Tackling air pollution in cities with modelling and simulation: Remote Group Model Building as an Educational Tool Supporting System Dynamics Modelling

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Abstract. The study introduces a System Dynamics Modelling (SDM) approach with a remote Group Model Building (GMB) component used as an answer to the climate problems of cities related to severe air pollution. The main objective of our research is twofold: to identify the factors and mechanisms that are key for the elimination of fossil-fuel boilers (FFBs) in Poland and to provide a system understanding of the underlying causal relationships and their implications to facilitate eradication of FFBs. The first phase of modelling process is presented: action research represented by remote GMB workshops, attended by 14 participants from Poland and Norway. The workshops' results help to identify the key variables, capture the main causal relationships between them, helping to develop the first outline of the causal structure to underlie the simulation model. Despite holding the workshops during social isolation, they proved to be good educational facilitation tool for a key element of the modelling process in the SD methodology - the collection of input data for model building, as well as raising participants' awareness of climate change issues. The novelty of the study lies in the application of a proven tool such as dynamic systems modelling to applied research for sustainable development. In particular, using modelling and simulation approaches to support development and practical implementation of the energy transition policies involving the elimination of FFBs and replacement with renewable energy sources. To the best of our knowledge, only a few such studies are being conducted.

Keywords: System Dynamics Modelling, Group Model Building, Education for Sustainable Development, Educational facilitation tool, Urban education.

1 Introduction

The issue of caring for the quality of the environment, including air quality, has been growing in importance for many years. The search for effective solutions to improve

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the quality of the environment, but also for knowledge on how not to destroy what nature has given us is a challenge for many people who care about the well-being of our planet. Awareness of the negative effects of our actions plays a key role in changing old, inappropriate habits. Tools that make it easier to plan future actions, anticipating their consequences, could be a support.

Caring for the environment requires an integrated strategy, engaging the participation of diverse stakeholders, beginning from government authorities, policy makers, through non-government organizations, media, local communities, educators, ending on individual users [1]. Ensuring effective communication between them is not one of the easiest tasks. However, in order to slow down the direction of man-made climate change, we must strive for change at global level, but also for change of individual, habitual behavior. Not many are interested in acquisition of the up-to-date knowledge in the field of environmental protection and changing their individual behaviors, habits. It is not new that people learn best through co-participation [2, 3]. Involving people in the decision-making process, working out effective solutions together, learning by doing, gives the best results. However, despite good intentions, such a process can lead to wrong decisions. After all, as humans we are fallible.

Mathematics and computer science are separate fields, but they have the great advantage of being able to use the tools they provide to solve important social problems, especially complex problems. One such tool is modelling based on systems dynamics methodology, which has been proven successful in many application areas over the years [4]. In this paper we would like to introduce a Systems Dynamics Modelling (SDM) approach used with a Group Model Building (GMB) component as an answer to the climate problems of future cities related to severe air pollution. The energies transition process will be supported by providing a simulation model to allow for exploration of various scenarios and development of the common understanding of the causal relationships underlying the complex socio-technical ecosystem of the city and its residents. The following main research questions that we formulated guided us through the research process:

Q1: Can GMB support the process of modelling complex systems carried out in social isolation?

Q2: Can the GMB be an effective tool to raise awareness and increase the knowledge of residents about the energy transition?

Q3: How a SDM with GMB component can enhance a pro-environmental decision making process?

This paper presents initial results of the first phase of the project, outlining the conceptual system dynamic model of the causal structures that are likely to underlie the dynamics of the process of elimination of fossil fuel boilers in residential areas in Poland. The causal structures were identified during an online workshop. The initial causal model was developed based on the data gathered from the project experts and refined based on the review of the relevant literature. In the paper we focus on presenting the elicitation process and the resulting model with references to relevant literature where necessary. The following section reviews the literature thus far. Next, we describe the applied methodology. The following section reviews the literature thus far. Next, we describe the applied methodology. The consecutive section presents

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the workshop and the initial system dynamics model. Finally, we outline further steps to be taken in the successive phases of our project.

2 Related Works

System dynamics was developed by Professor Jay W. Forrester in the late 1950s at the Massachusetts Institute of Technology in the late 1950s. It is a computer-aided approach for strategy and policy design. It uses feedback systems theory to develop computer simulation models. It is an analytical approach to tackle dynamic problems arising in complex social, managerial, economic, or ecological systems [5, 6] (see also [7]). System dynamics approach is especially useful where experts from different domains try to address a complex problem with problem-owners. The system dynamics models allow to create a shared understanding of the problem, providing effective tool for common exploration of possible solutions as well as for improvement of the fragmented individual or domain-specific knowledge. As system dynamics models draw on different expert domains, they are usually developed in a process of group model building [8]. Group model building (GMB), during which stakeholders are gathered around the table to share their insights, has been seen as an important social process in the model development phase, crucial for creating a shared understanding of complex systems and providing a platform for stakeholders to exchange information and ideas [9, 10].

The specialized system dynamics literature decarbonization transitions of residential buildings revealed two main projects research, which became the starting point for further analyses and system dynamics modeling dedicated for pilot case in Poland.

The first one is the HEW project: Integrated decision-making about Housing, Energy and Wellbeing, conducted in years 2011-2016 by University College London, Energy Institute [11]. The HEW project focused on the unintended health, social and environmental harms of decarbonizing the built environment. The main conclusion stressed the need to consider cross-sectoral policy objectives in close interconnection. Despite the numerous linkages to other sectors, there was a conspicuous lack of feedback in the energy efficiency model, suggesting that emphasis should be placed on creating decarbonization policies that take into account feedbacks across sectors of the system [12].

The second project taken into account presents research conducted in Australia on an impact of individual solar power installation on the conventional electricity networks. The installation of rooftop photovoltaic panels by individual consumers leads to a reduction in the need for energy from the conventional electricity networks and thus a reduction in the amount of energy purchased. The reduction in networks revenue with fixed operating costs leads to the need to increase tariff costs to compensate for electricity networks losses. This continues to exacerbate the problem [13]. The development of renewable energy sources represented by the increasing share of private solar power plants is a progressive process, affecting the grid significantly. The author of the study emphasizes the necessity of considering the presented issue in the

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context of a broad transformation, forcing the steps of planning an effective long-term energy strategy.

3 Methodology

The overall objective of our research is twofold:

O1: to identify the factors and mechanisms that are key for elimination of fossil-fuel boilers (FFB) in Poland;

O2: to facilitate development of a system understanding – shared among the project partners as well as between the project team and the stakeholders – of the underlying causal relationships and their implications on the process of FFB eradication.

To achieve this overall objective, we employ the system dynamics methodology. For the first model, we intended to conduct a group model building (GMB) session with experts representing the project partners.

Due to the changes in the work and social life introduced because of the COVID-19 virus, we had to amend the plan and conducted GMB sessions using the online scripts and tools developed at the University of Bergen (UiB). In particular, we have adopted established scripts from Scriptapedia [14] to facilitate the first model building workshop, in particular:

a. Graphs Over Time;
b. Variable Elicitation;
c. Initiating and Elaborating a Causal Loop Diagram;
d. Model Review.

Graphs Over Time and the Initial Variable Elicitation were carried out in the form of survey sent out to all project partners. The survey results were then analyzed and implemented into the interactive Miro whiteboard template for GMB developed at the UiB (see Fig. 2). This whiteboard with the initial causal structure identified through the survey was presented as a point of departure for the online workshop carried out with all the project participants. During the workshop we have focused on Model Review, identifying additional variables and causal relationships. The causal map was next used to develop the first outline of the system dynamics stock-and-flow model in Vensim[1].

4 Elicitation of the general causal structures

The initial elicitation of the general causal structures was carried out through a pre-workshop survey and an online modeling workshop. As a first step (May 2021), project experts took part in a survey. The goal of the questionnaire was to elucidate the problem scope for the GreenHeat project. Participants completed the qualitative questionnaires at their convenience and in their preferred form (electronic or paper version sent as a scan). Input was based on participants' expert knowledge and professional experience.

[1] https://vensim.com/download/

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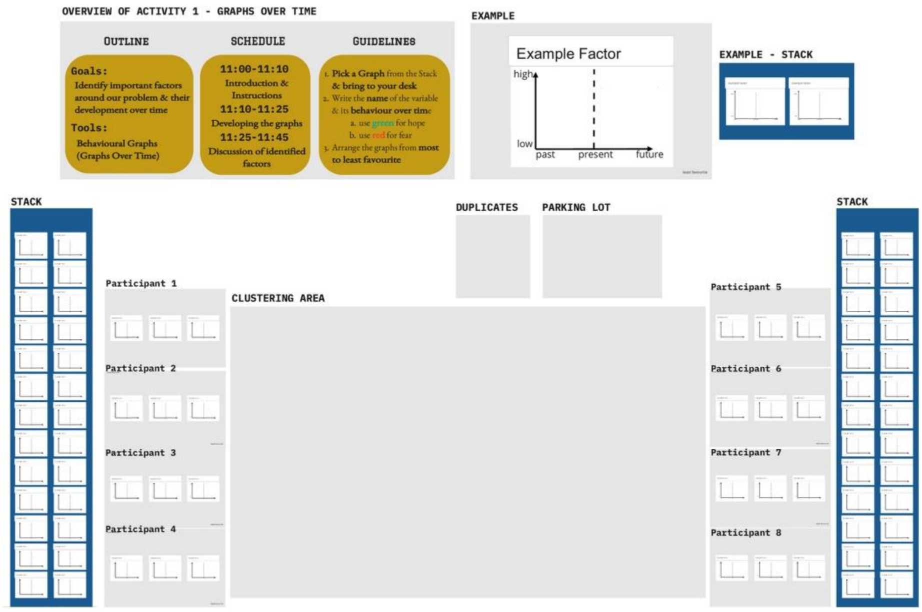

Fig. 1. Template for GMB developed at the UiB [15].

We received 11 completed questionnaires. The results of the survey were used to set the initial problem boundary, key system variables and relationships. As part of the preparation of the materials for the workshop, we analyzed the data from the questionnaires and transferred it to the Miro platform template in a structured form. Figure 2 shows a sample data from questionnaires completed by representatives of one of the partner institutions.

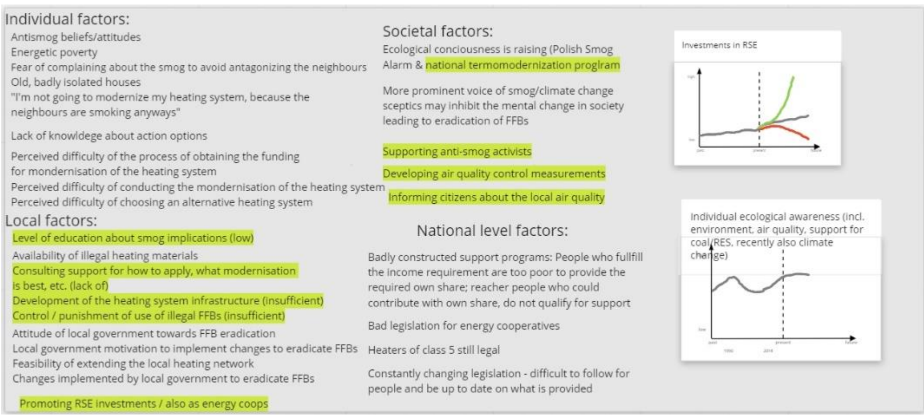

Fig. 2. Sample data from representatives of one of the partner institutions.

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Based on the survey responses, we identified around 100 factors, which were grouped into three operable levels:

The first, individual level included factors like: attitudes that deny the existence/harmfulness/scale of the smog problem; poverty, including energy poverty; old, houses, lacking effective thermo-insulation – very expensive to renovate and that cannot be connected to the district heating network; attitude, peoples' mentality, the thinking that "changing just my household does not change anything if others don't change" or "I won't change the stove until my neighbor does, because it will still smoke"; unfamiliarity with the possibilities of action, feeling overwhelmed by the whole process of obtaining financing, choosing a stove, carrying out thermo-modernization; environmental awareness; capacities; the cost of heat generation; equipment cost; maintenance cost; equipment failure rate and lifetime; applicability of the RES technology (heat pumps) in a certain area with a certain climate zone; culture factor, it is the way it has always been done; education level (knowledge on the environmental and health impact); reluctance of residents regarding potentially extensive renovations in their home.

The second, local level included following factors: lack of education about the dangers of smog; illegal coal dusts and pellets are still available; lack of advice on funding opportunities, assistance in furnace selection and thermo-modernization; insufficient expansion of district heating networks; insufficient control; insufficient availability of infrastructure; conflicting interests of key institutions; insufficient availability of market offer/services; load of heat pumps on the power network; economic factor, it is expensive to move to other heating technology; fear to resistance from industry; fear to resistance from the voters.

The third, national level included following factors: challenges with the national 'Clean Air' program - poorer people cannot afford to contribute their own money, from which they will later receive a return, and those who can, are already beyond the income threshold and are not eligible for subsidies; incorrect law on the establishment of energy cooperatives; 5th class solid fuel stoves still legal; changing regulations - people do not know what to invest in, whether the rules will not change in a few years; lack of political, long-term support for transition; prioritization of the change in the municipal policies; insufficient access to nationally distributed funds; load of heat pumps on the power grid; strong conviction that carbon is part of the Poland economy.

Based on the variables identified during the questionnaires and the reviewed literature, we have outlined the implied causal relationships into a preliminary causal loop diagram. The causal model with a description has been posted on the Miro platform and used as a basis for the model review at the time of the planned online workshop (see Fig. 3).

The online workshop was held on 21/05/2021 via the Teams application and the Miro platform. During the first session, workshop participants consulted and updated the diagram. It helped the research project team members to establish a common understanding of the problem. 14 people participated in the workshop. The first part of the workshop took two hours. As an introduction to the workshop, a presentation was made explaining SD basics on practical example, as interaction of two types of feed-

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back loops. Next the Icebreaker for participants who had not worked with Miro was provided. Then, participants were divided into two working groups, gathering representatives from each partner in each group. The model and the proposed causal relationships and loops were reviewed and discussed. The work resulted in an updated map with added structures, which we discuss briefly in turn.

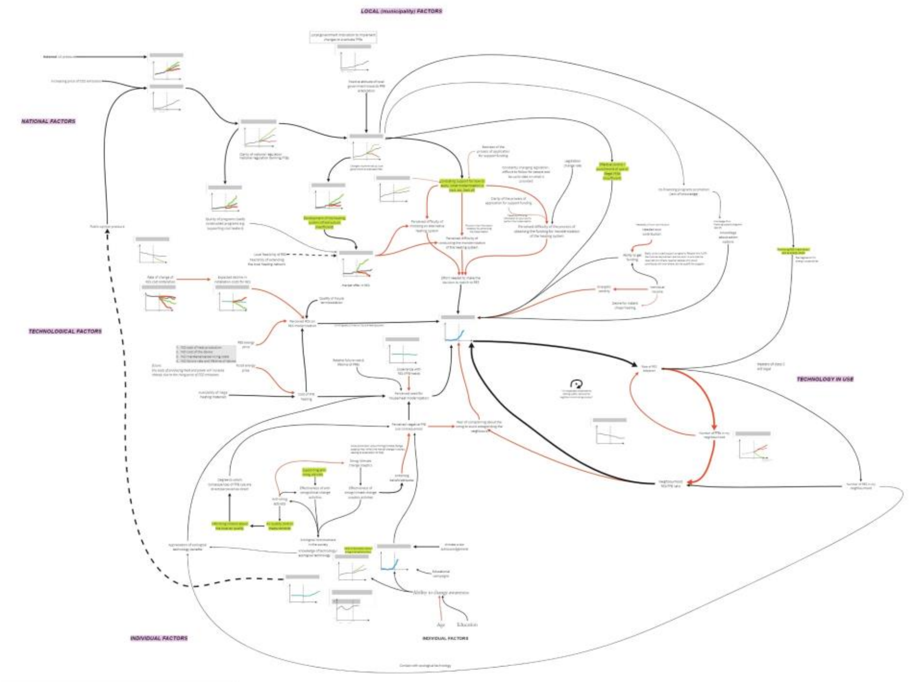

Fig. 3. Causal map based on survey and reviewed literature results.

The first group's discussion was focused on variables centered around the Word-of-mouth effect and the Expected return on investment structures.

The Word-of-mouth effect (see Fig. 4) reflects the impact of the information provided by current users of renewable energy-based systems. Very often users' knowledge can be based largely on conversations with neighbors, co-workers. If there are more satisfied users, with a pool of positive experiences, they will be a source of practical information on the process of installation replacement, system operation, will increase trust in energy innovation. The shaping of environmental awareness through social networks is shown by the phenomenon of the so-called social diffusion mechanism of innovation - the higher the density of PV panels in a neighborhood, the more likely more will appear. But if there are disgruntled users or people deliberately discouraging people from moving away from coal, their opinions will cause new investments to be abandoned, especially among those who are hesitant.

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The Expected return on investment (see Fig. 5) is strongly associated with installation costs. The design, complexity, and promotion of subsidy programs affect how the projected benefits of replacement are calculated. The cost of installation and the potential payback is important especially for the poorest, reducing investment costs can be done at the expense of fixed costs, through a credit system.

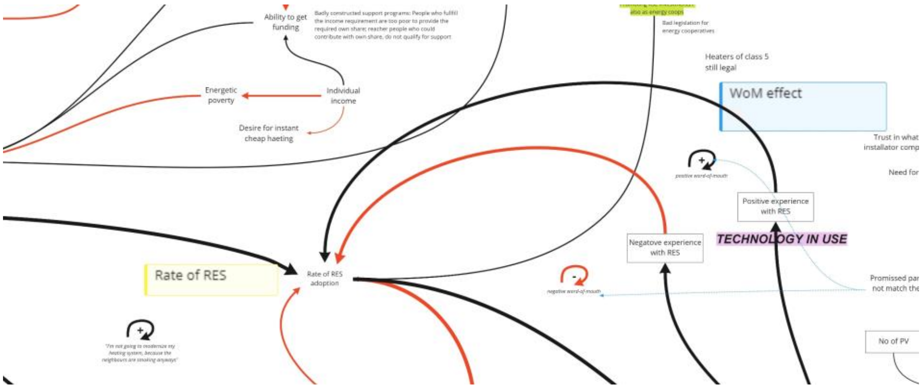

Fig. 4. Added Word-of-mouth effect structure.

Investment costs may remain at an all-time high due to the emergence of technological innovations that will become more and more expensive. Users will be concerned about investing in currently expensive technology that in 10 years may no longer be considered green and therefore economically supported, e.g. by relevant law regulations.

On the other hand, if the cost of installation drops too quickly, people will postpone the decision to replace the installation because it will pay of better in the future. This complicates the calculation of return on investment. In addition, the return on investment may remain unclear because of uncertainty about the costs of various resources and because of uncertainty about long-term regulation.

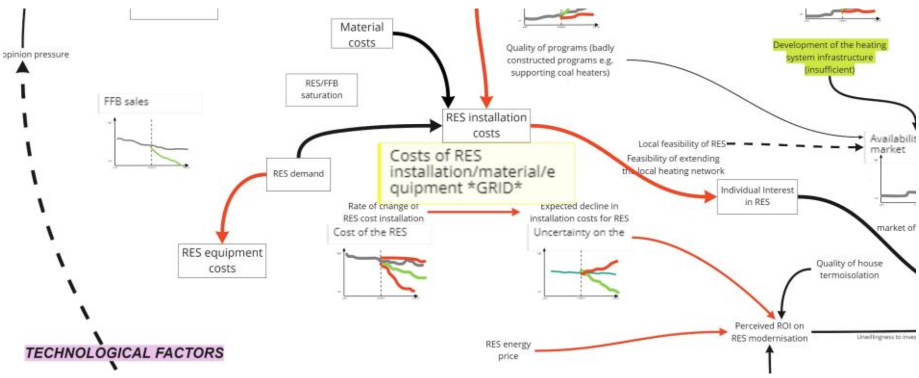

Fig. 5. Expected return on investment effect structure.

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The second group's discussion was focused on variables centered around the Willingness to change the heating system effect.

The Willingness to change the heating system (see Fig. 6) is linked to understanding what renewable energy system is. Consumers do not know or acknowledge the effects of coal-fired boilers. Mainly because these effects are not direct. Users want the cheapest possible heating here and now without considering the possibility of investment. If energy policies provide people with access to tools that make it easier to replace non-environmental installations, but people's awareness is at an insufficient level, they will not want or know how to make this change. Useful information is insufficiently promoted and most recipients have no practical knowledge about transition process.

Participants of the workshop said that consumers do not know about subsidy programs. Grant programs are too complicated and confusing for individual recipients. Moreover, they usually do not provide information on who and what companies can perform the services and the recipients are forced to look for this information themselves. The programs are also poorly structured, for example, they subsidize new fossil fueled boilers, so they lead to the beginning of the problem.

On the other hand the willingness to change depends on many individual factors as for example ecological consciousness. Participants of the workshop noticed that recipients often do not have technical knowledge, do not know the principles of green technologies, do not have contact with such technologies, so they do not see their advantages. The less knowledge will lead to greater resistance to unfamiliar technological innovations. Other voices stressed that there is also a risk of polarizing public opinion by the actions of anti-climate populists who spread theses about the lie about the harmfulness of coal and smog, invented by the EU and RES producers.

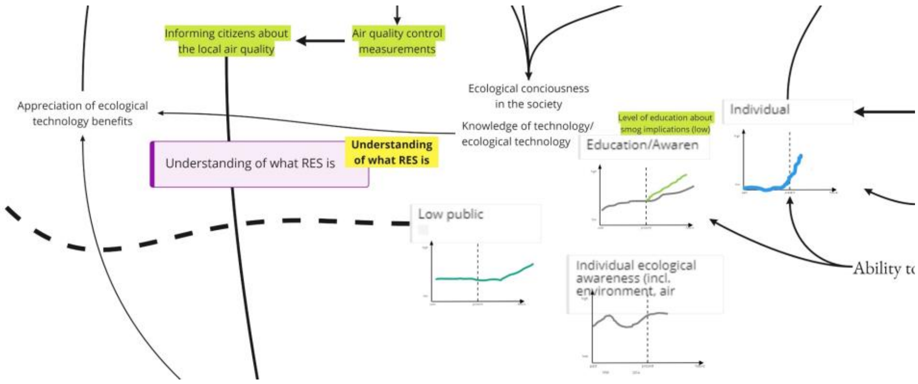

Fig. 6. Willingness to change effect structure.

The second part of the workshop took next two hours, during this time all participants worked as one group. During the discussion, the problem of creating energy storages, which on the one hand is an important element of the installation strengthening its efficiency and reliability, but on the other hand is costly, was strongly emphasized. The aim of the second part of the workshop was the further exploration of casual loop diagrams and identification of data sources needed for future analyses.

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5 Outline of the initial causal structures with discussion

Based on the causal model, we have started to develop a structure for the simulation, stock-and-flow model. The overview of its initial structure is presented in Figure 7. In this section we describe one of the parts that seems to be critical for sustainable local adoption of any renewable energy system that involves solar energy generation systems. This structure – highlighted in green – has been labeled the Death Spiral in the research report on the impact of individual solar energy systems in Australia [13].

The Death Spiral process is underlined by the reinforcing feedback mechanism triggered by the increasing number of individual households with solar energy systems (PV-systems). The more solar energy is produced by the individual households, the less demand for the traditional network energy, hence an increase in the unit network energy prices, leading in turn in even more interest and adoption of solar systems. Consequently, if uninterrupted, the process would inevitably lead to eradication of the traditional energy network providers, hence the "Death Spiral" label. Still, such an elimination of the traditional energy providers would require that individual household energy systems would be able to export or store the excess energy that is produced during daytime with much sun and relatively low energy demand.

The Death Spiral report indicates that the individual solar energy produ ction systems need to be accompanied by the appropriate storage capacity. Otherwise, their economic value would be dramatically depleted as the excess energy will be lost, instead of being stored or exported for use in the periods of low/none energy production. The importance of energy storage systems has been fagged also by the GreenHeat project partners during the workshop discussions. In Poland there has been already cases of unsuccessful PV-systems installations on the community basis, where the excess energy produced by the PV-systems installed in individual households led to exceeding voltage levels in the network. Consequently, the PV-systems could not be used [16].

Given that the GreenHeat project's objective is to eliminate the fossil fuel boilers at large, leading to installation HP/PV systems, it is important to be conscious of the side effects likely to occur when solar energy systems are deployed in a large number of households and to develop effective policies/interventions that would counteract such unintended, negative consequences of the change to the green sources of energy.

6 Conclusions and Future Works

In our study, we focused on the following research questions:

Q1: Can GMB support the process of modelling complex systems carried out in social isolation?

Q2: Can the GMB be an effective tool to raise awareness and increase the knowledge of residents about the energy transition?

Q3: How a SDM with GMB component can enhance a pro-environmental decision making process?

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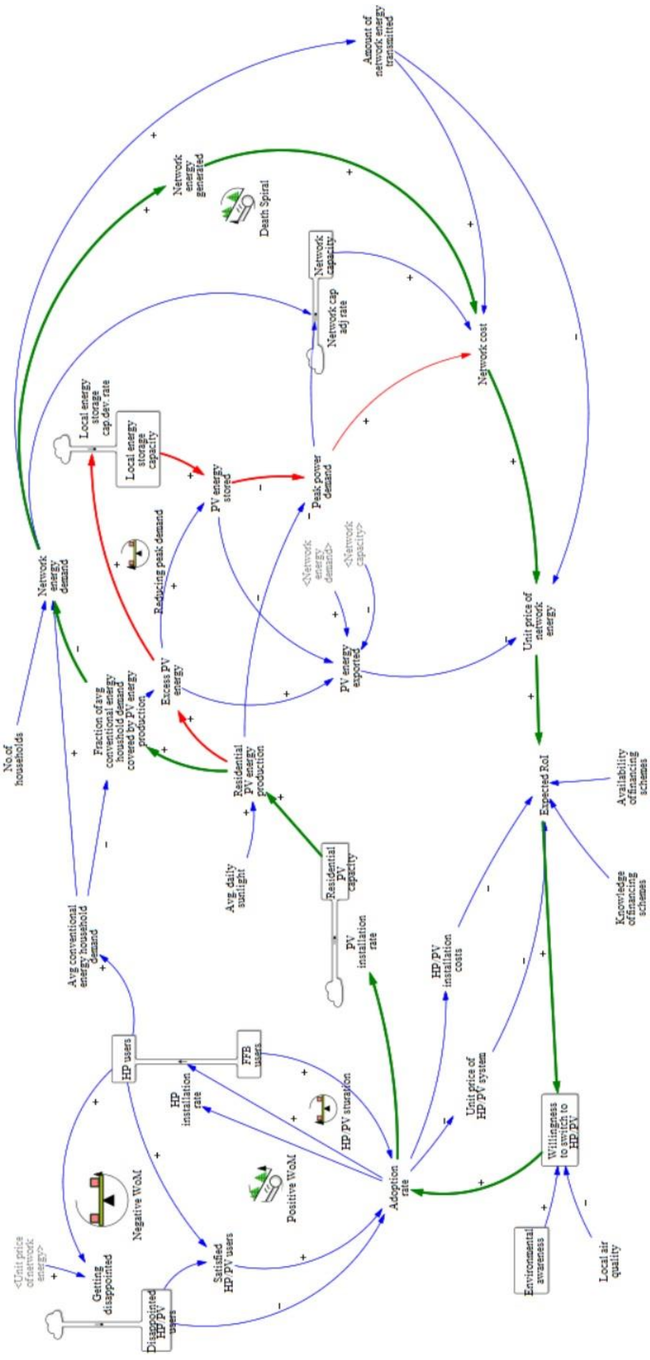

Fig. 7. The Death Spiral and the impact of local storage capacity on effectiveness of the PV systems.

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Referring to the first research question, based on our experience we believe that GMB to support the development of models may be carried out successfully even remotely. Despite holding the workshops during social isolation, the modelling approach proved to be an effective facilitation tool for a key element of the modelling process in the SD methodology - the collection of input data for model building. The online format provided also an additional advantage of making it easier to gather experts from distant places, also from abroad, as the workshop was attended by experts from Poland and Norway, residents of different cities. On the other hand, we note that the views of the experts involved in our project have been rather similar. In case of groups with more diverse participants, with substantially different opinions or backgrounds, the remote format may show to be more challenging and less efficient.

Referring to the second research question, at the moment we can conclude that the GMB shows indeed to be an effective tool to communicate the problem understanding across the expertise domains, and in that way helps to increase awareness of other possible aspects of the problem. The causal model helps to explicitly show the problem from different interdisciplinary perspectives. Joint discussions, especially when exploring the relationships between the drivers of the energy transition process, allowed for new insights, helping to develop a more holistic understanding of the problem. The workshop also allowed for the expansion and verification of the existing knowledge of those directly involved in SD modelling. In the next phases of the project, we will use the model to facilitate the discussions with the citizens and community decision-makers.

Referring to the third research question, we can see that the GMB exercise helped the project participants to reach a better and common understanding of the multiplicity of factors likely to influence the decision making process. In the next phases of the project, we will use the model as a tool to involve people who are to be directly involved in the energy transition process.

The current, more theoretical phase of the project is concluded. We will now turn to investigate in more detail the particular case of Legionowo. These investigations will allow us to develop the model that addresses the specifics of Legionowo community. Drawing on the findings of concurrent project work packages concerning viable technical solutions, present social structure of the pilot site, or feasible financial mechanisms, we will include and calibrate the factors likely to shape the willingness to switch to HP/PV system, as well as the factors likely to fuel both the positive and negative word-of-mouth processes. Structures governing the network energy demand and supply will be elaborated. Once the structures are refined, we initial simulation-based explorations will be conducted.

The novelty and originality of the study lies in the application of a proven tool such as system dynamics modelling to research for sustainable development, in particular to support local energy transition policies involving the elimination of fossil fuel boilers and replacement with renewable energy sources. To the best of our knowledge, few such studies are being conducted. Although the tool is tested in a specific city located in Poland, its universality allows for easy transfer to any city in the world.

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