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Procurement Chain Management of Heat Pump for Industrial and Residential Heating

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Abstract

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Title of the thesis **Procurement Chain of Heat Pump for Industrial and Residential Heating**		
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Abstract The thesis is devoted to theory research of new generation heat pumps and various approaches of procurement chain management. Currently, the world is trying to prevent climate change by applying different technologies to reduce global gas emissions and energy consumption. Heat pumps provide clean heat production with efficient electricity use, which led to environmental and economic advantages. A comprehensive study was carried out using a literature review and real examples. Methods and solutions in the management of the procurement chain and the evaluation of suppliers have been reviewed and modified for heat pump production. The market was also assessed, and future business models for technology deployment were developed. The key finding is represented in the form of a comprehensive overview of the heat pump market, a list of potential suppliers of heat pump components, and methods for evaluating supplier performance.		
Keywords Heat pump, procurement chain management, efficiency, potential suppliers		

Contents

1 Introduction

Nowadays, the world is trying to prevent climate change by the different tools and methods of reducing global gas emissions. The world produces around 50 billion tons of greenhouse gases each year, measured in carbon dioxide equivalents. Presently, most heat demands for heat production, industrial applications, and heating domestic and non-domestic buildings globally are covered by fossil fuel burning. These 3 sectors emit around 35-40% of the global greenhouse emissions. Suppose governments, companies, and people will not develop and facilitate renewable and clean energy sources. In that case, the current situation can increase global gas emissions and global warming. Therefore, new regulations such as decarbonized Europe, local limitations for fossil fuels burning for heating to limit air pollution and spread of hazardous gases, and special offers for clean energy, the utilization of fossils is under pressure. Increasing costs, taxes, and reduced availability of fossil fuels and technologies concentrated on its use are additional factors. (ec.europa.eu 2020)

Several technologies can play an essential role in decarbonizing the heat sector, and one of them is a heat pump (HP). Heat pumps provide clean heat production with efficient electricity use, which led to environmental and economic advantages. In Europe, the heat pump market accelerates, and the number of heat pumps grows annually, and it shows no signs of slowing down. With advances and development of technology, with new design advantages, technological and manufacturing innovations, and tighter legislation on gas emissions, high-temperature heat pumps (HTHPs) become viable and occupy a vital economic sector. However, even though renewable energy starts to be used for energy and heat production, the productivity of technology is one of the essential factors means to decrease green gas emissions and primary energy consumption. (iea.org)

Heat pumps are a way of producing high-temperature heat from low-temperature heat. Many companies are providing heat pump solutions and designs for temperatures below 100 degrees. Nonetheless, the number of manufacturers and suppliers for high-temperature efficient heat pumps solutions is relatively low. Additional research and development activities for the progress of efficient previously not available HTHPs are still required. HTHPs producing high-temperature T°C heat with relatively high power (> 100 kW) with the most efficient working fluids and optimized highly efficient processes can be frequently integrated into the various industrial processes in the future. (IEA Industrial Energy-related Systems and Technologies Annex 35/13)

1.1 Research objectives and scope

The thesis aims to contribute to analytical research of new generation heat pumps and procurement chain management of HP for industrial and residential heating. Additionally, this thesis is related to the commercialization of a mutual project of Lappeenranta-Lahti University of Technology (LUT) and LAB University of Applied Science. The theoretical scope is to comprehensively study the operational principle, types, efficiency, environmental friendliness, and new generation heat pumps market. Moreover, different approaches to the management of procurement and supply chains for the production of heat pumps should be evaluated. In addition, the case study aims to provide research on the procurement of components and improve the efficiency of supplier selection and effectiveness of the procurement system. The sub-goals can include:

- Analyzation of the theoretical aspects of heat pumps and their structure.
- Analyzation and research the procurement management system in companies.
- Analyzation of the theoretical aspects of procurement management and identify the specifics of the process approach to procurement management.
- Provide recommendations for improving procurement management processes.
- Development of a comprehensive criterion for optimizing supplier selection, considering the ratio of costs and risks in the procurement system.

All these goals can be achieved by the implementation of several stages:

- **Researching stage 1**. Heat pump theory research and data collection.
- **Researching stage 2**. Procurement chain management research and data collection.
- **Researching stage 3** Heat pump design, manufacturing methods, level of complicity, and materials of each component should be studied and evaluated.
- **Planning stage**. Components lists that will include all necessary factors should be created according to the gained information.
- **Collection stage**. Searching on the market for possible suppliers and manufacturers that can provide solutions for the project. Fulfilment the suppliers-components list.
- **Definition stage**. From 3 up to 5 best suitable suppliers should be defined according to several factors, and a second suppliers-components list should be created.

- **Selection stage**. The best suitable suppliers should be analyzed by the implementation of different approaches such as decision matrix analyses. Then, the best suitable supplier should be selected for each component or manufacturing method.
- **Evaluation stage**. The overall cost of design and each component, long-term relationships with suppliers, possible future barriers, and reduced cost and partner relationships should be evaluated.

The accomplishment of each of these objectives and utilizing the gained evidence can help the company avoid delivery gaps and partnerships with irresponsible and not-professional companies. These will help reduce the project's total price, evaluate the level of risks in the procurement system, and gain efficient suppliers' selection. Additionally, future market barriers, possible customers, current competitors, and their value on the market, the possibility of mass production, and supply chain management of this technology can be studied.

1.2 Motivation

New regulations, global and local restrictions of the usage of fossil fuels, development of renewable energy technologies, environmental trends, and demand in the new efficient way of generating green-clean heat and steam are leading to rapidly increasing demand in industrial heat pumps. In addition, the market demand is causing researching and creating new technologies and methods that can open new heat pumps opportunities to perform with high efficiency and new advanced features.

As one of the key drivers for the need of HTHPs is decarbonizing the generating of industrial heat, it can be confident that new technologies providing heat will emerge. Heat pumps differentiate from most other heat sources that use renewable energy sources by utilizing waste heat generated by industrial processes efficiently. The waste heat represents around 20-35% depending on country and climate zone of the total energy consumption by production industry such as ceramic, chemical, food, textile and printing industries, there is a specified need for heat pump technology in the right segments. (IEA Industrial Energy-related Systems and Technologies Annex 35/13)

Currently, green solutions the oil-free, clean technologies receive new market opportunities. Developments and innovations in heat pump design allow HPs to provide heat or cool efficiently while significantly reducing energy consumption. The developed advanced design with the application of modern technologies can influence the HPs efficiency growth and deployment of technology across the different market sectors. The possibility of providing a technology that can measure up to 150 C of heat generated will unlock completely new segments of the market that require heat at a higher temperature. This technology can have

both a unique advantage compared to conventional technology and a chance for unique positioning on the market. (IEA Industrial Energy-related Systems and Technologies Annex 35/13)

Therefore, there are several main reasons to study this topic. Firstly, the opportunity to participate in a large innovative project aimed at research, production, and creation of new previously non-existent technologies. The proof of concept can be explored and understood during the project. Moreover, various aspects are included in the project: from motivation and initial stages of the project to the final data structure and evaluation of results. Secondly, aspects of procurement chain management can be studied and applied to complete a project, leading to this technology's future growth and development in the market. Combining a business environment and engineering knowledge can be used and applied in the future in projects and start-ups in the market. Thirdly, this project is related to renewable and clean energy, and the opportunity to be a part of this project is a small contribution to our future.

2 Heat pumps overview

2.1 Basic concept

The heat pump is usually defined as a machine that converts heat energy from one location to another. In other words, a HP is a machine used to heat and sometimes cool space by transferring thermal energy from a cooler space to a warmer space using the refrigeration cycle. Therefore, the heat-transfer agent with low potential increases its potential to the required value by consuming mechanical or other energy sources. (Wikipedia 2021a).

The low-temperature T°C waste heat stream can be converted into usable high T°C heat using an HP unit. The various types of HPs have been created. The mechanical HP unit is the most widely applied. Its working principle consists of the compression and expansion of the working fluid. An HP unit consists of these main parts: a compressor, an evaporator, an expansion valve, a condenser, and an electrical motor, that drives the compressor. The working fluid streams through the evaporator, compressor, expansion valve, and condenser. The evaporator removes heat from the waste heat source. In the condenser, useful heat is transferred to the consumer at a higher T°C level. (Nick Connor, 2019). Figure 1 shows the operating principle of the HP.

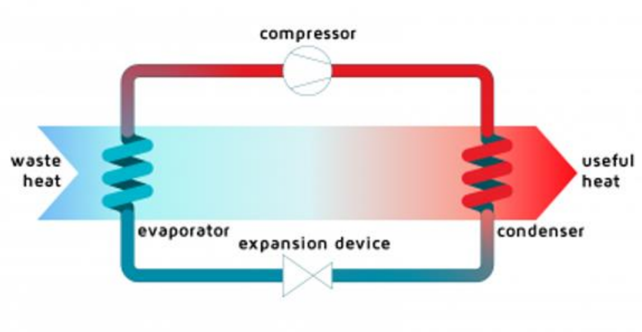

Figure 1. Operating principle of the HP (Indusrialheatpumps.nl)

2.1.1 Heat pump theory

All heat engines like internal combustion engines, refrigerators, steam engines operate cyclically. The term cycle indicates a continuous change in the state of the system as a result of which it returns to the initial state from which these changes began. A cyclical process is shown graphically as a closed line. In thermodynamics, cycles are considered, consisting of a strictly defined sequence of some of the most straightforward processes: isothermal, isochoric, isobaric, adiabatic, resulting in which the working fluid returns to its original state. (Wikipedia 2021b).

In 1824, engineer S. Carnot first used the thermodynamic cycle to describe and analyze an ideal heat engine operation. Nowadays, the Carnot cycle is a fundamental basis for evaluating the effectiveness of heat pumps because the efficiency of the Carnot cycle determines the theoretical limit for estimating the efficiency of a heat engine for a given temperature range. The HP can be considered as a reverse heat engine. Figure 2 shows the scheme of the ideal Carnot cycle. The Carnot cycle occurs between a high-temperature storage T_H and a low-temperature storage T_L. The horizontal axis is entropy. (Wikipedia 2021c).

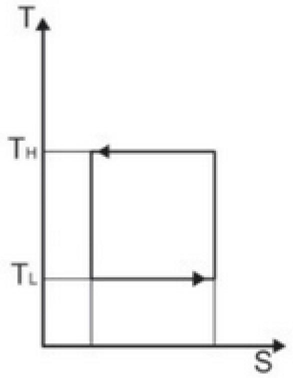

Figure 2. Carnot cycle (Wikipedia 2021c).

Abbreviations on Figure 2:

S – entropy.

T – temperature.

T_H – high temperature.

T_L – low temperature.

Direct cycles, also called engine cycles, are taking place in the thermal engine. By expanding high-temperature steam, we get useful work, and the temperature of steam decreases. The reverse cycles, also called refrigeration cycles are taking place in refrigerators and heat pumps. Energy should be supplied for this process to proceed since the second law of thermodynamics sets the direction of spontaneous thermodynamic processes; according to it, the transfer of heat from a cold source to a warm one is impossible. It means that by the consumption of energy, the temperature of the steam is increasing. (Wikipedia 2021b).

It is essential to understand that both the refrigerator and the heat pump operate according to the same thermodynamic cycle but in reverse. In the first case of the refrigerator, the goal is to create a lowered temperature inside the refrigerating chamber. Thus, with the influence

of the additional expended power, the heat from the refrigerator is removed to the environment. In the second case of the HP, the goal is to create an elevated temperature inside the room. Thus, with the help of the additional expended energy, heat from the environment is removed into the room, i.e., the environment is cooling. (Shafi 2021). Figure 3 shows the difference between engine, heat pump, and refrigerator.

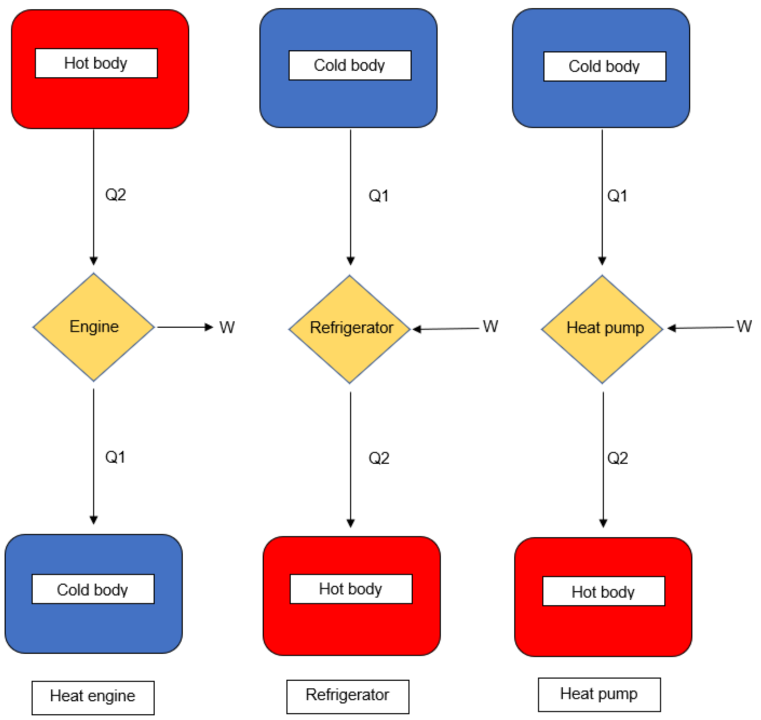

Figure 3. Operation of engine, heat pump, and refrigerator (adapted from mechanicalenotes.com).

The heat engine takes heat Q_2 from a high-temperature source or body and supplies it sink Q_1 at a low temperature, giving off useful work done W, equal to $Q_2 – Q_1$. The coefficient of performance or C.O.P is equal to Useful work done/ Heat used. Formula 1 represents the efficiency of the engine. (mechanicalenotes.com)

$$\eta_{engine} = \frac{W}{Q_2} = \frac{Q_2 - Q_1}{Q_2} \ (1)$$

The refrigerator required expenditure input of work W to take the amount of heat Q_1 from the cold body at low temperature and release the amount of heat Q_2 to the high-temperature source, $Q_2 = Q_1 + W$. In the refrigerator unit, the useful effect is the recovery of heat Q_1. The efficiency of the refrigerator unit is represented by formula 2. (mechanicalenotes.com)

$$\eta_{refrigerator} = \frac{Q_1}{W} = \frac{Q_1}{Q_2 - Q_1} \ (2)$$

The heat pump is operating similarly to the refrigerator. Heat pump required expenditure input of work *W* to take the amount of heat Q_1 from the cold body at low temperature and release amount of heat Q_2 to the high-temperature body, $Q_2 = Q_1 + W$. However, in the heat pump unit, the useful effect is the delivered amount Q_2. The efficiency of the heat pump is represented by formula 3. (mechanicalenotes.com)

$$\eta_{pump} = \frac{Q_2}{W} = \frac{Q_2}{Q_2 - Q_1} \quad (3)$$

If both in machines: heat pump and heat engine thermodynamic processes do not contain heat or work losses, then there is an ultimate margin of the efficiency of both machines, and for each of them, the ratio is Q_2 / W. Otherwise, it would be feasible to create an infinite motion machine, simply by a combination of one machine to another. (mechanicale-notes.com)

In the HP unit heat is supplied isothermally at the constant temperature T_L and isothermally extracted at a constant temperature T_H. Thus, compression and expansion are conducted at constant entropy. Figure 4 shows a diagram of a vapor compression heat pump. (Wik-ipedia 2021c)

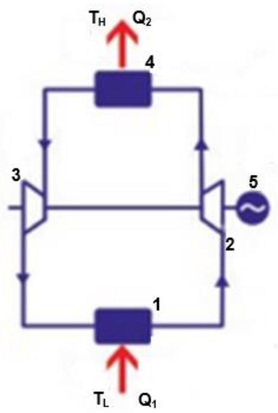

Figure 4. Vapor compression heat pump unit. (adapted from Meyer 2011).

Abbreviations of Figure 4:

1 – evaporator.

2 – compressor.

3 – condenser.

4 – expansion device.

5 – electric drive/ electric energy.

Heat pumps are using a working fluid called a refrigerant; usually, it is freon. This refrigerant is picked up according to its physical features during the various stages of the exploitation process inside a HP.

In the evaporator, thermal energy from the environment outside the building is transferred to the HP working fluid - a refrigerant circulating along the internal circuit. The refrigerant heats up, evaporates, and flows towards the compressor. The compressor compresses the working liquid from a state at lower pressure and lower temperature. As a result, the working liquid passes off at a higher pressure and temperature in a gaseous state. Then the compressed working liquid passes through the condenser, condensing and giving off heat to the consumer's system, such as direct air heating, heating system, or hot water supply for consumers. Further, the working liquid passes through the expansion valve, which reduces the pressure, accompanied by a decrease in temperature. (Meyer Josua Petrus 2011). Figure 5 illustrates a schematic work diagram of the most common HP.

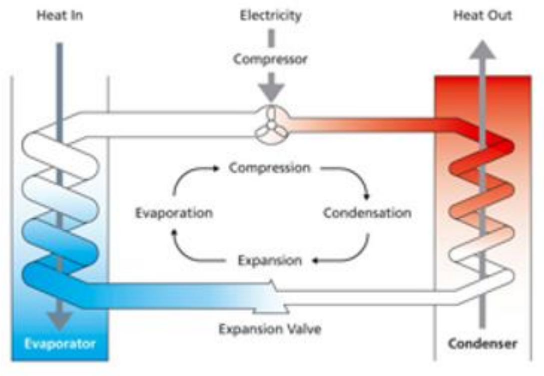

Figure 5. Work diagram of the HP (heatpumps.org)

2.1.2 Types of heat pump

The most common models can be defined by these categories:

- A system installed within heat source type.
- A primary external source of energy (power input).
- The heat pump itself - the type of coolant in the circuits.
- Principle of operation of HP.

However, it is possible to use other categories for a similar property. Each of them describes only one characteristic property of the unit. Therefore, in the definition of a heat pump unit, there can be several features. (Heatpumps.org).

Classification by system installed within heat type sources can be grouped into these categories:

- **Air Source Heat Pump System**. Air from the environment enters the heat exchanger. Heat is gotten from this air. According to geographic location, the air temperature changes at the source depending on the outside air temperature, weather, and climate change throughout the year. (Energy.gov).
- **Ground Source Heat Pump System**. HPs, using low-grade heat of the Earth: soil, water, are called geothermal heat pumps or GHP. The most common models of a closed cycle. The working fluid moves in a closed-loop, interacting with the source and consumer of heat through heat exchange in surface-type devices. The intermediate coolant is pumped through a closed-loop located in a reservoir, aquifer, or domestic wastewater. When installing the ground source heat pump or GSHP, there is a high installation cost for the evaporator. There are horizontal and vertical ground heat exchangers. In the first case, the closed-loop of the heat exchanger is laid in horizontal trenches 4-6 m deep and up to 100 m long. They require a large surface area. In the second case, the closed-loop of the heat exchanger is installed vertically into drilled holes to a depth of 100 m. (Energy.gov).
- **Water Source Heat Pump System**. There are two main solutions for the water source HPS: closed pipe-work loop of water and open loop. The first solution loop with liquid is submerged into a water source such as ocean, sea, lake, or river. On the other hand, the simple design of open systems allows the water passing inside to be heated, which subsequently re-enters the ground. Ideally, such a system works only in the presence of an unlimited volume of pure liquid heat carrier, which after consumption does not harm the environment. (Heatpumps.org).
- **Technological Sources of Heat**. Used in low energy type applications. These sources can be outgoing ventilation air, wastewater, the thermal energy of technological and domestic processes. (Heatpumps.org).

Heat pumps can be defined by the primary external source energy/ fuel source. Most widely, electricity is used for the process. However, sources of energy can be described in the following way:

- **Mechanical energy**. Electric motor, gas turbine, hydraulic drive, or fuel can be used to provide this type of energy
- **Thermal energy**. Thermal energy can be received by the combustion of fuels and with the usage of a thermoelectric heater.

The heat pumps can be described by the source and type of delivery mechanism, for example, Air-to-Water. Here the source is Air, and the delivery mechanism is water. (heatpumps.org). There are these types:

- Air-to-Water (A-W).
- Air-to-Air (A-A).
- Water-to-Water (W-W).
- Water-to-Air (W-A).
- Soil-to-Water (S-W).
- Soil-to-Air (S-A).

Typical models of heat pumps can be classified according to the principle of operation:

- **Compression heat pumps**. One of the main working components in their operation is the compressor. The principle of action is based on two physical phenomena. The first is the absorption and release of heat by a substance when the state of aggregation changes. The second phenomenon is based on the change in the evaporation and condensation temperature when the pressure changes. There are gas and steam compression heat pumps. (Energy.gov).
- **Sorption heat pumps**. Sorption refers to the action of absorption or adsorption processes. Absorption is a volumetric fusion of two substances that are in different states of aggregation. Absorption mainly occurs when gases are absorbed in a liquid volume. Adsorption is a process there is a physical adhesion of ions and molecules on the surface of a body of another state. The absorption of an impurity from a gas or liquid by a solid - an adsorbent. (Energy.gov).

There are other categories for HP. Each of them describes only one characteristic property of the unit. Therefore, in the definition of a heat pump unit, there can be several features. Heat pumps can be additionally classified by:

- features and structure of the cycle
- applications and consumers
- type of refrigerant liquid
- temperature range
- mode of operation and performance

2.2 The efficiency of heat pumps

As mentioned earlier, heat pumps use different types of energy to carry out thermodynamic cycles: mechanical or thermal. Therefore, to compare the efficiency of different types of heat pumps, a standard indicator is needed. This indicator can be the specific fuel consumption for heat generation or the coefficient of its use. For example, the energy efficiency of a vapor compression heat pump is characterized by an energy conversion ratio of heat generated / power expended to drive the compressor formula 4. (Carvalho 2015, 211.)

$$\varphi = \frac{heat\ generated}{power\ expended} = \frac{Q_{out}}{Q_{int}}\ (4)$$

The HP efficiency φ is conditioned mainly on the difference between the low-temperature heat source and the temperature of the heated medium at the outlet of the HP unit. The smaller the temperature difference Δ T between the sink/radiator and source, the greater the HP efficiency and vies verse. (Nowak 2018, 86.). Figure 6 represents the relation between the value of the conversion coefficient φ and Δ T.

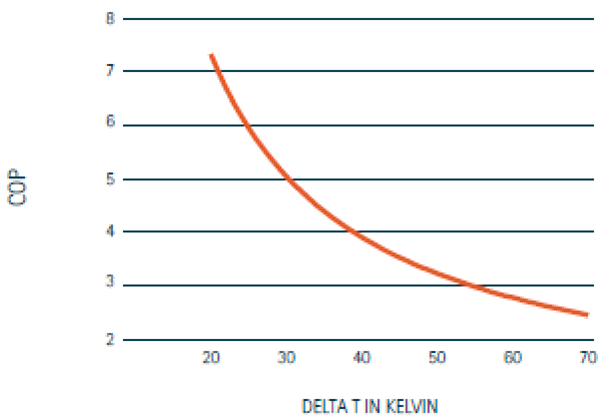

Figure 6. Relation between the value of the conversion coefficient φ and delta T in K (Nowak 2018, 28.)

European manufacturers of heat pumps providing an evaluation of the efficiency of an electrically driven compression heat pump in accordance with the EN 14511 standard. This allows for the comparison of different heat pumps in various conditions. Typically, the parameters of the power factor, performance factor, and utilization factor/ utilization/ seasonal performance factors (SPF) are determined. (Carvalho 2015, 211.).

Formula 5 describes the performance factor ε. The factor is the ratio of the current supplied thermal power to the effective power consumption of the device. (Popov 2005).

$$\varphi = \frac{P_{out}}{P_{int}}\ (5)$$

P_{out} - heat is given off by the heat pump per unit of time (W)

P_{int} - the average electrical power consumption of the appliance over a specified period, including the consumption of controller, feeders, compressor, and other components (W).

Power factors are measured at specific operating points. The operating point is defined by the intake temperature of the heat source medium, for example, air A or water W, to the HP unit and the outlet heating medium temperature. As mentioned earlier, the smaller the difference between the intake and output temperatures, the higher the power factor. Thus, the efficiency of a HP system and the inlet temperature of the heat source in operation is determined by the ambient conditions, climate zone, energetic quality. (Nowak 2018, 86.)

The utilization factor β of the HP unit indicates the system efficiency during a year, heating season, or the exploitation duration. This factor is counted by the relation between the whole delivered amount of heat per period of time to the amount of electricity consumed during this period of time by the heat pump installation as a whole. Moreover, this considers the energy fractions of pumps, controllers, auxiliary devices. Formula 6 illustrates the utilization factor. (Carvalho 2015, 211.).

$$\beta = \frac{Q_{out}}{W_{int}} \quad (6)$$

Q_{out} - the amount of heat supplied by the HP during the year (kWh).

W_{int} - the amount of electricity supplied to the HP during the year (kWh).

Factor β is utilized to ensure precise measurement and comparison of HP units across the various environment zones. It can provide a realistic picture of the energetic assessment and possibility of application of this technology. The different utilization factors can play an essential role for prospective climate zones evaluations and utilization of evidence worldwide, which will help design and install technology with maximum efficiency. The seasonal coefficient of a heat pump unit can change greatly depending on different factors such as regional environment ambiance, building structure, and requirements, demand for operation paraments. In different heat pump types, the additional local factors can significantly affect the seasonal coefficient. However, the difference between the heat source temperature and the radiator temperature is the most important factor for each heat pump unit. (Carvalho 2015, 211.).

Figure 7 shows the efficiency of some heat pump units. However, the performance is not comparable due to different influence factors. That is why SPF methodology is applied for calculation.

Heat pump	Country/Manuf.	COP/SPF	Source
GSHP	-	3 - 5	(Self, 2013)
GSHP	-	3.5	(Sarbu and Sebarchievici, 2014)
GSHP	-	3 - 4	(Mustafa Omer, 2008)
Air to water	-	4	(RHC-Platform, 2013)
GSHP	-	4.3	(RHC-Platform, 2013)
Brine/Water HP	BE, FR,UK	4.78 / 5.46	(Ecofys, 2013b)
Brine/Water HP	IT, ES	5.17 / 5.71	(Ecofys, 2013b)
Brine/Water HP	AT, DE	4.66 / 5.33	(Ecofys, 2013b)
Brine/Water HP	SE	4.34 / -	(Ecofys, 2013b)
Air to water		2.5 – 4.4	(IEA, 2011)
GSHP		2.8 - 5	(IEA, 2011)
GSHP	Central Europe	3.6	(EHPA, 2009)
Water to water	Daikin EWWD-J-SS	4 - 4.3	(Daikin, 2014)
GSHP	Daikin RWEYQ-T	5.2 – 5.9	(Daikin, 2014)
GSHP	Lenox MWC	3.9 - 4	(Lennox, 2014)
GSHP-water-air	Bosch-Geo 6000	4.3 -4.4	(Energy Star, 2014)
GSHP-water-air	Bosch Gr. Source	4.0 – 4.5	(Energy star, 2014)
GSHP with HW	BRYANT	3.6 – 3.8	(Energy star, 2014)
GSHP with HW	CARRIER	3.6 – 3.8	(Energy star, 2014)
GSHP with HW	ClimateMaster	3.8 – 4.6	(Energy star, 2014)
GSHP	GeoComfor	4.0 - 4.5	(Energy star, 2014)

Figure 7. Heat pumps efficiencies (Carvalho, 2015, 23.)

Figure 8 shows a comparison of the operation of three options for an autonomous source of heat.

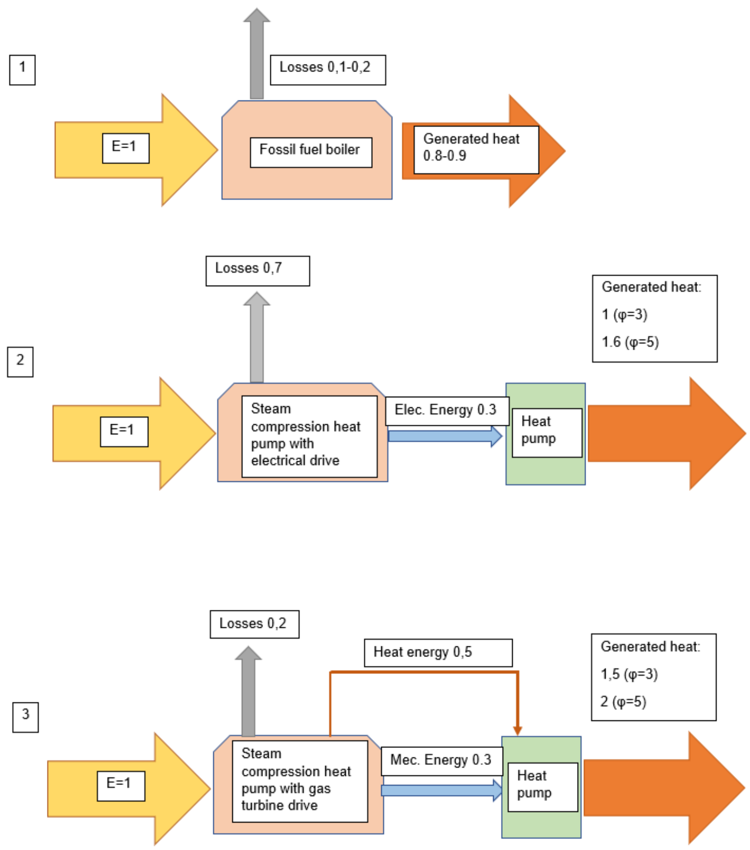

Figure 8. Comparison of heat production between 1. Fossil fuel boiler; 2. Pump with the electric drive; 3. The pump is driven by a gas turbine. (adapted from hyperphysics.phy).

All three devices are assuming the same amount of fuel E=1.

Losses during the work process are around 0.1-0.2 in the fossil fuel boiler, so generated heat is equal to 0.8-0.9. (CIPEC 2018).

In the case of HP with an electric drive from a thermal power plant, losses are around 0.7, so the total amount of electrical energy, which is delivered to the HP is 0.3. The pump's average value of low-potential heat at conversion factor φ = 3 equals 0.7 and φ = 5 to 1.3. Therefore, generating heat is equal to the sum of electrical energy and the average value of low-potential heat. In this case, 1 (φ=3) and 1.6 (φ=5). (hyperphysics.phy)

In the case of HP with a compressor drive unit that is powered by a gas turbine or engine, losses are around 0.2. The total amount of mechanical and heat energy delivered to the heat pump unit equals 0.3 and 0.5 values. The average value of low-potential heat of the pump at conversion factor φ = 3 is equal to 0.6 and φ = 5 to 1.2. Therefore, in the end, generate heat is equal to the sum of the amount of electrical energy, heat energy, and the average value of low-potential heat. In this case, 1.4 (φ=3) and 2 (φ=5). (hyperphysics.phy). From these results, it can be summarized that:

HP with an electric drive from a thermal power plant with a conversion factor φ <2.6–3 compared to a boiler does not provide fuel savings. Higher capital investment should be considered. HP with an electric drive can be economically justified at φ = 4-5. Using the HP with a compressor drive unit powered by a gas turbine or engine, the system can ensure operational fuel economy even at φ ≥ 1.5. However, the initial investment and additional costs can be much higher than the cost of a conventional boiler. Therefore, the economic feasibility of installing this HP unit must be considered in advance. Furthermore, if the conversion rate is low, it can influence the unreasonably long duration of the payback of the technology.

This simple example shows that the efficiency factor plays a great role in the outcome and viability of heat pump technology. However, in Sweden, electric-driven HPs are used even at φ <3, primarily due to the cost of electricity. In several European countries, nuclear and hydroelectric power plants are the basic power generating capacities, which means that electricity is relatively cheap. Therefore, even with φ ≤ 3, devices are economically feasible and are more profitable solutions since fossil fuel has a high price due to harmful emission taxes. (Nowak 2018, 86.)

2.2.1 Development of efficiency

New solutions and development of the performance of HPs are growing progressively. These solutions include modern design and mechanical engineering solutions, which can influence the heat pump operation performance. For the previous years, HPs efficiency had increased up to COP factor 6 in some cases. Currently, the average performance of GSHP is around 5, and A-W is around 3.5. (Miara, M, 2014). Figure 9 represents the evaluation of ground source and air-water HP performance data from 2008 to 2013.

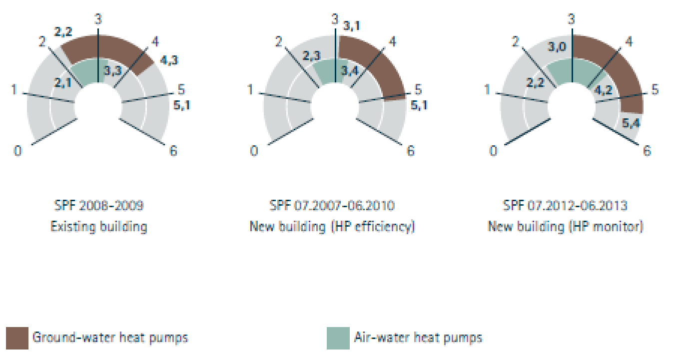

Figure 9. Evaluation of GSHP and A-W performance growth (Miara, M, 2014).

Lower input levels can be achieved with an increase in energy efficiency. Energy efficiency can be applied to different technological improvements:

- Heat pump systems with better efficiency.
- Replacement of fossil boilers.
- Reduction of carbon emission
- Decarbonization of technology

Let's compare input levels for different heating systems. For example, if a company uses electricity for space heating, replacing an electric system for space heating with an HP unit reduces 66% to 75 % of the electricity used according to the measured data. It means that the amount of energy required to warm one house with direct electricity can be used to warm 3 houses with HP system. (Nowak 2018, 86.). Therefore, this integration of HPs will lead to a sufficient decrease in total energy requirement. Figure 10 demonstrates the comparison of heat pumps over other heating solutions and will significantly impact renewable and environmental sides. Final energy demand means the amount of consumed energy to provide the amount of useful heat.

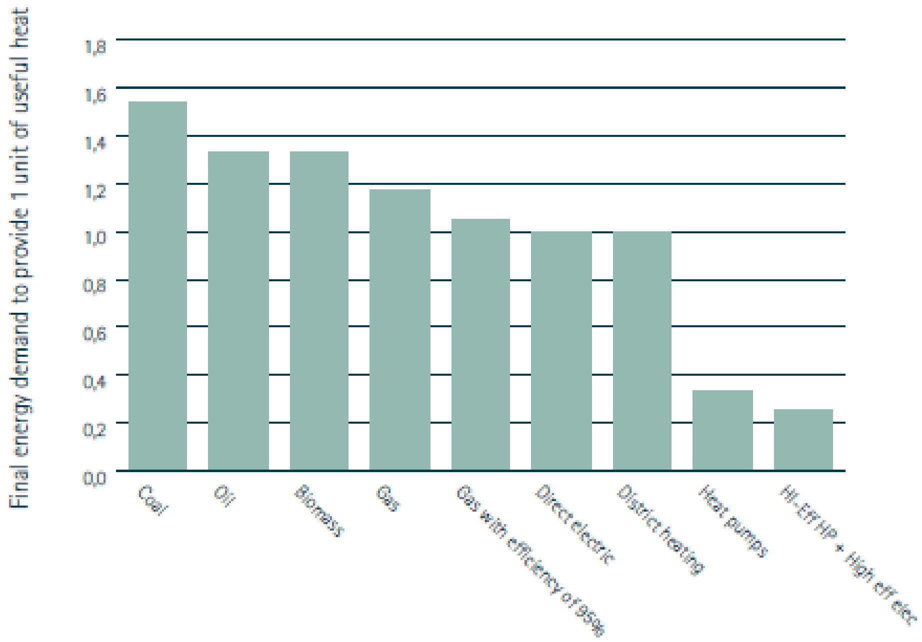

Figure 10. Comparison of energy consumption of different heating systems (Nowak 2018, 33.)

2.3 Environmental effect of heat pumps

Reduction of CO_2 emissions is one of the biggest goals of the whole world. Countries are trying to fight climate change and reduce harmful effects by developing new eco-friendly technologies. HP units can reach this target by switching from the usage of fossil fuels to renewable energy sources. However, many technology things are still stated in the developing stages. That is why a lot of questions and factors should be considered. (renewableenergyhub). These are factors that can influence the total CO_2 emission from heat pump technology:

- Manufacturing of a heat pump.
- Efficiency and energy consumption of heat pumps.
- Electricity grids.
- Location, climate zone, and design solution.

There are not exact values of CO_2 emissions and energy consumptions during the manufacturing process. However, heat pump technology can be referred to as renewable technology, which means that most raw materials and refrigerant fluids can be recycled. Therefore, this will reduce environmental effects and costs. (renewableenergyhub)

Lower input levels can be achieved with an increase in energy efficiency. The higher the COP of the HP unit, the more energy can be extracted from the environment per unit of electricity used to operate the pump. The decrease of CO_2 emissions from the HPs usage is measured as a difference of the HP CO_2 emissions to other possible technologies. (EHPA 2005). Figure 11 represents of CO_2 emissions of different systems.

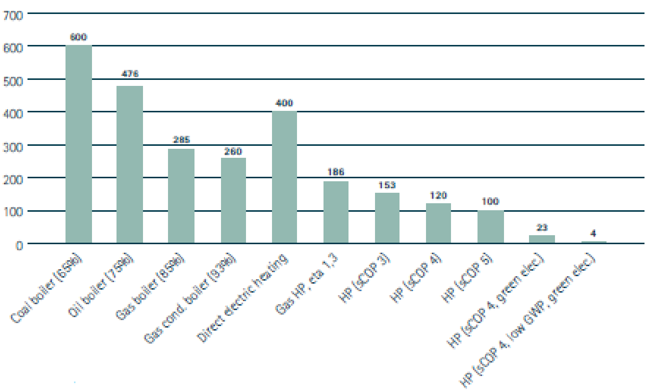

Figure 11. Comparison of CO_2 values of various heating systems (Nowak 2018, 34.)

From the figure can be seen, HPs can decrease CO_2 pollution by 40-65% when switching from gas and 70-85% when replacing coal or oil. These savings can play a huge impact on the environment.

Figure 12 shows how lower input levels for electrical grids and increased heat pump efficiency can reduce carbon emissions compared to gas or oil heating systems.

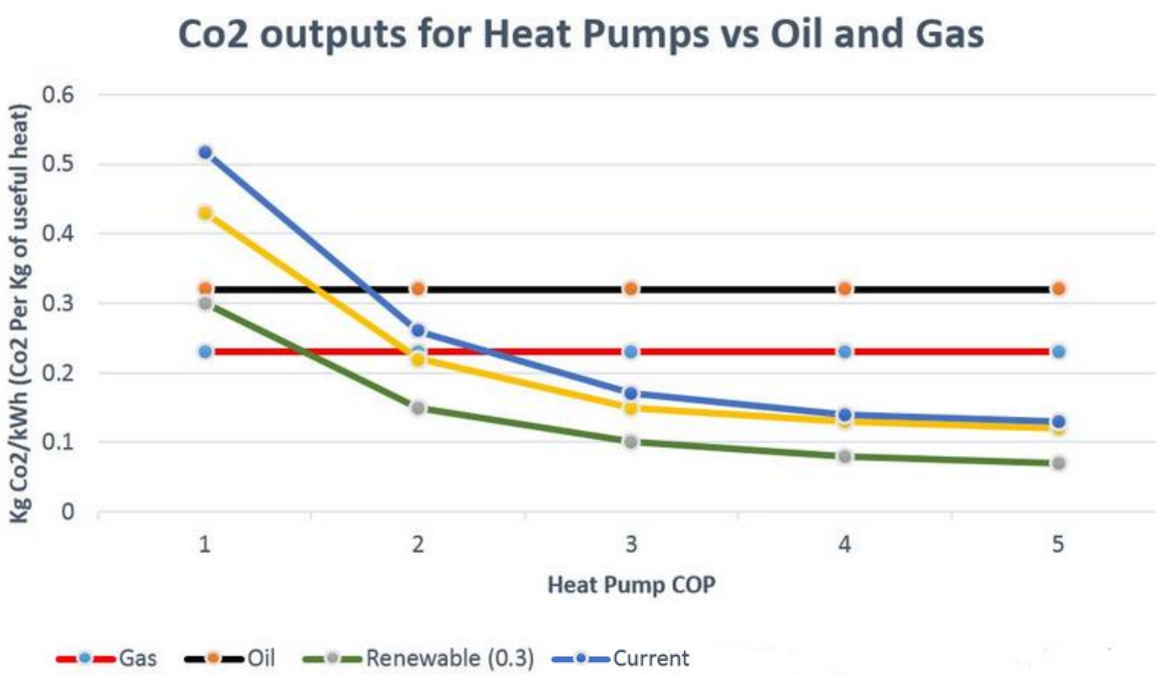

Figure 12. CO_2 outputs for different sources of energy (renewableenergyhub).

The red and black lines are showing pollution from gas and oil sources. The blue line indicates the CO_2 emissions for heat pumps using nuclear or coal power for electricity generation. The green line shows the level of emissions from the electricity that the renewable sources had produced. This figure demonstrates that the efficiency developments and improvements can reduce the demand for fuel boilers. Combination heat pumps with low-emission technologies can develop energy-efficient and renewables-based hybrid heat pump systems. (renewableenergyhub.co)

Moreover, the development of electrical grid systems can influence the growth of heat pump technology, efficiency, and reduction of CO_2 emissions. Future smart electricity networks will be focused on the flexibility of the energy demand and its continuous monitoring. (ectogrid.com). Figure 13 represents the scheme of traditional grid networks and future grid networks.

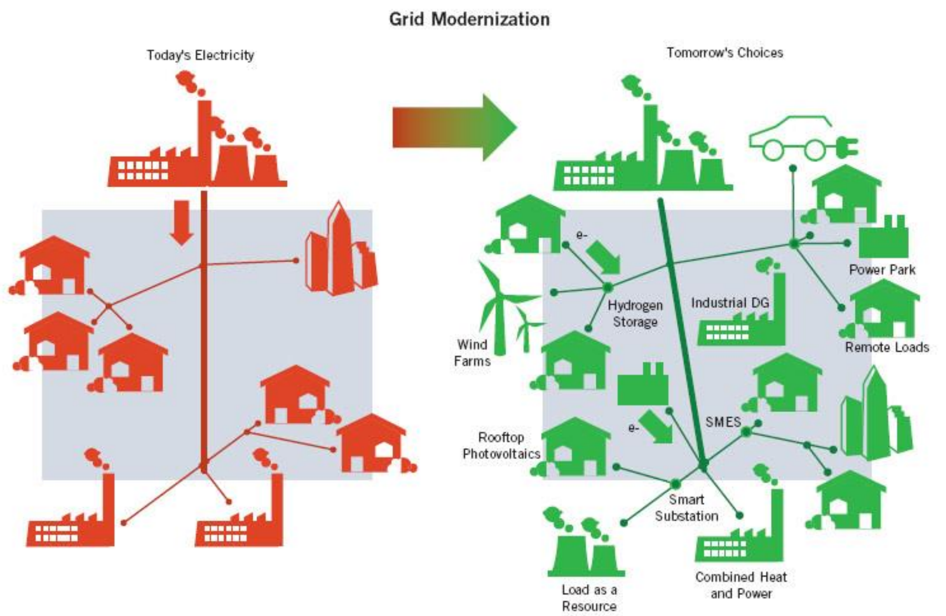

Fig. 1. The IEEE's version of the Smart Grid involves distributed generation, information networks, and system coordination, a drastic change from the existing utility configurations.

Figure 13. Traditional grids network and future grid network (Siméia Azevedo 2017)

From the figure 13 can be seen that electricity producer, for example, power plant or solar plant factories can monitor the demand from users and adjust the supply of energy in time. A smart network brings a digital web tech that opens a bilateral interaction between suppliers and users of energy. This interaction can lead to several advantages:

- **Less waste energy**. HP units and systems can be equipped with thermal or electric storage and batteries. Heat can be stored in these devices and used when demand occurs. (i-scoop.eu)
- **Less CO_2 emissions**. Sensors can provide real-time data about energy consumption. Moreover, self-learning systems can understand consumer demands and adjust parameters of temperature and energy consumption. As a result, these monitoring systems reduce the total amount of generating energy. (i-scoop.eu)
- **Less cost of energy**. A smart network can reduce the final cost of energy because it can be used properly. (i-scoop.eu)

Additionally, a proper construction of the building and correct installation of HP unit inside it can affect the final performance of the HP unit and its CO_2 emission level. Therefore, civil and construction companies should follow the following rules:

- Standardized proved solutions for different building types, sizes, and designs.
- Approaches that ensure heating, cooling, and supplying of hot water according to the climate zone and types of energy generation.

2.3.1 An overall picture of the environmental impact of heat pump integration

Climate change is a threat to the further development of humankind. Greenhouse gas emissions led to environmental pollution and an increase in the average temperature of the Earth. (EEA 2017). Greenhouse gas emissions are caused by the extraction and burning of fuels, industrial, road transport, and residential sectors. Figure 14 represents the amount of greenhouse gas emissions in Europe per period from 1990 up to 2017.

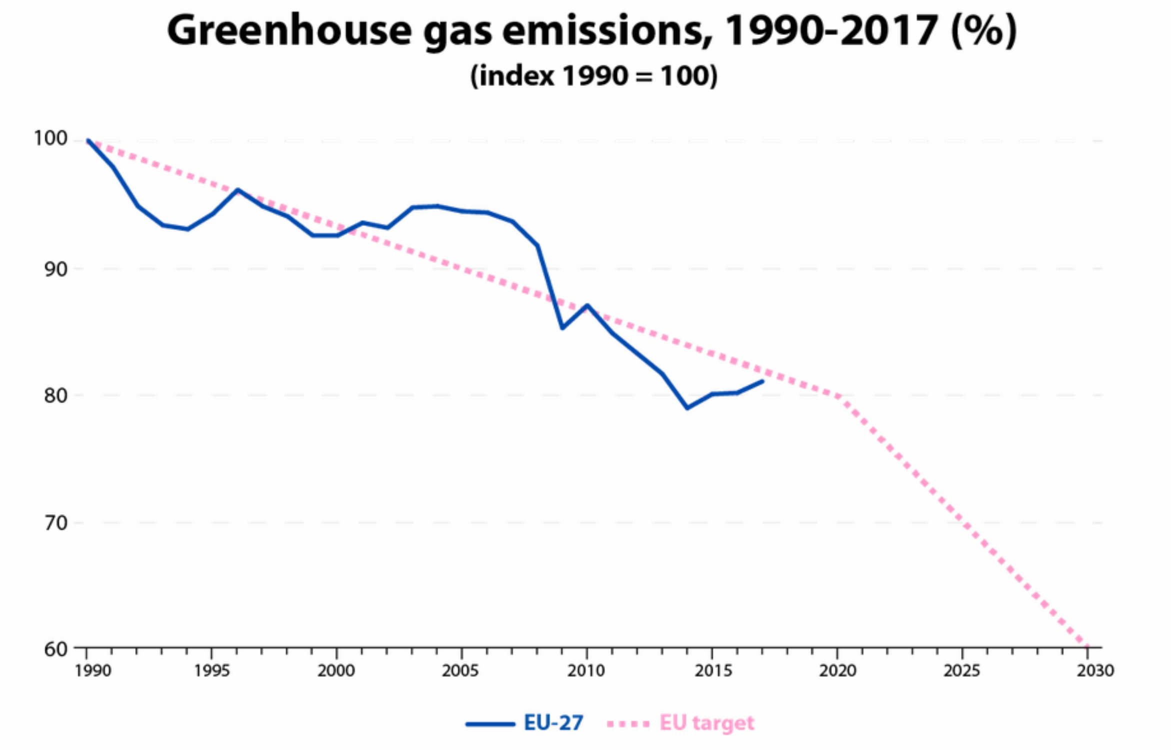

Figure 14. Greenhouse gas emissions, 1990-2017 (EEA 2017).

As shown in Figure 14, EU greenhouse gas emissions declined between 1990 and 2017. In 2017 amount of emissions had reduced by 20% compared to 1990. EU target for 2030 can be completed if EU countries continue developing renewable technologies and integrating them into society.

Figure 15 shows the share of EU greenhouse gas emission by type of industry sector for 2017.

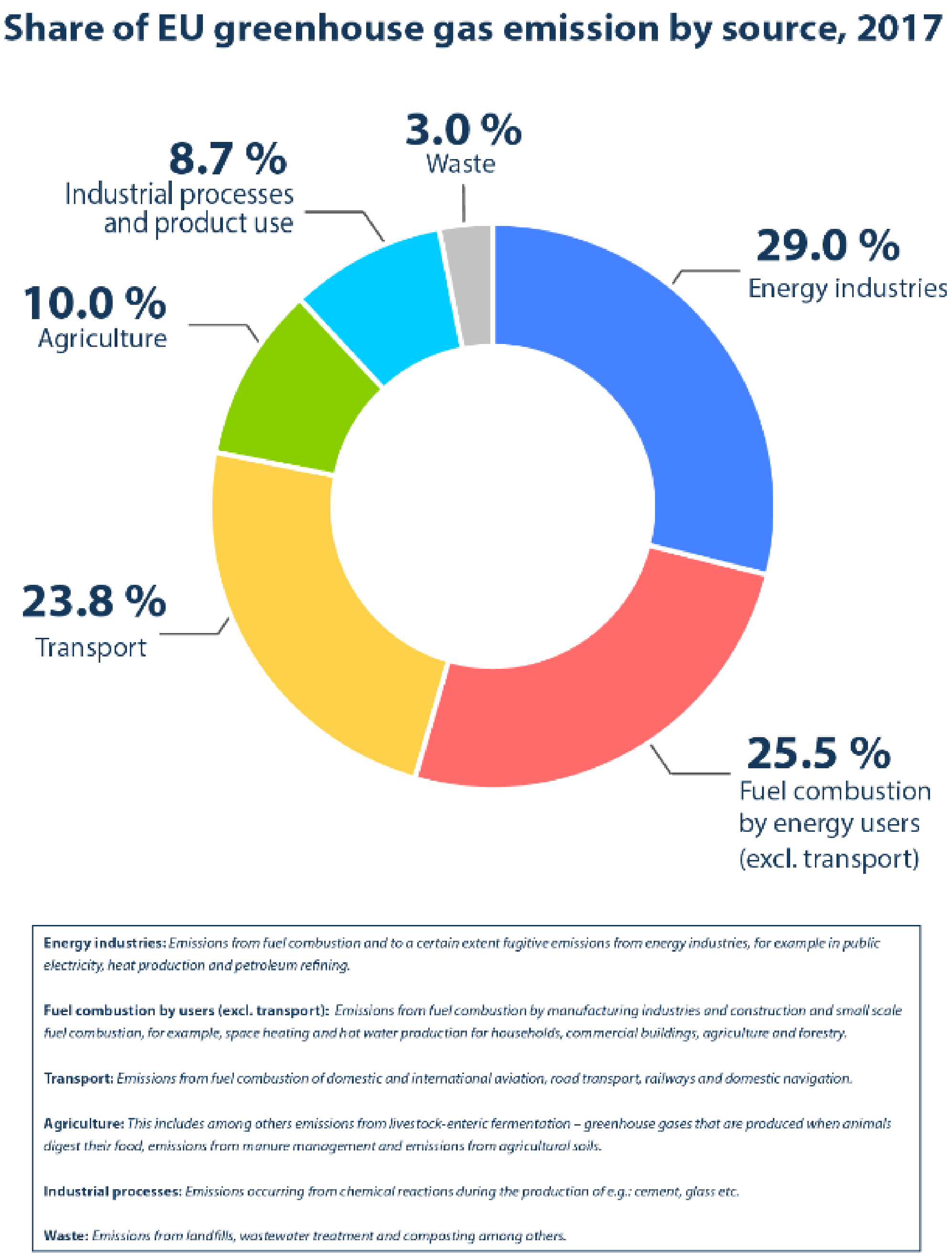

Figure 15. Share of EU greenhouse gas emission by type of industry sector for 2017 (EEA, 2017).

From figure 15 can be seen that large shares of EU greenhouse gas emissions are produced by the **energy industries** and **fuel combustion** sectors. Therefore, the integration of heat pumps can sufficiently decrease the usage of non-renewable energy sources in these sectors, eliminate the harmful CO_2 pollution effect. Figure 16 represents a difference of the final emissions of various heating systems.

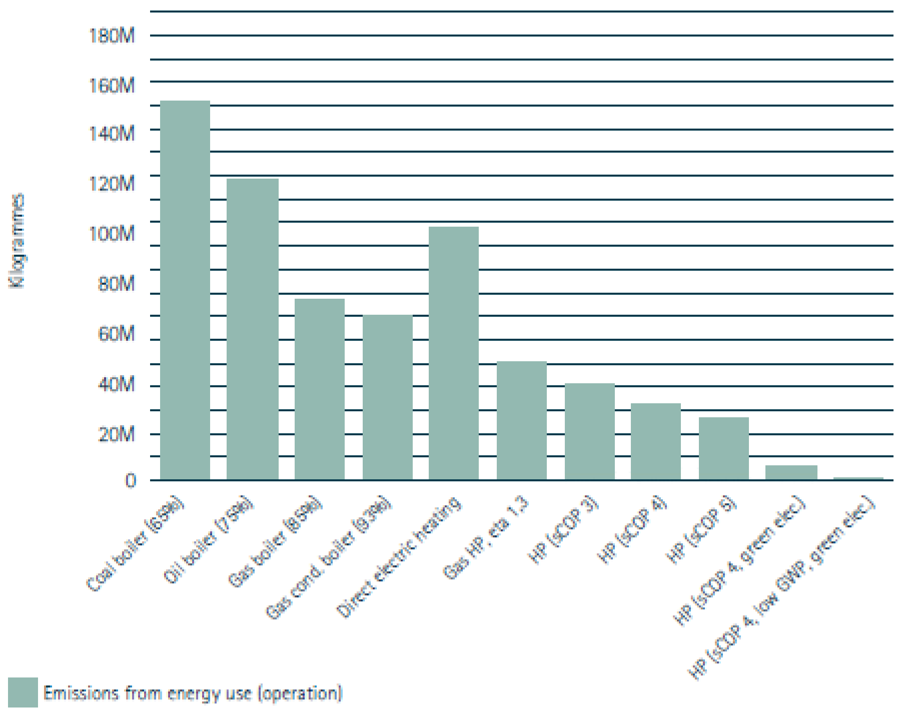

Figure 16. Total lifetime emissions of different heating solutions (EHPA 2017)

This figure shows that HPs with the smallest COP have lower emissions than the best fuel combustion unit. Moreover, this figure shows that developing electricity networks and combining this technology with HPs reduces sufficient emissions and opens the possibility of deploying smart-efficient HP systems with zero emissions.

2.4 Application of heat pumps

Nowadays, HPs are widely used all over the world. The fabrication of HPs in each country is mainly focused on meeting the requirements of the domestic market. (ehpa.org). However, most of all heat pumps find their deployment in two main market sectors:

- Residential and commercial construction sector.
- Industrial sector.

Heat pumps have numerous applications in the building sector:

- **Commercial buildings**. Heat pumps can be integrated into office buildings, restaurants, hotels, food courts, shopping malls, cinemas, athletic facilities. (ehpa.org)
- **Residential buildings**. Heat pumps can be deployed in private sectors and cottages, multifamily and single-family houses, dormitories. (ehpa.org)

- **Remote settlements**. Development of new and remote territories and construction there. For example, it is expensive and extremely inconvenient to import diesel fuel or coal to the islands. For this reason, of the 6500 islands in the Åland archipelago between Finland and Sweden, only 65 are inhabited. (ehpa.org)

New near-zero energy buildings and developed design solutions of buildings insulation, sufficient heat distribution surfaces and materials, air-ventilation systems, and other solutions allow efficient deployment of heat pumps. Combining all these factors will provide the interest from the side of end consumers and development from the side of manufacturers and building companies. The best heat pump efficiency rates and requirements from the aspects of heating, cooling, hot water supply, and dehumidification can be achieved only with modern approaches and design solutions. (ehpa.org) Figure 17 shows a representation of heat pump systems inside different buildings.

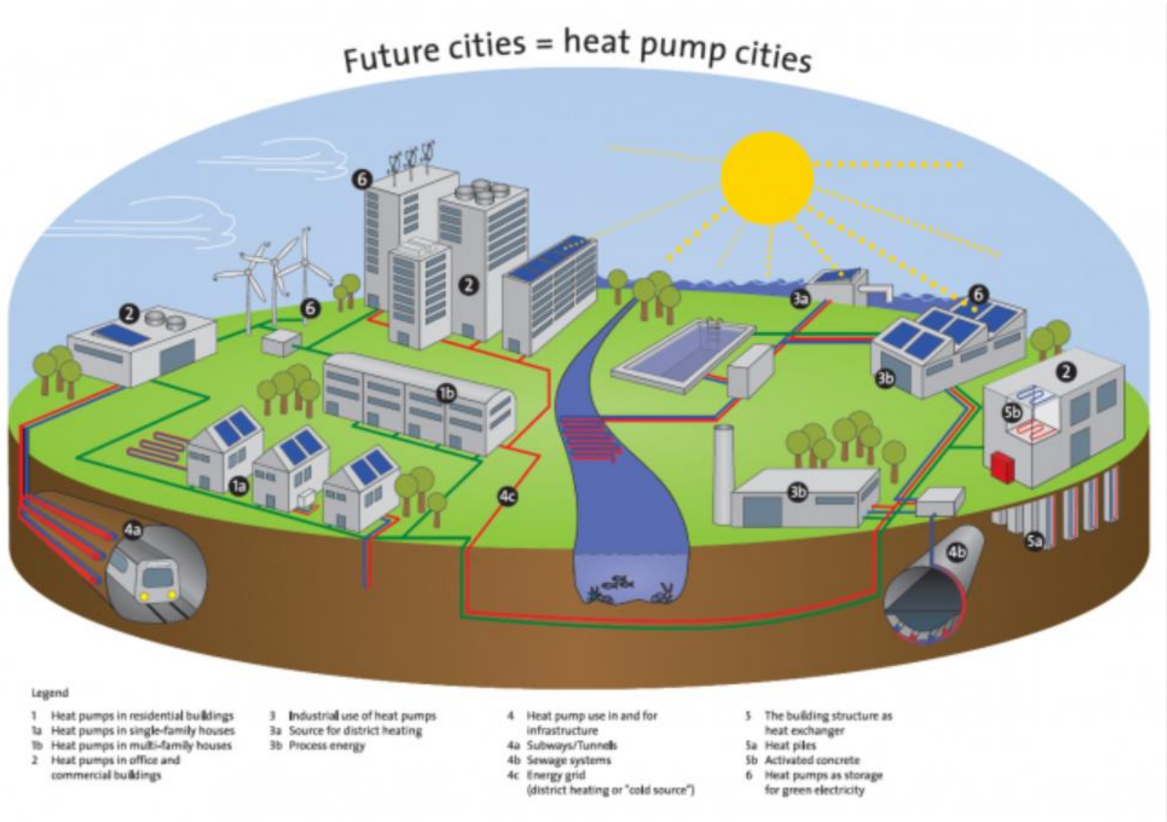

Figure 17. Heat pump systems inside different buildings (BUILDUPEU).

Example of actual application in the building sector. In low-rise, residential buildings located in the suburbs of Vienna, a HP system has been deployed to reduce the total cost of heating projects for buildings: higher capital costs pay off by offsetting lower operating costs. Outside air is utilized as a source of low-grade heat. Each apartment in the technical room has one heat pump with a 295-liter storage tank. The heating system uses a low-temperature

warm floor. Air-liquid heat exchangers are installed near the buildings. The HP provides hot water transfer and space warming. In the climatic conditions of the suburbs of Vienna, the heat pump system works quite efficiently: the conversion factor, in this case, is about 4. In several buildings for the preparation of hot water, solar water-heating collectors are provided. Some of the buildings are equipped, in addition to these collectors, with photovoltaic panels for generating electricity. (HPs in Modern Industry 2017, 204). Figure 18 shows a schematic representation of heat pump work operation for this example.

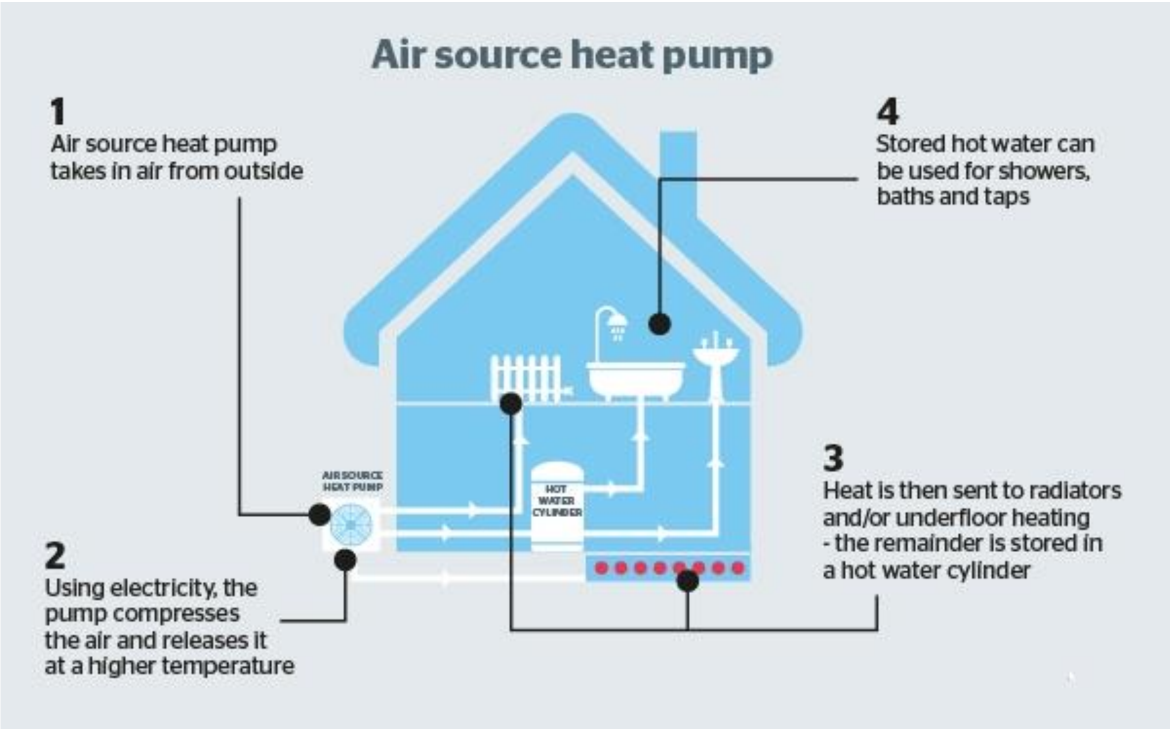

Figure 18. Air source heat pump operation in the cottage (SWDART).

Industry sectors are consuming a lot of energy for their demands. There is a great potential for industrial heat pumps to provide this energy efficiently and reduce related greenhouse gas emissions in the industry. The possibility of integrating HP technology in industrial exploitation varies on the T °C levels required in manufacturing. The market is interested in high-temperature industrial HP units with major capacities, which can provide temperatures more than 100 °C and unique solutions to reduce energy supply. However, the possibility of rapid deployment of these solutions in the nearest future is not expected. Therefore, technology is needed for future development and tests. (ehpa.org). Typical applications and industrial process where industrial heat pumps can be used are:

- **Food industry**. In the dairy products manufacturing process, milk should be pasteurized. Other manufacturing processes: sterilization of the product, the concentration of liquid product/juice, tempering, boiling.

- **Textiles industry**. Manufacturing processes like wash water heating, coloring, and drying of the end product.
- **Chemical industry**. Inorganic salt manufacture can use heat pumps in concentrating salt solutions.
- **Paper industry**. The drying process, bleaching.
- **Wood industry**. Pulp manufacturing can use in the process of concentration. Drying and gluing of the wood end products.
- **Plastics industry**. Supply of the heat during injection molding, preheating of the mold, or plastic. Drying of the end product.
- **Mechanical engineering industry**. Surface treatment of the product. Cleaning after the welding operation.

Figure 19 shows industrial applications of heat pumps.

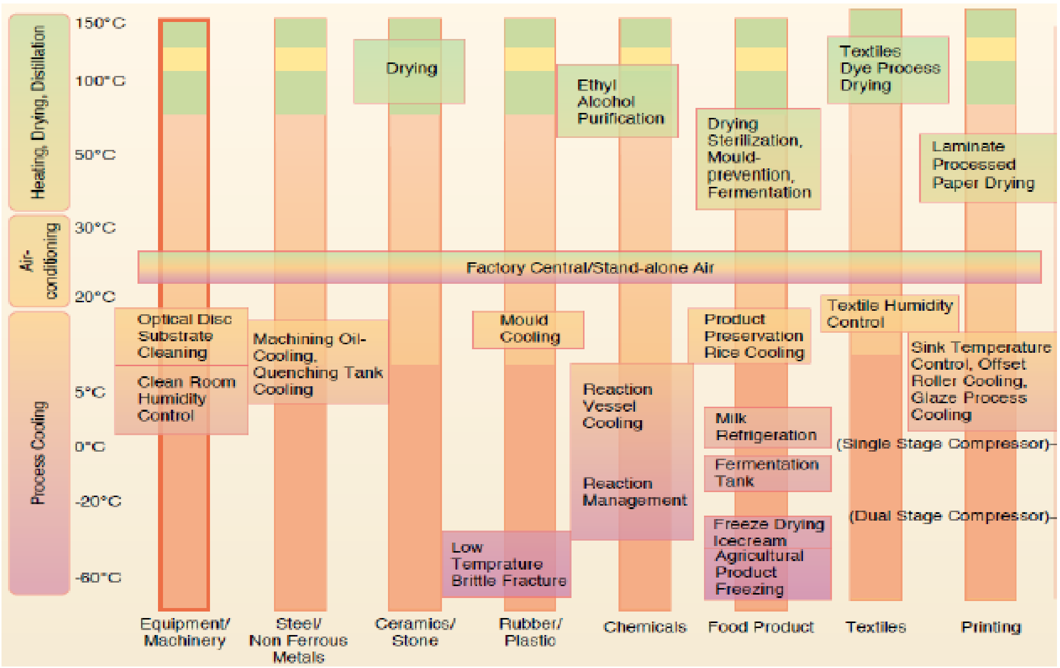

Figure 19. Industrial applications of heat pumps (IEA Heat Pump, Annex 35/13).

Figure 20 shows applications and temperature ranges for different industrial processes.

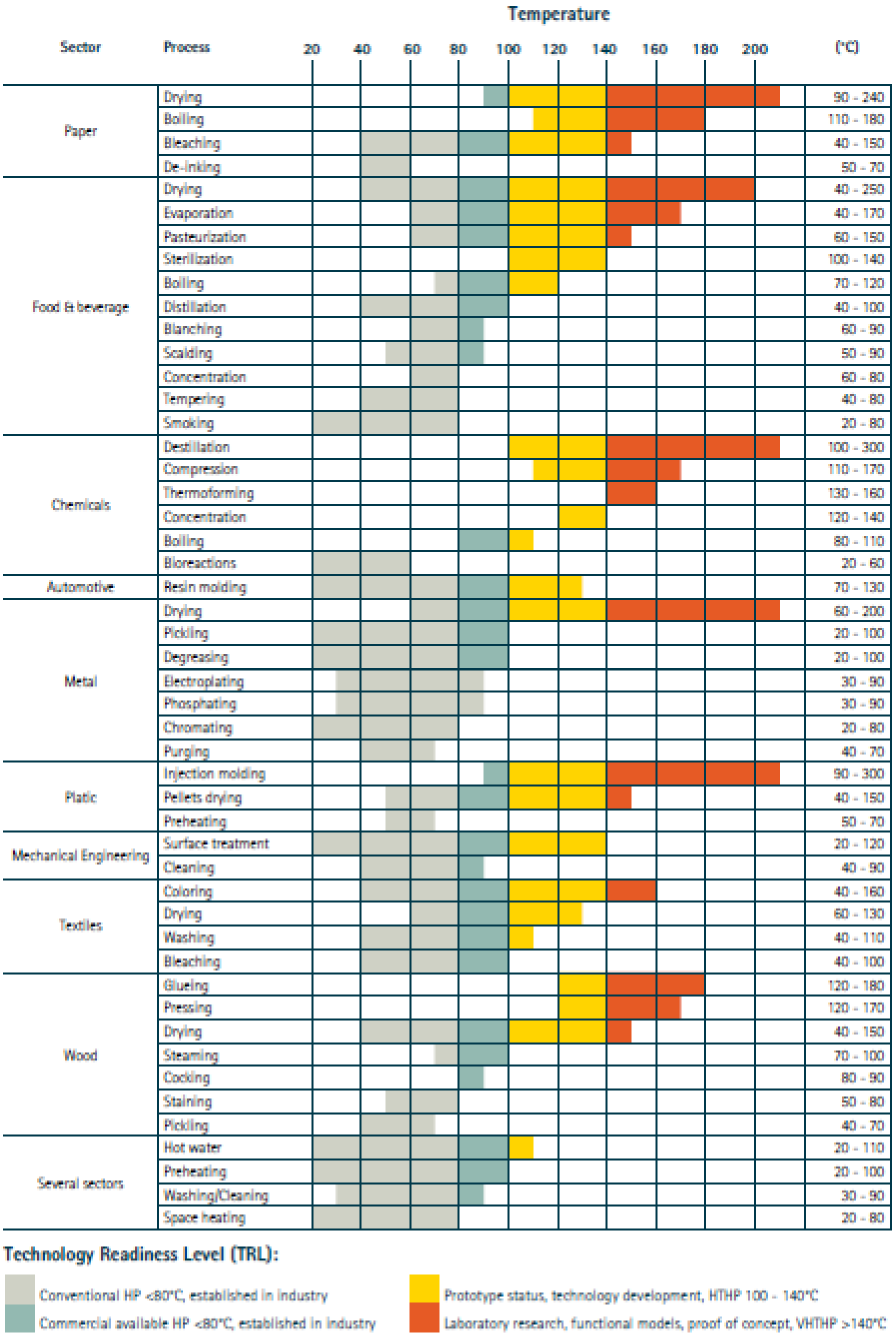

Figure 20. Temperature ranges of different industrial processes (Lauterbach et al. 2011).

An example of an actual application in the industrial sector is Katri Vala's HP plant. HELEN company has combined all previously mentioned approaches in one close energy cycle. This smart design consists of network grids, air ventilation, water heating systems, industrial heat-pump unit, and smart sensors. The combination of all these solutions balances the energy in the system, effectively utilizes available energy streams, decreases energy consumption and carbon emssions in a city. Katri Vala's HP plant is the biggest in Europe and consists of 5 large HPs. This construction can ensure heating and cooling simultaneously.

HPs are able to produce 90 MW of warming and 60 MW of refrigeration. The plant is linked to Helsinki city's district network; it means fewer heat losses and achievement of the highest efficiency. Smart-renewable energy city is already existing, and HELEN company is continuing researches and developments of new solutions. (HELEN 2017). Figure 21 shows HELEN's city energy system.

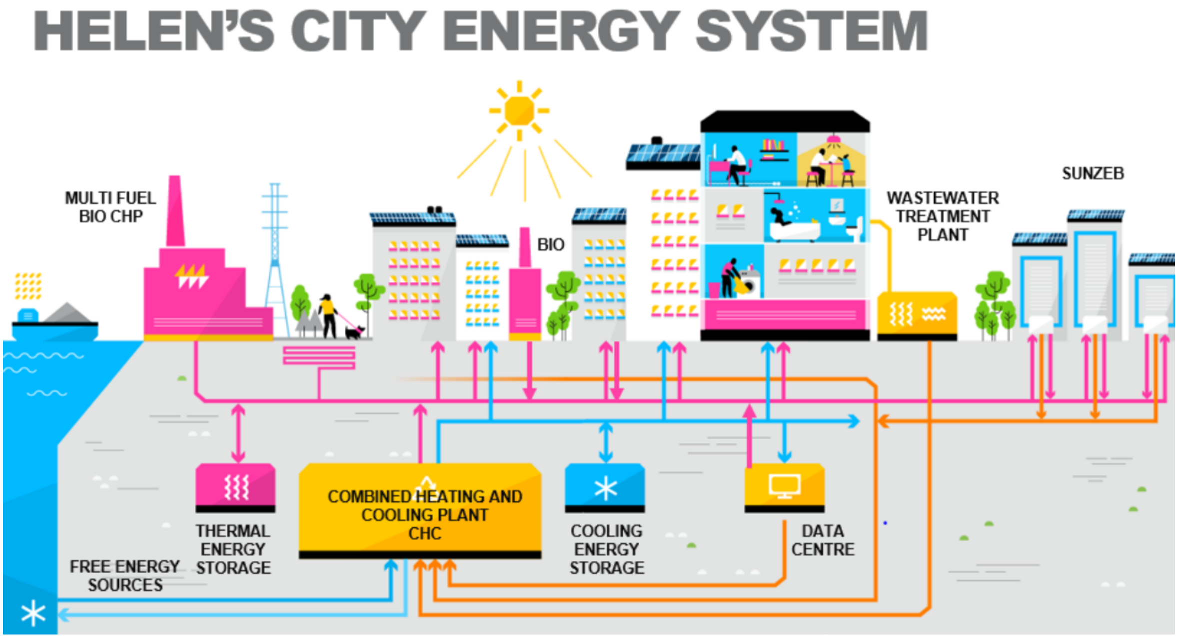

Figure 21. HELEN's city energy system (HELEN 2017).

3 Procurement and supply chain management

3.1 Procurement chain management

At the present stage, industrial enterprises should focus not only on their interests but also on the interests of consumers since the market is very competitive. In the world of entrepreneurship, procurement chain management is given special attention. Procurement chain management makes it possible to calculate the optimal costs and helps companies to save all the main resources. (Monczka 2009, 841.)

There is no single term in logistics management that would fully define what procurement management is. However, the management of the procurement chain is understood as a process of providing any enterprise with material resources. Therefore, procurement chain management has a certain specification, and it is defined as a separate element of enterprise management. (Monczka 2009, 841.)

The main functions of procurement chain management include identifying material resource needs, searching and evaluating existing offers, selecting suppliers, and concluding contracts and new orders. Regardless of whether it produces or sells goods, almost any enterprise has its service for purchasing, transportation, and storage of goods, using outsourcing services. (Monczka 2009, 841.)

In general, the term procurement chain management can be described as the company's activities that are aligned at assuring that the company receives the required quality and amount of raw materials, products, and services in the right place, from a reliable supplier that responds in good time to its responsibilities, with proper service and at a favorable price. (Monczka 2009, 841.).

Moreover, Procurement chain management can be considered from two aspects:

- **Tactical side**. The company deals with basic procurement according to a plan of everything necessary for the enterprise to avoid a shortage of the necessary material resources, goods, services, or finished products.

- **Strategic side**. The company deals with the procurement management process itself, communication, interaction with other departments of the company and external suppliers, and the needs and requests of the end user, planning, development of new procurement schemes and methods.

3.1.1 Detailed procurement chain

The procurement of goods by an enterprise or a trade organization is the most problematic stage in providing material resources. The company's marginal profit and profitability directly depend on the quality of the procurement system and assortment planning. Therefore, the management should pay close attention to the orderliness of the procurement process, unification of its algorithm, high quality of purchased products, and compliance with its standards to avoid the formation of illiquid trade balances in warehouses in the form of materials and products. (Monczka 2009, 841.)

Effective procurement management can become a competitive advantage for enterprises by reduction of manufacturing costs while maintaining the quality-level and comfortable rates for the end-users. Moreover, it is worth noting that the supply chain: procurement, production, and sales in modern conditions should be based on marketing concepts. For example, the concept of supply is developed, and only then the concept of the development of production and procurement. Marketing concepts are needed in order make research the supply market in detail. Aftermarket research, procurement chain management ensures the development of marketing concepts from an entrepreneurial perspective, which helps implement and expand existing developments. (kissflow.com 2021). The stages of procurement management include the following:

1. Identification and calculation of needs and procurement planning.
2. Searching for strategies and choosing a procurement method.
3. Market research and analysis to identify potential suppliers.
4. Selection of suppliers.
5. Preparation and formation of an order and a purchase plan.
6. Payment and delivery of goods from the supplier's warehouse.
7. Reception, delivery, and storage of the order.
8. Analysis and control of orders.
9. Minimization and elimination of losses during transportation.
10. Optimization of the final price of the order.

Moreover, when planning procurement and levels of safety stocks, an effective assessment of the negative consequences of various types of risks plays an important role. These risks

need to be assessed at different stages of planning. (kissflow.com). The following groups can be distinguished:

- Macroeconomic risks
- Arising risks from interaction with suppliers and intermediaries in the logistics procurement channels
- Logistic risks associated with the loss of consumer properties of the supplied materials, goods, services during delivery, warehouse processing of goods, customs operations.

3.1.2 Approaches in procurement chain management

The company's procurement process must have an exact algorithm. The procurement management service must consider the multistage and complexity of the procurement business processes and the fact that information about products and services passes through all subdivisions of the trading company. (Monczka 2009, 841.). Therefore, this service interacts with:

- Marketing service to analyze the pricing and competitiveness of commercial offers for the purchase of products.
- Logistics service to agree on the planned and minimum warehouse balances for the product line presented for the sale of goods.
- Warehouse service to coordinate issues on the placement of purchased products and their shipment to customers.
- Accounting department to resolve accounting and posting of products and issues related to the quantity and quality of purchased products.

The procurement chain management system is an essential link in business processes, including supply function, logistics, information, and analytical functions. The work of all other services, and first of all sales, depends on its effectiveness. Most often, these steps in the procurement chain process are performed sequentially. However, on any of them, there can be a backward move. For example, a company may need to research a new potential supplier in case of supply problems. Each of these stages is extremely important in the general scheme and has its specifics. Each stage must be automated so that the entire procurement process works as a whole. (Monczka 2009, 841.). Figure 22 shows the types, forms, and methods of procurement chain management.

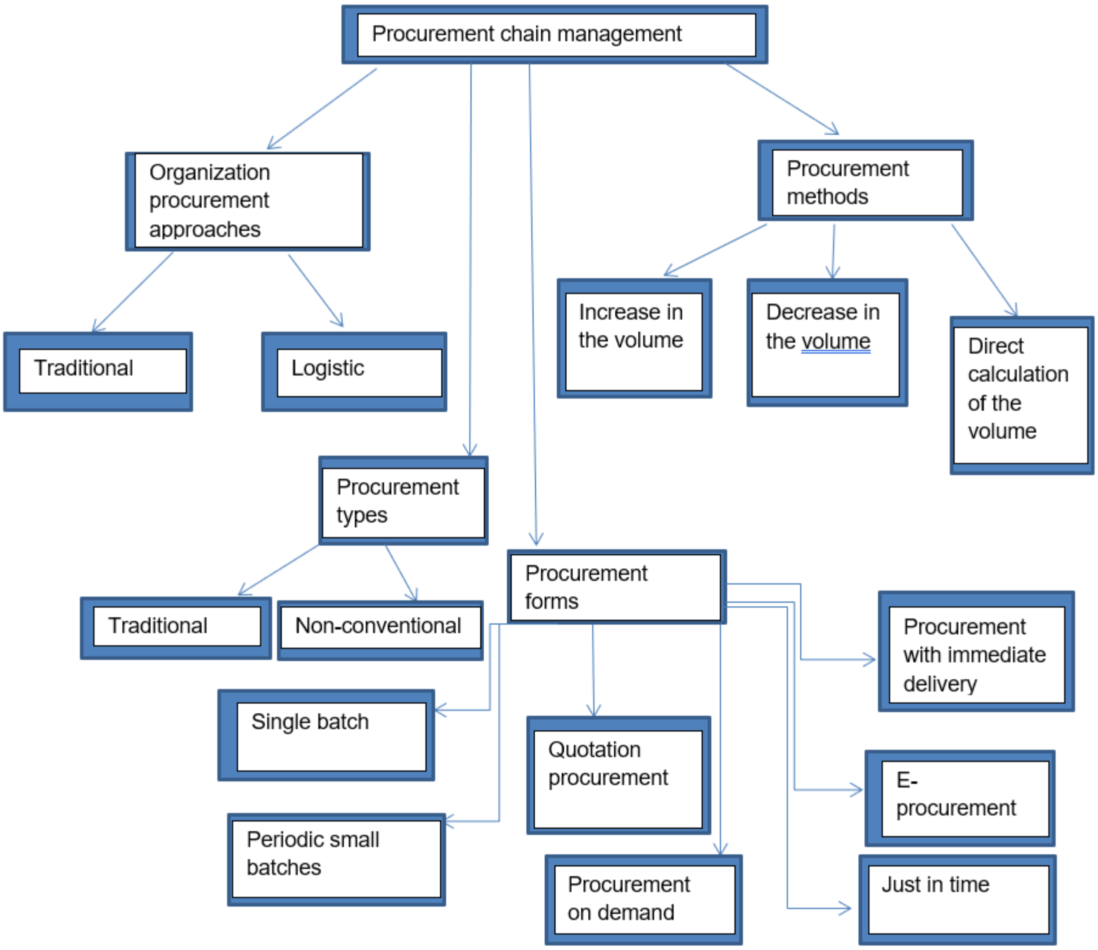

Figure 22. Procurement chain management approaches, types, forms, and methods. (adapted from Monczka 2009).

The organization of procurement chain management is based on two approaches:

- **Traditional approach**. Management of procurement logistics processes is divided between the divisions of the enterprise.
- **Logistic approach**. All procurement procedures are managed by one department. The logistics approach allows managing the procurement process more efficiently at all its stages.

There are also two types of the procurement:

- **Traditional type of procurement**. Particular goods and raw materials that are needed for a specific production.
- **Non-traditional type of procurement**. Services are quite comprehensive and include many services, such as advertising, audit services, insurance services, travel services.

When choosing the form of procurement, one should take into account such parameters as:

- The volume of consumption of the supplied products for each type.
- Shipping rates.
- The amount of transport.
- Availability of warehouses.
- The level of material costs.
- The presence of transport communications.

The company regulates its procurement activities according to the chosen method:

1. **The method of increasing the volume of procurement**.
    - The demand for certain types of goods is taken into account.
    - Demand is analyzed throughout the year.
    - The optimal number of stocks throughout the year is determined.
    - The stock accumulation decision is made based on the number of orders.
2. **The method of reducing the volume of procurement**.
    - Sales analysis is carried out monthly.
    - The types of products whose stocks should be reduced are highlighted.
    - Criteria are determined by which a decision is made to reduce certain types of stocks.
    - The share of non-marketable goods tends to a minimum.
3. **Method of direct calculation of procurement volumes**.
    - The calculation is carried out for a specified period.
    - The number of sold products is calculated.
    - The average amount of required stocks is calculated.

There are several forms of procurement. Table 1 shows an analysis of forms of procurement.

Form of procurement	Regularity	Advantages	Disadvantages
Based on the long term of the contract	Procurement on demand	Acceleration of capital turnover	Increase in the need for constant control of volumes and delivery times
Wholesale	Procurement of goods in one batch, single time	Representative discounts, documentation turnover, is simplified	Cost and inventory levels rise, warehouse demand increases
Procurement on a regular basis	Periodic procurement in small batches	Capital turnover accelerates, storage costs decrease	High probability of ordering goods in excess
Procurement on demand	Constantly used resources and goods	Capital turnover increases, storage costs decrease	Continuous control of stock levels and volumes
Procurement of goods with immediate delivery	Resources and goods that are rarely used	Delivery is timely; storage costs are reduced	Rising costs for documentation

Table 1. Forms of procurement. (adapted from studme.org).

Electronic procurement or E-procurement. The e-procurement system automates and expands manual trading processes, from requisition formation to payment to suppliers. E-procurement contains back-office ordering systems, e-marketplaces, and supplier webpages. Currently, companies frequently apply digital technologies to supervise their supply chains efficiently, predictably, transparently, and securely. E-procurement ensures up-to-date data on the condition of customer requirements and orders. It allows consumers to agree with the suppliers for the automatic delivery of products when the consumer’s stocks are close to zero. A company can track the stages and fulfillment of the order online. On the web page or in the special app, the delivery stage and location, the readiness of the order, or the payment details are displayed. It allows consumers to monitor the order online and save time on the calls and data requests.

Moreover, this can reduce the order time when companies have different time zones. Electronic exchange and storage of data improved the transparency of the orders. (Monczka 2009, 841.). E-procurement systems can be applied for the following purchasing functions:

- **Electronic application**. Create and approve purchase requisitions and place purchase orders using web-based software.
- **Electronic selection of suppliers**. Recognition of potential suppliers for a specific product category.
- **Electronic tenders**. Notifications of electronic tenders / electronic requests for acceptance, receiving bids.
- **Electronic administration**. Collection and dissemination of procurement information from internal and external parties, tracking and accepting goods, and payment authorization using Web technology.

The maintenance of its own logistics infrastructure is associated with the presence of conditionally fixed costs, the value of which is not directly determined by the volume of transported or stored stocks of raw materials, materials, finished products, or goods. Therefore, to make a final decision, it is necessary to compare the specific and general procurement costs from an outsourcer on the one hand, and own infrastructure, on the other. This task in supply chain logistics is known as make or buy or MOB. (Will Kenton 2021). Among the main reasons that can lead to the choice of the decision to do are:

- Maintaining the existing specialized experience and knowledge in production. The desire to reduce the cost of production.
- Lack of suppliers of products of the required quality and prevention of possible monopoly of suppliers.
- Insurance of a possible violation by suppliers of their obligations under supply contracts.
- Usage our surplus labor resources or production capacities (areas) and protect personnel from temporary dismissal.

Administrative and management costs are essential for inventory, which is characterized by low cost and high ordering costs. These costs can be reduced by automating the purchase order processing or by switching to Just-in-Time or JIT procurement. First of all, the undoubted advantage of the JIT strategy is its accessibility and simplicity. The required prod-

uct must be in production at exactly the moment when it is required. The result of this approach is to reduce storage costs and ideally bring them to zero. In other words, an enterprise should have stocks that are exclusively necessary for production, eliminate the appearance of defects in the procurement system, and most importantly, shorten the production cycle by reducing the time for procurement. It should be remembered that it is possible to prevent unwanted elements such as surplus, loss, and imbalance. (Caroline Banton 2021). Based on the approach, we can say that there are five consecutive steps to prevent potential losses:

1. Introduce the flow of materials.
2. Reduce equipment restart time.
3. Increase productivity.
4. Reduce batch sizes.
5. Introduce JIT.

The undoubted advantages of the approach include cost reduction, reduced analysis time, improved supply quality, rational production. However, despite several distinctive advantages, the JIT method also has some weaknesses. (Caroline Banton 2021). When implementing the approach, companies can face the following problems:

- Increase in the cost of transport.
- Dependence on a particular supplier is increasing.
- The risk of production losses increases due to delays in deliveries.
- An increase in the need for continuous information exchange.
- There is a need to move warehouses closer to the point of consumption.
- In unforeseen or critical situations, the company incurs heavy losses.

The company must consider various types of expenses. It is necessary to consider the administrative, management, marketing, and transaction costs associated with analyzing the market for goods and services and building relationships with suppliers in total costs. (Monczka 2009, 841.). Procurement costs included in total costs should be classified as follows:

- Expenses associated with market research on conditions, specific groups and types of goods, and their quality characteristics.

- Expenses of finding potential suppliers, negotiating, and establishing business relations with them.
- Expenses associated with assessing the quality characteristics of goods from different suppliers.
- Expenses of warehouse processing and storage of stocks.
- Purchase costs, customs duties, and payments, insurance services upon delivery of the goods.
- Expenses for packaging, shipping containers, labeling of goods.

The cost structure recommended when calculating the cost of performing logistics services or works by employees of companies with insourcing and purchasing them from third-party organizations with outsourcing. The break-even model can be used to consider the strategic plans for the development of an enterprise. This is a classical interpretation, which involves comparing the total production costs and proceeds from the sale of finished products. The minimum amount of income at which all costs are fully recouped is called the point of indifference. The larger the output volume relative to a given point, the more profitable the production will be and the faster the return on investment will occur. It is advisable to modify this model to solve the MOB problem. (Elyashevich 2016).

The volume V_i of services/works performed, at which it would be indifferent to the company to perform them on its own or to purchase from third-party contractors, is calculated according to formula 7. (Elyashevich 2016).

$$V_i = \frac{\sum_{j=1}^{N} C_{con.j}}{C_{sup.i} - C_{own.i}} \quad (7)$$

$C_{con.j}$ - conditionally fixed costs associated with maintaining its infrastructure for calculation items j=(1, …, N).

$C_{own.i}$ - variable costs per unit of service performed or work of the i-type when using own infrastructure.

$C_{sup.i}$ - the cost of a unit of an i-type service or work purchased from a third-party organization, supplier, and contractor.

If the amount of the resource purchased at the moment exceeds the break-even point, it can be advisable to consider the issue of organizing own production. If not, then it may be worth returning to this issue in the future, in accordance with the strategic plans for the development of the enterprise. When solving the MOB problem regarding logistics services,

in the denominator of the fraction of Formula 7, it is necessary to substitute the difference between the cost of a unit of service purchased from a third-party logistics intermediary and variable costs per unit of similar work performed using own infrastructure. (Elyashevich 2016). Figure 23 presents a graphical interpretation of the indifference point model for solving the MOB problem. Table 2 presents proposals for the cost structure of companies analyzed when solving the MOB problem for warehouse processing and storage of purchased operational resources, using their own infrastructure or third parties' involvement.

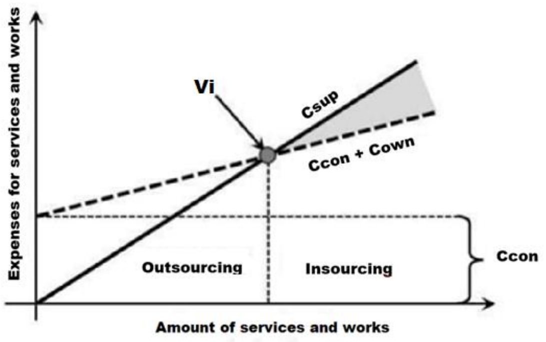

Figure 23. Graphical interpretation of the indifference point model for solving the MOB problem. (adapted from Elyashevich 2016).

Type of expenses	Equipment rent	Usage of own equipment
Equipment rental cost	YES	NO
Equipment maintenance cost	NO	YES
Expenses for auxiliary materials	NO	YES
Taxes for equipment usage	NO	YES
Equipment repair and maintenance costs	NO	YES
The cost of electricity consumed by the equipment	NO	YES
The cost of electricity for warehouses and shipping points	YES	YES
Social security contributions	YES	YES

Table 2. The cost structure of companies in solving the problem of MOB. (adapted from Elyashevich 2016).

3.2 The efficiency of procurement in the enterprise

As mentioned earlier, the procurement process, from the point of view of the buying process, is the awareness of the need for material resources, the search and selection of suppliers, and negotiations on the terms of the transaction. This requires many different skills, including predicting needs and maintaining good relationships with suppliers. Therefore, the procurement management service should be formed carefully and thoughtfully, using modern technologies, and be integrated into a single complex with other key services of the trading company, sales, logistics, warehouse. Their effective interaction is a guarantee of the company's profitability and long-term presence in the market. A competent and efficient procurement system helps to minimize costs and increase the company's profits. (Monczka 2009, 841.) An effective procurement chain management system allows:

- Reduce purchasing prices for products and services.
- Optimize the purchased volume and make purchases in quantity sufficient for productive and uninterrupted operation.
- Improve sales performance by efficiently picking trade balances.
- Build an effective staff structure without overloading the company with a large amount of staff.
- Improve the financial performance of the organization.

When determining the effectiveness of procurement operations, it is necessary to comprehensively evaluate the work of the firm's procurement service, taking into account:

- Implementation of the procurement plan in terms of volume and quality indicators.
- Fulfillment of the firm's budget and the amount of savings.
- The volume and value of lost sales.
- The total volume of transactions.
- Labor productivity.
- Transport costs.

Based on these data, it is possible to roughly determine the cost of a particular logistics operation in the process of implementing procurement functions. Also, three main indicators by which the procurement chain management activities are monitored are time, prices, and supplier reliability. (studme.org)

1. **The time factor**. It means monitoring delayed deliveries as well as the consequences of delays. Also, indicators such as:
   - The share of backorders.
   - Percentage of cases when delivery delays caused tangible problems.
2. **Price factor**. It means analyzing the prices paid for the procurement of products, particularly comparing them with previously targeted prices, and trying to avoid such deviations from the procurement budget. A comprehensive analysis should be subjected to:
   - Standard or estimated prices for basic material resources.
   - Index of average prices paid for products by product groups.
   - Price changes resulting from negotiations, analysis, better packaging, and rationalization of transportation.
3. **Supplier reliability factor**. It means the conformity of the quality and volume of its deliveries to the conditions fixed in the contracts. The following parameters should be taken into account when choosing a supplier:
   - The share of late deliveries and delivery refusals.
   - Share of deliveries that do not comply with product quality contracts.
   - The share of orders delivered contrary to the agreement, not in a single batch.
   - The quality of services of various carriers, measured by travel time and the number of damaged goods.

The company can view the quality of the suppliers' fulfillment of their contractual obligations by accumulating and processing statistical information on deliveries of purchased operating resources. Table 3 shows calculated indicators for analyzing the supplier base to segment it and develop solutions to improve the efficiency of procurement activities.

Indicator	Unit	Definition
Share of defective resources	%	The ratio of the number of defective resources to the total amount of supplied resources over a period
Accuracy of filling out the order documentation	%	Number of errors in invoices
Completeness of order fulfillment	%	The ratio of the number supplied resources to the total ordered amount of resources
Lead time deviation of the order	%	The ratio of the average deviation of the lead time to the average supplier lead time for the period
Percentage of orders delivered on time	%	The ratio of the number of orders delivered on time to the total number of orders for the period
Unit purchase costs	EUR/ product	The sum of costs of purchased resources of a specific assortment divided by the total demand for these resources

Table 3. Calculated indicators for analyzing the supplier base. (adapted from studme.org)
The obtained results can be used for:

- Development of relationships with the most reliable suppliers.
- Coordination of economic and technological planning.
- Termination of business relationships with suppliers.

Moreover, when managing the procurement chain of operational resources, it is advisable to divide companies' suppliers into three categories: replacement suppliers, preferred and

strategic. This classification allows you to rank suppliers according to the importance of establishing cooperation ties and long-term cooperation in supply chains. (studme.org). Table 4 represents the possible classification of suppliers.

Supplier category	Features
Replacement suppliers	• Indiscernible or easily replaceable resources. • Low cost and minimal importance of resources for • Short-term relationships with suppliers. • High competition of suppliers in the market.
Preferred suppliers	• The importance of reliability and efficiency in supply chains is high. • Replacing the product may cause temporary disruption to the cycle. • Competition exists, although it may be partially limited. • Regular communication should be maintained with suppliers.
Strategic suppliers	• The selection of suppliers is carried out according to strict criteria. • Changing the supplier can lead to severe losses for the company. • The number of suppliers for each category of resources is minimal. • Long-term supplier relationships.

	• The implementation of modern processes for the development of cooperation is being carried out.

Table 4. Classification of suppliers. (adapted from studme.org).

In conclusion, it should be noted that to determine the effectiveness of the procurement chain management of an enterprise, a comprehensive assessment of the work of the entire procurement service, and not of its individual divisions, should be carried out. It is important to consider compliance with the different factors and apply different approaches for detailed assessment. (studme.org)

3.3 Supply chain management

There are many different supply chain formulations and visions. In general, a supply chain refers to a network of organizations that transforms raw materials and initial components into final products and provides final products to meet the end consumer's demands. It should be noted that, in general, there are two approaches to defining the essence of supply chains: object and process approaches:

- The object approach allows you to decompose the supply chain structure to determine its main participants. In general terms, the supply chain is represented by the central company, a set of suppliers and consumers, and various intermediaries interconnected by the supply chain. (studme.org).
- The process approach is effectively used when the supply chain is investigated and designed in the form of a sequence of processes and various kinds of flows between the supply chain links. (studme.org).

The nature of the presented approaches to the definition of the supply chain has a somewhat limited vision of the supply chain. Therefore it is necessary to merge the two approaches for a more complete and comprehensive definition of the supply chain. It turns out that the supply chain is a linear, ordered set of participants in the logistics process who carry out the corresponding logistics operations and are interconnected by the movement of material, information, and other related flows. Moreover, it is necessary to clarify and define the boundaries of the supply chain. For example, according to the territorial principle, depending on how many states the supply chain is located within, the supply chain can be national or international. Therefore, the supply chain can be described in more detail as a linearly ordered set of participants in the logistics process who carry out appropriate logistics operations and are at the same time in the customs territory of different states, which are

interconnected by the movement of material, information, and other accompanying streams. (studme.org). Figure 24 shows a typical supply chain consisting of logistics links and demonstrating the stages of the life cycle of a product, from the purchase of raw materials and components for its production to services related to the use of goods by the end consumer.

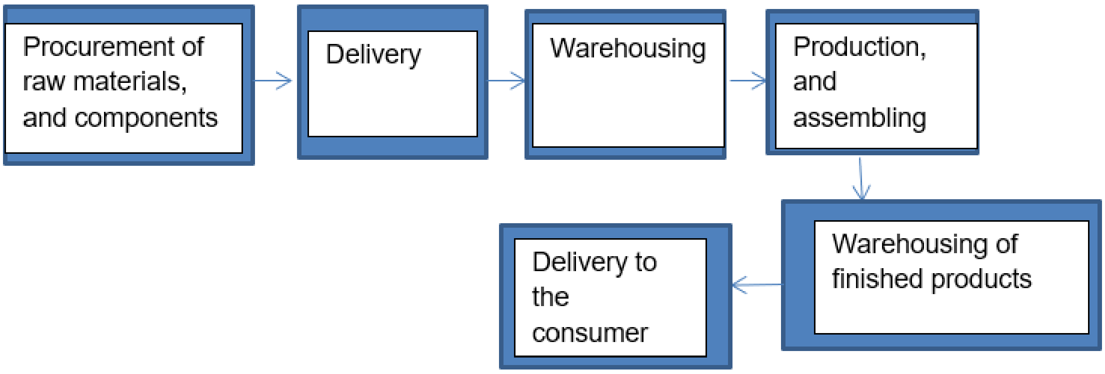

Figure 24. Supply chain structure. (adapted from Hari Vasudevan 2014).

The main companies in the supply chain links can be functionally subdivided into the following participant groups:

- manufacturer
- suppliers
- consumers
- intermediaries.

All participants can be conditionally allocated depending on the degree of influence exerted on the management of logistics processes.

- Key participants in the supply chain are represented by independent companies that directly impact the flow of logistics operations. (studfile.net)
- Auxiliary participants are represented by participants, who indirectly affect the management of the operations in the supply chain by providing services to key participants to perform their direct functions. (studfile.net)

The differentiation of the companies in the supply chain is necessary to simplify the management of operational processes. Therefore, the auxiliary companies can be defined in the earlier stages. These companies can ensure the required assistance to the key participants

by utilizing the specific knowledge, skills, years of experience, and facilities. (studfile.net). Figure 25 represents key and auxiliary participants in the supply chain.

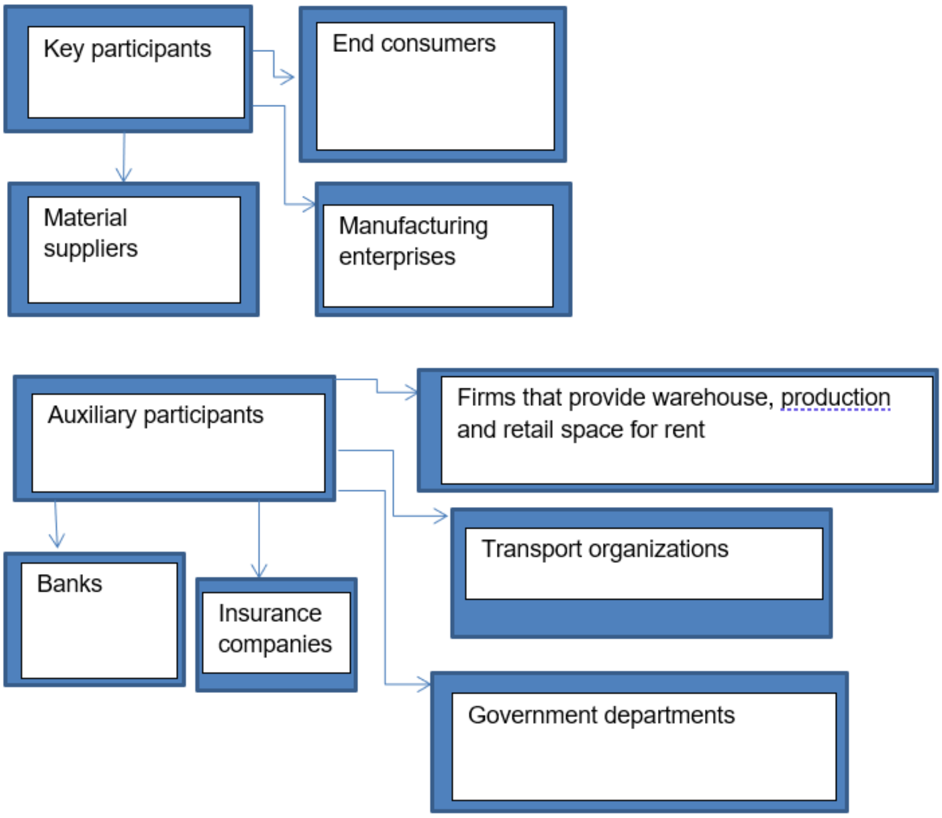

Figure 25. Classification of participants in the supply chain. (adapted from studfile.net).

In the supply chain, logistics links are interconnected by the movement of material and information flows, which, due to certain features, can be both direct and reverse. Material flow is the main flow of the supply chain and is a set of inventory items that have weight and size, cost, and other characteristics and are in a state of movement along with the logistics links of the supply chain. In the physical movement of inventory items, they are subjected to various types of activities: loading, unloading, packing, transportation, sorting. In addition to being in a state of motion, elements of the material flow also constantly change their physical state. (studfile.net). Thus, the entire life cycle of the material flow in the logistics supply chain can be represented by the following stages:

1. At the procurement stage, the material flow is represented by raw materials.
2. During the production process, it is transformed into an unfinished product.
3. Upon completion of the production process, the output is finished products.
4. The material flow is converted into a flow of goods, falling into distribution centers.

5. In the sphere of consumption, the flow of goods is transformed into a flow of consumer goods.

The effective movement of the material flow is accompanied by auxiliary flows: financial and information flows. (studfile.net).

- Financial flow is a set of funds moving in a specific direction between logistics links in the international supply chain, which are necessary to ensure the uninterrupted movement of material flow along the supply chain. It arises from financial transactions in the form of payment for raw materials, settlement with banking institutions, payment of customs duties in the form of taxes and customs duties, receipt of proceeds. (studfile.net).
- The process of movement of material and accompanying financial flows generates a large amount of information that requires timely processing, systematization, and communication to counterparties of supply chains. The collection of all information and messages that move within the international supply chain and serve as the basis for managing logistics processes is called information flow. Thus, information flow plays an essential role in coordinating logistics processes in the supply chain. This flow is the initiator of the material flow, generates its occurrence, determines its direction, intensity, and content. (studfile.net).

3.3.1 Market overview

It is necessary to assess and analyze the global and local market, the prerequisites for the deployment of technology, possible barriers, and problems when carrying out commercial activities. In our case, this is the production of heat pumps. Therefore, the planning stage in supply chain management is the initial and one of the most important stages. At this stage, customers' needs are investigated, the market and the possibility of technology integration are assessed, market barriers and competitors are studied. Moreover, the planning of operational stocks and volumes is carried out, the volume of supplies of raw materials and materials is calculated, the location of warehouses and delivery points is planned, the management of inventory items along the entire supply chain is assessed.

The European Heat Pump Association EHPA reported that in 2020 the stock of heat pumps totaled 13.9 million units. This amount of heat pumps influenced the reduction of carbon emissions by 38.3 million tons. Figure 26 shows the contribution of total heat pumps amount and sold HPs in 2018. (stats.ehpa)

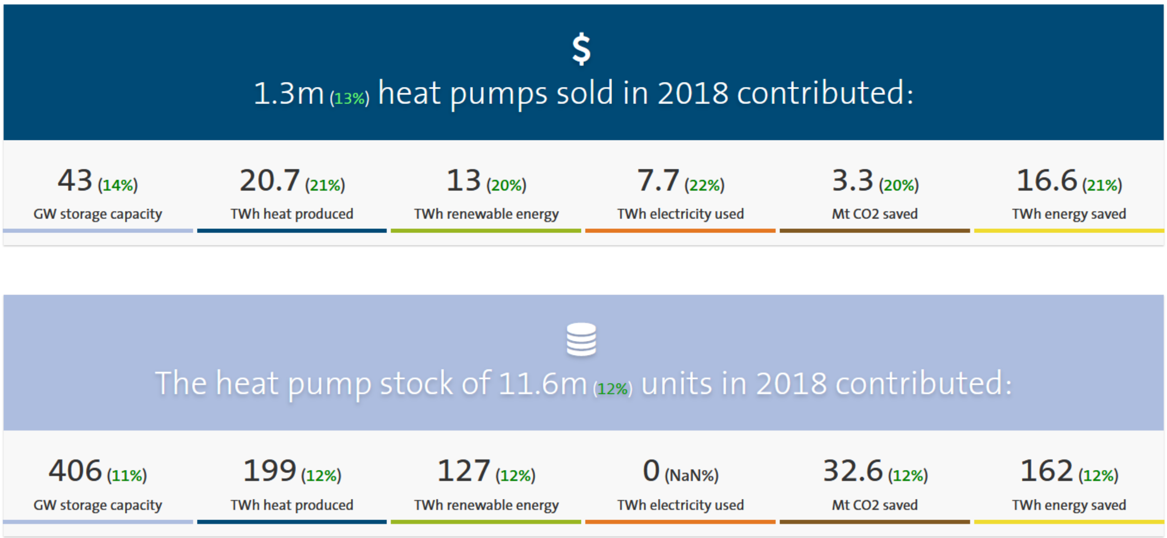

Figure 26. Heat pumps contribution on the EU market for 2018 (stats.ehpa).

It can be seen that heat pumps amount increases and sufficiently influences the market and future technology development and deployment. The European heat pump market and sales have been growing steadily from 2012 to the present. Sales have exceeded one million per year over the past three years, and at the moment, there are no prerequisites for a decrease in sales. Figure 27 shows the development of the market over the past 10 years.

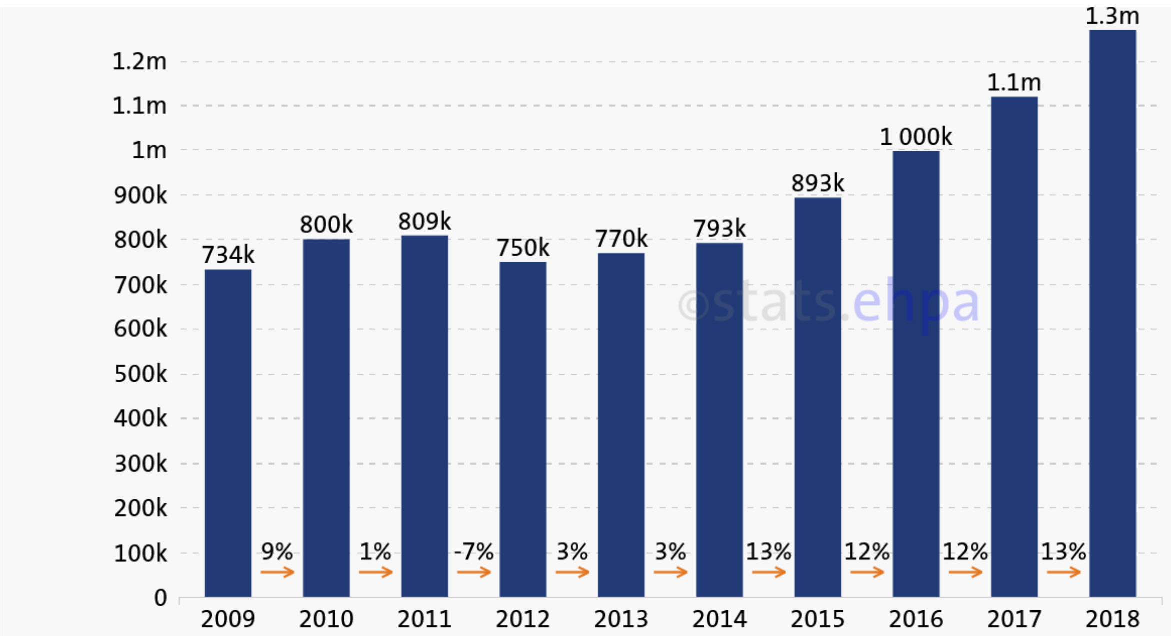

Figure 27. Sales development (stats.ehpa).

France, Italy, and Spain are the three largest consumers of heat pump technology. Therefore, these countries have the highest sales figures for heat pumps in the European market. Moreover, the sales of heat pumps in relation to 1000 households in a particular country a

kind of density of distribution of heat pump equipment, the five leaders are as follows: Norway (46 per 1000), Estonia (29 per 1000), Finland (28.8 per 1000), Sweden (23.4) per 1000), Denmark (21 per 1000). The most significant potential for growth is seen in Germany and the UK. Figures 28 and 29 represent these data.

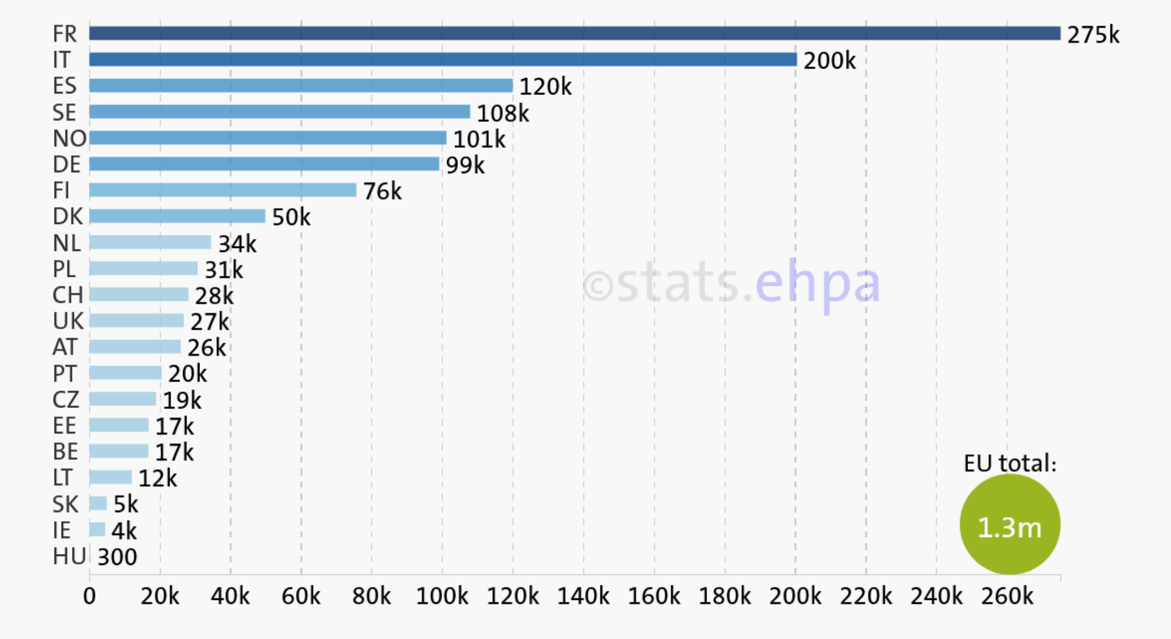

Figure 28. Heat pump units sold by country (stats.ehpa).

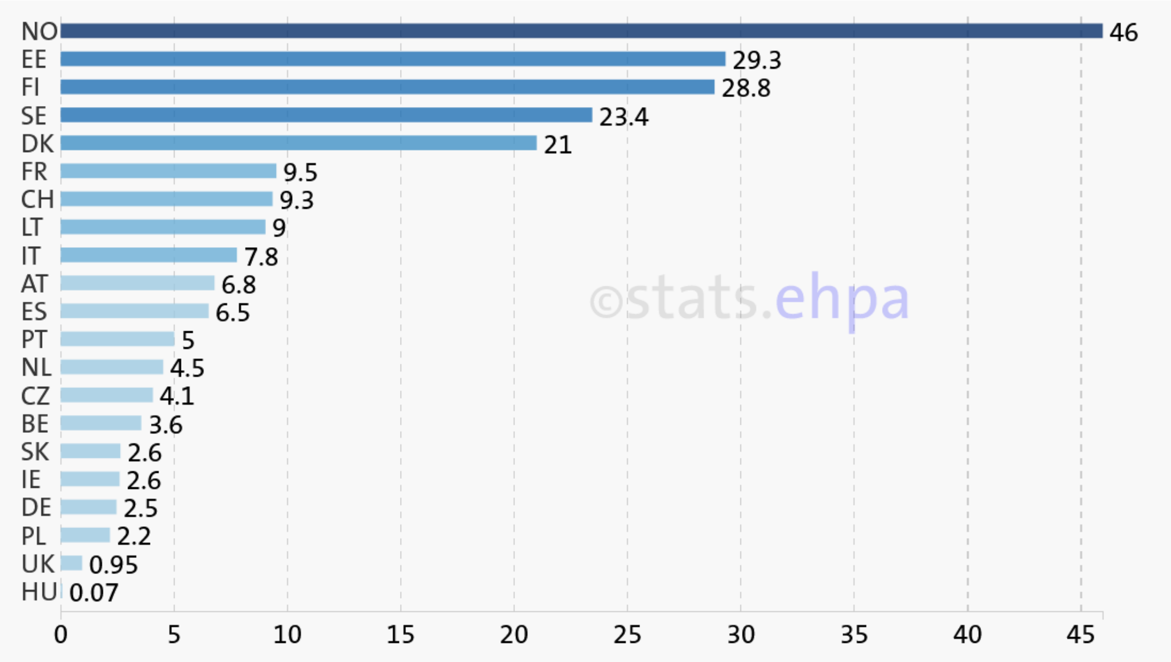

Figure 29. Units sold in relation to 1000 households (stats.ehpa).

The types of heat pumps by energy source used are shown in Figure 30. It can be seen that air source heat pumps currently dominate on the market, and their amount is almost

50% of the total sales. Nonetheless, the sale of ground source pumps in Sweden has achieved high acclaim. About 30% of private houses are currently heated by various systems with heat pumps. Moreover, heat pumps for hot water supply and extract air are becoming more and more important, and their sales are also growing rapidly.

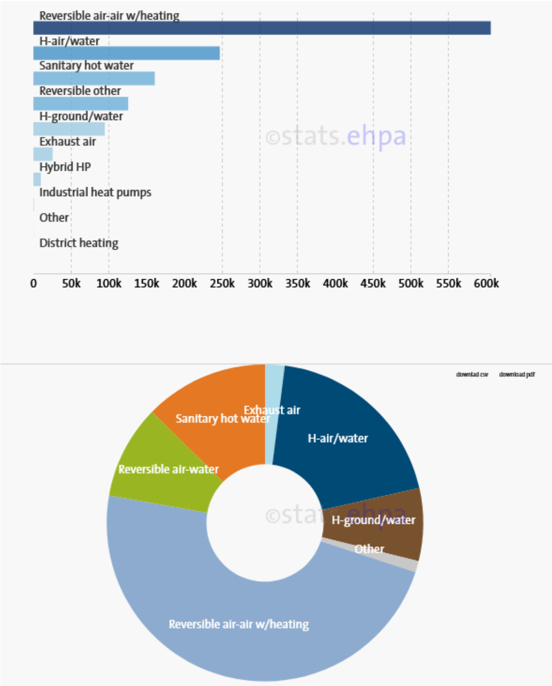

Figure 30. Types of HPs by energy source (stats.ehpa).

The company needs to study the market, understand where there is the most significant potential for growth, analyze what types of heat pumps can be in great demand. Companies should consider market barriers that are not conducive to technology deployment and factors that may affect the effective integration of heat pumps. When market sectors and possible consumers are found, effective smart supply chain approaches should be applied.

At the moment, many different barriers affect the deployment of heat pump technology. (Nowak 2018, 86.). The following barriers should be highlighted:

- Low level of acceptance and awareness in technology in various countries.
- High upfront capital costs and investments.
- High replacement costs.
- High electricity rates in some countries.
- Low efficiency of heat pumps.

These barriers can be crossed by several factors that influence the development and implementation of technologies:

- Improvement of heat pumps efficiency and developing new design solutions.
- Close cooperation with construction companies and renewable energy companies.
- Close cooperation with the government. Government subsidies to switch from liquid fuels and electric heating to heat pump heating.
- Government grants, special offers, and discounts.
- Development of electrical smart grids and decrease in the electricity tariffs.
- Increase in the fossil fuel taxes and decrease of renewable energy taxes.
- Innovative heat pump systems that can monitor and prove economic reliability.
- Decrease high upfront costs by the technology development, selection of proper material, manufacturing methods, and supply chain approach.
- New support schemes and business models.
- Supply chain SCM, ERP EDI approaches.

Currently, in Northern Europe, many private houses are heated or cooled with heat pumps. Since people trust and use these technologies, subsidies and grants for green technologies are allocated as in these countries. However, in Eastern European countries where there is no such effective government support, people do not trust these technologies because they do not see the need for a complete replacement of fossil fuel boilers in old houses. It is much cheaper to repair a boiler than to design and install a new system. Therefore, regulators need to provide support for new green heat pump technologies to reduce CO_2 emissions. (iea.org). Here are some examples of regulation of the situation with the decarbonization of Europe:

- For residential buildings in Norway, electric heating is usually used along with wood burning. Over the past 20 years, more than 1 million HPs have been mounted in buildings. It is now a growing market: the old air-to-air heat pumps are being replaced by modern ground source heat pumps, which are more efficient even in the coldest winter months. Heat pumps must be designed for lower temperatures down to –20 ° C. (EHPA 2018).
- As a source of heat energy in Finland, the most common source in cities is the district heating network in rural areas - its boiler or, increasingly, a heat pump. In new

> construction, the main criterion is the energy efficiency of the system. According to EU legislation, all EU countries have very strict requirements for the use of primary energy. To implement international climate policy, Finland has taken serious and very tough steps to reduce CO_2 emissions. The main goal is to reduce the use of coal. At the end of 2018, new legislation was passed banning coal for heating and electricity generation by the end of 2029. (sulpu.fi)

Moreover, the expensive installation and initial investment inhibit the widespread adoption of heat pumps. Therefore, it is necessary to establish close cooperation with energy and construction companies in the design stage of buildings and structures to reduce this negative factor. Cooperation can make it possible to correctly select the type and power of the heat pump and increase its efficiency. At the same time, it allows the heat pump manufacturer to select and purchase the necessary components correctly and at a specific time, which ultimately reduces the cost of both the heat pump and its installation. (BUILDUPEU).

Additionally, it is necessary to create suitable business models and marketing so that future buyers can see what a heat pump is and evaluate its efficiency. The right approach to a delivery system such as SCM leads to a significant reduction in the cost of heat pumps, making them more attractive products to potential customers. Also, the development and optimization of the choice of reliable partners and suppliers of components and the systematic organization of cooperation with them is the basis for the timely delivery and installation of the pump and reduces production costs. (Monczka 2009, 841.).

When investing in the installation of the entire system, consumers of heat pumps will consider their installation in case of further dynamics of the growth of tariffs for electricity or gas. With the constant rise in prices - the payback period of heat pumps can be even faster. However, the heat pump installation is calculated based on the current tariffs, average annual conversion factor. Moreover, consumers pay attention to the life of the equipment. Operational life is a great advantage of heat pumps, as they are designed for a long service life of more than 15 years. (heatpumps.org)

4 Case study

4.1 Basic information

This chapter describes the basic information, details, and procurement chain approaches of the commercialization of a mutual high-temperature heat pump project of Lappeenranta-Lahti University of Technology (LUT) and LAB University of Applied Science.

Industry sectors are consuming a lot of energy for their demands. Therefore, there is a great potential for industrial heat pumps to provide this energy in the most efficient ways and reduce related greenhouse gas emissions in the industry. However, HTHP and VHTHP are still not available on the market. Single start-ups of private companies and laboratory prototypes appear at present, but they do not enter the market for now. The market is interested in high-temperature industrial HP units with major capacities, which can provide temperatures more than 100 °C and unique solutions in the reduction of energy supply. An efficient HP unit providing high-temperature heat with relatively high power > 100 kW needs high-speed compressors and electric machines. High-speed kinetic turbo compressors have better efficiency and better reliability than reciprocating oil-lubricated compressors. High-speed magnetic levitated rotors offer needed reliability at very high speeds and high temperatures. With bearingless motors, even smaller footprints, lower costs, higher speeds, and better reliability are possible, leading to higher integration and efficiency. Oil-free compressor technology enables the use of the most efficient and ultra-low global warming potential working fluids, which in most cases are sensitive or unsuitable to work with compressors that require lubricants. Therefore, potential previously not available high-speed magnetic levitated bearingless HTHP is in development. This technology is mapped to prove the potential and possibility of effective deployment on the market unique solution with competitive advantages.

Currently, there are researches on oil-free heat pumps. (Arpagaus et al 2018). However, actual design solutions and prototypes were not created, only some analytical researches and hypotheses according to possible energy demand, efficiency, CO_2 reduction, and final cost. Therefore, for the proof and realization of this prototype HTHP, should be developed and studied these technologies:

- The suitable compressor for HTHP operation levels.
- The design solution and selection of the working liquids.
- Proper circulation system.
- Design of integrated vibration and temperature sensors.

Many different researches regarding the heat pump technology, control and monitoring systems, and electronics have been accomplished in the LUT space. Therefore, the combination and usage of all past scientific research and works in these fields can help to cross many design problems and unclarity in different moments. The design of the entire structure of the compressor unit was carried out by specialists from various fields, such as hydrodynamics, compressor technology, magnetic levitation, mechanics, electrical engineering. The detailed component models, assembly models, and manufacturing drawings, with all specifications, manufacturing, and machining details, were created with the help of 3D-modeling software SOLIDWORKS

The high-temperature heat pump can bring the following advantages:

- **Profitability**. Low power consumption is achieved through high efficiency.
- **Environmental friendliness**. Environmentally-friendly heating and air conditioning methods both for the environment and for people in the space. Heat pumps mean saving non-renewable energy resources and protecting the environment, including reducing CO_2 emissions into the atmosphere.
- **Safety**. No open flame, no exhaust, no soot, no diesel smell, no gas leakage, no fuel oil spill. There is no fire-hazardous storage for coal, firewood, fuel oil, or diesel fuel.
- **Reliability**. A minimum of moving parts and friction with long service life.
- **Independence**. Independence from the supply of fuel material and its quality. Power outage protection. The service life of the heat pump is 15-25 years.
- **Reduction of total operational cost**. Reduction of taxes, special government grants, and tariffs for electricity and zero-emission energy.
- **Flexibility**. The heat pump is compatible with any circulation heating system.
- **Convenient design** with smaller machine footprints, less maintenance, and online monitoring using integrated sensors can lower heat costs, higher safety, and better customer confidence in the technology.
- **Unique power and temperature ranges**. The wide power and temperature range can easily solve the issues and be applied to diverse sectors.

This solution will have both a unique selling point compared to conventional technology and a chance for unique positioning on the market. The high temperature provided by the heat pump, smaller machine footprints, less maintenance, short payback times can unlock other

industrial processes and new customers. This technology can create an untapped market area, new demand, and deployed new renewable energy relations with different companies and market sectors.

4.2 Heat pump structure and components

This technology is completely new and not available on the market. Consequently, the created design consists entirely of components that are not existing on the market. In the proof of concept (PoC) project, most components should be ordered from the possible manufacturers according to their custom design and specifications. The process of commercializing a new product requires a step-by-step conceptual approach. All these data were studied and considered to draw up a convenient classification of part categories, including all components of the compressor assembly. The compressor unit consists of 7 main component groups:

- Compressor assembly.
- Electrical motor assembly.
- Bearing unit assembly.
- Frame assembly.
- Mechanical components. These components are not related directly to some specific assemblies, such as the compressor or electrical motor.
- Electrical components. Sensors, wires.
- Standard purchased components that are available on the market. For example, washer, nuts, pins, screws.

The centrifugal compressor is a radial type dynamic compressor. The direct purpose of such devices is to compress the gas by decreasing its volume and increasing its density while simultaneously increasing the pressure and temperature of the compressed medium. The principle of operation of the centrifugal compressor is based on the transfer of energy from the rotating impeller/compressor wheel to the gas. The electric motor is used to drive the compression wheel. The shaft of the centrifugal compressor is connected to the shaft of the drive motor. Gas is sucked through the inlet into the center of the rotating radial impeller and pressed against the center by centrifugal force. This radial gas movement results in an increase in pressure and the generation of kinetic energy. The kinetic energy is converted into pressure by passing through a radial diffuser. At the end, gas flow is received by compressor volute and directed to the outlet pipe. The gas acquires additional static pressure

due to the centrifugal force of movement. (studfile.net). Figure 31 shows the design and key parts of the centrifugal compressor, and Figure 32 shows the design of the proof of concept heat pump.

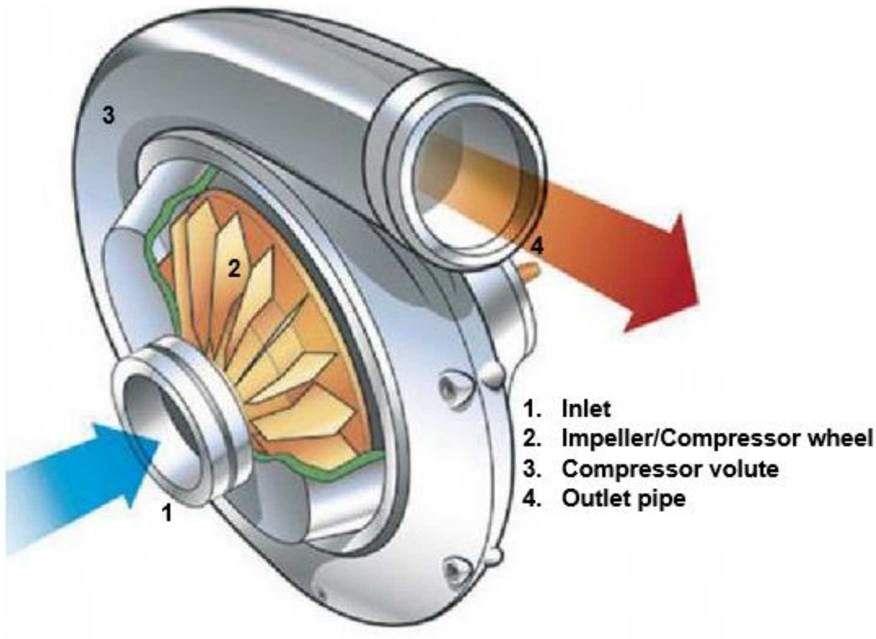

Figure 31 Centrifugal compressor (adapted from studfile.net).

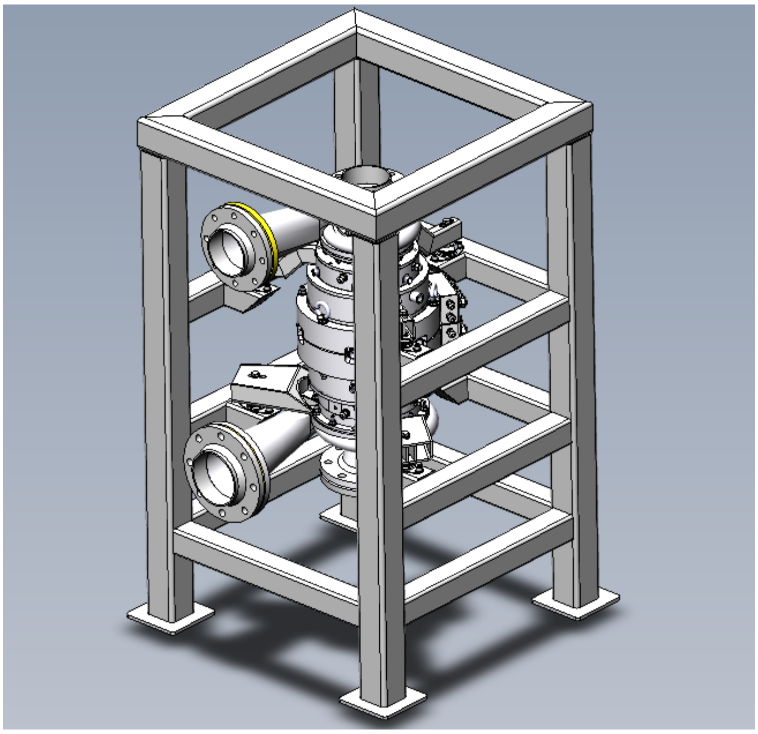

Figure 32. Construction of compressor unit.

4.3 Suppliers searching, definition and selection

The key components of the PoC heat pump were categorized into the following categories:

- Compressor assembly.
- Electrical motor assembly.
- Bearing unit assembly.
- Mechanical components.
- Frame.

Each mechanical component group is consisting of different components. Therefore, a potential supplier was searched for each component. The process of finding possible suppliers was determined primarily by the manufacturing process for each component. In the case of the most important and complex components, a search was made for suppliers who were based only on the production of this component, for example, the compression wheel. The search process itself was carried out through the Internet, browsing and evaluating the pages and catalogs of various suppliers. The table of potential suppliers consists of:

- Mechanical component group.
- Component part.
- Supplier company name.
- Manufacturing method or production technology.
- Available materials for production.
- Opportunity for a custom design according to requirements additionally prototyping services for single orders.
- Location Finland/Europe/Asia/USA.
- The web page of the company with detailed information and references.

There were a lot of same suppliers companies for different mechanical components because they have different machines and working capabilities to perform turning, milling,5-axes machining, and other manufacturing processes in their space. Moreover, the number of possible suppliers for each component was too large. Therefore, it was decided to make a second table of possible suppliers based on the first table's data. The classification of the

components, in this case, was based on the production method. The following component production groups were identified:

- Complicated machined parts (5-axes machining). This manufacturing method is performed for the components with precision or complicated geometry.
- Machined parts. Turning, milling, and drilling manufacturing operations for various parts from different components from different components groups.
- Cast parts.
- Mechanical components of electrical machine.
- Steel structural work. Cutting, sheet metal processing, bending, welding, and assembling. Basic operations and fairly affordable machines in general mechanical work-shops.

In the case of the machined parts group, suppliers can perform turning and milling machining. This means that this supplier can manufacture all the required components according to their geometry, manufacturing method, and specifications. However, in the case of the most important and complex components, a search was done for suppliers based on the production of this component. For example, for components from the mechanical components group of an electrical machine, almost every part had to be looked for from different suppliers. This is because the manufacturing methods for each component are very different from each other. In addition, some production technologies are complex or new. Therefore, some of the companies are based only on the production of specific technologies and components. The second table of potential suppliers consists of:

- Production technology.
- List of components according to manufacturing method.
- Supplier company name.
- Available materials for production.
- Opportunity for the custom design according to requirements (additionally prototyping services for single orders).
- Location Finland/Europe/Asia/USA.
- Web page of the company with detailed information and references.

In the second table number of possible suppliers was reduced. The search for possible suppliers depended on the location and was concentrated on Finnish and European manufacturers. This search was done for several reasons:

- Faster delivery time.
- Less shipping value.
- No customs fee.
- Support for local manufacturers.
- Possible reduction in the cost of the prototype.

After creating the second table of potential suppliers, it was necessary to grade, evaluate, and select the best potential suppliers. The initial ranking of potential suppliers was based on the decision matrix analysis. This approach can help to analyze a number of similar alternatives to conclude a final choice. (mindtools.com). Simple decision matrix consists of:

- List of the criteria regarding to which the evaluation of alternatives proceeds.
- List of alternatives-potential suppliers.
- Scores for each criterion. In this case, the ranking was based on a scale of 1 to 5. Score 5 is the best, and score 1 is the lowest.
- The total amount of all scores for each alternative.

List of the criteria for the potential supplier’s evaluation consists of:

- **Location.** This criterion indicates the distance from the manufacturer to the consumer/warehouse. For example, in our case, the heat pump is assembled in Finland, so suppliers from Finland are labeled with 5 scores, from the European Union 4 scores, from Europe 3 scores, Asia and North America 2 scores.
- **References.** This criterion indicates the number of partners who use the services of this manufacturer and the presented completed projects and components in the areas of the manufacturer's work. For example, 5 scores are given to companies with an extensive background, with fewer partners from 4 up 2 scores, if the references are not shown with 1 score.
- **Available materials.** This criterion indicates the number of available working materials for manufacturing. For example, 5 scores are given to companies with a wide

number of various materials and complicated alloy, from 4 up 2 scores with less number of materials, 1 score if the company is working with one type of material.

- **Custom-prototype design.** This criterion indicates the ability to provide and manufacture custom designs according to specific requirements. For example, 5 scores are given to companies based on the production of single prototypes, 4 scores for companies that mentioned that they could produce single prototypes, 3-2 scores for companies that produce small and medium batches, 1 score if the information was not mentioned.
- **The appearance of the Web page.** This criterion indicates the information accessibility and convenience of the company's website. All major sections of the company are structured and separated. The site contains all the information necessary for a rational assessment of the company. For example, 5 scores modern, data-full website, 1 score unclear and inconvenient page.

Figure 33 shows the example of a simple decision matrix used to select a potential supplier.

	Alternatives		
Criteria	**Supplier A**	**Supplier B**	**Supplier C**
Location	5	3	2
References	3	4	5
Available materials	5	3	5
Custom-prototype	3	4	5
Appearance	3	3	3
Total	**19**	**17**	**20**

Figure 33. Simple decision matrix.

As it can be seen, alternative supplier C has the highest total score in this example, despite the fact that its location is far away from the end consumer. Supplier C has the best references, available materials for manufacturing and is based on the production of prototypes. Therefore, it can be marked as the best option for manufacturing. This ranking selection was performed for each production technology group or specific component in some cases.

A weighted decision matrix was not used for the initial potential suppliers ranking. However, after the PoC can show that the device actually works, then it is very much advisable to focus on maximizing the procurement chain by applying more complicated and precise evaluation methods. Success on both the technological and business sides can lead to increase series production. Small series production is quite different from the production of a single prototype. Many factors can influence a successful and profitable production. Initially, when

managing the procurement chain of operational resources, it is advisable to divide companies' suppliers into three categories: replacement suppliers, preferred and strategic. This classification allows to rank suppliers according to the importance of establishing cooperation ties and long-term cooperation in supply chains. The detailed classification of suppliers is mentioned in Table 4 on page 42. This ranking can help save time when looking for new suppliers, and at the same time, can prevent disruption of relations with strategic suppliers. Different factor values should be used for the evaluation of supplier performance for each supplier category. Secondly, the alternating potential suppliers' selection should be accomplished. This selection can be made in case of different reasons:

- The current supplier is not able to produce the needed number of parts.
- The performance, quality, delivery of the current supplier does not meet the requirements.
- The contract with the current supplier ends up.
- Mass production grow-deploying more products require new suppliers.

The ranking of the alternating potential suppliers can be based on the weighted decision matrix analysis. This approach can help to analyze a number of similar alternatives to conclude a final choice. The main difference to a simple decision matrix is that not every criterion has the same importance. (mindtools.com). The weighting of each criterion is added to the table using a common scale. Weighting decision matrix consists of:

- List of the criteria regarding to which the evaluation of alternatives proceeds.
- List of specific weights according to the importance of each criterion. The scale of weights from 1 to 5. Weight with value 5 has the highest importance in the selection; weight with value 1 is least significant.
- List of alternatives-potential suppliers.
- Scores for each criterion from the potential supplier side. In this case, the ranking is based on a scale of 1 to 5. Score 5 is the best, and score 1 is the lowest.
- A list of the total score for each criterion means that both weight and criteria score are used for evaluation. The total is calculated by weight x score.
- The final amount of the sum of weighted scores.

The criteria for the potential supplier's evaluation can depend on the situation, component, and other factors. The same difference can be with relative importance values for each criterion. Common criteria can be:

- **Manufacturing cost**. The total cost of manufacturing includes design, machine adjustment, manufacturing, post-machining, and surface treatment.
- **Delivery cost**. This cost includes the preparation and dispatch of finished products. It may also include the cost of delivering working raw materials to the production line.
- **Total cost**. This cost includes manufacturing, delivery, documentation, taxes, and other expenses.
- **Ensured quality**. The required quality according to the components specification.
- **Manufacturing capacities**. The number of manufacturing machines and production capacities.
- **Service level and past references**. The number of partners using the services of this manufacturer, and the level of service, interest emanating from the supplier.
- **Contract length and type of relationships**. Long-term relationships with special terms and discounts or single contracts.
- **Reliability**. Reviews on the positive or negative aspects and financial healthiness of supplier.

Figure 34 shows the example of a weighted decision matrix, which can be used to select potential suppliers.

		Alternatives					
Criteria	**Weighting**	**Supplier A**		**Supplier B**		**Supplier C**	
		Score	**Total**	**Score**	**Total**	**Score**	**Total**
Manufacturing cost	4	5	20	3	12	4	16
Delivery cost	4	5	20	3	12	4	16
Total cost	5	4	20	4	20	4	20
Ensured quality	4	3	12	5	20	3	12
Manufacturing capacities	3	2	6	4	12	5	15
Service level	3	3	9	4	12	4	12
Contract length	3	2	6	4	12	3	9
Reliability	3	3	9	4	12	2	6
Total			**102**		**112**		**106**

Figure 34. Weighted decision matrix.

Suppliers A, B, and C are different from suppliers mentioned in the previous example on page 59 Figure 33. As it can be seen, alternative supplier B has the highest total score in this example, so that it can be marked as the best option for manufacturing.

Moreover, the supplier's performance must be evaluated during mass production and the extensive introduction of the technology to the market. Therefore, there are three main indicators by which the procurement chain management activities are monitored:

- **The time factor**.
- **Price factor**.
- **Supplier reliability factor**.

The company can view the quality of the suppliers' fulfillment of their contractual obligations by accumulating and processing statistical information on the results of deliveries of purchased operating resources. The calculated indicators for analyzing the supplier base to segment it and develop solutions to improve the efficiency of procurement activities are presented in Table 3 on page 41.

4.4 Future estimations

If technology is proven, new potential customers and market end-users should be mapped out. The developer of the PoC should constantly monitor the market and innovations. Interest and desire from potential consumers depend not only on proper marketing but also on:

- New laws prohibiting the use of different types of fuels.
- Higher taxes and fuel prices.
- Government subsidies.

Of course, the developer of the PoC also needs to provide the proper marketing, create effective business models and implement an improved supply chain. Therefore, potential users should be interviewed to find out their needs and expectations. The interviews allow exploring the different factors that drive the focus groups’ customers into using their current solutions and provide intel on how to structure a new solution. Moreover, the developer of the PoC needs to study competitors' offers and use different approaches to determine the competitiveness of solutions in the fields. Seeking information on the rivalry of the competing technologies in the different fields and benchmarking this solution versus them allow the developer of the PoC to assess the entry requirements, difficulties and create more efficient marketing and advertising. Finally, all the advantages can be listed.

The creation of new business models can improve the current technology and increase the number of end-user. There are several possible business models:

- Technology to heat pump suppliers.
- Technology to renewable energy companies. Renewable energy companies can combine this solution and demonstrate advantages.
- Technology to construction companies. Construction companies can integrate heat pumps into the new building design.
- Directly offered to end-users, with different service possibilities.

These business models depend on the interest and requirements of the different fields of industry. In some cases, it can be more profitable and efficient to sell the technology directly to third parties and HP suppliers. On the other hand, in market sectors or countries where demand is high or growing rapidly, technology deployment can be based directly on end-users.

Correct and competent application of the Supply chain management concept determines an enterprise's income, providing an increase in profits and a simultaneous decrease in costs. In addition, the use of SCM allows you to reduce inventory, transaction costs, improve the quality of service, and the accuracy of demand and supply planning. Therefore, constant monitoring of procurement, supply, demand systems is necessary to effectively apply the concept, rationally choose reliable partners, and organize close and trusting cooperation.

5 Summary

The thesis is devoted to market research of heat pumps and various approaches to the management of the procurement chain. A comprehensive study of the types, efficiency, environmental friendliness, areas of application, and the development of the market for new generation heat pumps was carried out. Moreover, an analysis of various modern approaches to managing procurement and supply chains for the production of heat pumps was carried out.

The main findings of this study include:

- A list of potential suppliers for heat pump components has been developed.
- Methods and comprehensive criteria for selecting suppliers and evaluating the effectiveness of suppliers have been developed.
- The analysis of the market, applications, possible barriers to the deployment of the technology has been performed
- Possible business models and areas of application of the technology have been developed.
- An analysis of the future possibilities of heat pump technology was made.
- An analysis of the relationship between heat pump efficiency and environmental influence was carried out. In addition, the contribution to the possible development of heat pumps from renewable energy sources and construction companies was assessed.

In conclusion, it should be mentioned that interest and demand for efficient and eco-friendly heat pump technology will increase in the future, according to the monitored statistical data. This means that the number of new competitors and solutions will grow up and occur on the market. Both continuous technology and business development should proceed for the successful deployment and consolidation in the market. Moreover, efficient cooperation with different industrial sectors, government authorities, and end-user should be accomplished and developed. Proper supply and procurement chain management can influence the final cost, the number of suppliers and consumers, and the effectiveness of the technology deployment.

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