

D8.7 – REWARDHeat Serious Game: general aspects and guide for administrators.



Renewable and Waste Heat Recovery for Competitive District Heating and Cooling Networks

REWARDHeat



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1 Introduction

EU Horizon 2020 project “REWARDHeat” aims at the demonstration of how to make a transition to a new generation of low-temperature district heating and cooling and effectively utilize low-potential waste heat for that purpose. REWARDHeat Serious Game is a part of the project, which focuses on dissemination and educational aspects of the transition.

REWARDHeat Serious Game is a web-based game (<http://rewardheat-game.hawk.de/>) which allows players to learn about the heating sector and how a transition to a more sustainable model of district heating might work. The players take up different roles, each with its own goals and gameplay. In a simulated virtual gaming environment, players are supposed to explore interdependencies between key technical, economic, ecological and sociopolitical aspects as well as among stakeholders (producers, consumers, government) and develop strategies for a successful transformation of the heat supply system of a fictional town to a sustainable low-temperature district heating (LTDH) system.

This report includes the objectives, the basic description of the game, and the guide for administrators with links to additional game-related documents and tutorials.

1.1 Objectives

The objectives of the game are defined as following:

- to simulate and show the interaction between different stakeholders in heating sector of a fictional town;
- to simulate and show how existing fossil fuel-based heating systems can be transformed to the “green”, sustainable ones, e.g. from the existing high-temperature district heating to the new kinds of low-temperature district heating [1,2] which are characterized by significant reduction of the temperatures in the network and wide utilization of renewable energy sources;
- to increase knowledge and raise awareness of students, engineers, involved citizens, building owners, investors, local authorities, decision-makers and all stakeholders and individuals who are interested in sustainable development of both technical, economic, ecological and sociopolitical aspects related to the heating sector and potential advantages of low-temperature district heating.

2 REWARDHeat Serious Game

2.1 Gameplay

The following sections present and describe the initial conditions, roles and main tasks in the game.

2.1.1 Initial conditions

The events of the game take place in a fictional town with no renewables utilized and a small share of district heating in the beginning. The town is divided into nine districts, each of them is further divided into nine subdistricts. Table 1 displays the initial conditions before the first round of the game. As the game progresses, the conditions for the next rounds are changed. The map of the town in the beginning of the game is shown in Figure 1.

Table 1. Initial conditions before the first round.

Population [mln people]	Fossil fuel share [%]	Number of CHP plants [-]	District heating [-]	Share of demand covered by		
				Gas CHP plants [%]	Individual gas boilers [%]	Players in round 1 [%]
0.1-0.2	100	2	High-temperature	15	50	35

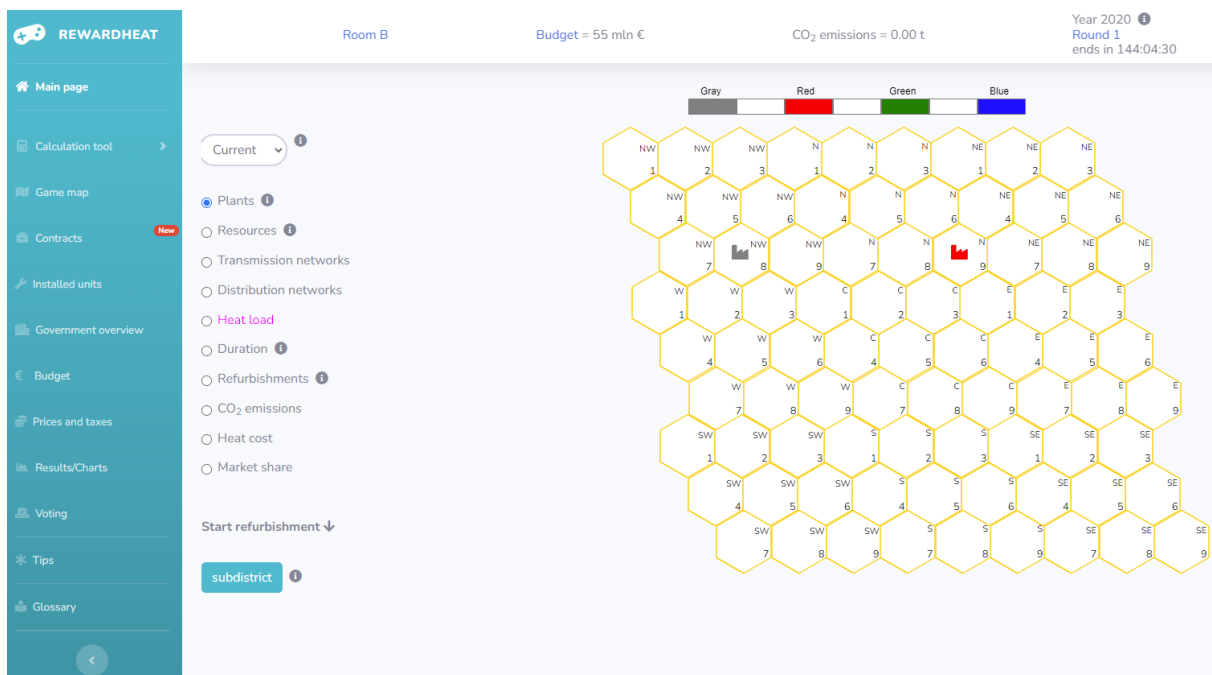


Figure 1. The map of the town in the beginning of the game.

2.1.2 Roles

The Game includes three different roles for players, each of them corresponding to different individual goals (Table 2). Table 3 shows the distribution of the roles among players depending on the total number of players. When there are more than 4 producers, they will play in teams (2

producer-players per company) because only 4 companies are present on the heating market of the game.

The role of the Government implies an autonomous local-level administration. It is responsible for subsidies, taxation and allocating money to different sectors of the local economy. The other players rate the performance of the government based on both energy and non-energy policies it pursues. Thus, the government should pay attention to its approval rating to stay in power.

Half of producers in the Game are long-established heat supply companies which already have plants and networks, and the other half are newcomers who have to establish themselves on the market and construct their plants and networks from scratch.

Since the consumer-player role represents not one household or one industrial enterprise but the whole district with numerous consumers, it would be more correct to use the term “consumers’ union representative” or “district manager”. For the sake of simplicity, just “Consumer” is used for defining such players.

Although the role of investor is not included in the game, players can get loans from an abstract bank controlled by an algorithm. Therefore, there are three options for money-related operations: to pay from one’s own account, to get a loan, and to request for a government’s subsidy before paying.

Table 2. Roles and goals of players in the game.

Role	Number of players	Goal
Government	1	CO ₂ emissions reduction
		High approval rating
Producers	from 3 to 8 (3-4 companies)	Profit growth
		Share of the market
Consumers	from 6 to 9	Low heating costs
		Sustainable and reliable heating supply

Table 3. Distribution of roles in the game depending on the number of players.

Players	Number of		
	Consumers	Producers (companies)	Government
10	6	3 (3)	1
11	6	4 (4)	1
12	7	4 (4)	1
13	6	6 (3)	1
14	7	6 (3)	1
15	8	6 (3)	1
16	9	6 (3)	1
17	8	8 (4)	1
18	9	8 (4)	1

2.1.3 Main tasks and activities

The Game covers a period of 25 years. It consists of 5 rounds each representing a 5-year period, and the following sequence of actions takes place within each round:

- initial conditions and random events (gas and oil prices fluctuations, political and economic instabilities, natural disasters, global pandemics and so on) set up boundary conditions for a round;
- producers and consumers identify the subdistricts where heat is needed; producers additionally pay attention to the existing plants and networks and think of how they can be utilized; the government uses the government tool to plan how to spend budget money and identifies its sociopolitical priorities;
- producers and consumers use calculation tools (simplified algorithms on annual basis) to estimate levelized cost of heat (LCOH) and CO₂ emissions for different heat supply options (decentralized, centralized, fossil fuels, renewable energy sources from Table 4); the government considers subsidizing projects of producers and consumers;
- interaction between the government, producers and consumers;
- decision-making phase;
- assessing economic and ecological results of a round and rating the government.

Table 4. Available heat supply options in the game.

Individual heating			District heating				
gas boiler	biomass boiler	ground source heat pump	gas CHP plant	biomass CHP plant	deep geothermal energy plant	large-scale heat pump	solar thermal plant

The decision-making phase comprises several tasks for different roles:

- the government should decide which sectors of economy to allocate budget money to and which projects of producers and consumers to support financially (subsidies);
- producers should decide which consumers to send offers and whether to use their existent plants and networks or to build new facilities (it especially comes into question when the lifetime of old plants and networks comes to an end); if so, which plant to build (Table 4) and where;
- consumers should decide whether to sign a heat supply contract with a producer and connect to its network (for the period of one round) or to install their local heat supply sources taking into account the lifetime of equipment. The decision of whether to renovate the building stock is also required from consumers.

2.2 Transition to LTDH

One of the goals of the game is to show challenges and complexity of the transition from the high-temperature district heating to the low-temperature one. One of the challenges is the complexity of the heating sector and interconnections between different technical, economic, ecological and sociopolitical aspects as well as between stakeholders, each of whom might have different objectives and motivations (Figure 2).

The government is supposed to be the main driving force of the transition and should create incentives for producers and consumers to implement necessary measures for the transformation. One of such measures and prerequisites for the consumers is to do refurbishment of buildings in their subdistricts in order to reduce the heat demand. Several types of refurbishment are available in the game. Meanwhile, in order to make the transition happen, producers should focus on adopting renewable energy sources.

However, it is up to players to elaborate an effective playing strategy according to their goals and the market situation, but also to decide which decisions to make. Eventually, players' decisions as well as their responses to random events shape the course of the game. It might happen that no DH transformation takes place during the game, or the game ends with a transitional state, or really poor development paths are chosen by players. Thus, the game is supposed to just give them an opportunity to experience and to lead the transformation, which might, in turn, affect the real world through the players' higher awareness, understanding, acceptance and involvement into the transformation of real-world district heating systems.

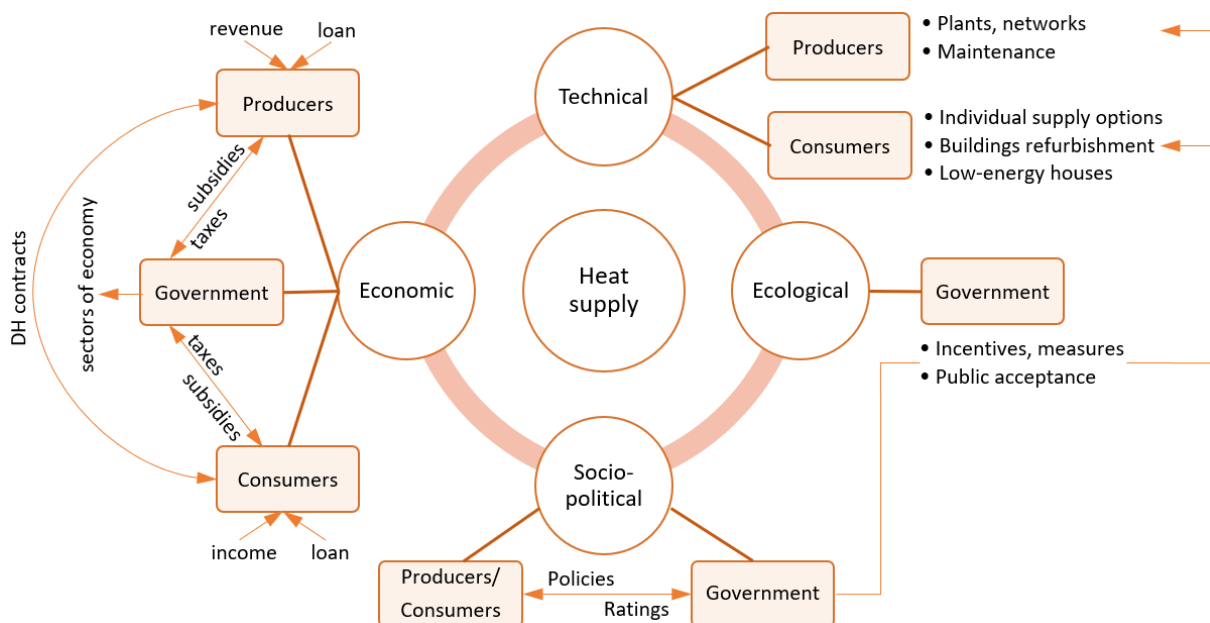


Figure 2. Model of the heating sector in the game focusing on technical, economic, ecological and sociopolitical aspects and showing the interaction between stakeholders in each aspect [3].

2.3 Tools in the game

The game includes simplified tools for all three roles in order to help players make decisions and influence the game. Short descriptions of them are presented in the following sections. The technical and economic data for the consumers' and producers' tools were taken from the Danish technology catalogue [4].

2.3.1 The consumers' tool

The calculation tool for consumers allows them to calculate levelized cost of heat (LCOH) and CO₂ emissions of local individual heat supply units (Table 4) that they can potentially install in the game. They should also request heat supply offers from producers, make comparison with individual options, and choose the best heat supply solution for a subdistrict. If a consumer cannot install a

local heat supply source or conclude a contract with a producer, the uncovered heat demand will be automatically covered with 10 % higher tariffs than the highest tariff in the current round.

The calculation tool for consumers include the following formulas for estimating CO₂ emissions:

$$B_{gas} = \frac{3600 \cdot Q_{out}}{LHV_{gas} \cdot \eta_{boil}^{av}} \quad (1)$$

$$E_{hp} = \frac{Q_{out}}{\eta_{hp}^{av}} \quad (2)$$

$$V_{co2}^{boil} = LHV_{gas} \cdot B_{gas} \cdot v_{co2}^{gas} \cdot 10^{-6} \quad (3)$$

$$V_{co2}^{hp} = E_{hp} \cdot v_{co2}^{el} \cdot 3.6 \cdot 10^{-3} \quad (4)$$

where B_{gas} - annual natural gas consumption, [m³/a]; Q_{out} - annual heat output, [MWh_{th}/a]; LHV_{gas} - lower heating value of natural gas, [MJ/m³]; η_{boil}^{av} - average annual coefficient of performance of boiler, [-]; E_{hp} - annual electricity consumption, [MWh_{el}/a]; η_{hp}^{av} - average annual coefficient of performance of heat pump, [-]; V_{co2}^{boil} - annual CO₂ emissions by boilers, [t/a]; v_{co2}^{gas} - specific CO₂ emissions (gas), [t/T]; V_{co2}^{hp} - annual CO₂ emissions by heat pumps, [t/a]; v_{co2}^{el} - specific CO₂ emissions (electricity mix), [t/T].

And the formulas (5) - (9) are used for defining levelized cost of heat:

$$OPEX_{fuel}^{boil} = B_{gas} \cdot C_{gas} \cdot 10^{-6} \quad (5)$$

$$OPEX_{fuel}^{hp} = E_{hp} \cdot C_{el} \cdot 10^{-6} \quad (6)$$

$$OPEX_{co2} = V_{co2} \cdot C_{co2} \cdot 10^{-6} \quad (7)$$

$$CAPEX^{an} = CAPEX \cdot \frac{(1+r)^L \cdot r}{(1+r)^L - 1} \quad (8)$$

$$LCOH = \frac{CAPEX^{an} + OPEX_{fuel} + OPEX_{co2} + OPEX_{const} + OPEX_{var}}{Q_{out} \cdot 10^{-6}} \quad (9)$$

where $OPEX_{fuel}^{boil}$ - annual operational expenditures related to fuel for boilers, [mln €/a]; C_{gas} - natural gas price, [€/m³]; $OPEX_{fuel}^{hp}$ - annual operational expenditures related to electricity for heat pumps, [mln €/a]; C_{el} - electricity price, [€/MWh_{el}]; $OPEX_{co2}$ - annual operational expenditures caused by CO₂ tax, [mln €/a]; C_{co2} - CO₂ tax, [€/t]; $CAPEX^{an}$ - annualized capital expenditures on boilers or heat pumps, [mln €]; $CAPEX$ - capital expenditures on boilers or heat pumps, [mln €]; L - operation lifetime, [years]; r - discount rate, [-]; $LCOH$ - levelized cost of heat, [€/MWh_{th}]; $OPEX_{const}$ - constant (fixed) operational expenditures (administration, operational staff, payments for service agreements, network or system charges, property tax, and insurance), [mln €/a]; $OPEX_{var}$ - variable operational expenditures which include consumption of auxiliary materials (water, lubricants, fuel additives), treatment and disposal of residuals, spare parts and output related repair and maintenance [4].

In the Figure 3, the interface of the calculation tool for consumers can be seen. A consumer-player should choose a supplied subdistrict and a desirable type of individual heat supply source. Technical and economical characteristics of the subdistrict and the heat supply source appear in the same window in the tables below and are shown in Figure 3. After the input data is entered, the player should click the "Calculate" button, and the results appear in the same window below.

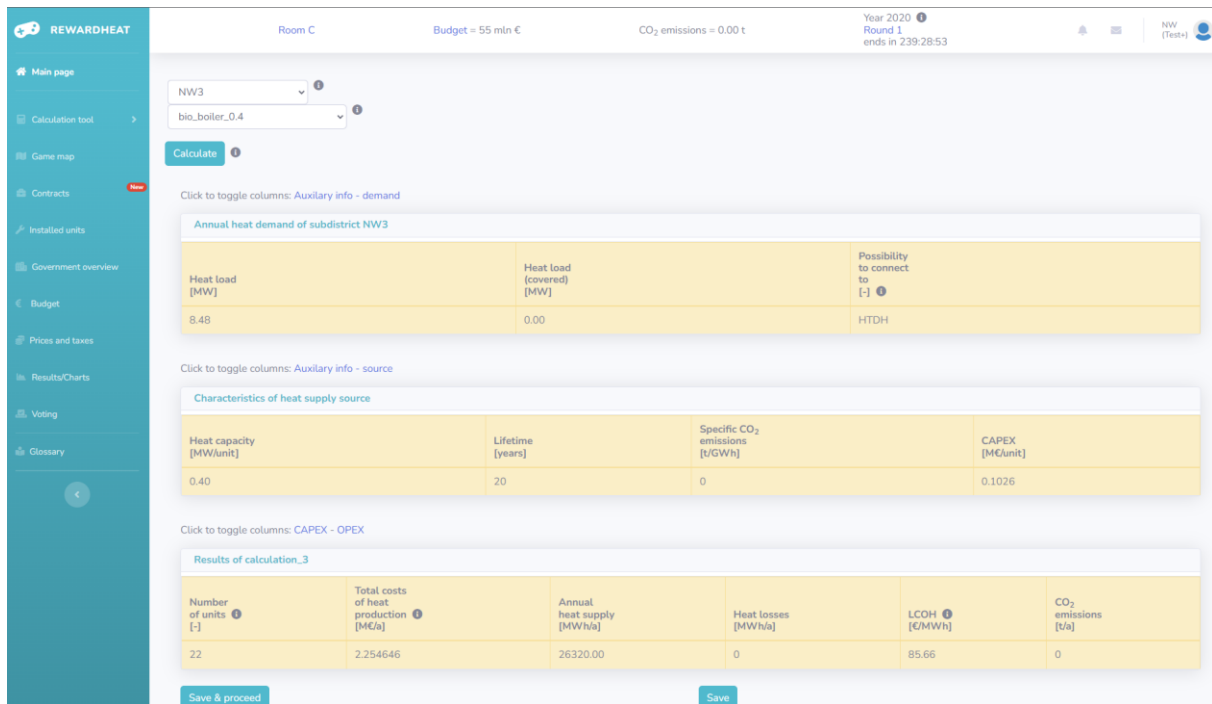


Figure 3. Interface of the consumers' tool. Input data and results of calculation.

2.3.2 The producers' tool

The calculation tool for producers is designed for calculating LCOH (and heat tariff, consequently) and CO₂ emissions from several available district heating (DH) supply options (Table 4). Other elements of the DH system (pipes of the network and heat substations) are also to be chosen by producers, so that the whole system operates correctly. In order to make the transition to LTDH network, some modernization and renovation are required from producers and, as already mentioned, from consumers as well. Producers should be interested in finding consumers so that plants operate at full load, the fixed operational costs are attributed to larger output, and the COPs of plants are higher.

Formulas (1) – (4) are correct for CHP plants and large-scale heat pumps, but the annual heat output additionally includes the heat losses in the network:

$$Q_{out} = Q_{req} + Q_{hl} \quad (10)$$

where Q_{req} – annual heat demand (required), [MWh_{th}/a]; Q_{hl} – annual heat losses in the network which are calculated as a fraction of Q_{req} , [MWh_{th}/a].

For economic calculations, formulas (5) – (8) are correct, but the prices of natural gas and electricity for non-households are applied [5], and additional costs related to the network and thermal energy storage (if needed) should be included:

$$CAPEX = CAPEX_{plant} + CAPEX_{net} + CAPEX_{subst} + CAPEX_{TES} \quad (11)$$

where $CAPEX_{plant}$ – capital expenditures on the plant, [mln €]; $CAPEX_{net}$ – capital expenditures on the network (transmission and distribution network), [mln €]; $CAPEX_{subst}$ – capital expenditures on the heat substations, [mln €]; $CAPEX_{TES}$ – capital expenditures on the thermal energy storage (considered only for solar thermal plants in the game), [mln €].

In formula (9), Q_{out} should be calculated taking into account the heat losses in the network, and operational expenditures related to the heat carrier pumping should also be added for the producers' tool, and then the formula for LCOH calculation will be as follows:

$$LCOH = \frac{CAPEX^{an} + OPEX_{fuel} + OPEX_{co2} + OPEX_{const} + OPEX_{var} + OPEX_{pump}}{Q_{out} \cdot 10^{-6}} \quad (12)$$

where $OPEX_{pump}$ – operational expenditures related to the heat carrier pumping, [mln €/a];

$$OPEX_{pump} = e_{pump} \cdot Q_{out} \cdot C_{el} \cdot 10^{-9} \quad (13)$$

where e_{pump} – specific electricity consumption for pumping, [kWh_{el}/MWh_{th}];

The value e_{pump} is assumed to be $5 \frac{kWh_{el}}{MWh_{th}}$ (basic value) if a heat supply source is located in the supplied subdistrict [6]. For adjacent subdistricts, the simplification is made that e_{pump} is increased by $0.5 \frac{kWh_{el}}{MWh_{th}}$ (correction value). And for distant subdistricts, the further they are from the heat supply source, the more times the correction value is added to the basic value.

LCOH considers only break-even point, therefore, in order to get profit, it is up to a producer to add a margin to LCOH and send it to consumer(s) as a heat tariff. After the round ends, OPEX are calculated again automatically to correspond to changed external conditions, and Q_{out} can be decreased depending on consumers, all of which leads to changes in LCOH. Then already connected consumers should receive a new tariff from the producer and decide whether they want to cancel the contract or prolong it.

For CHP calculations, one of the main questions is how to allocate capital and operational costs and CO₂ emissions resulted from the production of electric and heat energy at CHP. There is still no consonance on which approach among numerous ones to use [7]. Although power bonus method is widely used nowadays, it was shown in Ref. [8] that it is very sensitive to a change in operation parameters of a CHP plant. That is why it was decided to use the simplest method of allocation – energy method – even though it does not take into account the quality of energy. The allocation factor for heat production at CHP is calculated as following:

$$f_Q = \frac{Q_{out}}{Q_{out} + E_{out}} \quad (14)$$

where f_Q – allocation factor for heat production at CHP, [-]; Q_{out} – annual heat output, [MWh_{th}/a]; E_{out} – annual electricity output, [MWh_{el}/a].

When calculating LCOH and CO₂ emissions for heat production at CHP, the formulas (3) and (12) are correct if they are multiplied by the allocation factor f_Q .

Two other available options for producers are deep geothermal energy and solar energy. The above-stated formulas are, in general, correct for these cases as well. But there are some details to be clarified:

- in formulas (3) and (4), only CO₂ emissions during the manufacturing and construction of heat supply sources can be considered, but it is simplified and ignored in the game;
- in formula (12), $OPEX_{fuel}$ and $OPEX_{co2}$ are equal to zero;
- for solar energy, $CAPEX_{TES}$ is a necessary component in formula (11).

The interface of the calculation tool for producers is similar to the tool for consumers, except for some additional options related to the network available to producers. A producer-player should choose a supplied subdistrict(s), a desirable type of heat supply source, location for the plant, location for the network, a type of pipelines and substations. Technical and economic

characteristics of the chosen options appear in the same window in the tables below. After the input data is entered, the player should click the “Calculate” button, and the results appear in the same window below.

2.3.3 The government tool

The government role is a powerful role in the game because it can affect the boundary conditions of each round. In the government tool, different taxes and investments in different sectors of economy are available (Figure 4). The government can change fuel and CO₂ taxes, which affects its approval rating. Investments in different sectors (or lack of them) can simplify (or complicate) the achievement of the goals of producers and consumers. For example, if the government does not invest enough in public services, then the bureaucracy level in the town increases, which can halt the refurbishment works. If social acceptance is low, then local citizen initiatives can block the construction of geothermal and solar plants in the game.

Some sectors require investments in each round in order not to deteriorate (parameters marked with red bars), while other sectors stay stable even if no investments have been made.

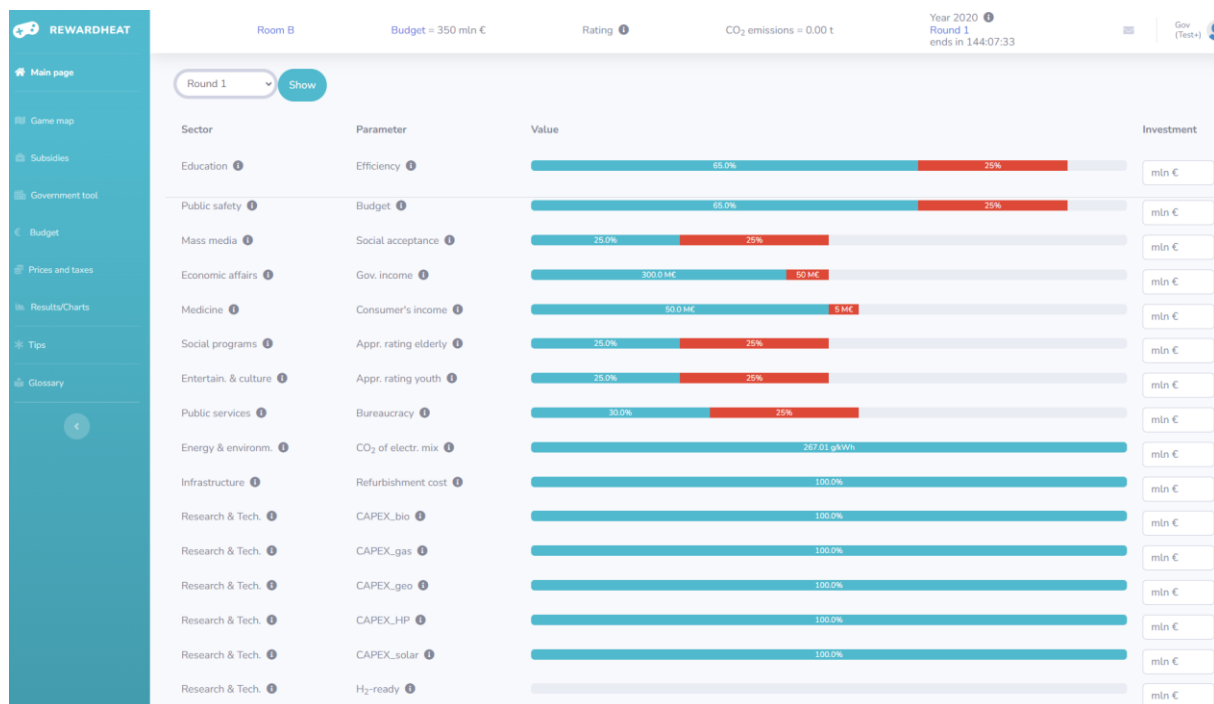


Figure 4. Interface of the government tool.

2.4 Results and winners in the game

As mentioned before, the final results of the game depend much on the players’ strategies and performance. Figure 5 shows an example of how the game map can look in the end of the game. Comparing it with Figure 1, one can see that more thermal plants appeared on the map built by different companies.

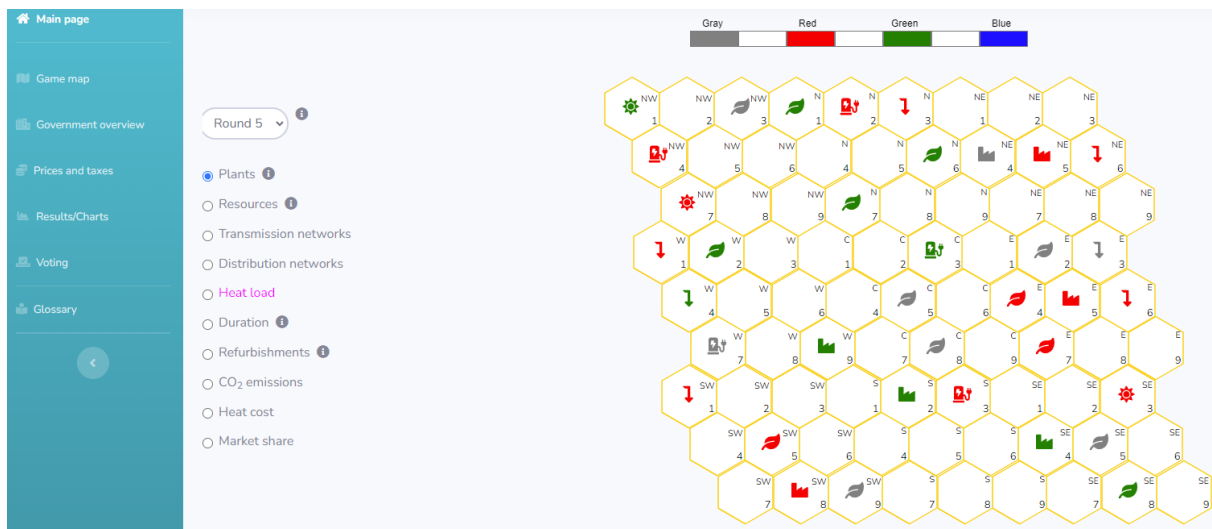


Figure 5. Example of the map after the end of the game.

The tab “Results/Charts” in the game shows the progress and changes from 2020 to 2045 of various parameters such as CO₂ emissions, budget, heat tariff, heat demand, share of resources in the heating sector and so on. An example of the final results is shown in Figure 6.

Winners in the game are defined separately among producers and consumers. Several categories are important for that: budget, specific or total CO₂ emissions, and total supplied heat (only for producers).

The highest possible point for each category is given to a player with the highest budget, the lowest CO₂ emissions and the highest amount of supplied heat (only for producers), respectively. Zero points for each category are given to a player with the lowest budget, the highest CO₂ emissions and lowest amount of supplied heat (only for producers), respectively. The players who get values between the minimum and maximum in each categories receive proportional amount of points.

E.g. in the end of the game, player A has a budget of 100 mln €, player B has 50 mln €, player C has 90 mln €. In this case, player A gets 100 points (if 100 is the highest possible score) for 'Budget' category, player B gets 0 point, player C gets 80 points.

Winners among producers and consumers are defined by the highest total score after the fifth round.

The government wins if complete decarbonization of the town by the end of the game is accomplished and the approval rating after the end of each round is at least 50%.

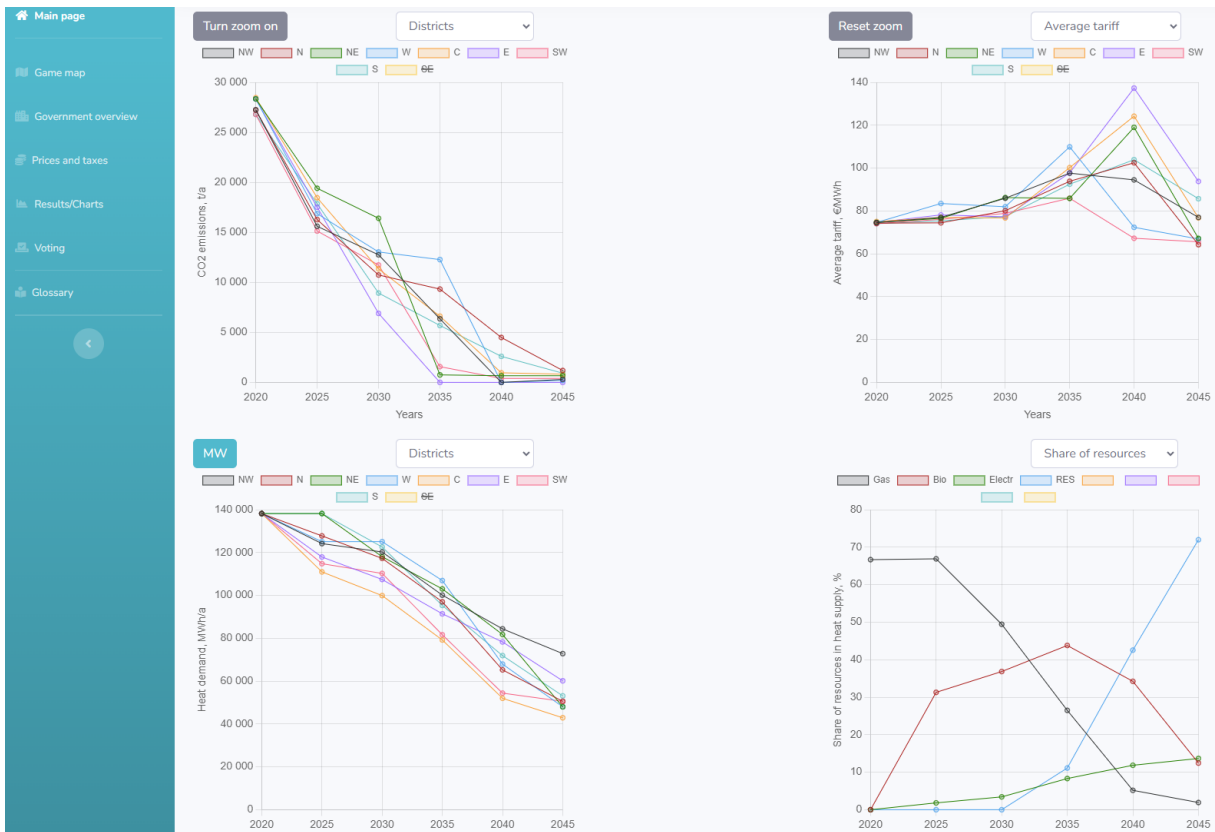


Figure 6. Example of possible results of the game.

3 Presentation and testing of the game

The game, its idea, main functions, features, and results of workshops have been presented at four conferences:

- 17th International Symposium on District Heating and Cooling (DHC) Nottingham, UK (08.09.2021) [3];
- 7th International Conference on Smart Energy Systems, Copenhagen, DK (22.09.2021);
- 17th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), Paphos, Cyprus (10.11.2022);
- 1. Konferenz zur Norddeutschen Wärmeforschung, Göttingen, Germany (09.06.2023).

One promotional video was created <https://www.youtube.com/watch?v=0SFei9tWsys>.

Multiple workshop sessions were organized internally for the students of the HAWK in Göttingen to test the game. Additionally, the game was tested with participants from external organizations during several workshops listed in Table 5.

Table 5. Game workshops held with external participants during the project time.

No	Date	City	Country	Event / Host	Target groups	Number of players	Version
1	14.06.2022	Helsingborg	Sweden	REWARDHeat GA	engineers, researchers	14	Short
2	26.08.2022	Göttingen	Germany	DHC+ Summer School	students, engineers, researchers	22	Long
3	17.01.2023	Nuremberg	Germany	Energie PLUS Concept GmbH	engineers, researchers	14	Short
4	01.03.2023	Gothenburg	Sweden	Göteborg Energi	city administration, utility company, researchers	15	Short
5	15.03.2023	Tallinn	Estonia	TalTech University	students	15	Long
6	04.04.2023	Aalborg	Denmark	Aalborg University	students	11	Long
7	10.05.2023	Topusko	Croatia	REWARDHeat GA	engineers, researchers	10	Short
8	25.08.2023	Tallinn	Estonia	DHC+ Summer School	students, engineers, researchers	35	Long
9	14.09.2023	Skanderborg	Denmark	Kamstrup	engineers, managers	32	Medium

4 Guide for administrators of REWARDHeat Serious Game

4.1 Before the game workshop

4.1.1 Prerequisites for playing

- One or two groups, each of 10 – 18 players (max. 36 players) with their own computers/laptops;
- One or two administrators per group;
- Browsers: Microsoft Edge, Google Chrome or Opera (**please avoid Mozilla Firefox and Safari**);
- If played in person, a room (or two rooms) with power supply, WiFi, large screen, projector (beamer), tables and chairs;
- Duration:
 - short version: 0.5 hours (home preparation) + 4.5 hours;
 - long version: 7-8 hours (one-day event).
 - Suggested schedules can be found via the link: <https://cloud.hawk.de/index.php/s/R6jiwjlm6MAyAd9>

4.1.2 Arrangement of tables

A photo of the desired arrangement of tables can be found via the link:

<https://cloud.hawk.de/index.php/s/mq25yM8gYcj7oio>

The players sit at tables in a rectangular arrangement, and there is a passage (or better two passages forming a cross) in the middle of the room to make it easier for players to come to each other and communicate. This would be the best arrangement or alternatively, a big round table can also be suitable.

4.1.3 Check power supply, WiFi and the equipment in the room[s]

Power supply (socket boards if needed), WiFi connection, and a beamer are important technical prerequisites for playing the game which should be checked before the workshop.

4.1.4 Passwords

The administrator should receive a .zip archive containing individual .txt files with passwords for each player (logins are the names of .txt files) and two Excel files with the summary of passwords and logins. The administrator can send the text files containing the corresponding passwords to each player via email. Alternatively, the passwords can be printed out and given to players before the workshop. For the latter option, open file 'Passwords.xls' and don't close it. Open the to-be-printed file called 'Passwords_to_print.xlsx'. Check that the data in 'Passwords_to_print.xlsx' is updated from 'Passwords.xls'. Then print the file 'Passwords_to_print.xlsx'.

4.1.5 Account for testing

The account with the login name "Test" allows the administrator to take any role in the game (Figure 7). Additionally, this account is used during the introduction (see 4.2.1). For unexperienced administrators, it is recommended to use "Test" account before the workshop in order to get acquainted with all the roles in the game and their functionalities. Combining "Test" and admin accounts (e.g. in different browsers), one can simulate the whole game to track decisions of different roles throughout the game and check how the game develops. **Be careful using "Test"**

account during the rounds of the actual game! All your actions (e.g. refurbishment, building a plant etc.) will be performed for actual players in the game. However, you may safely monitor the game map, the charts and the performance of the players during the actual game via "Test" account.

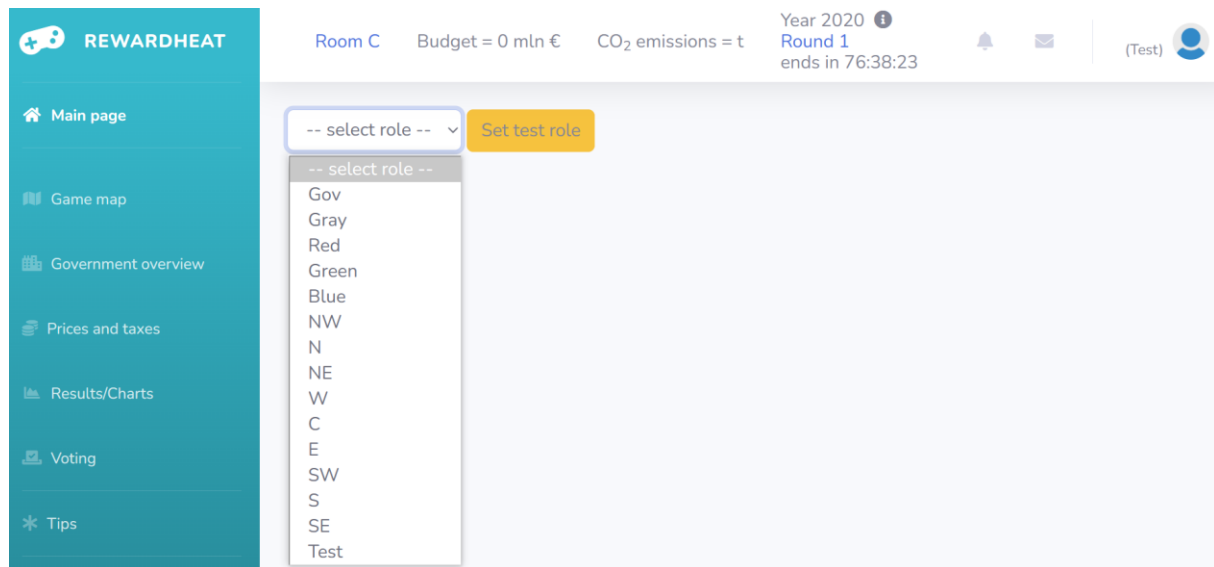


Figure 7. Main page of "Test" account with the possibility to choose any role in the game.

4.1.6 Ask players to prepare for the game if the short version is chosen

The preparation includes a presentation (with or without narration), a brief tutorial (the description of the player's role is enough), a video tutorial (the videos for the player's role + "General" are enough) and some tasks for corresponding roles (to log in the game and to try out its functions). Presumably, this can take 30-45 minutes in total. **Do not forget to send logins and password to players via email in advance.**

1. Simple presentation (17 slides):

<https://cloud.hawk.de/index.php/s/XGrm33jz3bj7J4N>

1. or narrated presentation (17 slides -> 9 minutes):

<https://cloud.hawk.de/index.php/s/CRZeSCbmjHXrtrm>

2. Brief tutorial (2 pages):

<https://cloud.hawk.de/index.php/s/7F5n4grYZrnCA8T>

3. Video tutorial:

<https://cloud.hawk.de/index.php/s/RRP9JQimFc5ex8K>

4. Tasks:

<https://cloud.hawk.de/index.php/s/2Kkbd3foxdLiw7w>

4.2 During the game workshop

4.2.1 General steps

1. Present the game: its purpose, roles of players and gameplay

(<https://cloud.hawk.de/index.php/s/XGrm33jz3bj7J4N>);

2. Show and explain the main functions and features via the "Test" account in the game

(<https://cloud.hawk.de/index.php/s/mke7nA3dqBDZ3La>);

3. Set the initial conditions in the game;
4. Launch an introduction round – **only for the long version**;
5. Set the initial conditions in the game (restart the game) – **only for the long version**;
6. Launch (the first) round;
7. Analyze the map and the charts for players after the round ends;
8. Ask the government to shortly present its results and launch voting after the round ends;
9. Change the government if the current one is voted out;
10. Show the table with projected winners in the game (header of the page -> Room A or B);
11. Repeat steps from 6) to 10) for the next round;
12. After the end of Round 5, conclude the results of the game, congratulate winners and ask for players' feedback.

4.2.2 Interface of the administrator's panel

The interface is shown in Figure 8. All buttons and corresponding functions are explained in the sections below.

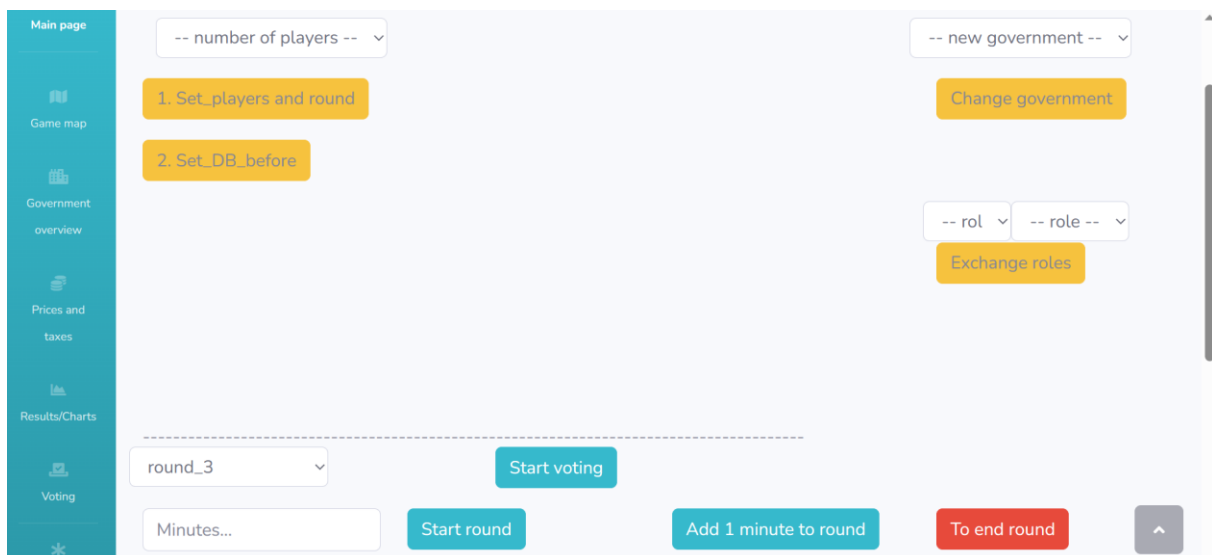


Figure 8. Interface of the administrator's panel.

4.2.3 Set the initial conditions in the game

In order to set the initial conditions, go to the main page of the administrator's account and then:

1. Select number of players;
2. Click button "Set_players and round";
3. Click button "Set_DB_before";
4. Click button "To calculate CHP_1" (this button appears after clicking the previous button);
5. Click button "To calculate CHP_2" (this button appears after clicking the previous button);
6. Click button "To calculate indiv. plants" (this button appears after clicking the previous one);

7. Click button "Set_DB_after" (this button appears after clicking the previous button). Please wait a bit longer after clicking this button until the script is executed.

4.2.4 Launch round

In order to launch the round, go to the main page of the administrator's account and then:

1. The round is selected automatically;
2. Input the amount of minutes in the field below the round (values from 20 to 60 are allowed);
3. Click button "Start round".

4.2.5 Launch voting

In order to launch voting, go to the main page of the administrator's account and then:

1. Click button "Start voting" (appears above the button "Start round" after the round ends);
2. Wait for players to vote;
3. Click button "End voting" to finish the voting (appears after "Start voting" is clicked) and click on the menu "Voting" (the panel on the left side) to see the results.

4.2.6 Change the government

During the voting, consumers can offer their candidacy to become the next governor in case the current one is voted out. When it happens, the administrator should exchange roles between the leaving government and the most successful candidate among consumers. A table with the points for all candidates will be shown if the government is voted out and there is at least one candidate.

In order to change the government, go to the main page of the administrator's account and then:

1. Select the login of the consumer from the list "new government";
2. Click button "Change government";
3. Both players will be logged out of the game;
4. They should log in again using their old passwords but new logins.

Please see the example in Table 6 and Table 7 below.

Table 6. Logins and passwords before changing the government.

Name of player	Login	Password
Dmitry	Gov	12345
Stefan	NW	abcde

Table 7. Logins and passwords after changing the government.

Name of player	Login	Password
Dmitry	NW	12345
Stefan	Gov	abcde

4.2.7 Auxiliary functions

- a) The administrator can exchange roles of any other players similar to the procedure described in 4.2.6. This may be helpful when the roles have been distributed before the workshop, and during the workshop some changes become necessary (e.g. some players not showing up). Please use two lists below the button “Change government”, and when the roles are selected, click button “Exchange roles”.
- b) The administrator can add one minute to the duration of the current round by clicking button “Add 1 minute to round”. There is no limitation on how many times the administrator can click this button.
- c) The administrator can end the current round prior to the scheduled time by clicking button “To end round”. This may be helpful to avoid waiting when all players have finished all their activities in the round earlier than scheduled. **Be careful with this function! The action is irrevocable.** There is no back up to restore the round after it had been ended.

4.2.8 Summary of important links

- Website of the game: <http://rewardheat-game.hawk.de/>
- Promotional video: <https://www.youtube.com/watch?v=0SFei9tWsysc>
- Schedules for the workshop: <https://cloud.hawk.de/index.php/s/R6jiwjJm6MAyAd9>
- Arrangement of tables: <https://cloud.hawk.de/index.php/s/mq25yM8gYcJ7oio>
- Simple presentation: <https://cloud.hawk.de/index.php/s/XGrm33jz3bj7J4N>
- Narrated presentation: <https://cloud.hawk.de/index.php/s/CRZeSCbmjHXrtrm>
- Presentation to introduce the main functions and features: <https://cloud.hawk.de/index.php/s/mke7nA3dqBDZ3La>
- Brief tutorial: <https://cloud.hawk.de/index.php/s/7F5n4grYZrnCA8T>
- Video tutorial: <https://cloud.hawk.de/index.php/s/RRP9JQimFc5ex8K>
- Tasks for the introduction round: <https://cloud.hawk.de/index.php/s/2Kkbd3foxdLiw7w>
- **Back-up folder with the files above (the last update on 05.09.23):** <https://cloud.hawk.de/index.php/s/RQFiYEgGBBRXH9M>

5 Appendix A. REWARDHeat Game – brief tutorial

Producer: Main Goal: Make profit and obtain the largest market share.

Tips:

- Send offers for heating supply to consumers;
- Apply for government subsidies;
- Build plants and networks;
- Use the map and charts to get an overview of the situation in the town;
- Vote in the end of each round;
- Red badges (alerts) notify you about events in the game; info badges give you more details.

Calculating district heating options:

- Use the calculation tool to find out which district heating options are the most advantageous. Select the type of plant, its location, as well as the network's reach and click "Calculate" (calculations can also be done on the map page);
- In the calculation tool, you can apply for a government subsidy, but you will have to wait until the Government approves your request before you can send the offer.

Setting up Contracts:

- After having calculations done, click "Save & proceed" to immediately make an offer. Alternatively, you can save your calculations using "Save and Quit" and then make the offer on the page "Saved".

Building plants and networks:

- Once the offer is accepted by the consumer, go to the "contracts" page;
- The plant is constructed by clicking the blue "?" in the "ID plant" column on the contracts page;
- Use the blue highlighted "build" button in the table to construct transmission and distribution networks.

Consumer: Main Goal: Supply your subdistricts with heat at the lowest price and do not neglect sustainability aspect.

Tips:

- Use the calculation tool to evaluate individual heating options;
- Compare individual heating options with the offers made by district heating companies (the producers);
- Refurbish your subdistricts to reduce their heat demand;
- Apply for government subsidies for refurbishment;
- Use the map and charts to get an overview of the situation in the town;
- Vote in the end of each round and offer your candidacy for the government office if not satisfied;
- Red badges (alerts) notify you about events in the game; info badges give you more details.

Individual Heating Options:

- After having finished calculating, you can either construct the selected heating option right away by clicking "Save & proceed" and then "Buy and Install" or you can choose to build the heating option later in the "Saved" page of your calculation tool (use the "ID Plant" Column on the "Saved" page).

Refurbishment:

- On the map, the button “subdistrict” under the list of layers can be used to invest in refurbishment options which will reduce the heat demand of the affected subdistricts. If bureaucracy level in the town is high, refurbishment can be halted.

Signing a Contract:

- To sign (or decline) a new contract simply click the “?” mark in the “signed” column and click “sign” (“decline”) in the pop-up window.

Government: Main Goal: decarbonize the heating sector in the town completely and stay in power.**Tips:**

- Allocate money to different sectors of economy;
- Pay attention to the sectors that degrade if no investments are made;
- Set some money aside to subsidize projects of other players;
- Set taxes in the town;
- Keep your approval rating in the end of each round higher than 50%;
- Red badges (alerts) notify you about events in the game; info badges give you more details.

Investments:

- Investing is done on the “Government Tool” page
 - Input the amount of money (in million €) into the white fields in the “Investment” bracket of the government tool. The value bar will shift to reflect the projected effect on the sector’s stability;
 - Keep an eye on your Budget at the top of your screen. If you are running low on money you can take a loan from the bank by clicking the blue “Budget” text in the header.
- Every sector of the economy affects the game in some way. The parameters affected are listed next to the sector’s name (e.g. Economic affairs affect the government player’s income)
 - It is recommended to invest first in “Education” (see the info badge on the page);
 - Public services affect “bureaucracy” parameter;
 - High public safety prevents bad events in the town;
- Players are automatically notified about the investments made.

Subsidies:

- You can access the information about the requested subsidies and projects on the “Subsidies” page;
- When accepting or declining a request you can leave a short message to the requesting player;
- Be quick to respond to the requests as the other players cannot finalize their projects until you have done so.

Taxes:

- Taxes can be set on the “Government Tool” page. Increasing taxes will cause a decrease of your final approval rating and vice versa.

6 Appendix B. REWARDHeat Game – video tutorial

The folder with the short videos explaining general functions and specific functions corresponding to different roles in the game can be accessed via the link:

<https://cloud.hawk.de/index.php/s/RRP9JQimFc5ex8K>

This tutorial can be used by players together with the access to the game before the workshop in order to get acquainted and be prepared for it. The tutorial can be particularly helpful when the short version is played, and there is not much time for introduction during the workshop.

7 References

- [1] Lund H, Werner S, Wiltshire R, Svendsen S, Thorsen JE, Hvelplund F, et al. 4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems. *Energy* 2014;68:1–11. <https://doi.org/10.1016/J.ENERGY.2014.02.089>.
- [2] Buffa S, Cozzini M, D'Antoni M, Baratieri M, Fedrizzi R. 5th generation district heating and cooling systems: A review of existing cases in Europe. *Renew Sustain Energy Rev* 2019;104:504–22. <https://doi.org/10.1016/j.rser.2018.12.059>.
- [3] Romanov D, Holler S. District heating systems modeling: A gamification approach. *Energy Reports* 2021;7:491–8. <https://doi.org/10.1016/J.EGYR.2021.08.078>.
- [4] Danish Energy Agency. Technology Data for Generation of Electricity and District Heating. *Technol Data Gener Electr Dist Heat* 2020:414.
- [5] The statistical office of the European Union 2020. <https://ec.europa.eu/eurostat> (accessed December 12, 2020).
- [6] International Energy Agency. District Heating. IEA-ETSAP Technology Brief E16. ETSAP - Energy Technol Syst Anal Program 2013:7.
- [7] Comparison of Energy System Using Life Cycle Assessment, a Special Report of the World Energy Council. 2004.
- [8] Tereshchenko T, Nord N. Uncertainty of the allocation factors of heat and electricity production of combined cycle power plant. *Appl Therm Eng* 2015;76:410–22. <https://doi.org/10.1016/j.applthermaleng.2014.11.019>.