A serious game for the low-carbon transition: local energy community framework

Nina Colin, Jérôme Le Dréau

A serious game for the low-carbon transition: local energy community framework

Nina Colin [1], Jérôme Le Dréau [2]
[1] Strasbourg University, AHP-PReST UMR CNRS 7117, Strasbourg, France
[2] La Rochelle University, LaSIE UMR CNRS 7356, La Rochelle, France

1 Introduction

Recent EU legislation [1], [2] has encouraged the development of low-carbon production systems and energy communities at the local level. As part of a research project, a participatory committee was set up to discuss the carbon footprint of photovoltaic (PV) panels and a serious game was developed to foster participation.

1.1 The development context of the serious game : Atlantech, a "low-carbon" district, incubator of a collective self-consumption operation

Atlantech is a low-carbon urban district located at the northern end of La Rochelle, France. It consists in an area of activity dedicated to the energy transition, making this district an incubator for innovation and a large-scale demonstrator. While some see it as a "beta" version of the city of the future, others see Atlantech as "closed in on itself". This sense of separation from the rest of urban life is encouraged by its modern design and architecture, which visually mark its distinction from the adjacent neighbourhoods, and is reinforced by its spatial configuration. Within the neighbourhood itself, groups are defined according to different activities: living, working or learning [3]. A research project is underway in the Atlantech district, the RECA project for "carbon reduction for collective self-consumption". This project started in July 2020 and will continue until July 2023.

One of the aims of this research project is to evaluate the carbon footprint of photovoltaic panels integrated within the Atlantech district, including both the environmental impact of the local production and storage (if any) systems and the interaction with the national grid. Production and consumption at a decentralised level is known as self-consumption and has developed worldwide in recent years due to its economic attractiveness. Two configurations of self-consumption can be distinguished: individual vs. collective. In the case of individual self-consumption, the electricity generated from renewable energy sources is primarily consumed by the producer; the excess energy (if any) is then sold or given away to the main grid. In the case of collective self-consumption, the energy produced within the organisation is shared with

nearby consumers according to commonly agreed rules, thus minimising excess energy. In this article and in the research project, we focus on collective self-consumption because of the societal challenges posed by energy sharing.

The environmental impact of PV panels was performed by researchers and quantified by evaluating the carbon emissions avoided by the PV panels (units in $t_{CO2\ eq}$/year). Thermal and electrical simulations of the Atlantech district were performed for different time horizons (2019, 2035, 2050). Hourly simulations were required to better account for the variability of production, consumption, and emission over time. The first results of the research project indicated a positive impact of collective self-consumption even for future energy scenarios. Sensitivity studies were also carried out (Figure 1) and highlighted the strong influence of design choices on the environmental impact of the local production system [4].

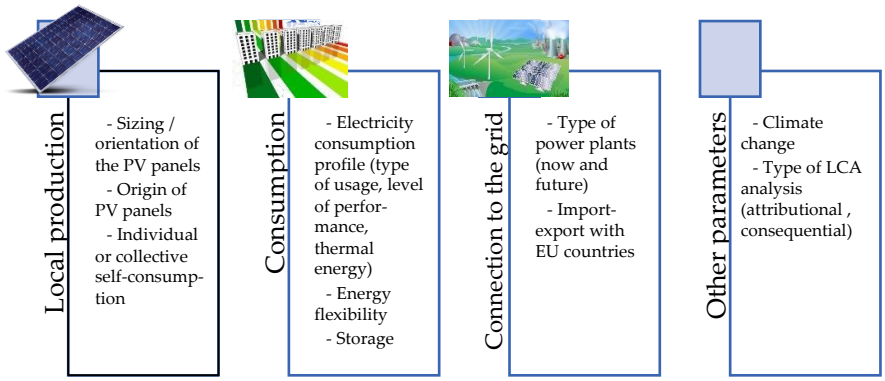


Fig. 1: Parameters tested in the sensitivity analysis.

1.2 The participatory committee of the research project

The other objective of the research project is to share and discuss the results outside the academic field. As shown in Figure 2, the participatory component of the RECA project, by bringing together energy experts, users, and local authorities, aims to integrate all the actors concretely involved in the development of a district through a participatory committee by acting on three points: (i) enabling citizens to reflect on their needs and energy consumption patterns, (ii) analyse the overall energy chain to identify carbon emissions, (iii) implementing and testing a common evaluation method between energy providers and citizens, in order to be able to objectively analyse the emissions of the collective self-consumption operations set up. In this respect, the Atlantech district is part of a collective self-consumption operation that questions the production and circulation of knowledge through participation. Participation, as a means of responding to specific issues, is relevant in the face of the incertitude caused

by climate disruption, and indeed, it is also relevant in the projects inherent to the ecological transition [5].

ADEME, which is funding part of the project, is showing its willingness to integrate citizens more and more in research projects by funding "participatory research" projects. Several definitions of participatory research have been proposed. Thus, the Houllier report for the Ministry of Higher Education, dating from 2016, defines participatory science and research as "forms of scientific knowledge production in which non-scientific-professional actors participate in an active and deliberate way" [6]. Another definition is proposed by the CNRS ethics committee, which refers to "sciences with citizen virtues, at the service of society in their organisation and functioning" [7] and reflects the idea that this mode of research aims to provoke social change and work for the transformation of science by providing concrete solutions, "for action" [8]. Several authors have highlighted the strengths and limitations of participatory serious game design [9][10]. They point out that it "increases public engagement with research and facilitates learning and change, ensuring that technologies are tailored to people's needs". However, despite its popularity, participatory design has remained limited in the design and development of serious games and is often restricted to critical feedback on games [41] . Therefore, the idea of creating a serious game (called Solaropolis) was discussed. Our approach is intended

to serve as a concrete example of co-design of a serious game, on a minor theme addressed by serious games: collective self-consumption.

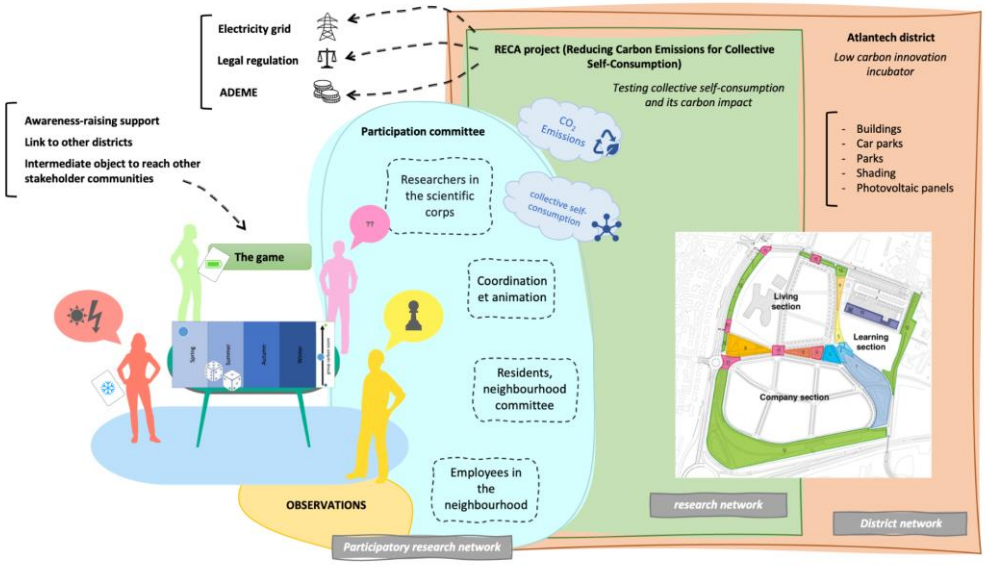


Fig. 2: Project and stakeholders ecosystem. Solaropolis game is represented as an "frontier object", mediating between the different components of the RECA project, the Atlantech district and beyond.

We have documented the entire participatory co-design process of the Solaropolis game. In fact, the action research [11] presented here is based on participant observations made during the 7 meetings of the RECA participatory committee over a period from January 2021 to April 2023 (Fig. 3), as well as on interviews conducted with meeting participants. This is action research as the researchers are directly involved in the search for strategies and methods of action, the main objective being to prepare the group for change through the participatory process and by creating a form of individual and collective liberation, empowerment. Participatory observations are carried out by the project coordination and facilitation team and result in reports for the participatory committee. At the same time, a logbook is used to record the various key moments of the project, which will form the basis of a broader analysis as part of a thesis in progress[1]. The comprehensive interviews [42] carried out at the beginning and during the project (between September 2021 and December 2022) are 19 in number and constitute the first phase of a more global study around the RECA project and its

[1] Nina Colin - Participation as a mode of research: between plurality of practices and potential for replication. Through the study of a territorial case: the energy and low carbon transition in La Rochelle.

participatory committee, they will be coupled with a second phase of interviews in June and July 2023, at the end of the project.

The article will first present the potential of mobilising the co-design of the game as an anchor for the exchanges of the RECA participatory committee and then, in a second step, we will discuss the co-construction of the game experience itself.

2 Mobilizing the game framework as an anchor for the RECA participatory committee's discussions

The purpose of this section is to illustrate the intent and the contribution of game co-design to (i) the RECA research project; (ii) the researchers; and (iii) the users. By analysing the evolution of the objectives of the participatory committee, let us begin to study the genesis of the serious game.

2.1 Evolution of the objectives

During the set-up phase of the RECA project, there was a real desire to integrate the future users — residents, workers, students — of the self-consumption loop into the research carried out, with the initial objective of building a simplified and robust methodology to assess the carbon impact of self-consumption at the scale of the Atlantech district. This involvement of users in the project does not stem from an initial need on their part, but rather from the framing of the project coupled with the will of the funder. The participants are either individual volunteers or from neighbourhood organisations who are obliged to attend Atlantech events. It should be noted that this obligation concerns the organisations, but the participants as individuals are all volunteers. The committee is also made up of researchers who have little experience of participatory research but who are convinced of its importance.

Extracts from the interviews conducted at the beginning of the project (phase 1)

Employee 1 in the Atlantech district	Resident 1 of the Atlantech district
"Maybe I wouldn't have provoked it, but it was an opportunity. Afterwards, as we said earlier, it was obvious ... and it was part of the job."	*"I think that it is quite representative of the general population, in a general way, we speak about the environment, we speak about energy saving, we speak about ... here we are, about ... managing energy [...] but and ... what do we do? And what can I do, at my level? That's the big question."*

This initial configuration is not necessarily conducive to the implementation of participation. The users were initially quite critical about the project, lamenting the technocratic choices made in the district. After the first meeting, they only expressed the wish to build "something that stays", they were willing but waiting to know "what to do together".

Extracts from the interviews conducted at the beginning of the project (phase 1)

Resident 1 of the Atlantech district	Resident 2 of the Atlantech district	Employee 1 in the Atlantech district	Resident 3 of the Atlantech district

"[…] for concrete action, yes, and something we can touch."	*"So what now ... the next step? Where do we go, what do we work on? With whom? And our projects? Is the project feasible? Will we be able to see the evolution of the neighbourhood? because the neighbourhood is evolving ..."*	*"[…] But in any case to build something, yes, that will allow us to easily talk again even when there is no longer this system of animation like that. And then to make collective choices on energies, well, on things to put in place."*	*"I don't know yet, in relation to the meetings, because we haven't done much […] where we want to go and where we are going? And I think now, in the next few meetings, we're going to have to settle down and start doing ..."*

As meetings are held, the involvement of the committee led to a shift in the participants objectives towards the followings: the appropriation of a new technology, involving the entire neighbourhood (2 km) by a small group and the accompaniment of the energy and environmental transition through energy sobriety. So the idea of creating a serious game was proposed by the animation section and discussed and agreed by the committee.

At this stage of the article, it seems important to specify that three levels of objectives are intertwined in the RECA project: (i) the objective of the RECA project itself corresponds to the development of a methodology for calculating carbon emissions for collective self-consumption; (ii) the objective of the participatory committee is to provide reflective feedback on the work of the RECA project researchers. This objective requires an improvement of the group's knowledge and skills in the field of energy. For this purpose, the collective creation of the serious game seems relevant, as it is able to set the framework and channel the exchanges. It also responds to the group's desire to create something that will last beyond the project. Finally, (iii) the objective of the serious game — which is in the design phase — is to inform citizens about the design and operation of an energy community and the environmental impact of self-consumption. It also makes it possible to disseminate the results of the RECA research by presenting the principle of collective self-consumption to future users or communities, and/or to encourage future investors to join an energy community. Finally, it is also intended to teach the right gestures for the optimal use of collective self-consumption in order to guarantee a reduction in carbon emissions. In

fact, through this energy management game, the committee will have to make decisions, react, give its opinion on several indicators and/or co-construct these indicators.

2.2 The game as a framework

Djaouti et al. [12] date the official birth of the term ‘serious game’ to the early 2000s. These are experiential environments [13], playful objects, diverted — at least in part — from their initial use: to entertain us to focus on reflection, information or stimulation. They are tools for simulation and even co-construction [14]. A recent review from Morganti *et al.* [20] highlighted the positive influence of serious games on energy-saving behaviours. The development of the game presented here is based in particular on (i) collective creation times, (ii) an "ultra-simplified" carbon calculation model. The game itself is based on the allocation of roles and the organisation of debriefing by the facilitator at the end of the game session.

The serious game developed during the research project is related to energy, which level of knowledge within the population is known to be relatively low [15]. This level of knowledge is sometimes defined as energy literacy: it encompasses not only the understanding of the nature and role of energy in the world and in everyday life, but also the ability to apply this understanding to answer questions and solve problems [16]. Several reasons can explain this energy-illiteracy: complexity to visualise energy flow, distance from the centralised production systems or energy sources, and difficulties to identify the capacity of actions [17]. Moreover, in the case of the development of collective self-consumption, understanding energy is not sufficient, but citizen’s active participation is the foundation for the acceptance and development of new technologies [18]. The game co-design is therefore used here as a basis for the group to appropriate and understand the technique.

In a certain way, the game serves also as a framework for the exchanges of the participatory committee by its capacity to give rhythm to the passing of time: it guarantees that the participants, whose wish it was, have an objective. Indeed, as we have seen previously, participation is conditional on the investment of time and energy being used for something, and the research process does not guarantee an outcome, let alone a usefulness [19]. This is particularly apparent during the preparation phase of the group sessions, where certain elements of the game framework (e.g. preparing a workshop to create "random event" cards or to reflect on the different roles in the game) structure the issue to be addressed in connection with the research project (such as the origin of the photovoltaic panels, the indicators to be taken into account, the governance, etc.). These numerous possible connections are as many "entry points" to apprehend the complexity of the research objects that are self-consumption and the calculation of carbon emissions. During the collective high points, the discussions and

debates are then channelled around the objective of creating the game. The game framework sets the conceptual model that allows for exchanges. Beyond the general direction given by the project, this space of exchange between experts (researchers and engineers) and users is also a space to raise awareness of energy sufficiency, presented as an essential aspect of the energy transition.

The "game" object is a mediator for the appropriation of this technology to be used in "common". The common construction of the intermediate object allows the participants to build a common representation of their system allowing in a sense to lead the group towards a new form of decisional autonomy concerning the consumption of electricity, stronger than if they had only participated in a game session. Thanks to the facilitator training that will be organised in the near future, participants in the game design will be able to become "game ambassadors" if they wish, by facilitating and broadcasting game sessions, along the lines of LittoSim-Gen and the "LittoTeam", for example [21]. These are overflows that we cannot foresee or anticipate at the moment, which will be the subject of a second phase of analysis (from July 2023).

2.3 The facilitator, a necessary game master?

As Ghelli [39] reminds us, *"The question of accompaniment is fundamental in the design of an educational game: the game does not have the same constraints if it is designed to be played independently or if, on the contrary, it requires the presence of a facilitator."* [39]. The participatory committee imagined a game that requires the presence of a facilitator, whose role is to facilitate during and after the game, during the debriefing phase. For the committee, this is not a "Saturday night game", but a learning and awareness tool dedicated to specific moments and organised by a third party.

During the game, the facilitator acts as a narrator, but is also responsible for ensuring that the participants understand the mechanics of the game. He is at the same time a "game master" who explains the rules at the beginning of the game, a companion who guides the players during the game, and also a "knowledge broker" [40] who is able to provide information and approach theoretical concepts when necessary. In short, he is the guarantor of the pedagogical objectives and therefore of the "serious" dimension of the game [14].

At the end of the game, he or she will also be responsible for conducting the final debriefing. Based on the model of the “2-ton” workshop, the aim of this debriefing is to allow the group to discover how it could have improved "even more" the carbon footprint of the self-consumption operation designed by the team. It also serves to ensure the "double process of translation and interpretation" inherent in the use of a boundary object, allowing the interpretation of what happens in the virtual world of the

game for the real world. It makes it possible to understand and analyse the results of the game in terms of action in the real world [33].

3 Co-constructing a game experience, from intention to action

The purpose of this section is to present the existing serious-games related to energy communities and then describe the co-design phases and the gameplay. We will focus on the development of the game within the RECA project and the role given to the participatory committee and the researchers. It was decided to create a new game, rather than hack an existing one, for several reasons: (i) after a survey of existing serious games on the subject, we found few board games linking the themes of energy and carbon on an annual scale. (ii) The original creation of a game made it possible to capture all aspects of the design and therefore of the project, implying a stronger bond of the collective creating something unique. Nevertheless, it should be noted that the group was inspired by the mechanics of several games, including: (i) Galerapagos (Gigamic, 2017) for its resource management aspect and its extension in terms of roles and character cards, (ii) Carbon Lean (ThemeIsle, 2020) for its game mechanics around carbon calculation.

3.1 State-of-the art of existing games

Serious games on energy-related topics are seen as one of the solutions to overcome the knowledge gap on energy. In this article, we will focus on games related to the development of renewable energy systems. Regarding the level of study, some games target the country- or city-scale with the objective to develop a complete energy system made up of different sources (e.g. *CityOne* [22], *Power Matrix* [23], *EcoVille* [24]). Other games focus on a smaller scale and deal with the local production of energy connected to an electrical grid (e.g. energy communities). A recent review proposed by Nykyri et al. [25] lists the serious games developed in the context of energy communities. Table 1 provides an overview of the characteristics of these serious games. The objectives are quite similar for all board games, i.e. to provide a better understanding of local production systems and to initiate cooperation/ negotiation. From this table, it can also be observed that the games focus on different stages of development: the design/investment phase (*Changing the game*, *Energy Game*), the operation phase (*Social Mpower*, *Sous Tension*) or both phases (*Electric City*, *DLT Energy Game*). The games developed were either digital (2D or 3D) or board games. For some authors, board games were seen as advantageous as it allowed keeping an overview on the whole system [18]. Regarding the timescale represented in the game, a large variety can be observed, from one day (*Social Mpower*) up to 30 years (*Changing the game*, *Energy Game*). Finally, it should be highlighted that some games proposed a physical representation of energy in the form of brick to overcome the problem of materialising energy use (*Changing the game*, *Sous Tension*).

Table 1: List of serious games related to local production and consumption of energy and local energy communities.

Name of the game	Learning objective	Format	Role	Unit	Duration	Cooperation
Social Mpower [13]	Understanding RES, Energy sharing	3D simulator	Inhabitants	Energy	Typically a day, until a player run out of energy	Yes (negotiation among players)
Changing the game – Neighbourhood [18]	Create a district and its energy system (electricity, heat, transport), CO2 reduction	Board game	District designers	Energy and CO2	30 years	Yes (for global targets and for unpopular actions)
Electric City [26]	Secure and manage electricity, food and water	2D island simulator	Inhabitants	3 dimensionless resource scales	6 turns	Yes (negotiation)
DLT Energy Game [27]	Understanding of peer-to-peer energy trading and DLT	?	Inhabitants (with PV or without PV)	Energy and Cost	2 rounds (with and without exchange)	Limited (sharing only)
Energy Game [28]	Design a neighbourhood energy supply and earn as much money as possible	3D environment	Developer	Energy and Cost	30 years	No
Sous Tension [29]	Share energy among apartments	Board game	Inhabitants of the building	Energy	1 week (divided in 3 hrs)	Yes

3.2 The game context

Game synopsis:

Welcome to the Solaropolis district! Today, you will play the role of citizen-builder by participating (or not!) in a local renewable energy production project. Together, you will have to develop your district in two stages: you will start by initiating a self-consumption project, and then you will have to develop it throughout the year by

limiting its carbon footprint, despite the dangers and interests of your characters! Don't forget: sobriety and resilience will be essential to finish the game with the lowest possible carbon footprint, while saving your wallet...

The synopsis of the game (see text above) aims to allow the player to enter the game universe through 'setting in narrative' [14]. This storytelling, coupled with the different possible scenarios, serves as mediation by allowing players to immerse themselves in the message conveyed by the designers. In this case, it is the participatory committee that produced the synopsis, through a collective intelligence workshop proposed during a group highlight. We note the emphasis on the collective and cooperative dimension in the synopsis of the game produced by the committee.

3.3 Design Phase

One of the main challenges of designing a serious game consists in simplifying the complex mechanisms of the real world by a few clear rules, which will provide the framework for the execution of the game [18]. Moreover, to achieve the learning goals, the game should include the following features: pleasure, reward and progression over time [30], [31]. The initial design of the game started in June 2022 and the test phase is still ongoing to date (Fig. 3). We will thus describe the first outcomes of the design process.

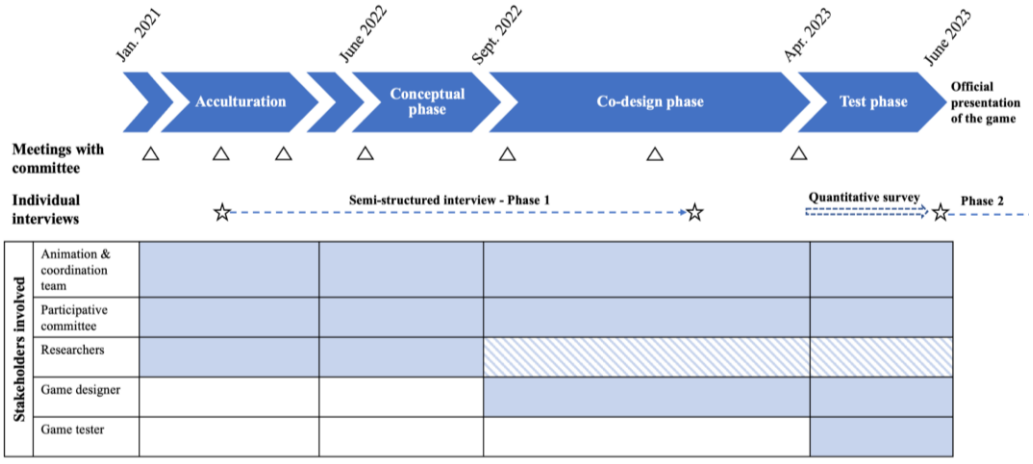


Fig. 3: Game development timeline.

The overall design phase was twofold: first three meetings were set-up to acculturate the committee to the topic of energy and self-consumption and four meetings were then organised over a one-year period to design the serious game in cooperation with the participatory committee. In addition to these regular meetings, two persons were more

closely involved in animating and coordinating the participatory committee and ensuring that the results of the meetings (sometimes with conflicting opinions) were incorporated into the game design.

Different topics were discussed in groups to develop the game: format, cooperative vs. competitive, gameplay, roles, rules, indicators, storytelling, etc. Various game formats were proposed: mobile application, escape game or board game. During the discussions, the board game was favoured due to its ease of deployment and to support the exchanges between players. The participants also agreed that the game should be deployed during collective times (neighbourhood committee, events, etc.), which makes the board game more suitable. A debate was also opened on the interaction between players, and more specifically if the game should be cooperative or competitive. Due to the collective nature of (collective) self-consumption, it was quite natural to propose a cooperative game and a large part of the committee agreed on this choice. However, some proposals later in the design phase tended to be more competitive as this format was seen as a way to spice up the game and foster participation. This will be checked during the test phase.

Another important part of the co-design phase included the definition of rewards and penalties in coherence with the scientific project. As highlighted by Prilenska [28], the development of the gameplay should avoid the bias from oversimplified models. The order of magnitudes should be in line with the scientific results to avoid misleading the players. In order for the participatory committee to get a better understanding of the carbon footprint of self-consumption, a simplified model (see Fig. 4) was proposed by the scientists to observe the variation of the carbon emissions depending on the design and operation of self-consumption (see parameters in Fig. 1). The committee could explore a spreadsheet on their own, to estimate the gains or losses from various design choices. However, the committee did not really make use of this spreadsheet and relied more on scientists to provide them with accurate figures. This role of external and trusted advisor was also identified by Voinov [32]. Among the different factors that can influence the carbon footprint of collective self-consumption, it was decided to focus on a few of them, namely: the origin of the PV panels (China vs. EU), the size of the powerplant, the influence of seasons, the behaviour of participants (energy conservation, flexibility) and the energy efficiency of buildings. Moreover, the committee decided to have both monetary and carbon units in the game, as these two indicators could lead to conflicting choices for the players.

It should be highlighted that the lessons learned from the game are not specific to the district evaluated (i.e. the Atlantech district). In fact, the results and conclusions will be alike for other sites in France (similar annual PV production), other district sizes (effect of scale only) and other years (sensitivity study over four different years). However, the conclusions will not be valid if there is a drastic change in electricity use (e.g. industrial district, or a district with a limited use of electricity for space heating or domestic hot water).

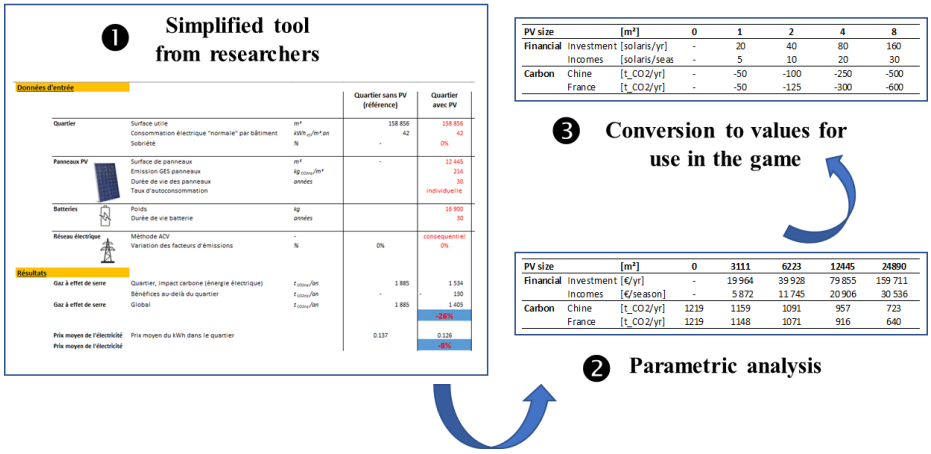


Fig. 4: Presentation of the workflow for defining the data to be used for the design of the cards.

3.4 Gameplay and game material

The game involves the design and operation of an energy community in the Atlantech district. Residents, investors and workers must work together to design and operate a PV system that both improves the district's carbon footprint and generates savings.

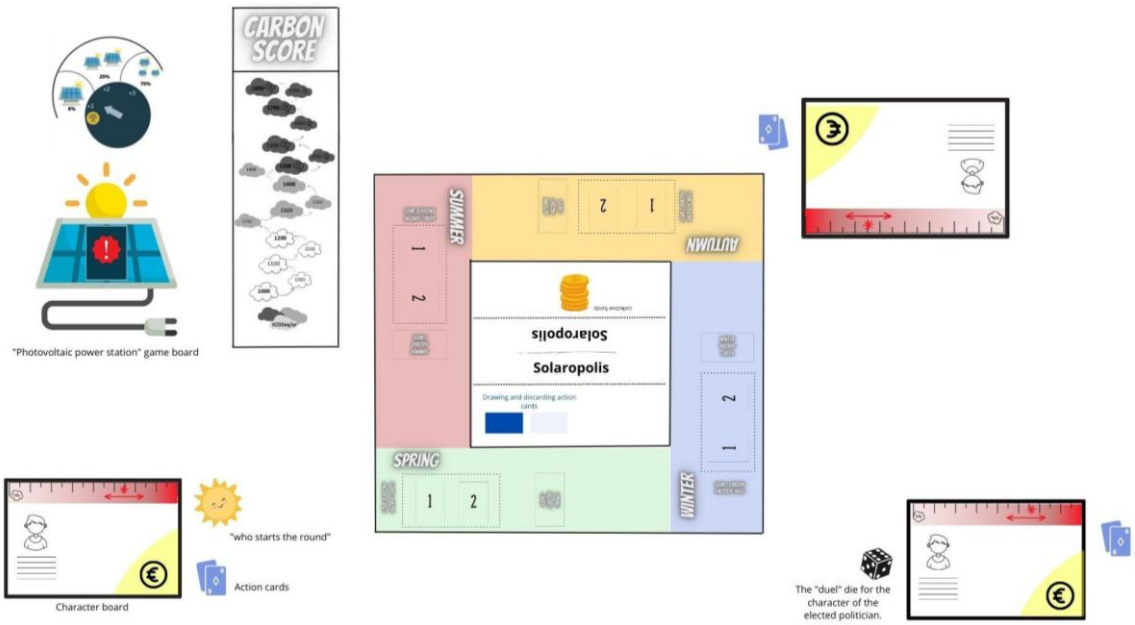
The game material consists of a wooden board with chips manufactured locally (see Fig. 5). Before starting the game, each player chooses a card with a role assigned to it (family living in the neighbourhood, young adult renting an apartment, landlord, CEO of a company, etc.). These roles will define individual objectives to reach (either more focussed on the money, or on the carbon emissions) and different interest in the installation of PV systems (depending on their electricity consumption). The game is organised in five rounds: the design of the PV system is performed during the first round, and the four last rounds are related to the operation of the system during four seasons (autumn, winter, summer, spring). The objective of the first round is for the player to understand the interest (financial or carbon) to group their investment in a shared local production plant. The last four rounds focus on the challenges related to a variable production system and the need to adapt the consumption of the district. The

group wins if they manage to get electricity all year long and if they reach their collective target to decrease the greenhouse gas emissions.

Fig. 5: Provisional gameplay. The photovoltaic power plant is built during the first phase of the game. The game board comes into play during the second phase of the game and represents the four seasons, each season consists of risk cards (weather, circumstances, ...) the change of season takes place when each player has drawn a risk card and possibly performed an action during the season, the end of the game is called when all four seasons have been played. Each player has in front of him: a character card and action cards. The carbon scoreboard makes it possible to follow the evolution of the carbon impact of the collective self-consumption operation over the course of the game. (Illustration : Mégane Haenn).

4 Discussion

4.1 Matching the game's intent (part 2) to the game's mechanics (part 3)



E.Ostrom [37] pointed out that the conditions for cooperation within the commons are not reduced to access to the resource. They depend largely on the degree of commitment to the collective and the trust that its members maintain [38]. Factors that facilitate cooperation include the ability of participants to communicate with each other, their ease of entering and leaving the collective, and their ability to project themselves over the long term [37]. Through the organisation of shared sessions between several social worlds, the game aims to enable mutual knowledge between the users of the self-consumption community and the different actors involved (producer, organising legal entity, distributor, etc.), thus ensuring long-term involvement within

the energy community. Bourazeri et al [13] also use Ostrom's notion of the commons to design a social serious game that aims to enable collective awareness of energy consumption, while showing that the serious game is an effective way to change users' behaviour and habits around energy consumption.

4.2 Beyond the participatory approach, the appropriation of a technique

This section aims to highlight the impact of the game design on the participatory committee and in the appropriation process of the collective self-consumption technique. As Barreteau et al. [33] note, *"knowledge sharing is a privileged means of changing the relationships between individuals, as well as the relationships between individuals and the resource".* Thus, the serious game presented here - which is still in its design phase - can be described as an intermediate object (IO), in the sense that it allows for collective reflection between several types of actors: "laymen", "researchers", "technicians" and "facilitators" (Figure 2).

The game is an artefact [43] that helps to structure the committee by giving it consistency, a clear and tangible objective and stability over time. It also fulfils the three characteristics of IOs as defined by Dominique Vinck [34][35].

Thus, the game is an intermediary object for the participatory committee, but also subsequently for all future players. By becoming the mediator of change, it allows the exploration of different transformation options and their consequences, of different possible transition paths. More precisely, it is a frontier object because it can be used by multiple actors from different social worlds. This frontier object induces a situation of mediation in which the actors seize the object differently while sharing a common goal: testing different scenarios of self-consumption, possibilities of development of the operation and can interpret roles without direct impact on reality [21].

4.3 Playful transmission of technique use

One of the objectives of the RECA participatory research project is to analyse the potential for replicating collective self-consumption operations, such as the one carried out in Atlantech, in other districts. The game, which is not specific to Atlantech but aims to represent a typical neighbourhood, seems to be the ideal intermediate object to allow future users of these neighbourhoods to understand the technique that will be used there. In fact, the data used in the project are applicable to other cases of study because the indicators taken into account are: the French climate and the "residential area" aspect.

We have therefore decided to involve them in the participatory process during the test phase of the game (Fig. 3). We will therefore organise three test sessions of the game with the future users of two districts of La Rochelle, before the day of the return of the project and the official presentation of the Solaropolis game on 1 June 2023. The

test phases of the game will take place between 6 and 20 May 2023. To document this phase of the project, we have planned (i) a quantitative study analysing the dynamics and mechanics of the game, the pedagogy of the game and the initial knowledge of the respondents on the energy field. This quantitative study will be coupled with a focus group to explore in detail the testers' experience of the game. This is part of the ongoing RECA research.

Conclusion

In this article, the potential of mobilising the co-design of a serious-game as an anchor for the exchanges of a participatory committee was presented and the game design and experience were described. Three levels of objectives were intertwined in the research project: (i) for researchers, the development of a methodology for calculating carbon emissions for collective self-consumption; (ii) for the participatory committee, the discussion of the outcomes of the RECA projects; (iii) for the serious game, the information of citizens on the design and operation of a self-consumption installation.

Thus, through the co-design of the serious game, the technology is "experimented" and discussed among the players involved in the game. Existing literature also supports this finding, it has been confirmed that a game is beneficial for learning knowledge considered outside the normal expertise of a player [27]. However, we recall here that at this stage of the study, the game has not yet been tested, so we are waiting to find out whether the game is really pleasant, what impact the facilitator has on making the game pleasant and instructive, and whether the educational objective of the game is achieved. The aim is to involve the participatory committee in the testing phase to get feedback and ensure that the game is playable. The public release of the game prototype is planned for 1 June 2023.

The limits of the participatory process will be discussed and analysed at a later stage of the study, when the second phase of interviews has been conducted. For the moment, the game seems to have reduced the asymmetries between "researchers" and "users", but we note a form of asymmetry inherent in the seniority of the participants in the participatory committee. In fact, we decided at the beginning of the process to leave the participatory committee open to the renewal of participants. This proved to be necessary because not all participants were available for every meeting, although a 'core' group formed over time. Nevertheless, the last people to join the committee showed more difficulty in integrating into the process, as evidenced by their difficulty in speaking up, the number of suggestions they made, and their degree of socialisation. We will try to explore this aspect of the study in more depth in the near future.

Acknowledgements

— The authors would like to thank all the members of the RECA participatory committee and the Atlantech animation team, without whom Solaropolis would not have been possible. They would also like to thank Mégane Haenn for her important contribution during the co-design and testing phase of the game. —

References

[1] European Commission, *Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU. 2019.* 2019.

[2] European Parliament, *Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources*. 2018.

[3] V. Helfrich, T. Cuenoud, L. Houanti, et P. Schäfer, « Structuration d'un écosystème pour la gestion d'un commun : le cas du parc bas carbone Atlantech », *fcs*, nº NS-12, Art. nº NS-12, juin 2022, doi: 10.4000/fcs.9217.

[4] ARMINES, ENGIE Lab, et ADEME, « INCER-ACV - Incertitudes dans les méthodes d'évaluation des impacts environnementaux des filières de production énergétique par ACV », 2021.

[5] Y. Barthe, M. Callon, et P. Lascoumes, *Agir dans un monde incertain. Essai sur la démocratie technique*. Paris: Le Seuil, 2014. [En ligne]. Disponible sur: https://www.cairn.info/agir-dans-un-monde-incertain-essai-sur-la-democrat--9782020404327.htm

[6] F. Houllier et J.-B. Merilhou-Goudard, « Les sciences participatives en France ».

[7] C. Ethique et M. Leduc, « COMETS AVIS 2015-31 - Les sciences citoyennes ».

[8] S. Lardon, M. Houdart, S. Cournut, L. Gouttenoire, N. Hostiou, et M. Taverne, « Recherches participatives sur les exploitations agricoles et les territoires: des démarches innovantes. », 2010.

[9] J. Vines, R. Clarke, P. Wright, J. McCarthy, & P. Olivier. Configuring participation: On how we involve people in design. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 429-438, 2013. https://doi.org/10.1145/2470654.2470716

[10] E. B. N. Sanders, & P. J. Stappers. Co-creation and the new landscapes of design. CoDesign, 4(1), 5-18, 2008. https://doi.org/10.1080/15710880701875068.

[11] R. Barbier, *La recherche action*. Anthropos Paris, 1996.

[12] D. Djaouti, J. Alvarez, J.-P. Jessel, et O. Rampnoux, « Origins of Serious Games », in *Serious Games and Edutainment Applications*, M. Ma, A. Oikonomou, et L. C. Jain, Éd. London: Springer London, 2011, p. 25-43. doi: 10.1007/978-1-4471-2161-9_3.

[13] A. Bourazeri et J. Pitt, « Collective attention and active consumer participation in community energy systems », *International Journal of Human-Computer Studies*, vol. 119, p. 1-11, nov. 2018, doi: 10.1016/j.ijhcs.2018.06.001.

[14] C. Henriot et N. Molines, « Netcom, Appels à contributions ».

[15] J. E. DeWaters et S. E. Powers, « Energy literacy of secondary students in New York State (USA): A measure of knowledge, affect, and behavior », *Energy Policy*, vol. 39, nº 3, p. 1699-1710, mars 2011, doi: 10.1016/j.enpol.2010.12.049.

[16] U.S. Department of Energy, « Energy Literacy: Essential Principles for Energy Education », 2017. [En ligne]. Disponible sur: https://www.energy.gov/eere/education/energy-literacy-essential-principles-energy-education

[17] J. Burgess et M. Nye, « Re-materialising energy use through transparent monitoring systems », *Energy Policy*, vol. 36, nº 12, p. 4454-4459, déc. 2008, doi:

10.1016/j.enpol.2008.09.039.
[18] M. Lanezki, C. Siemer, et S. Wehkamp, « “Changing the Game—Neighbourhood”: An Energy Transition Board Game, Developed in a Co-Design Process: A Case Study », *Sustainability*, vol. 12, nº 24, Art. nº 24, janv. 2020, doi: 10.3390/su122410509.
[19] J. Janiw et E. Hassenforder, « Le développement de la culture de la participation : avancées et réflexions »:, *Sciences Eaux & Territoires*, vol. N° 35, nº 1, Art. nº 1, oct. 2021, doi: 10.3917/set.035.0024.
[20] L. Morganti, F. Pallavicini, E. Cadel, A. Candelieri, F. Archetti, & F. Mantovani, Gaming for Earth : Serious games and gamification to engage consumers in pro-environmental behaviours for energy efficiency. *Energy Research & Social Science*, *29*, 95-102. 2017 https://doi.org/10.1016/j.erss.2017.05.001
[21] A. Laatabi, N. Becu, N. Marilleau, M. Amalric, C. Pignon-Mussaud, B. Anselme, E. Beck, X. Bertin, A. Monfort, C. Hayoun, & F. Rousseaux. LittoSIM-GEN : A generic platform of coastal flooding management for participatory simulation. Environmental Modelling & Software, 149, 2022. https://doi.org/10.1016/j.envsoft.2022.105319
[22] IBM, « CityOne », 2010. [En ligne]. Disponible sur: https://www.ibm.com/cityone
[23] Siemens, « PowerMatrix Game », 2013. [En ligne]. Disponible sur: http://www.powermatrixgame.com/
[24] Ademe et Hespul, « EcoVille Le Jeu », 2010. [En ligne]. Disponible sur: http://www.ecovillelejeu.fr/
[25] M. Nykyri, T. J. kärkkäinen, S. Annala, et P. Silventoinen, « Review of Demand Response and Energy Communities in Serious Games », *IEEE Access*, vol. 10, p. 91018-91026, 2022, doi: 10.1109/ACCESS.2022.3202013.
[26] A. Singh, H. W. van Dijk, B. O. Wartena, N. Romero Herrera, et D. Keyson, « “Electric City”: Uncovering Social Dimensions and Values of Sharing Renewable Energy through Gaming », in *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, New York, NY, USA, Abril 2015, p. 1519-1524. doi: 10.1145/2702613.2732929.
[27] J. W. Veeningen et N. B. Szirbik, « Using Serious Gaming to Discover and Understand Distributed Ledger Technology in Distributed Energy Systems », in *Advances in Production Management Systems. Production Management for Data-Driven, Intelligent, Collaborative, and Sustainable Manufacturing*, Cham, 2018, p. 549-556. doi: 10.1007/978-3-319-99704-9_67.
[28] V. Prilenska, « Serious game for modelling neighbourhood energy supply scenarios », *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 410, nº 1, p. 012091, janv. 2020, doi: 10.1088/1755-1315/410/1/012091.
[29] Eco-SESA, « Sous Tension », 2018. [En ligne]. Disponible sur: https://ecosesa.univ-grenoble-alpes.fr/scientific-production/serious-game/
[30] B. M. Winn, « The Design, Play, and Experience Framework »:, 2009, p. 1010-1024. doi: 10.4018/978-1-59904-808-6.ch058.
[31] G. Zichermann et C. Cunningham, *Gamification by design: Implementing game mechanics in web and mobile apps*. O’Reilly Media, Inc., 2011.
[32] A. Voinov et F. Bousquet, « Modelling with stakeholders », *Environmental Modelling & Software*, vol. 25, nº 11, p. 1268-1281, nov. 2010, doi: 10.1016/j.envsoft.2010.03.007.
[33] O. Barreteau, F. Bousquet, M. Étienne, V. Souchère, et P. d’Aquino, « La modélisation d’accompagnement: une méthode de recherche participative et adaptative », in *La modélisation d’accompagnement: une démarche en appui au développement durable. Paris (France): Quae éditions*, 2010, p. 21-46.
[34] D. Vinck, « Les objets intermédiaires dans les réseaux de coopération scientifique: Contribution à la prise en compte des objets dans les dynamiques sociales », *Revue française de sociologie*, p. 385-414, 1999.
[35] D. Vinck, « Accessing material culture by following intermediary objects », *An*

ethnography of global landscapes and corridors, p. 89-108, 2012.
[36] B. Latour, *Science in action: How to follow scientists and engineers through society*. Harvard university press, 1987.
[37] E. Ostrom et É. Laurent, « Par-delà les marchés et les États. La gouvernance polycentrique des systèmes économiques complexes », *Revue de l'OFCE*, nº 1, Art. nº 1, 2012.
[38] A. Buchs, C. Baron, G. Froger, et A. Peneranda, « Communs (im) matériels: enjeux épistémologiques, institutionnels et politiques. Introduction au dossier «Communs (im) matériels. Conjuguer les dimensions matérielles et immatérielles des communs» », *Développement durable et territoires. Économie, géographie, politique, droit, sociologie*, vol. 11, nº 2, Art. nº 2, 2020.
[39] R. Ghelli, « La ville en jeux et les jeux pédagogiques urbains », *netcom*, nº 34-1/2, Art. nº 34-1/2, janv. 2020, doi: 10.4000/netcom.5614.
[40] M. Meyer, « The rise of the knowledge broker », *Science communication*, vol. 32, nº 1, Art. no 1, 2010.
[41] R. Khaled, & A. Vasalou. Bridging serious games and participatory design. International Journal of Child-Computer Interaction, 2(2), 93-100, 2014. https://doi.org/10.1016/j.ijcci.2014.03.001
[42] H. Dumez, "*What is qualitative research?"* - epistemological, methodological and theorisation problems. - (2), p. 29- 42. ESKA. 2013.
[43] J. Alvarez. Design des dispositifs et expériences de jeu sérieux. Multimédia [cs.MM]. Université Polytechnique des Hauts-de-France, 2019. tel-02415027v2