processes of energy transition.

The research described in the following article was conducted...
within the framework of the COMPLEX project, a four-year multi-disciplinary research project on knowledge systems for achieving the Low-Carbon Economy, then defined in accordance with the Low-Carbon Roadmap 2050, now subsumed into the EU Climate and Energy Framework.\(^1\) The overarching aim of our research was to support the uptake of climate mitigation activities, in particular, the development of renewable energy (RE), by building spatial digital support tools together with key implementing actors, like local and regional policy makers, landscape planners, and local communities. Recognizing the multi-level nature of energy transitions\(^2\) the project sought to engage representatives from different levels of governance in order to understand the energy transition in each case study country before moving to the tool development stage. The aim of this paper is therefore to illustrate how the process that was followed led to two different outcomes in each case, and to draw out key lessons for the development of spatial digital tools and processes to support RE development at the local scale.

The paper is structured as follows. In Section 2, we introduce our case studies and describe our research methods. Next (Section 3), we describe the initial phases of the work in each case study area and show how this led us to frame the core task of decision-support tool development in different ways. In Section 4, we describe the models, and show how we approached the challenge of integrating the information co-developed with stakeholders during the participatory process in each case. In Section 5, we discuss the outcomes of the participatory process and reflect on the extent to which the tools produced can address the stated goal of supporting local-scale energy transitions. Section 6 Concludes.

2. Background and research methods

2.1. Case study selection

Two case study areas were chosen, on the basis of the contrasting experiences in RE implementation in recent years. In the Netherlands, little progress had been made on achieving overall national RE targets, but there had been an enormous growth in local-scale sustainability initiatives of all kinds, including prosum- ing, with crowdsourcing of RE installations, and community energy\(^6,7,8\). In Spain, RE was deployed on a large scale throughout the country, beginning in the early 1990s, until a moratorium on RE developments are more common.

2.2. Local-scale sustainable energy development: Netherlands

In the Netherlands, there is a substantial gap between the promised ambitions for RE and what has actually been developed. As of 2017, only 6.6% of the power consumed by the Netherlands came from RE\(^11\), ranking the country near the bottom of Europe-ean countries. Large scale energy operations on land face signifi- cant public pressure and the government has been more focused on the development of larger scale off-shore wind farms and energy efficiency efforts (and these have also been lagging)\(^12\). Despite this failure at the national level and the resulting unfavorable institutional circumstances, the number of grassroots energy ini- tiatives has significantly increased since 2010\(^13\). According to Ref.\(^14\) there were at that time over 360 different local grassroots initiatives involved in the development of RE. This surge in SLRE development is due to a number of factors such as policies regul- ating the production of household solar energy, various subsidies for green energy and strong history of local community groups and action. However there are certainly still serious barriers to social acceptance around the siting of wind turbines and other de- velopments deemed to reduce the quality of the landscape or aesthetics of culturally significant areas\(^15\).

2.3. Local-scale sustainable energy development: Spain

The RE boom in Spain, which came to an abrupt halt in 2012 when the government cut subsidies and imposed a number of legal obstacles\(^9,10\), was mostly driven by large firms like Elecnor, Abengoa, Renovalia (solar), and Iberdrola and Acciona (wind), leaving SLRE initiatives entirely at the margins. However, with the emergence of green energy cooperatives (REScoops), like Som Energia, GooiEner and Zencer, who, for a small initial subscription (usually around 100€), supply 100% green energy to their members at cost-competitive prices, this is beginning to change\(^16\). How- ever, although REScops own and operate their own solar, wind and biogas installations on behalf of their members\(^17\), the diffi- culty of raising sufficient capital to build RE installations, exacerbated by the abolition of public subsidies for RE in 2012, means that most of the RE they supply must be purchased from the market. However, the cooperative model is growing rapidly, with at least 17 REScoops operating in Spain, serving over 25,000 members\(^18\).

2.4. The need for digital support tools for local-scale initiatives

SLRE developments are favored in areas where there is extreme pressure on land and space, such as in the Netherlands, or where the project is driven by small communities or groups with limited resources. There has been great interest in recent years in the phenomenon of “community energy”, which refers to different degrees of participation in the development of sustainable and RE- related initiatives\(^1\). These kinds of initiatives are not necessarily driven by citizens alone. Often, as in the Dutch case described here, local government is strongly supportive or a direct initiator. Even

\(^1\) https://ec.europa.eu/clima/policies/strategies/2030_en.

\(^2\) See http://www.viuredelaire.cat/es/el-proyecto-evolucion-del-proyecto.html for a detailed account of the difficulties.
where projects are not explicitly citizen-driven, directly including citizens in local-scale spatial planning is often beneficial. In principal, it can help planning authorities access and incorporate local knowledge [19] particularly in the initiation phase of the planning process [20], and it can lead to an increased acceptance and ownership of the process and the final plan [21]. The energy transition itself involves many different stakeholders and numerous avenues for development and as such the associated planning processes can be quite ‘wicked’ [22,23]. The community wind turbine development process described by Ref. [24] gives a flavor of the enormous complexity of planning and executing a single local scheme. Nevertheless [25], identified a lack of commitment of the Dutch government in wind power development in the past and a limited understanding of motivations leading to local opposition. The same authors describe in another paper that wind power related inclusive decision-making approaches are not yet institutionalized at local planning levels and “public consultation usually occurs after the plan is officially published” [26, p.103]. Ref. [27] observed for Australia that the majority of community-driven RE initiatives failed to implement larger projects due to the complexity of the institutional environment and regulatory challenges.

Digital support tools, as in other areas of environmental management (see e.g. Ref. [28]), are likely to be relevant to these kinds of initiatives, for example, to enable better communication, joint decision making, and the co-creation of plans and plan alternatives [29]. The use of such tools also needs to deal with the same issues faced in regular planning processes such as power imbalances of stakeholders (and their various political goals) [30], time and resource constraints of the general public, and the development of trust [31]. At present, however, research into the use and potential of such tools in the context of energy planning is scarce.

Two broad types of spatial support tools can be identified. On the one hand, public participatory GIS (PGGIS) involves the use of computerised map-based tools for including the public in policy making [32]. Such tools may be web-based or (more recently) mobile phone-based, and typically incorporate a digital map and accompanying interface to facilitate user interaction. Their purpose is often geared towards community empowerment and data collection and validation in planning processes. However the extent to which these tools can move participation processes beyond just engaging stakeholders in the initial stages of decision-making is unclear [20].

Spatial Decision Support Systems (SDSS) are similar to PPGIS approaches in that they also involve computerized, map-based tools, but are specifically designed to provide analysis and advice to decision-makers [33]. In spatial planning, they are generally used to support collaboration with expert stakeholders and less so for the general public [34]. Lack of involvement of end users has been identified as a key weakness in such tools, which are frequently not as well-used as tool developers had anticipated [33,35–37]. While the literature identified numerous reasons for this, there is broad consensus around the need to move away from technocentric solutions – the old “out-of-the-box toolkit” paradigm [28] – towards facilitative, enabling, approaches to tool development which maximize the engagement of key stakeholders at all stages [33,38].

In this paper, we move beyond earlier studies by analysing the role of spatial digital tools to support sustainability transitions [39], and specifically, local-scale energy planning. While these kinds of tools seem likely to be useful in a sustainability transitions context, such processes are notable for their high degree of social complexity arising from the dynamic interactions of actors like energy companies, local governments, and sustainability activists. To better understand how digital support tools can help these kinds of initiatives provides our key research question: What kinds of digital support tools are likely to be useful for local-scale energy transitions, and how can they best be applied?

2.5. Research methods

We followed an integrative research approach [40–42] combining implementation theory with participatory research methods to engage stakeholders and begin a process of knowledge co-construction. We used a theoretical framework for the study of implementation policy known as Contextual Interaction Theory (CIT) (e.g. Ref. [43–45]), to understand the key characteristics of actors involved in implementation of RE, and a well-known form of action research called Participatory Action Research (PAR) (e.g. [2,46,47]): to elicit data from stakeholders through workshops and interviews. PAR helps link theoretical objectives to practical goals, and is useful for breaking down the barriers to understanding that typically emerge between researchers and practitioners (see e.g. Ref. [36]). Ref. [33] suggest the use of PAR-based approaches in the development of digital support tools to help resolve key issues of engagement and credibility. The process is described in detail for each case study area in Section 3. As a direct outcome of the participatory processes in each country, two computer-based tools were developed, an electronic touch table and Participatory Geographical Information Systems (PGIS) tool named the Collaborative Location and Allocation Gaming Environment (COLLAGE), and a spatial simulation model known as the Actor, Policy and Land Use Simulator (ApoLUS).

The COLLAGE tool was developed by Cheryl de Boer and Johannes Flacke in 2015 to respond to the need to better involve and enable local actors to participate in knowledge co-development activities around installations in the landscape (see Ref. [48]). COLLAGE is a GIS-based interactive tool that allows stakeholders to discuss the context, location, amount and type of RE installation that could be deployed within their municipality. In the research described here, COLLAGE was used to facilitate discussion around RE installations but could potentially be adapted for other types of installation, e.g. urban developments, intensive agriculture, infrastructures etc.

The APOlus model [49,50] is based on a spatial modeling approach known as cellular automata, in which transition rules are applied to a computerized map of existing land use (urban, agricultural, forest, solar energy etc) and simulations are then carried out to reveal how land use may change at future dates, in response to the input variables used to determine the transition rules. Typically, these input variables include cell neighborhood (the degree of attraction of a particular land use to other land uses in its vicinity, and the distance at which they are attractive), accessibility (the attractiveness of particular land uses to networks, like roads, rivers or electricity supply), suitability (the biophysical characteristics of particular locations, since: e.g. cereals do not usually grow on mountain tops, solar farms are not usually built on steep slopes) and zoning (spatial planning rules and restrictions; e.g. protected areas). The aim of the tool in this case was to produce simulations of future land use under various scenarios of expansion of RE.

The participatory process that was followed for development of the two support tools was slightly different in each case, but mainly comprised three main stages, 1) Scoping and stakeholder engagement; 2) Tool development; 3) Evaluation of Outcomes. These are described in the next sections.

3. Participatory tool development in the Netherlands

3.1. Scoping and stakeholder engagement

In the Netherlands, work began with a detailed scoping study of energy transition policies and initiatives in the Netherlands and its provinces, drawing on a wide variety of academic and non-academic documentary sources. Subsequently, key stakeholders
were contacted and workshops were organized to introduce the project to them. The identification and initial engagement activities took place at two levels, national and regional/local scale. At the national scale, the team made contact with the Committee on Sustainable Development, a national-level working group that is part of the Dutch social-economic policy advisory body, the Social Economic Council. In order to get access to local initiatives the team used the stakeholder contacts developed by the national platform and network organizations that already existed to support local-scale energy, like the Sustainable Villages Network (NDD). At the time the scoping study was undertaken the NDD included 66 villages, the majority of which were in the provinces of Friesland and Overijssel. Contact was made with sustainable energy initiatives in the NDD, which eventually led the team to an active and interesting group of stakeholders in the municipality of Dalfsen, Overijssel.

3.2. Tool development

Once contact had been made with the municipality of Dalfsen, the initial intention had been to work with these local stakeholders to collectively develop a land use model, using the APoLUS framework, that would support the development of appropriate and stakeholder-supported RE development. Following the initial scoping interviews to determine the main dynamics at play in the area (one of the most progressive in the Netherlands), it became clear that this type of strategic participatory modeling exercise was not well aligned with the current context. In particular, there was a mismatch between the type of information the team was receiving from stakeholders, with very detailed references to plans, policies and local actors’ views on RE development, and the type of information required by APoLUS, ideally general information on behavior of all stakeholders in the wider region, as well as geographical variables relating to the specific location of existing RE developments. The team therefore decided to look for new ways to elicit information about stakeholder perceptions, motivations and resources around RE in spatially explicit terms (i.e. explicitly linked to a geographical location through coordinates or maps). This process of exploration of stakeholder requirements led to the development of the GIS-based interactive planning support tool known as COLLAGE [34,48]. COLLAGE comprises three key components:

1. Mapping component, that enables stakeholders to allocate RE installations within the municipal area;
2. Calculation component, calculating total land consumption, MW production, cost & benefits per RE installation;
3. Output component, displaying results for relevant indicators (land consumptions for MW production, costs and benefits) in bar charts.

The interactive mapping component allows allocation of different types of RE installation simply by selecting a specific type (solar or wind) and allocating single grid cells in the case of solar, or a location for a wind turbine. The calculation component automatically calculates a number of indicators for each type of RE installation, like total energy capacity produced, land area consumed, costs and benefits per RE installation, etc. based on the characteristics of each type.

The tool was implemented on a large-scale interactive map table supporting stakeholder interaction and collaboration (Fig. 1). Direct interaction of the stakeholders with the tool takes place in the form of placing different types of RE installation on the landscape according to the preferences of the stakeholders. Often the stakeholders are provided a particular target to achieve (or not) in terms of RE produced. Results take the form of a map of preferred locations of various types of RE installation. However, the interaction between the stakeholders while working with the tool is considered an important contribution to the planning process as it provides insights related to barriers to implementation and new ideas for placement. It also allows learning to take place amongst the stakeholders as they share local information with each other and receive direct feedback from the model about the impacts of and potential for the different RE installations (see Fig. 2).

The COLLAGE tool was tested at a stakeholder workshop held in the municipality of Dalfsen. The main activity carried out in the workshop was an interactive mapping exercise where participants located different types of RE on a map of their municipality with the COLLAGE tool. COLLAGE aimed to help stakeholders to collaboratively define their expectations and goals related to the trade-offs they experienced between land use quality and implementation of RE. COLLAGE thus fulfilled a need that had clearly emerged through our discussions with the stakeholders and at the same time provided a link between the knowledge held by the community and the spatial information required by the project team.

The workshop was therefore mainly centered around the municipal level decisions affecting land use (through locating wind, solar or biofuels installations in core areas) as well as around household level decisions with respect to insulating their home or undertaking solar panel investments. There was also a desire to understand stakeholders’ opinions about the achievement of their respective goals. For example, we were interested in what types of actions they found to be compatible with different land use categories and how they perceived the trade-offs required between the land uses and RE production to achieve their goals. Stakeholders put their expertise into practice by working directly with the COLLAGE tool. In the main activity of the workshop, stakeholders discussed Dalfsen’s energy goals and then experimented with various implementation scenarios directly on the touch screen. Following the practical sessions, the workshop concluded with a discussion between all participants. We found that the COLLAGE tool was able to contribute very successfully to the stakeholders’ ability to explain their motivations, perceptions and resources related to concrete suggestions of land use change.

At present, COLLAGE runs in the proprietary GIS software ArcGIS including the CommunityViz planning support extension. In future, the tool will be modified to run in free-and-open-source software (e.g. QGIS).

3.3. Evaluation of outcomes

The most important outcomes relate to knowledge exchange and social learning facilitated by the discussions using the COLLAGE tool. In particular, COLLAGE enabled knowledge about installations in a given locality to be co-developed by stakeholders local to, or knowledgeable about, the chosen locality of Dalfsen. COLLAGE provided considerable opportunities for learning and knowledge transfer between researchers and other stakeholders. In the preparatory phases of the workshop, stakeholders:

- Identified the types of RE installations that are important for including in the COLLAGE tool.
- Shared information related to the application of land use plans, zoning laws and how they affect implementation of RE.
- Contributed to determining the appropriate scale for incorporation into the COLLAGE tool.

During the workshop, stakeholders:

- Provided and received local and spatially explicit information about the pros and cons of different RE installations types and the trade-offs associated with them.
Helped each other learn about the different qualitative perspectives held by their fellow inhabitants about the implementation of RE.

Contributed to a collective product that outlined preferred pathways to achieving the CO₂ Neutral goals of the municipality.

Following the development and testing of the COLLAGE tool, it was used on several occasions for participatory evaluation of municipal RE development schemes (see Ref. [34]), and continues to garner attention with local-level stakeholders in the Netherlands.

4. Participatory tool development in Spain

4.1. Scoping and stakeholder engagement

In Spain, work was initiated with a national scale appraisal of the RE implementation process for all Spanish regions, drawing on available published and unpublished sources [51]. Subsequently, six Autonomous Communities were selected for in-depth study involving semi-structured interviews with stakeholders carried out by telephone [9]. Stakeholders in implementation were identified initially through a brainstorming process, and subsequently...
The three scenarios are described as follows:

The first Scenario, “Scenario 1: The big fish run the game” had already become clear by the end of the interview process prior to the first workshop, and was intended to reflect a situation of strongly centralized control of the RE development process (Table 1). In the first workshop, the wide range of challenges identified by the stakeholders and the solutions they proposed allowed a second scenario narrative to emerge. This was “Scenario 2: Local Action for a world in Crisis” (Table 1). In the second workshop, the detailed information about deployment in the different regions of the study area allowed a third scenario to be developed to reflect the widespread concern about landscape planning: Scenario 3: Regional Green Consensus (Table 1).

To enable these scenarios to be simulated, the APoLUS model was built and calibrated for the Navarre region by a process of iterative adjustment of parameter settings and comparison against reference maps until acceptable goodness-of-fit was obtained [49]. To demonstrate the working model, we ran two simulations to the year 2050 (Fig. 3), the first (Fig. 3: Simulation 0) showing a business-as-usual case in which new solar energy installations are developed on agricultural land and close to the electricity network, as had occurred in the past. A second experimental scenario (Fig. 3: Simulation 1) was run to test the effect of local actors grouping together in a single municipality to promote solar energy development. This test was not intended to be realistic – clearly, Fig. 3: Simulation 1 (bottom panel), which shows the entirety of a municipality occupied by solar energy, is not a believable outcome – but to demonstrate the capability of the model to represent the scenarios.

4.2. Tool development

The APoLUS model was built and calibrated on the basis of the information provided by participants in the workshop. It was clear from the detailed discussions and feedback from stakeholders during the scoping phase (Section 3.2), that the implementation of RE was a highly political process, and a conventional land use change model would be inadequate to reflect the sudden, often local-scale nature of decisions to develop wind or solar energy in particular locations. In response to this, a new model parameter, known as actor dynamics (D) was introduced to reflect the process of negotiation around a particular region or municipality [49]. We drew on both implementation theory and participatory action research approaches to model the behavior of actors responsible for developing RE, as follows.

First, the list of implementing actors defined by the key RE stakeholders from the region of Navarre in the first workshop was used as the basis for the actor dynamics. Subsequently, we developed a set of rules to govern the behavior of each actor. These were: motivation (degree of intention to develop RE), cognition (knowledge about the RE development process), resources (ability to develop RE), affinity (degree to which development of RE aligns with an actor’s core values or interests) and power (the power to develop RE, in comparison with other actors). To create the rules, each actor was assigned a simple score on a 3-stage scale for each characteristic, (e.g. for motivation: low = 0.1, medium = 0.5, high = 0.9). The intention was not to precisely quantify the behavior of real actors as observed by our stakeholders, rather to use their observations about the implementation process to develop a set of typical actor behavioral responses to improve the model’s ability to simulate local-scale decisions. The modeling of actor dynamics under this framework is described in more detail by Ref. [54,55].

Secondly, the information obtained through the rapid appraisal of RE implementation in Spain, the semi-structured interviews carried out with regional and national level stakeholders, and the two local-level workshops was used to develop a set of three scenarios of RE and land use. The intention was to produce maps of future land use in the Navarre region for each of the three scenarios. The three scenarios are described as follows:
Table 1: Narratives and key dynamics of actors.

| Scenario                                      | Motivation                                                                 | Resources                                                                                   | Description                                                                                     |
|-----------------------------------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Scenario 1: The big fish run the game         | Government and big energy companies opposed to further development of RE.     | No incentives at national level (Feed-in-Tariff cut). Disincentives to local-level stakeholders (grid connection payments). Investors take flight. | A RE paralysis scenario that reflects real events in Spain after 2011. Emphasizes top-down control by powerful national-level actors. |
| Scenario 2: Local Action for a world in Crisis | Government motivated to promote RE, but weak and indebted due to economic crisis. Emergence of strong local energy autonomy movements. Big energy companies break up into smaller parts and citizens take control to drive a just transition. | Weak economy and the climate crisis lead to privatization and loss of state control of energy. Severe austerity leads to declining energy demand and collapse of large energy companies, which are replaced with community energy initiatives and locally-owned utilities. | A climate emergency scenario in which powerful actors lose control because of severe impacts on citizens. Anti-austerity and energy democracy movements take control of energy at the grassroots level. RE development is disparate and highly localized. Emphasizes local control by social movements. |
| Scenario 3: Regional Green Consensus          | A new government takes control and makes a strong commitment to tackle the climate emergency and drive a clean energy transition. Strong development of networks between local government, regions, national government and citizens. | Economy recovers from austerity and incentives are restored for RE. Strong investment in clean energy as all actors come together to tackle the climate crisis. | This scenario seeks to seriously address the 2050 climate targets while at the same time trying to avoid impacts to the natural environment through strong spatial planning at the regional level. Despite good will on all sides, there is high potential for conflict over RE development in natural protected areas and their vicinity. Emphasizes pragmatic negotiation between multiple levels of governance. |

been planned, it has subsequently proved useful as a research tool, with several ongoing use cases (e.g. Ref. [56]).

5. Discussion

The team’s intention had been to develop a participatory decision support tool with local energy stakeholders in parallel in two case study regions, Overijssel in the Netherlands, and Navarre, in Spain. However, due to the differences between the case study regions, the researchers’ ideas about the work, and the stakeholder communities who were involved in the participatory process, we ended up building two different tools, reflecting the contrasting preferences and interests of the stakeholder groups.

In the Dutch case, COLLAGE was well-received by the participant group, and the pilot workshop with the Dalfsen group led almost immediately to a follow-up session in the city of Enschede [48]. In the Enschede workshop, participants’ evaluation of the tool and process was highly positive. 85% of participants found the session helpful for getting to know the views of others on RE, more than 80% agreed that they were able to share their views on RE with the other participants during the workshops and almost 75% felt that they had learned something about RE [48]. The tool continues to be used to work with local stakeholders in other Dutch municipalities.

In the Spanish case, it had been anticipated that the APoLUS model would be used to generate simulations of possible future land use outcomes based on the scenarios that had been co-developed with the stakeholders (Table 1), paving the way for a detailed discussion about land use impacts of RE and potential trade-offs. The cancellation of the final workshop meant that this did not take place, and since the stakeholders did not see the final version of the tool, as had been planned, their precise opinion of the model is hard to gauge. However, it was clear that our stakeholders were more interested in the politics of the Spanish energy transition than in spatial land use allocation.

Given the differences between the processes in each of the two case study regions, and the tools which emerged as a result of them, it is worthwhile to consider these differences in more detail in order to answer a key aspect of our research question namely, “What characteristics should a digital decision-support tool have to be useful for supporting local-scale RE development?” To this end, eight key differences between COLLAGE and APoLUS were identified (Table 2). These are used to structure the following discussion.

5.1. Target users

There were major differences between COLLAGE, where users were identified early on and a tool built to respond to their needs, and APoLUS, which was built as an explanatory model, with users anticipated, but not specifically targeted. In the Dutch case, the decision to engage directly with local groups through the municipality was taken early on, and a clear focus was maintained on providing a tool for these stakeholders. In Spain, the group sought to understand and model the dynamics of RE implementation using a spatial model. The usability of the model as a tool for supporting decisions was a secondary consideration. While it was hoped that regional-scale planners, like the Observatorio Territorial de Navarra (OTN), would work with the model, we did not engage with, or target, these potential users clearly enough at an early enough stage in the process to make this a realistic proposition.

5.2. Target scale of action

In Spain, by focusing on understanding top-down support and policy mechanisms for RE development, researchers were able to build scenarios of the way that the RE transition might develop in the future. In the Netherlands, this aspect was not consciously addressed. Instead, the Dutch team identified, and worked with, locally-based stakeholders to work on the specific problem of spatial planning of RE installations in order to meet municipal clean energy targets. The question of the scale (spatial and governance) at which the tool was targeted perhaps explains why the APoLUS model did not generate as much interest as was hoped for among its intended beneficiaries. This is what [57] have referred to as the scale mismatch, where the group of stakeholders recruited to co-develop the model operates at a different scale to the main dynamics that the model represents. Although our stakeholders were very well-situated to inform us on current RE policy in Navarre and its likely future direction, there were less focused on specific questions of spatial planning at a local scale than the participant group in Overijssel. While overarching strategies are decided at the level of the autonomous region, planning of specific developments...
in Spain is mostly undertaken by municipalities, and municipal planners were not represented in our stakeholder group. Clearly, decision support tools that aim to have real impacts on practice are unlikely to achieve them if participants involved in their development and the scale of action are mismatched in this way. In the Netherlands, however, stakeholders recruited had a strong interest in RE spatial planning, and moreover, were actively involved in it at a local scale — they were active at the scale at which the COLLAGE model was designed to operate.

5.3. Relevance to users’ needs

In the Netherlands, engagement early on with local communities interested in local-scale energy planning suggested a high level of
Researchers acted responsively to develop a tool to address their key concerns. In Spain, researchers were mainly concerned with translating the information received by stakeholders about the national policy change from supporting RE development to opposing it (Table 1: Scenario 1) into a spatial model. Given that these were investigatory (scientific) criteria, unrelated to action on implementing local-scale energy initiatives; it is unsurprising that the model never really engaged with stakeholders’ needs. A further point of interest relates to the different national contexts within which our work was conducted. At the time of our project, Spain had recently undergone a dramatic policy shift from strong government support for RE to withdrawal of incentives, erection of legal barriers to small-scale developments, and consequent RE paralysis [9]. In this context, it was logical that our discussions with stakeholders in a strongly pro-RE region like Navarre tended towards the political and away from the practical questions of implementation. Indeed, Spanish stakeholders regarded further RE development as highly unlikely given the policy shift, and as such, questions of siting and spatial planning were far from their minds. Though the Netherlands has been a notable laggard in RE development, there had been no such dramatic shift and policies remained broadly supportive of small-scale RE initiatives. Dutch stakeholders, as in Spain, were mostly pro-RE, but unlike in Spain, saw that they were able to realize the opportunities for small-scale RE development. The open policy environment found in the Netherlands contrasted with the closed situation in Spain, and may explain in large part the different directions taken by the participatory research in each case.

5.4. Interactive quality

The interactive component of the COLLAGE tool, with its attractive touch table interface was central to the goal of drawing stakeholders’ attention and encouraging them to try to work with the tool. This “high-tech” element was a key to raising stakeholders’ desire to participate, while the instantaneous display of charts showing RE targets added an addictive gamification component that enticed users to “play”. Conversely, APoLUS had limited interactivity, with only a simple graphic interface running in the R environment, and some command-line operations.

5.5. Key emphasis

In the case of COLLAGE, the key emphasis was on immediately providing easily digestible information on achievement of RE targets in a visually attractive way. APoLUS was principally concerned with providing land use simulations of particular energy outcomes. This is time-consuming, since qualitative information from scenarios needs to be converted into quantitative model inputs. In addition, calibration of the model requires technical knowledge which takes time to learn and apply.

5.6. Level of complexity

The level of complexity of the COLLAGE tool was clearly appropriate to the goal of encouraging stakeholders to discuss spatial planning on RE targets. The tool itself was simple, yet it encouraged discussion of more complex dynamics and trade-offs that quickly emerged when participants tried to meet their targets with specific types of installations. For example, stakeholders were mostly amenable to the idea of rooftop solar, and generally opposed to wind turbines, but quickly found their targets very difficult to meet with solar alone, leading some to shift their negative perceptions of wind turbines. APoLUS, on the other hand, was too complex for the benefit to stakeholders to be quickly apparent. Yet is also true that while COLLAGE is simple to use and operate, its outcomes are also fairly simple. The greater level of complexity of the APoLUS model allows a wider range of potential outcomes to be explicitly simulated, and hence, potentially a deeper exploration of the process of competition between land-based actors with different interests.

5.7. Ease of communication of tool rationale

We found the rationale behind COLLAGE to be almost self-explanatory. The rapid display of accompanying information on achievement of targets as soon as a RE installation was added to the virtual map showed users very clearly the tool’s potential for discussion and negotiation in the specific context of local energy siting. APoLUS, with its emphasis on future projections of land use change and the evolution of RE through scenarios, was less easy to effectively communicate. Stakeholders in local-scale energy initiatives are more likely to want to communicate with each other about the development of specific projects, with reference to maps or photos, than they are to discuss long-term tendencies and trends. The earlier-described question of scale is clearly relevant here also. Yet at regional scales, specific questions of land use impacts may resonate less with stakeholders.

### Table 2

| Criteria/aspect | COLLAGE | APoLUS |
|-----------------|---------|--------|
| 1 Target users  | Clearly defined target users – local energy planners and community energy stakeholders | Target users not clearly defined early on. The tool mostly aimed at researchers in planning (e.g. Observatorio Territorial de Navarra), rather than planning practitioners. |
| 2 Target scale of action | Local scale | Regional scale |
| 3 Relevance to users’ needs | Tool responds to target users’ clearly-defined needs | Tool developed for researchers’ needs |
| 4 Interactive quality | Highly interactive and visually-based user interface (touch device) | Scientist-oriented interface (R and tcltk) with basic visual support (tcltk buttons, maps, graphs) |
| 5 Key emphasis | Emphasis on visualization of immediate outcomes | More difficult to use (training required), but capable of producing more complex outcomes (e.g. trade-offs and competition between land areas and actors) |
| 6 Level of complexity | Simple to use (minimal training required), but with correspondingly simplified outcomes (e.g. no direct representation of trade-offs, which instead emerged through discussion) | Harder to explain to non-specialist |
| 7 Ease of communication of tool rationale | Easy to explain to non-specialist | Tool and platform free |
| 8 Cost | Tool free, platform proprietary | Tool and platform proprietary |

The earlier-described question of scale is clearly relevant here also. Yet at regional scales, specific questions of land use impacts may resonate less with stakeholders.
5.8. **Cost**

In the case of APoLUS, researchers were keen to develop software that was free-to-use and multi-platform, in keeping with both the ethos of the COMLEX project and of Open Science. However, the most important barriers to the stakeholders using the APoLUS model were related to aspects other than cost — e.g. poorly aligned with their needs, too complex, limited interactivity. In the case of COLLAGE, though a software license was required to run the GIS background application (ArcGIS and CommunityViz PSS), this was not a problem, since the tool was always provided by researchers on their own touch device. However, in the event that future users wished to use the tool on their own devices, this might prove to be a barrier to future uptake.

6. **Conclusions: how can digital support tools help local-scale energy transitions?**

By considering the eight key differences between the two models, we have shed light on a number of important aspects and highlighted ways in which digital support tools might help enable local-scale transition processes. The success of COLLAGE in the Dutch case is due to several factors, such as correctly matching the ambition of the project to the local scale at which such interventions were currently being actively planned, the familiarity of Dutch municipal level actors with computerized support tools, the attractive and easy-to-use interface, and, above all, its direct relevance to their real practical concerns. Additionally, the process required by COLLAGE can be completed in a single session. This is particularly useful when the participant stakeholders are drawn from a wide range of different sectors and backgrounds (as was the case in our study) and thus scheduling can become in itself a barrier to successful implementation. In the Spanish case, while we tried hard to turn our stakeholder group into participant modelers, the need to hold multiple workshops proved to be a problem, with the last workshop being cancelled due to stakeholders’ commitments. However, while our participants did not use the software itself, their interest and knowledge of the politics of RE steered the work in this different, but productive direction, leading to important insights into the clean energy transition in Spain [9,42]. At the same time, though the model development process did not lead to such direct tangible outcomes as in the Dutch case, the longer process of engagement between stakeholders potentially offered substantial co-benefits in the form of increased opportunity for knowledge exchange. Social learning through knowledge exchange plays a key role in the change of understanding necessary for successful transitions (Safarzyńska et al 2012). We should therefore be wary of assigning “success” or “failure” based only on whether the tool was developed and used as anticipated.

This point aligns with the first part of our research question: **what kinds of tools are useful for supporting local-scale energy transitions?** Sustainability transitions are multi-level processes involving complex constellations of actors (see e.g. Ref. [3]), and it is likely that actors will want different kinds of tools depending on their type of involvement in the transition process. For example, future scenarios of land use are clearly useful to strategic level decision making, while other stakeholders are likely that actors will want different kinds of tools depending on their type of involvement in the transition process. For example, future scenarios of land use are clearly useful to strategic level decision making, while other stakeholders may be interested in the answers they may provide than in the tools themselves. Indeed, the key themes that were raised during the participatory process in Spain, especially those concerning different actor motivations and barriers to energy transition were enthusiastically discussed by participants [52]. We suggest that tools like APoLUS, which are aimed at exploring the land use impacts of strategic policy decisions at regional scales are less likely to find end-users outside of the research community. This goes a long way towards explaining why these kinds of models are typically not really used in practice [35,36,58] — outside of research, they have no natural end-user. Rapid, easy to use, highly visual discussion facilitation tools like COLLAGE, on the other hand, seem to have a natural user-community in the groups of local-level stakeholders determined to push for a sustainable energy transition from the grassroots, often with the support of their local government.

This allows us to answer the second part of our research question: **how can such tools best be applied?** The difference between the two participatory processes described clearly points to the tension noted by Ref. [59] between descriptive-analytical and transformational modes of sustainability science. On the one hand, APoLUS serves as a vehicle for policy testing and provision of evidence, which corresponds most clearly with the descriptive-analytical science paradigm described by these authors. On the other, COLLAGE, with its highly visual approach to negotiation about landscape impacts of RE, seems better aligned with the transformational mode they observe.

In this sense, it is not at all clear that the COLLAGE tool would have been applicable in the Spanish context — as a tool for exploring the spatial allocation of SLRE, it’s hard to imagine it being enthusiastically adopted in a situation where the power of local communities to implement RE at all had been effectively vetoed at a national level. APoLUS on the other hand, might have met with interest from Dutch stakeholders at a strategic planning level, but would have been at odds with the goals of the municipal level stakeholder group that the project had engaged. The question is thus not just about finding the right scale of action in institutional terms, as [57] have observed, but also about finding the right temporal scale — the tools need to appropriately match the transformational stage of the activity or practice that the tool aims to support.

This idea of finding the right transformational stage seems especially relevant when we consider the broader policy context around RE in Spain and the Netherlands. Prior to the policy shift of 2012, Spain had previously enjoyed a much more progressive position on RE than the Netherlands, but their deployment had been driven by big business, with small-scale community level projects remaining at the margins [1]. In the Netherlands, national policy has been, until very recently, quite resistant to decarbonisation or clean energy transition; nonetheless, the country has been a forerunner in community energy [60]. These differences emerged clearly in our stakeholders’ attitudes to the project, and as a consequence, in the tools that were eventually developed.

Spanish stakeholders were infuriated that the government had put the brakes on the RE transition (see Ref. [9]) and suspected interference from powerful lobbyists [10,52], something that emerged very clearly in the scenarios (Table 1). Dutch stakeholders saw their government’s foot-dragging as shameful, and seized on the opportunity to explore ways to drive forward the implementation of small-scale energy projects. Though the participatory process aligned with the development of the APoLUS model was responsible for bringing the highly politicized nature of the Spanish RE debate to our attention, it also raised the question of whether descriptive-analytical science approaches are useful in transformation contexts. On the other hand, without analysis of the political dimension, there is a risk that a tool like COLLAGE can lead stakeholders into a naive expectation of change, when in reality, it may be that no change is likely to occur. Noisy negotiation around options which are not really on the table is a classic indicator of what [61] called “token” citizen participation.

Our findings shed further light on the contemporary debate around the use and relevance of digital support tools in
environmental planning generally. To the extensive arguments presented by various writers on this topic (e.g. Ref. [33,36,62]) we can add a further consideration that is likely to affect the uptake or interest by practitioners and potential end users: whether the tool that will be produced is intended to transform current practices, or merely support them “as is”. In the former case, some potential end users might be resistant to adoption because they do not agree about the need for transformation. In such cases, involving initially unwilling or skeptical stakeholders in implementation-heavy tools like COLLAGE is unlikely to be successful — they would probably not agree to participate or do so only reluctantly. On the other hand, tools like APoLUS, with its emphasis on learning about possible environmental futures, might be more useful - helping expose such stakeholders to evidence that challenges their deeply held views, leading to social learning [63], and eventually, a change of understanding e.g. around environmental degradation and its possible causes and solutions.

In the current context of international political inability to adequately tackle the climate crisis, countered by an increasingly engaged civil society, facilitative spatial planning tools able to span discursive-analytical and transformational science modes are likely to become increasingly relevant. Future work on the tools described in this paper is likely to focus on bridging the divide they so clearly represent to increase their flexibility in spanning these distinct action research modes. For example, APoLUS could be made more visually appealing, while COLLAGE could be adapted to allow simulation of actors’ negotiations under scenarios like those described for the Spanish case. Finally, our work points to an important research gap at the interface between support tools for implementation of established policy (e.g. Ref. [33,36]) and support tools for transformative actions at a local scale. We tentatively propose a new class of “transition support tools” which make this distinction apparent, and suggest this as an interesting topic for future research.

CRediT authorship contribution statement

Richard J. Hewitt: Conceptualization, Methodology, Data curation, Writing - original draft. Cheryl de Boer: Data curation, Writing - review & editing. Johannes Flacke: Data curation, Writing - review & editing.

Acknowledgments

The authors gratefully acknowledge funding from the European Union under FP7 project COMPLEX (grant agreement no. 308601) and H2020 project SIMRA (grant agreement no. 677622). We also express our deep gratitude for the generous collaboration of our participant groups in Spain and the Netherlands without which the research described here could not have been undertaken.

References

[1] R.J. Hewitt, N. Bradley, A. Baggio Compagnucci, C. Barlange, A. Ceglarz, R. Cremades, B. Sleé, Social innovation in community energy in Europe: a review of the evidence, Front. Energy Res. 7 (2019) 31.
[2] A. McIntyre, Participatory Action Research, vol. 52, Sage Publications, 2007.
[3] J.M. Wittrnayer, N. Schäpe, F. van Steenbergen, J. Omann, Making sense of sustainability transitions locally: how action research contributes to addressing societal challenges, Crit. Pol. Stud. 8 (4) (2014) 465–485.
[4] T. Villasante, M. Montañes, J. Martí, in: La Investigació Socialparticipativa: Construyendo Ciudadanía, Cataluña, El Viejo Topo, 2000.
[5] G. Verborg, F. Geels, The ongoing energy transition: lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004), Energy Pol. 35 (2) (2007) 1025–1037.
[6] M. Aretnsen, S. Bellekom, Power to the people: local energy initiatives as seedbeds of innovation? Energy Sustain. Soc. 4 (1) (2014) 2.
[7] F.P. Boon, C. Dieperink, Local civil society based renewable energy organisations in The Netherlands: exploring the factors that stimulate their emergence and development, Energy Pol. 69 (2014) 297–307.
[8] D. Vanclay, T. Hopper, Modes of governing and policy of local and regional governments supporting local low-carbon energy initiatives; exploring the cases of the Dutch regions of Overijssel and Fryslân, Sustainability 9 (1) (2017) 159.
[9] F.M. Alonso, R. Hewitt, J.D. Pacheco, L.R. Bermejo, V.H. Jiménez, J.V. Guillén, C. de Boer, Losing the roadmap: renewable energy paralysis in Spain and its implications for the EU low carbon economy, Renew. Energy 89 (2016) 680–694.
[10] I. Solorio, Spanish climate change policy in a changing landscape, in: The European Union in International Climate Change Politics: Still Taking a Lead? 1, 2016, p. 159.
[11] CBS, [https://www.cbs.nl/nl-gb/news/2018/22/share-of-renewable-energy-at-its-high-point](https://www.cbs.nl/nl-gb/news/2018/22/share-of-renewable-energy-at-its-high-point), 2018.
[12] B.D. Koivula, Y. Araghi, M. Kroesena, A. Ghorbani, P.M. Herder, Trust, Awareness, and independence: insights from a socio-psychological factor analysis of citizen knowledge and participation in community energy systems, Energy Res. Soc. Sci. 38 (2018) 33–40, 2018.
[13] H.J. Kooij, M. Oteman, S. Veenman, K. Sperling, D. Magnusson, J. Palm, F. Hvelplund, Between grassroots and treetops: community power and institutional dependence in the renewable energy sector in Denmark, Sweden and The Netherlands, Energy Res. Soc. Sci. 37 (2018) 52–64.
[14] M. Oteman, H.J. Kooij, M.A. Wiering, Pioneering renewable energy in an economic energy policy system: the history and development of Dutch grassroots initiatives, Sustainability 9 (360) (2017) 1–21.
[15] F. Hvelplund, Between grassroots and treetops: community power and institutional dependence in the renewable energy sector in Denmark, Sweden and The Netherlands, Energy Res. Soc. Sci. 37 (2018) 52–64.
[16] J. Roderigo fiigo, Alcolea del Río construye la primera planta solar de España sin primas ni subvenciones, http://sevilla.abc.es/provincia/sevilla-alcolea-construye-primera-planta-solar-espana-sin-primas-subvenciones-201511270738_noticia.html, 2015.
[17] Union Renovables Coop, Organisation website. http://www.unionrenovables.org, 2018.
[18] L. Natarajan, Socio-spatial learning: a case study of community knowledge in participatory spatial planning, Prog. Hum. Geogr. 33 (6) (2017) 1–23.
[19] C. Brown, M. Kytra, Key issues and research priorities for public participation GIS (PPGIS): a synthesis based on empirical research, Appl. Geogr. 46 (2014) 122–136.
[20] R.J. Burby, Making plans that matter: citizen involvement and government action, J. Am. Plann. Assoc. 69 (1) (2003) 33–49.
[21] J. Rotmans, R. Kemp, Managing societal transitions: dilemmas and uncertainties: the Dutch energy case-study, in: OECD Workshop on the Benefits of Climate Policy: Improving Information for Policy Makers, vol. 12, 2003.
[22] G. Valkenburg, G. Cotella, Governance of energy transitions: about inclusion and closure in complex sociotechnical problems, Energy Sustain. Soc. 6 (1) (2016) 20.
[23] Viure de la Faire, Organisation website, Available online at: http://www.viuredelaire.cat, 2018. accessed August, 2018.
[24] S. Breukers, M. Wolsink, Wind energy policies in The Netherlands: institutional capacity-building for ecological modernisation, Environ. Polit. 16 (2007a) 92–112.
[25] S. Breukers, M. Wolsink, Wind power implementation in changing institutional landscapes: an international comparison, Energy Pol. 35 (2007b) 2737–2750.
[26] F. Mey, M. Diesendorf, I. MacGill, Can local government play a greater role for community renewable energy? A case study from Australia, Energy Res. Soc. Sci. 21 (2016) 33–43.
[27] R. Hewitt, C. MacLeod, What do users really need? Participatory development of decision support tools for environmental management based on outcomes, Environments 4 (4) (2017) 88.
[28] J. Flacke, R. Shrestha, R. Aguilar, Strengthening participation using interactive planning support systems: a systematic review, IJCI 9 (2020) 49.
[29] J. Forester, Planning in the Face of Power, University of California Press, Los Angeles, California, 1989.
[30] J.E. Innes, D.E. Booth, Consensus building and complex adaptive systems: a framework for evaluating collaborative planning, J. Am. Plann. Assoc. 65 (4) (1999) 412–423.
[31] R. Sieber, Public participation geographic information systems: a literature review and framework, Ann. Assoc. Am. Geogr. 93 (3) (2003) 491–507.
[32] I.K. Matthews, G. Schwarz, K. Buchan, M. Rivington, D. Wither agricultural DSS? Comput. Electron. Agric. 61 (2) (2008) 149–155.
[33] J. Flacke, C. De Boer, F. van den Bosch, K. Pfeffer, Interactive planning support systems with citizens: lessons learned from renewable energy planning in The Netherlands, in: S. Geertman, J. Stillwell (Eds.), Handbook of Planning Support Science, Edward Elgar Publishing, 2020.
[34] D. Uran, R. Jansen, Why are spatial decision support systems not used? Some experiences from The Netherlands, Comput. Environ. Urban Syst. 27 (2003) 511–526.
[35] I. Borowiec, M.P. Hare, Exploring the gap between water managers and researchers: difficulties of model-based tools to support practical water
