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Comparison of Suitable Business Models for the 5th Generation District Heating System Implementation through Game Theory Approach

Ieva PAKERE[1]*, Marika KACARE[2], Lina MURAUSKAITE[3], Pei HUANG[4], Anna VOLKOVA[5]

[1,2]*Institute of Energy Systems and Environment, Riga Technical University, 12/1 Azenes iela, Riga, LV1048, Latvia*

[3]*Lithuanian Energy Institute, Breslaujos g. 3, Kaunas 44403, Lithuania*

[4]*Dalarna University, Högskolegatan 2, 791 31 Falun, Sweden*

[5]*Tallinn University of Technology, Ehitajate tee 5, 12616 Tallinn, Estonia*

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Abstract **– District Heating and Cooling (DHC) technology is widely recognised as a promising solution for reducing primary energy consumption and emissions. The 5th Generation District Heating and Cooling (5GDHC) network is the latest DHC concept characterised by low-temperature supply, bi-directional heating network operation, decentralised energy flows, and surplus heat sharing. Unlike the 4th Generation District Heating (4GDH) technology, the 5GDHC technology switched to a consumer/prosumer-oriented perspective. The introduction of 5GDHC solutions requires high investments, an important barrier to further developing DHC systems. Therefore, a novel pricing and business model could include introducing co-owners or energy managers into the system. Three different local market business models for 5GDHC at the community level have been tested. The reverse technical and economic simulation has been used for a feasibility study to determine the resources, business models, and combinations closest to the break-even point with lower costs and higher gains for all involved stakeholders.**

Keywords **– Business models; game theory; prosumers; 5th generation district heating.**

1. INTRODUCTION

The 5th generation district heating and cooling network (5GDHC) or ultra-low district heating is a novel solution based on thermal energy exchange between buildings of different needs using ultra-low temperature networks [1]. Distributed heat storage buffers fluctuate between heat and cold supply and demand and use heat pumps to increase the temperature to desired conditions [2]. Consumers, suppliers, and prosumers are interacting with each other through two pipe systems. It is a low-temperature, bi-directional, and decentralised solution [3]. Consumers are the heat and cold end-users, mostly residential buildings, and prosumers are the heat users that can recover the heat and transfer it to heating networks, for example, data centres and shopping malls. Each participant in the system needs an individual heat pump that is connected to the general network [4].

* Corresponding author.
E-mail address: Ieva.Pakere@rtu.lv

Small-scale 5GDHC is beneficial for the communities that are open to cooperation and aim for more independence from the larger-scale energy market. Albeit, changing the infrastructure and whole technological concept of district heating (DH) will lead to a situation when existing business models are not beneficial for most stakeholders anymore. In addition, these changes require investments that will most significantly exceed the financial possibilities of the community. While there are long-term benefits from primary energy reduction compared to traditional high-temperature DH, the actual likelihood that 5GDHC will be used depends on the economic justification of the transition. Good and up-to-date exploration of the possible business models that would create guidelines could facilitate the process of decision-making for the potential shareholders and motivate them to participate in such innovative initiatives. The business model concept here is based on the ownership of the technologies and the interactions of the main participants of the business network of the implemented 5GDHC.

Since the technology itself is not extensively used, there is a lack of data and detailed blueprints of how the scheme would work out in a particular scenario. Theoretical evaluation of the possible business models could encourage potential investors. The game theory elements might replace missing information regarding the market processes. Game theory is a field of study that applies mathematical models to estimate behaviours of the rational agents and predict their interactions. Rational agents are any participants in the system that can make decisions based on the available information. For instance, that could be a person, a company, or even a computer algorithm, especially if machine learning is implemented. It is widely used in business analytics to evaluate the market situation and choose the best strategy. It simulates real-life events through sequential games to predict the players' most possible and best actions [5].

Project management uses various tools in decision-making. Many are based on mathematical models such as investment analysis tools, force field analysis, the life cycle cost method, internal rate of return, prospect theory, Net Present Value method, Monte Carlo analysis, linear programming, queueing theory, etc. Whichever project management strategy is chosen, game theory would help choose the right action in every interaction with customers or partners. However, it focuses on the company's strategy as an individual player. Game theory is particularly useful when various players are going for the same outcome through competition or cooperation and can independently make decisions [6].

Game theory is valuable in business and project management. It implies that many interdependent factors are closely related; decisions cannot be isolated from other possible decisions the player or competitor might make [7], [8]. The Nash Equilibrium addresses non-cooperative games that involve strategic interactions between players where no one is reconsidering their decisions after hearing the decision of others. Even if that doesn't necessarily mean the best possible outcome, it is still the winning situation for all involved parties [9]. Use of necessities and infrastructure needed to cover the needs of the population, such as heating systems, the regulatory mechanisms are needed to ensure the best possible price and not settle to the situation where every participant, especially the customers, is losing. Often in business situations, to protect the interests of the end-users exploring the options and implementing the framework of regulations that would aim for the Pareto optimum is a responsibility of the legislators.

Project management practices must be implemented to estimate the business process and interconnections. External factors affecting the business, such as political, environmental, legal, technological, social, and economic, affect the dimensions of the business organisations and people, information and technology, partners, suppliers, value streams, and processes.

Altogether, those factors impact the products and services the business can offer the customers – the created value [10].

The business reacts to the opportunity and demand in society to create value – the positive outcome removes costs or risks for the client. The engagement with the consumer helps to plan and design the service improvements and deliver them to the customer, repeating the process iteratively. Various options are possible at each interaction with a customer or the service relationships with partners, meaning they can be affected by other players. The business network interactions implement the service relationships – the agent is playing both the customer and the service provider; for example, the heat provider is a consumer from the infrastructure manufacturer. The best solutions should be evaluated to ensure continual improvement at each interaction, and here the game theory could help [10], [11].

'Co-opetition' is a business and economy concept based on game theory. It explores how companies' synergy can create extra value even if they compete in some aspects. To summarise, competitors are organisations that decrease your market by offering a similar product. At the same time, complementors are the agents outside of the company that beneficially influence your customers. Balancing the interaction among players, added values, rules, tactics, and scope leads to equilibrium among the business network participants and growth [8]. Game theory in the energy sector is previously used in different research [12]–[14], mostly to create numerical models of the effects of various heat and power tariffs.

The game theory analysis method has been applied in the research by evaluating different cooperation models to implement innovative 5GDHC solutions. Three different local market business models for 5GDHC at the community level have been tested:

- Thermal Energy Purchase Agreement: the DH operator finances and owns the 5GDHC network and then sells heating and cooling services to end-users at agreed prices;
- Local Thermal Energy Provider: real estate companies invest in and operate the 5GDHC network, purchasing heat from various sources;
- Local Thermal Energy Community: the local community owns and operates the 5GDHC network, with various participants sharing the ownership.

The article aims to design, test and evaluate three local market business models for 5GDHC at the community level. This research considers the possibility of deep cooperation and energy sharing between various participants. Business models for various actors are explored, creating a new sustainable market for the future energy sector.

2. METHODOLOGY

Game theory elements might appear at any interaction where various probabilities occur; it also highlights any cognitive biases or standardised actions that players tend to make (see Fig. 1). The literature review links the main topics at the article's core – game theory, business management, and the 5GDHC concept. The theoretical basis is improved according to the needs while evaluating the results, so the process is iterative.

The first step of the research is the risk and benefits analysis to identify the 5GDHC desirable for the participants. The general preliminary estimation is made to connect, identify, and weigh factors impacting the process to create a sustainable strategic goal and minimise risks. It is based on the already existing SWOT matrix for 5GDHC in literature [15]. When connections among the players are established, other algorithms such as value networks can be created.

The second step includes the development of a value network – interconnections and variations of actions. According to the business competition principles [8] the value network shows the interconnection of the rational agents in the business. It helps to understand the links that are affecting the supply chain. Links are analysed from the view of each rational agent.

The optimistic bias, as defined by Daniel Kahneman [16] suggests that the main reason for the failure of the new enterprises is not considering competitors as equal members of the market – the reason why the business is failing might not be because of the lack of competence or quality of the service, which are the factors that entrepreneurs and investors are usually considering, but just because an alternative, already implemented options are just good enough.

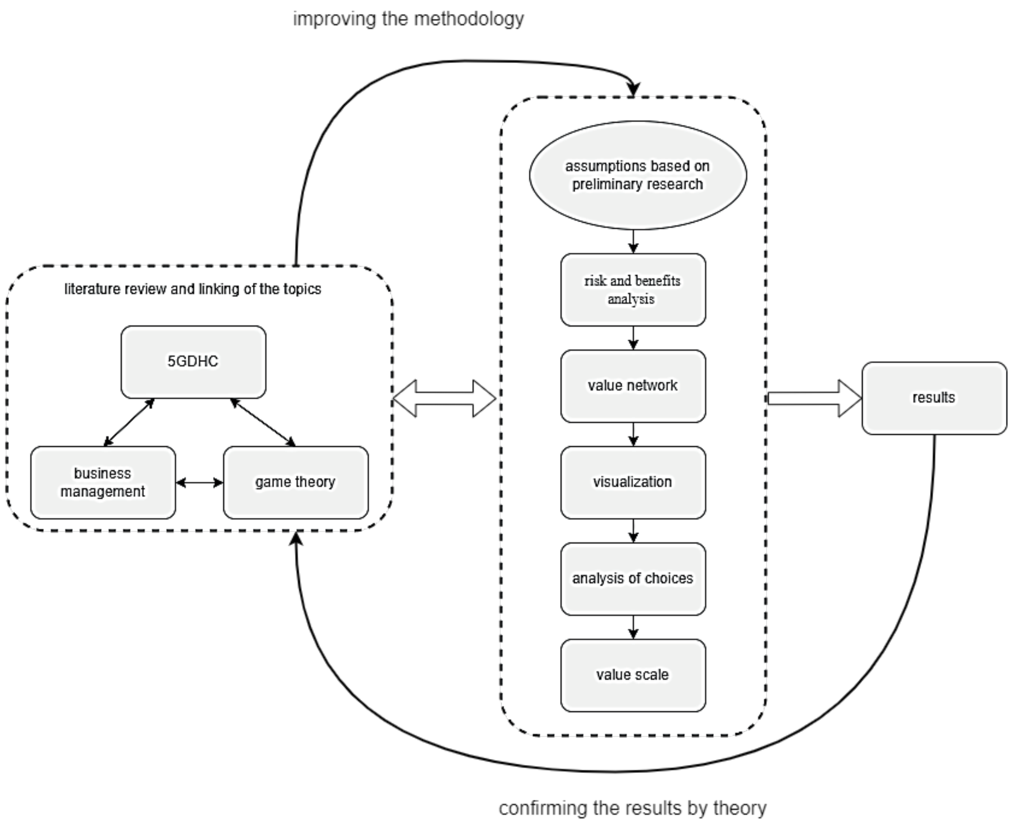


Fig. 1. Workflow of the research.

The general overview of the 5GDHC business chain is evaluated to predict possible development directions. While the process for changes initiator is primarily motivated by possible gain, there is no way that the business process can be successfully launched without the benefits for other parties. Evaluating the needs of each player helps to see how to achieve Nash equilibrium – the situation that is good enough for every stakeholder. In this state, no player changes their actions even knowing the actions of the rest of the parties.

Within the third step, the conceptional schemes are drawn to identify the connections among the participants in the market, their differences and strong points, and the money flow.

Further, it is necessary to identify the choice and the backup option – who will start the game? Each scenario has a different owner responsible for the maintenance, which also has the highest risk and who is responsible for including every other player in the process. The initiating party affects the process and choices that other players will have. The process flow chart is drawn to inspect possible processes and the parties influencing them. Here the possibility of failure and cancellation of the project is also included.

In the last step, the possible business model scenarios are evaluated. First, it is necessary to determine the factors affecting the system's business value for the case study. The authors consider an imaginary example which represents the neighbourhood with five multi-flat buildings with an average living area of 1500 m^2 each and five commercial buildings with an average of 2000 m^2. The specific heat and cold consumption of the buildings are represented in Table 1 along with other technical assumptions. It is assumed that heat from cooling systems of commercial buildings could be recovered and transferred to the heating grid via heat pumps. The total length of the ultra-low temperature heating and cooling network is around 1000 m presenting a local scale system. Additional heat is delivered from an alternative heating source associated with a biomass boiler house.

TABLE 1. MAIN TECHNICAL ASSUMPTIONS FOR 5GDHC IMPLEMENTATION

Assumption	**Residential buildings**	**Commercial buildings**
Specific heat consumption, kWh/m^2 per year	90	60
Specific cooling energy consumption, kWh/m^2	20	40
The efficiency of heat pumps (COP)	4	
Proportion of recovered heat, % of total cooling consumption	0.8	
The efficiency of cooling equipment (EE)	3	
Heat production efficiency	0.8	
Supply temperature, ºC	18	
Return temperature, ºC	14	
Linear heat transfer coefficient, W/m/ºC	0.23	
Length of heating/cooling networks, m	1000	

The main differences in various heating and cooling supply business models can be described by different costs and revenues for involved parties. Therefore, the total heating and cooling costs are calculated considering the necessary investments, fuel costs, network losses and other related heat and cold production costs. Based on the literature review, different cost-related assumptions are estimated for the whole process for the technology's life cycle, which is summarised in Table 2.

TABLE 2. MAIN TECHNICAL ASSUMPTIONS FOR 5GDHC IMPLEMENTATION

Assumption	**Value**
Electricity tariff, EUR/MWh	140
Costs of heat pump, EUR/kW	1000
Equipment operating time, years	25
Heating and cooling networks costs, EUR/m	250
Accumulation tank costs, EUR/kW	50
Cooling equipment costs, EUR/kW	500
Alternative boiler costs, EUR/kW	500
Alternative fuel costs, EUR/MWh	40

In addition, the possible business models have been compared under different end-use heat and cold tariffs. It has been assumed, that price of cooling energy is 20 % higher than the heating price. The important factor in future cooperation among stakeholders is the offered heat and cold purchase price which is assumed different in each business model.

3. Results

This section presents in-depth analyses of suitable business models and a simplified numerical comparison of identified scenarios. The implementation of 5GDHC is evaluated using the current DH solutions as a starting point.

3.1. Risk and Benefit Analysis

In the case of the widespread connection to conventional DH, participants are less willing to switch to initial technologies due to high initial costs. However, conventional DH might signal the readiness for centralised solutions [17]. Most opportunities of the 5GDHC system are related to higher independence levels from outside the system. The question of expenses is the most sensitive regarding rural areas and small towns.

Implementing the system affects the participants differently, so from the business perspective, opportunities for one might present threats to the other. Overall, the main strengths of the 5GDHC are the ability to utilise waste heat, providing both cooling and heating simultaneously, and significantly decreasing primary energy consumption and energy loss [18]. Reduced energy consumption through heat recovery and higher energy efficiency levels, results in lower fuel consumption, health, and environmental benefits [19].

However, the switch of the system is costly. It needs significant initial investments that participants are not motivated to make if the existing DH system is working well. Electricity consumption that is needed for operating local heat pumps increases. If any stakeholders are not ready for the change, the whole system rapidly loses value. Creating a new business model is both an opportunity and a threat, so choosing it right is crucial.

3.2. Value Network and Key Players in the Game

The key difference among different models considered within the article is the owner regulating the 5GDHC network. In each business model, producers operate the cooling and heating system that produces all the needed heat or ensures cooling up to the needed level, compensating for the energy shortages after heat recovery from prosumers. The technological equipment might belong to the regulator of the 5GDHC network or some other external holder that has an agreement with the owner. For the value network, those two functions overlap.

In the case of individual heating or conventional DH, prosumers would not be a part of the chain. They would become regular consumers. In the case of 5GDH, they are the key participant of the value network, adding their excess heat. The main co-opetition processes are going on between the rational agent and complementor; in the case of 5GDHC, it also means that they are a vital part of the whole business process to exist since not only prosumer would become a regular customers if 5GDHC is not implemented, but also without the prosumer the whole network cannot exist. Therefore, to apply the game theory for the business model analyses it has been defined that the main aim of each involved stakeholder is to reduce the overall costs for the heat and cold supply. From the value network analyses, it has been identified that the following participants could be included as stakeholders or players in the future 5GDHC system business models:

– Consumers – the heating and cooling sector customers connected to the 5GDHC network. The strategy of the Consumers for reducing the total heating and cooling costs is to lower their demand through energy efficiency measures in buildings or seek the lowest possible heat tariff of the system;

- Prosumers – both customers of the heating and cooling sector and the holders of possible waste heat sources. The strategy of the Prosumers for cost reduction can be either to recover the heat and deliver it to the 5GDHC system or to reuse it inside the buildings;
- Energy producers – external energy producers who generate the necessary heat and cold for the 5GDHC network to cover the part of demand which cannot be covered by waste heat sources. To reduce the total costs energy producers can either choose the energy source with a lower price, increase the energy generation efficiency, or seek to increase the total amount of generated energy to reduce the specific costs of each energy unit;
- System operator– associated with existing DH system operator or new operator who owns the heating grid and is responsible for aligning the demand and supply of energy. To reduce the total costs the system operator aims to maximise the use of energy sources with the lowest associated costs.

3.3. Proposed Business Models for the 5GDHC System

Three different possible business models have been identified as suitable for the 5GDHC system implementation, however, each of them is associated with certain benefits and risks.

3.3.1. Scenario 1. Thermal Energy Purchase Agreement

The scenario implements that the DH operator finances and owns the 5GDHC network and then sells heating and cooling services to end-users at agreed prices. The owner's responsibility is to maintain the whole infrastructure and ensure that everyone's needs are covered. It might or might not own the producing technologies, but it's the operator's responsibility that customers get the supply of the needed heat. The operator is the central point for all financial deals. It gets paid by the customers and partly prosumers for the offered service. It gets all the investments and grants related to the project. Still, it also must take on all the risks.

Further, two sub-scenarios could be formulated. In addition to the participants mentioned before, an operator might act as the network owner (see Fig. 2). The operator, in this case, is primarily concerned with the business side of the process and is not directly related to energy production. Heat pumps can be owned and maintained by the operator including the maintenance costs in the tariff or owned by the users that are connected to the network, making the operation at the individual level the responsibility of the customer. The owner has the highest business potential and the greatest financial risk here. The owner is an external player and might put its business interests first. This will most likely not be the cheapest option for the consumer, but it is the most hassle-free if the operator has the necessary experience in eating system maintenance.

Such a system is implemented in Sedrun, Switzerland. The system operator shall determine the input and installation costs of the substation to the user and set the delivery limit and the total costs, including a one-time connection fee and a basic annual fee calculated in proportion to the substation reference volume flow rate [20].

Alternatively, that might be an energy producer who invests in the new technology and directly offers it to the customers (see Fig. 3). In that case there, the number of participants is reduced. Since the operator has mostly business management value not specifically analysed here and mostly deals with the redistributing of the energy produced by the producer and prosumer, in the observed initial relationship of producer-prosumer-consumer in most cases, the operator and producer might be assumed as the same unit in the processes.

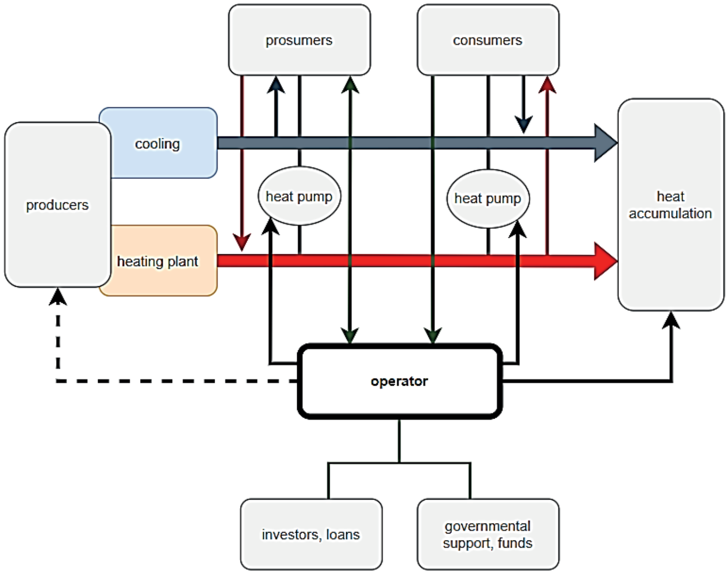


Fig. 2. Scheme of Scenario 1a. Thermal Energy Purchase Agreement with external heat producer.

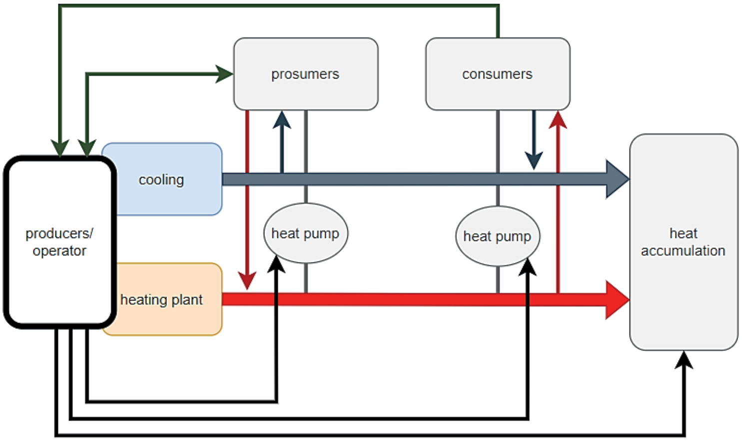


Fig. 3. Scheme of Scenario 1b. Thermal Energy Purchase Agreement without external heat producer.

3.3.2. Scenario 2. Local Thermal Energy Provider

In this scenario, the real estate companies invest in and operate the 5GDHC network, purchasing heat from various sources (see Fig. 4). This business case would be more suitable for a small-scale 5GDHC system where the development of a heating network accounts for a smaller part of investments. There is no external operator; prosumers such as shopping mall owners regulate the energy and value network. In addition to the 5GDHC system, prosumers might own the production of the additional energy, such as the heating boilers and the cooling equipment. Alternatively, the owner might be the company that owns the production system; in that case, prosumers are selling the excess energy to them.

Since the owner has the greatest financial risks, its company being part of the network and benefiting financially and energy-wise might be another motivator to initiate the change. Real estate companies of a particular area will invest in that area, making the situation more stable and less affected by the changes in economic processes. Excluding extra players might decrease prices for the customer.

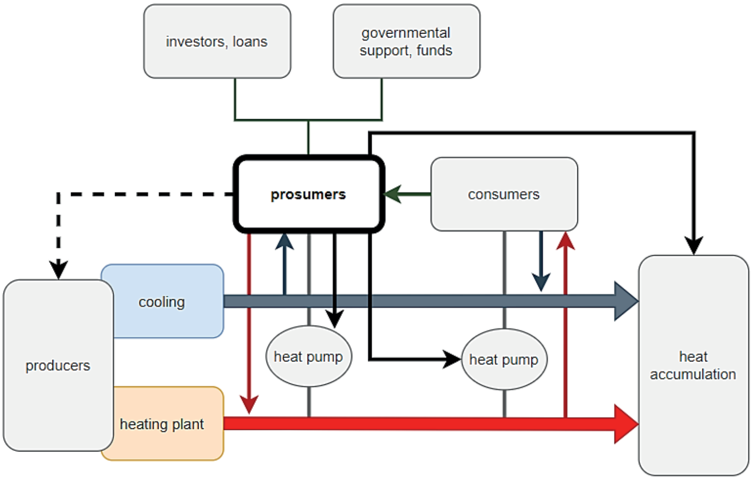


Fig. 4. Scheme of Scenario 2. Local Thermal Energy Provider.

3.3.3. Scenario 3. Local Thermal Energy Community

This scenario is implementing the social initiative and the local energy community. In this scenario, the consumer is protected the most, but there are also risks to the management since self-organised institutions with many members can potentially be unsustainable (see Fig. 5 next page).

As a grassroots self-organising institution, energy communities are preferable from the aspect of strengthening cooperation in society [21]. Additionally, this benefit might get a higher approval rate for projects or governmental funding that could cover part of the expenses. However, in case of the loans, banks would prefer to deal with long-existing organisations that can prove their viability.

3.4. Choice and the Backup Option – Who Will Start the Game?

The probability of the resulting scenario largely depends on who will initiate the process hence having the first hand in deciding which 5GDHC business model will be the most likely. Annex Fig. A1 shows the detailed assessment to identify the most beneficial business model scenario.

The process can be initiated by the external operator – the business owner. The investor might initiate the change as well, but further on, the administrative responsibilities are, either way, primarily laid on one of the main players. If the investor keeps the management position, Scenario 1 is implemented, and the investor becomes an independent operator.

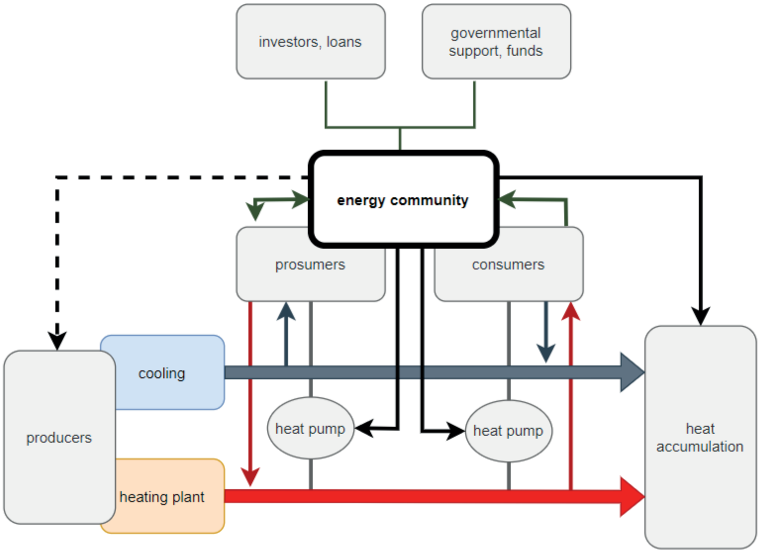


Fig. 5. Scheme of Scenario 3. Local Thermal Energy Community.

If consumers and prosumers can cooperate, they might organise through the energy community (Scenario 3). The main problem for prosumers and consumers is the administrative capacity; they might offer leadership to a competent party, such as a producer or an external operator (Scenario 1). Prosumers might become an owner of their own (Scenario 2) for certain small-scale projects. If none of these works, the project must be cancelled.

If that is consumer or prosumer, the first step is to evaluate the management and administration capacity since those are not a primary function of either inhabitants, shopping malls, or other commercial building owners. Additionally, here 'consumer' and 'prosumer' are used as single players who act in a unified way. In real life, both consist of multiple owners, and they all must agree on a common energy supply system model.

The initial business model is chosen when the preliminary risk assessment is done, and the project seems viable. It can change later after further investigation and planning. For the most part, an agreement among all involved parties should be made.

Here comes the most important part – cost estimation. The 5GDHC system is costly and requires significant initial investments. Lower maintenance and energy costs are long-run benefits. It is not helping much at the initial stage when it is necessary to go through the administrative procedure, risk assessments, buy the equipment, perform the related construction works, and switch the fuel, which means changing the whole supply chain.

At the next stage, the infrastructure is built by the player that will become an owner, meaning that the corresponding scenario is launched. That is where the project fits together in the public network of heating solutions, and all external agents from the created value chain are linked.

3.5. The Value Scale and Evaluation of the Benefits in Each Scenario

To test the identified business models, the game theory method has been applied and different game strategies were tested for each player to maximize the total gains of the system – cost reduction of heat and cold. Every scenario is analysed from each stakeholder's perspective.

Based on the technical characteristics of the needed equipment and possible revenues from energy sales, approximate costs, and revenues for evaluation of each scenario are established (see Fig. 6) to compare the benefits for each player and the total value in the certain business models. The total cost and gain results are uncertain and would differ for every case, depending on the energy price, region, readiness to cooperate, available investments and governmental support. However, it indicates the main differences between potential cooperation strategies and monetary flows.

As shown in Fig. 6, the lowest total costs for residential and commercial building heat and cold coverage are reached under Scenario 2 when the prosumer initiates the system development and administrates the heat and cold supply to residential buildings. In this scenario, prosumers can reduce the overall building heat and cooling costs compared to other scenarios, however, the implementation and operation of the system require additional costs. Scenario 3 represents the energy community business model scenario. In this case, it has been assumed, that the energy community will be developed by involving both prosumers and consumers in overall 5GDHC system development and there will not be an external system operator. The system administration costs are now covered by consumers which results in higher total heating and cooling costs compared to other business models. The highest revenue share is reached in the Thermal Energy Purchase agreement business model (Scenario 1b) when the system operator is also the heat producer to cover the heat and cold demand shortages. In the case of Scenario 3, investment costs and the other additional responsibilities are on the energy community based on the cooperation among the consumer and prosumer.

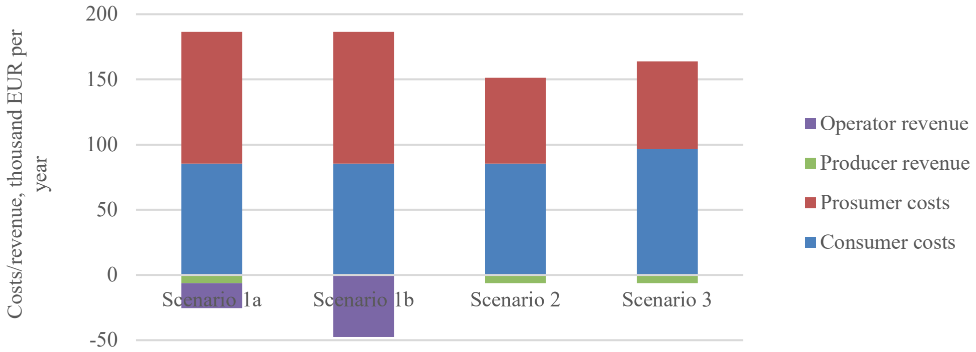
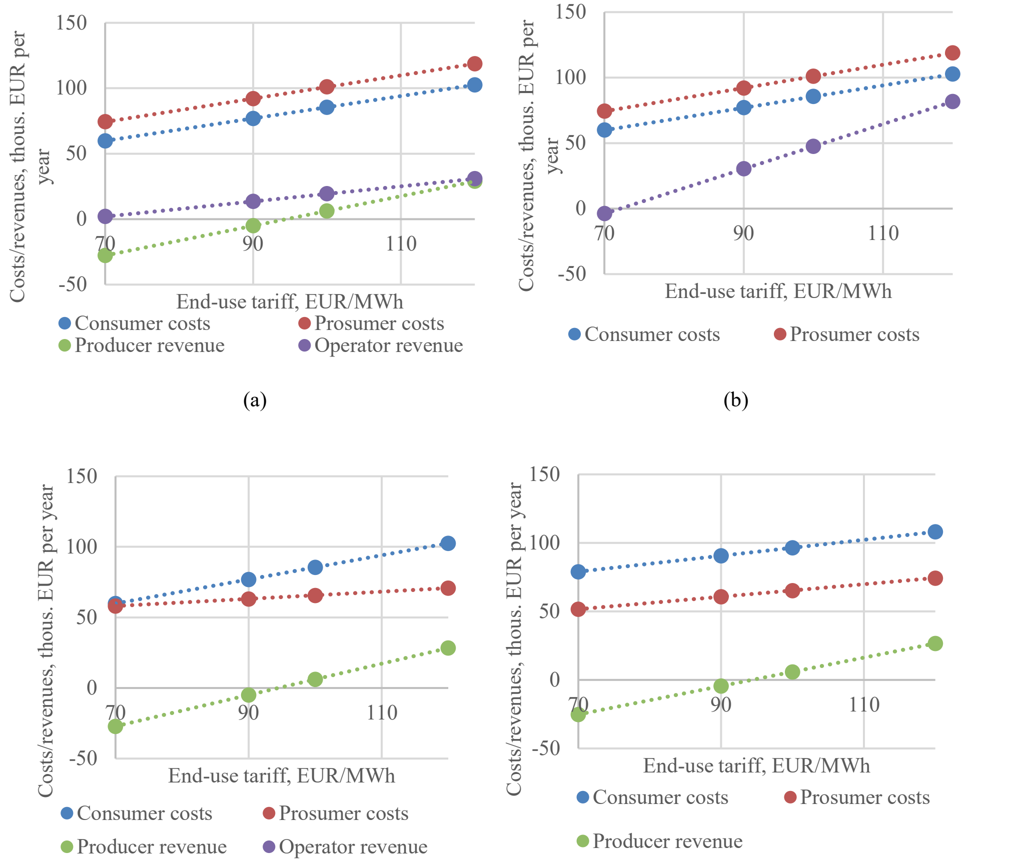


Fig. 6. Main cost and revenues for involved stakeholders under different business models.

Fig. 7 shows the cost and revenue changes under different end-use heat tariffs. The end-use price for cooling is linked to the heat tariff and is assumed to be 20 % higher. Within the conducted sensitivity analyses it has been assumed that the energy resource prices and power prices remain constant, therefore, the producers' revenue increase has been higher. From Fig. 7 it can be concluded that the business model presented in Scenario 1b could reach the lowest end-use heat tariff, which is beneficial for all involved parties.



(c) (d)

Fig. 7. Changes in main costs and revenues under various end-use heat tariff assumptions: a) Scenario 1a; b) Scenario 1b; c) Scenario 2; d) Scenario 3.

From the conducted analyses the most significant gain and cost changes are for the prosumers and the external energy producer. Therefore, when the 5GDHC system implementation has been planned it is crucial that there are added value for these stakeholders to be involved in the system.

4. Conclusions and Discussion

The main barrier to the 5GDHC development in the Baltic States are well maintained and widespread high-temperature DH in all three countries. Based on that, it is assumed that the existing DH is the main competitor for implementing 5GDHC, another being individual heating and cooling solutions for every building. Compared to the existing DH, the new system could have lower operating costs and more possibilities for optimisation, which would significantly contribute to paying off the investments in countries with high salaries and expensive human resources workforce. However, both approaches interact with the same customers that 5GDHC implementers are trying to reach and the same suppliers since many technological needs will overlap.

Therefore, innovative business models are crucial in the districts where implementing the 5GDHC system would be beneficial. While the general technical principles are not changing in various business scenarios, the price for the customers can be significantly affected by them changing the cost balance. It is crucial to find the optimal model that would be interesting enough for the investors but at the same time would allow pressuring energy questions to be solved where it is needed the most – at the consumer level, especially where increased prices are contributing to the energy poverty.

The research identifies three different business models for 5GDHC system implementation and highlights the role of each involved stakeholder. In each scenario, the system owner is the one who gets the funds and a large part of the income and carries the highest risks. While socially, it is the most beneficial for society to lower the price for the customers, lack of professional management is the weak point of the scenario that anticipates energy communities.

Scenario 1 implements that the operator owns the system. If that is an independent business, in case of forfeiture, it may quit the project without extra losses. Scenario 2 and Scenario 3 are organised by the players directly linked to the particular location, so they have fewer possibilities to quit, thus being more motivated to make changes to work. The main driver for the operator is financial gain, so it is interested in making prices as high as possible. The risk for the rural areas is that independent operators might choose any location for investments, meaning that there might be places where no investor is interested even if they have a good heat recovery and accumulating potential.

The performed cost and gain assessment shows that with all players considered, Scenario 2 is with lower costs, however, only if the prosumer is ready to administrate the system. Also, the energy community option would work in favour of everyone. Still, the previously mentioned administrative risks must be considered. The starting point of the decision tree and the consequence paths to the choice of the scenario depends on who was the initiator of the switch toward the 5GDHC. All possible loans and investments should be considered, preferably with the involvement of governmental and legislative techniques. Despite all efforts, the initiator could always be open to cancelling the project at any stage to avoid larger losses further on and effort justification bias.

Currently, it is difficult to predict how exactly the participation of prosumers in the market will go into account that in many countries, the existing market regulations forbid different heating tariffs. Prosumers might push for equal prices for heat and cooling, making heating more expensive than it could be.

Within the study, it is assumed that there will be no competition among various providers, such as various companies wanting to invest in the same location. However, the approach may become more favoured in the future. The implementation of the 5GDHC is likely to pay off if the heat tariffs and taxes of existing systems are high, meaning that those economic parameters are critical for balancing out the likelihood of the change of existing DH systems. Governmental subsidies and other kinds of support can significantly change the equilibrium.

Further research should analyse the application of proposed business models in real case studies to identify other benefits and barriers to 5GDHC system implementation.

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ANNEX

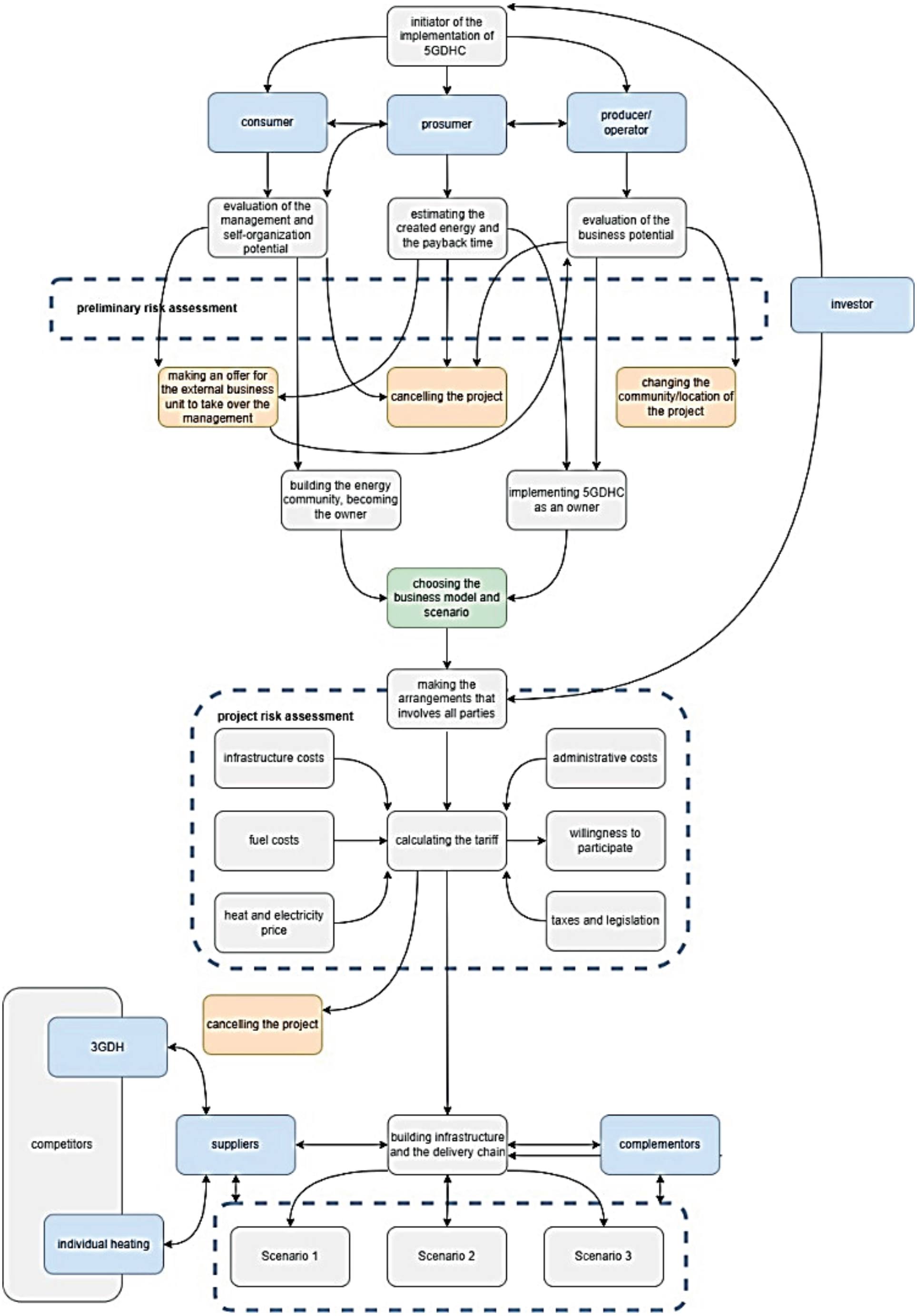

Fig. A1. Main steps to identify the most beneficial business model scenario.