Stockholm School of Economics

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Master Thesis

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# A greenhouse solution to heavy industries' greenhouse gas problem

A case-based study on transaction structures for monetization of industrial waste heat

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**ABSTRACT**

In this thesis, we study a range of Swedish greenhouse projects and how their commercialization of industrial waste heat have been financially structured. The aim of this thesis is to analyze the financial risks and benefits of such projects and how they have been managed. To understand the financial challenges of these projects we conducted a case-based study where several greenhouse projects were explored. We find that the main risks for greenhouse operators to engage in these industrial waste heat recovery projects were the complexity of the investment and the risk of not having internal control of the heat needed to operate the greenhouse. And for waste heat owners, such as pulp and paper plants, the main hurdle was the potentially high capital expenditures required. The main motivations for engaging in these projects were found to be cost savings and improved environmental performance. The findings suggest that a specialized intermediary structuring the exchange of waste heat between waste heat owners and greenhouses can mitigate financial risks as experienced by greenhouses and waste heat owners respectively and enable more efficient waste heat transactions.

**Keywords:** Corporate sustainability, waste heat, intermediation, resource efficiency, industrial symbiosis

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# 1. INTRODUCTION

## 1.1 Introduction and problem formulation

Globally, industries such as steel, cement, chemical, pulp and paper consume about one third of total primary energy, with coal, oil and gas still being the dominant energy sources (IEA, 2020). More than half of this energy input is not converted to useful work but is instead being lost in the process as residual heat energy, much of which is being wasted (Forman et al., 2016). Waste heat may be defined as heat that is generated as a by-product in a process that aims to generate another product. For example, when producing steel, the primary goal is not to produce heat, but it is rather a necessary by-product of producing steel. Recycling such waste heat, and thereby increasing the fraction of the energy input that is used for productive purposes, has financial as well as environmental benefits.

A number of actions may be taken to avoid greenhouse gas emission intensity. First, fossil energy sources may be replaced with renewable ones. Second, energy use can be reduced. Third, energy efficiency can be improved, for example by recycling energy that is currently being wasted. This thesis focuses on the latter and specifically studies how residual heat can be used in greenhouses, and to some extent aquaculture operations. The core benefit of such heat recovery lies in that otherwise wasted energy can be used to produce useful goods and service, in this case food, activities which otherwise need to be supplied with heat energy from other sources.

Currently, many industrial plants and power plants are simply letting their residual heat go to waste. This heat often needs to be cooled down before emitted into the surrounding environment, a cooling process that often implies a direct cost to the industry. Moreover, from the point of view of an industry that has residual waste heat, not selling waste heat that could be monetized may be seen as a foregone revenue, i.e., a type of cost. In other words, industrial waste heat may be viewed as a “hidden asset” i.e., a resource with underutilized potential to generate cashflows. If monetized, this asset has potential to generate additional cashflows while simultaneously lowering the environmental footprint of several industries.

This bears relevance not only for existing industries but also for emerging ones. For example, green hydrogen is expected to play a significant role in the energy transition, not least in fossil free steel production. Furthermore, in the process of electrolysis which converts (renewable) electrical energy to chemical energy in the form of (green) hydrogen, a significant amount of the energy input is lost as waste heat.

In summary, industries have waste heat that they are not able to or have little interest in making use of themselves internally. Other companies, such as greenhouses, need heat to run their operations. This supply and demand form the basis of a potential heat transaction between those parties. Facilitating this transaction in a mutually beneficial way is both an engineering and financing problem, financing being the focus of this thesis. Specifically, this thesis investigates the potential problems which involved parties face in facilitating an exchange, and how these problems might be overcome by different ways of financial planning and structuring.

If industries can monetize more of their waste heat, for example by selling it to greenhouses, environmental footprint may be improved in a financially profitable way. In addition, such greenhouses can contribute to a more local and sustainable food production system, while supporting food security.

## 1.2. Purpose

The main purpose of this thesis is to investigate case-based data to provide insights into how transactions of waste heat can be structured in financially efficient ways. The main research questions are:

*How have waste heat transactions between waste heat owners and greenhouses been financed and structured?*

*What are the financial motives for the project parties to engage in and invest in enabling waste heat transactions?*

*What are the major financial risks in such projects, and how have they been mitigated?*

### 1.3. Scope of this thesis

This thesis aims to explore challenges with waste heat monetization in greenhouses from a project finance perspective. By investigating existing greenhouse operations and the financial preconditions for their external heating processes this thesis aims to answer the above questions.

### 1.4. Contribution

There is growing interest in academia to understand the financial viability of the overall green transition of the economy. Prior studies have evaluated the technical and economic viability of recycling industrial waste heat in greenhouses. A financial case-based study researching how similar energy efficiency projects have been established and financed can add relevant practical evidence to this body of literature. This may be of interest to general readers who have an interest in green finance projects. Furthermore, it may be of particular interest to businesses, including greenhouse operators, industries with waste heat, and project developers, as well as to investors considering investing in such projects.

### 1.5. Outline and Structure of the thesis

Section 2 covers the theoretical framework for the thesis, including a review of relevant previous literature. Section 3 outlines the methodology used in this thesis. Section 4 establishes the background for the cases, while in Section 5 the cases studied in this thesis are presented. Section 6 presents the results and in section 7 the results and implications of the thesis are discussed. Finally, Section 8 presents the conclusions from the study and suggestions for further research.

## 2. Theoretical framework

In this section the theoretical framework of this thesis is presented.

### 2.1 Industrial Symbiosis

The expression “symbiosis” builds on the notion of biological symbiotic relationships in nature, in which at least two otherwise unrelated species exchange materials, energy, or information in a mutually beneficial manner—the specific type of symbiosis known as mutualism (Miller, 1994).

Similarly, "industrial symbiosis" consists of place-based exchanges among different entities. "By working together, businesses strive for a collective benefit greater than the sum of individual benefits that could be achieved by acting alone. This type of collaboration can advance social relationships among the participants, which can also extend to surrounding neighborhoods" (Chertow, 2000).

The following cases mentioned in Chertow (2000) help better illustrate the concept.

### 2.1.1 Kalundborg, Denmark

The model of industrial symbiosis was first fully realized in the eco-industrial park at Kalundborg, Denmark. The primary partners in Kalundborg are an oil refinery, power station, gypsum board facility, pharmaceutical plant, and the City of Kalundborg. They share ground water, surface water and wastewater, steam and electricity, and exchange a variety of residues that become feedstocks in other processes. The waste exchanges alone amount to some 2.9 million tons of material per year. Through the project, water consumption has been reduced by a collective 25%, and 5000 homes receive district heating.

Indeed, the very term "industrial symbiosis" was coined by the power station manager in Kalundborg, meaning "a cooperation between different industries by which the presence of each increases the viability of the other(s), and by which the demands [of] society for resource savings and environmental protection are considered".

### 2.1.2 Londonderry Eco-industrial Park, New Hampshire

The Town of Londonderry assembled a 100-acre land area near the airport at Manchester, New Hampshire specifically to create an eco-industrial park. The project was turned over to a private developer, Sustainable Development and Design, who agreed to purchase the land and follow a set of performance requirements and environmental guidelines and practices. A 720-MW combined-cycle gas power plant built by AES Corporation has been permitted and several other tenants have moved to the eco-industrial park site. The power plant will use wastewater from a nearby sewage treatment plant for use in its cooling towers, thereby eliminating the need to seek alternative sources and lead to lower costs. The Londonderry Eco Industrial Park was financed with a mix of developer equity and conventional bank financing.

### 2.1.3 Monfort Boys Town Integrated Biosystem, Suva, Fiji

The Fiji project was designed primarily to accommodate spent grain from breweries that would otherwise be discharged into the sea, smothering coral reefs. The brewery waste is brought to the grounds of a school for boys where the rest of this smaller scale industrial symbiosis is undertaken. Applying a process designed through the U. N. University, the system uses the brewery waste as a substrate to grow mushrooms; the mushrooms break down the waste, making it a high-value pig feed; waste generated from the pigs is processed through an anaerobic digester; and the treated waste is piped to fishponds where the nutrient rich water spawns food for four trophic layers of fish. The waste also creates fertile soil for growing vegetables. This sort of project, which mixes agriculture and industry, is known as an integrated bio-system.

## 2.2 Role of intermediaries in innovation

Howells (2006) defines an innovation intermediary as “An organization or body that acts as an agent or broker in any aspect of the innovation process between two or more parties. Such intermediary activities include: helping to provide information about potential collaborators; brokering a transaction between two or more parties; acting as a mediator, or go-between, bodies or organizations that are already collaborating; and helping find advice, funding and support for the innovation outcomes of such collaborations.” The value of intermediaries lies in their ability to create new possibilities and dynamism within an innovation system, along with improving its connectedness (ibid.).

The European Commission published a staff working document in 2010 on “Making public support for innovation in the EU more effective” after conducting a survey of over 1000 enterprises and 430 innovation intermediaries.

This paper identified “Eco-innovation” as a crucial opportunity to tackle and overcome the environmental challenges of the next decades in a cost-efficient way that ensures the competitiveness of the European economy and creates new and better jobs, while also mentioning that too few solutions find their way to commercial exploitation, however.

As for challenges to innovation, the innovation intermediaries surveyed in the paper consider lack of access to finance as the most pertinent factor hampering companies from bringing innovation to the market. This view is also reflected in the responses of the enterprises surveyed. Some of the other factors frequently highlighted by the intermediaries include the lack of access to international markets, lack of market information and lack of information on available innovation support measures.

“In transitions of large sociotechnical systems, intermediary organizations can emerge as mediators in between several actor groups and facilitate collaboration towards common goals” (Backhaus, 2010). “When operating space opens for organizations that can act between established actor groups these intermediaries are able to network, articulate, translate, and align interests within and across multiple levels and multiple stakeholders in order to enable and facilitate changes. In the energy system’s transition towards a sustainable future, intermediaries are able to take over the tasks of management and governance by establishing actor networks, articulating and aligning interests (across political, geographical or sectoral levels) and mediating between stakeholders” (ibid.).

In addition to private consultants, several other organizations such as innovation and business development agencies, universities and research centers, chambers of commerce and business associations, incubators and science parks, can function as intermediaries in various capacities (Küçüksayraç et al., 2015).

In the sustainability field, the paper suggests five main roles for intermediaries providing innovation support, as follows:

- Awareness raising and identifying possible potentials and needs on sustainability and design for sustainability for Small and Medium Enterprises, SMEs.
- Comprehensive consultancy and reporting on sustainability for Large Enterprises, LEs.
- Design for sustainability consultancy and implementation for both LEs and SMEs.
- Incubating start-ups that work on sustainability.
- Creating and implementing business plans for radical innovation or sustainability.

According to the authors, these roles are fulfilled using various "support instruments" which are broadly classified as:

- Financing/facilitating financing
- Networking and cooperation
- Awareness raising
- Internationalization
- Technology/knowledge transfer
- Identification of potential and needs
- Innovation management
- Creation of specific skills

## 2.3 Information asymmetry

Information asymmetry is a condition wherein one party in a relationship has more or better information than another. It results in situations such as adverse selection, moral hazard problems and monopolies of knowledge (Bergh et al., 2018).

In relation to innovation management, most literature on information asymmetry is divided in two categories. According to Barbaroux (2014), "information asymmetry plays a dual role as it constitutes both a major source of market failures and a condition for entrepreneurial opportunities to exist. On the one hand, information asymmetry is considered as a major source of market failures because it affects the quality of innovative goods and services available on the market and disturbs the process of allocating resources efficiently. On the other hand, information asymmetry is presented as a major source of market opportunities, the latter existing only because individuals do not possess the same - exhaustive and complete sets of – information" (ibid.).

When it relates to cost of capital, Armstrong et al. (2010) find that information asymmetry has a positive relation with firms' cost of capital in excess of standard risk factors when markets are imperfect and no relation when markets approximate perfect competition, showing that the degree of market competition is an important conditioning variable.

## 2.4 Literature review on waste heat and utilization in greenhouses

### 2.4.1 Waste heat transformation technologies and economic feasibility

Waste heat is prospected to become a more negative externality of industrial production in the future, as the planet warms, and temperatures rise (Puaschunder, 2018). Puaschunder (2018) predicts that society will heavily charge waste heat sources in the future, via higher taxes for example, making it expensive for industries to not find ways to utilize their heat emissions.

Brückner et al. (2015) describe and compare the main heat transfer technologies for waste heat recovery available at the time of writing. They study absorption chillers producing cold, and heat production using compression and absorption heat pumps. The study conducts an economic analysis of those technologies for three different consumer types, namely Industry, Real Estate and Enthusiast. The three different consumer types are defined to represent different expectations in interest rate, payback period and the resulting annuity factor. Maximum acceptable investment cost for each technology is estimated by expressing the yearly operational savings in present value which is then compared with the market cost at the time of writing.

For industrial use cases, a high interest rate of 10% and low payback period of 5 years were assumed. For use in real estate, where adoption is foreseen in commercial buildings, an interest rate of 5% and payback period of 15 years were assumed. Lastly, the enthusiast category reflects use in the private sector by early adopters, who want to get the new technology and are content if it does not cause additional cost. The assumed interest rate is 1% and the payback period is equal to the life span of most technologies of 25 years.

The results indicate that, given the technology costs at the time of writing, absorption heat pumps are already profitable for all consumer types for more than 3000 operating hours per year. For Real Estate and Enthusiast even 1000 operating hours and less were found to be economically feasible. Assuming 24 h operation per day, 3000 h equal 125 days. In comparison, average winters in Germany, for example, have about 250 heating days. Similarly, absorption chillers were found to be profitable for Real Estate consumer types in almost all scenarios, and for Enthusiasts when operated for at least 2500 h per year. However, more than 6500 h per year were found to be needed in order to be profitable for Industry consumers.

### 2.4.2 Waste heat utilization in greenhouses – previous studies

Studies have also shown the range of benefits that can be realized by greenhouse operators by using waste heat to warm their facilities.

Parker and Kiessling (2016) indicate that "by combining the use of surplus energy with harvest of society's organic side flows, for example, food waste and aquatic-based cash crops, sustainable food systems are possible, to the degree that it can play a significant role for global food security." The potential sustainability benefits of such an effort, according to their study, are substantial and multifaceted. For example, by improving resource efficiency and avoiding negative externalities.

Andrews and Pearce (2011) present a case study of a heat exchange between a tomato greenhouse and a flat glass manufacturing plant in Canada and find that the waste heated greenhouse system is significantly more economic to operate than a purely natural gas-powered system.

Danielsson and Torgnyson (2014) investigate the environmental, technical and economic potential of recovering low grade industrial waste heat for heating greenhouses, specifically for tomato cultivation. Tomato plants require temperatures between 21 and 35ºC (Puaschunder, 2018), and energy costs constitute more than 30% of total costs for cultivators in Sweden, owing to the cold climate (Danielsson and Torgnyson, 2014). There is a great potential to reduce the carbon footprint from the production of tomatoes by utilizing waste heat and that the amount of industrial waste heat in Sweden would be more than enough to make the country self-sufficient in tomato production. Sweden, as of 2011, imports 86% of its tomatoes. The majority of which is produced in the Netherlands (ibid.). However, there are several barriers to utilizing waste heat at greenhouses, including lack of knowledge among greenhouse operators about the available amount of industrial waste heat, lack of continuous flow of waste heat and uncertainty regarding the design of an agreement for pricing the waste heat (ibid.).

## 2.5 Financing of projects

When it comes to arranging financing for new projects, firms broadly have two different ways. The more traditional option is for the firm to directly finance the project on its general credit along with the rest of the business and repay any debt from the combined cashflows of its entire assets and businesses. The other option is to secure "Project Finance" by separating the proposed project's cashflows from the rest of its businesses and using only those cashflows to repay any creditors. This is usually done by structuring the new project as a separate entity or a Special Purpose Vehicle (SPV) - (Finnerty, 2013).

### 2.5.1 Project Finance

Esty, Chavich and Sesia (2014) defines project finance as "Project Finance involves the creation of a legally independent project company financed with nonrecourse debt (and equity from one or more corporate entities known as sponsoring firms) for the purpose of financing investment in a single-purpose capital asset, usually with a limited life." Globally, project finance investments grew ten-fold during the period 1994-2013 from $41.3 billion to $415 billion respectively. In the 15 years to 2013, despite three major crises, the project finance industry has shown a strong long-term growth rate, with a compound annual growth rate, CAGR of 8% (ibid.).

It has proven to be a very useful financing technique throughout the world and across a broad range of industry sectors. Project financing often involves taking on very high leverage, 70 percent or more debt initially on average (Finnerty, 2013).

In Chen, Kensinger, and Martin (1989), the authors observed that project financing is widely used for medium-size, low-risk projects, such as cogeneration facilities. They documented that project financing had become the dominant method of financing independent electric power generating facilities, including cogeneration projects developed for several Fortune 500 companies.

In Shah and Thakor (1987) project financing is shown to reduce the signaling costs associated with raising capital under asymmetric information, particularly in the case of large-scale, high-risk projects. The authors further state that “project financing can reduce agency costs since management's discretion to reinvest cash flow net of operating expenses—to the possible detriment of outside equity investors as well as lenders—is restricted contractually.”

In a different study, John and John (1991), the authors, similarly to Shah and Thakor (1987) also argue that project financing increases value by reducing agency costs, reasoning that the underinvestment incentive is countered. They further add that “project financing increases the value of interest tax shields. Because more projects are financed, more debt is issued, and therefore more interest tax shields are created. Both factors enhance shareholder value.”

Going back to Finnerty (2013), the book states four types of sponsors generally involved in Project Finance transactions:

- Industrial Sponsors, who see the initiative as upstream or downstream integrated or in some way as liked to their core business.
- Public sponsors (central or local government, municipalities, or municipalized companies), whose aims center on social welfare.
- Contractors/sponsors, who develop, build, or run plants and are interested in participating in the initiative by providing equity and/or subordinated debt.
- Purely financial investors seeking a competitive return for their capital.

On the requirements for a Project Finance deal, Finnerty (2013) states that "since a project has no operating history or credit profile at the time of initial debt financing, its creditworthiness depends on the anticipated profitability and on the indirect credit support provided by outside parties through various contractual agreements." The lenders require assurances that the project will be placed into service and on the technical feasibility, the economic viability, availability of raw materials for the life of the project, and capable management to oversee the operations.

According to Finnerty (2013), typical risks in project finance transactions include:

- Operating risks, such as completion risk
- Market risks, such as demand or supply or price risk
- Regulatory and Political risk
- Financial risk, for example, leverage.

# 3. Methodology

## 3.1 Research Design and Data Collection

To study the research questions presented in this thesis a case-based method was used. Although widely used in practice, case studies are sometimes criticized. According to Yin (2014), some have criticized the method for not being rigorous enough and therefore prone to biases. This can be true in some cases but can be avoided by proper preparation and documentation (ibid). This research method has also been criticized for lacking scientific generalization power (ibid).

This choice of methodology is influenced by the fact that the sample size would have been too small for statistical inference in a quantitative study. To the best of our knowledge, there are not that many greenhouses using waste heat and the data is normally privately held since greenhouses are typically relatively small private companies. Since we aim to research transactions related to heat exchange but could not find such information readily available, it was decided to conduct interviews to procure relevant information. Therefore, the data sources primarily include interviews along with any public and private information available, which form the basis for this study. This study therefore assumes a qualitative role by studying relevant specific cases. The generalization of the results in this thesis therefore relies on our analytical ability to apply the results in a broader context.

This study follows an inductive approach by developing theory in light of empirical data (Saunders et al., 2009). It uses multiple case studies, which are useful in building theories by providing replications, extensions and contrasts (Eisenhardt, 1989). Case studies can be retrospective, current or a combination of these two types (Eisenhardt and Graebner, 2007). The ones discussed here are a combination of both, however mostly current.

The case framework and selection of interviews, which are the primary data source in this thesis, is based on intentional selection (Yin, 2014). This method of selection concludes the most relevant data, as it has a strong connection to the topic the interview aims to cover (ibid.). The interviews were conducted in a semi-structured manner (Merriam, 1998), where main questions were prepared before the interviews, but additional follow-up questions were formulated at the time of the interview, allowing us to maintain flexibility, and respond to the situation at hand and to new points of discussion brought up by the interviewees. In line with the research questions aimed to be answered by this thesis, the interviewees were broadly questioned about their experiences with waste heat recovery projects, their motivations – both financial and otherwise - for undertaking/planning such projects, major financial risks and challenges encountered/foreseen, financing structures adopted, and their general views on the current landscape for such projects.

The interviewees were chosen carefully and mainly included experts who have been involved in establishing and financing greenhouse waste heat recovery projects. Greenhouse operators, industrial players, intermediaries specializing in waste heat exchange, and a representative from an industry association - to provide an outside observer's perspective - have been interviewed. The interviews have all been held digitally through the use of video telephony due to its practical ease, keeping in mind the geographical distance limitations and public health concerns over the ongoing pandemic. The interviews were recorded, to the extent that consent to do so was provided by interviewees, to make it easier to go back and review the conversations at any time. The interviews were all transcribed soon after and the perceived information was sent to the respective interviewees for their confirmation to ensure its accuracy.

## 3.2 Research Quality

The research quality of this thesis is affected by the choice of adopting a case study methodology. There are four tests that are commonly used to establish the quality of case study research (Yin, 2014). The construct validity test aims to ensure that the case study procedure leads to an accurate observation of reality. The internal validity test on the other hand, concerns the ability to draw causal conclusions from a case study (ibid.). Using multiple sources of evidence can strengthen the construct validity (ibid.) and the internal validity (Merriam, 1994). This method is referred to as triangulation and is defined as the use of several information sources and methods to corroborate the same finding (ibid.). In this thesis, information was collected from a range of relevant actors, such as greenhouse operators, industrial players, waste heat intermediaries, and industry associations. Further, the information in the cases was not only obtained from the interviews but was also complemented by publicly available material.

The external validity test aims to determine whether the findings of a study are possible to generalize beyond the study. The form of questions can either hinder or enable the researchers to achieve external validity (Yin, 2014). It is argued that "why" or "how" type research questions better enable generalizations than research questions that do not contain a "why" or "how" (ibid.). As such, the first and third of our research questions enable generalizations better than the second research question. The possibilities to generalize the findings in this paper can be considered reasonable given the fact that it builds on multiple case studies from various stakeholders, rather than just one isolated study. The last test is the reliability test. The objective of the test is to ensure that a later investigator makes the same findings and reaches the same conclusions, given that the later investigator repeatedly conducts the same case study and follows the same procedures as the earlier researcher (Yin, 2014). It has been argued that reliability can be improved by enhancing the transparency and replicability of the case study procedure (Gibbert et al., 2008). In line with what Yin (2014) suggests, we have documented all the interviews conducted as well as the topics covered during each interview to allow a later researcher to replicate the study. However, the answers provided by the interviewees can be assumed to be influenced by the interaction between the interviewers and interviewees, the recollection ability of the interviewees which may differ from time to time or be selective or biased to their specific interests, it may also be affected by the setting in which the interviews were conducted as well as the proximity in time to the events covered in the interviews. It is also possible that even some of the publicly available sources relied upon by this thesis at the time of its writing may be biased or influenced by current external factors, thereby limiting the effectiveness of the findings herein. Consequently, it cannot be concluded that a later researcher following the same procedures would end up with the exact same findings.

| **Interviewee** | **Organization** | **Role** |
|---|---|---|
| Andersson Susanne | Trollåsens Tomat AB | Owner |
| Brännström Daniel | Agtira AB (previously Peckas Naturodlingar) | Co-founder |
| Engström Ingrid | BillerudKorsnäs AB | Senior Director Technology |
| Indebetou Fredrik | Wa3rm AB | Co-founder |
| Lilija Thomas | Elleholms Tomatodling AB | CEO & Chairman |
| Orrestig Kristin | Svegro AB | Supply Chain Director |
| Söderlind Marcus | Söderlinds Ekologiska Grönsaker | Owner |

| | | |
|---|---|---|
| Wikström Hugo | BigAkwa AB | Founder |
| Ydstedt Anders | Industrigruppen Återvunnen Energi, IÅE | Spokesperson |

*Note: Order by surnames*

*Table 1: List of Interviewees*

# 4. Case background

## 4.1 A global food system under pressure to change

Agriculture and land-use accounts for about one fourth of global greenhouse gas emissions (Drawdown Report, 2021) and is a large contributor to other environmental problems such as overfishing, eutrophication and loss of biodiversity (Campbell et al., 2017). Since farming is sensitive to weather patterns it is furthermore expected that more volatile weather patterns caused by climate change, with more frequent drought and severe rainfall, may have a negative effect on future yields in many geographies (UN Academic Impact, 2021).

While there is certainly no silver bullet solution to such complex problems it can be noted that food production in greenhouses stands out in a number of ways. For example, as the growing environment can be controlled it is less exposed to weather risks, and the yield per area is significantly higher than for outdoor growing. Moreover, excess carbon dioxide can be pumped into the greenhouse to support plant growth, and there is a possible synergy with fish cultivation as fish waste can be used as nutrients for the plants. Greenhouses can also utilize existing residual heat flows that have few alternative use cases and would otherwise be wasted.

## 4.2 Monetization of waste heat

Several projects and techniques for utilizing and monetizing residual waste heat exist. Their feasibility depends on a number of variables, not least the temperature of the heat and the distance to the user of the heat (Brückner et al., 2015).

In this section an overview of three different use cases for residual waste heat are presented. First, conversion to electricity, second, usage for heating of buildings, and third, heating of greenhouses. It should be noted that these three use cases are neither mutually exclusive nor an exhaustive list of use cases. For example, some of the waste heat could be converted to electricity and the remainder could be used in a greenhouse. Further, waste heat could also be used in different industrial processes such as drying and processing. Because waste heat recovery through district heating is more established than waste heat recovery through greenhouses this technique is given special attention in this section.

### 4.2.1. Conversion of thermal energy to electrical energy

Organic Rankine Cycle is a process by which thermal energy such as industrial waste heat can be converted to electricity (Tchanche et al., 2011). It is currently being utilized for heat recovery in industries such as shipping, steel and power production, for example by companies such as Ormat, Climeon and Turboden (Company websites, 2021).

### 4.2.2. Heating of buildings through district heating networks

District heating is a system whereby heat is transported through a network of pipes to heat buildings. It is a common source of heating for residential and commercial buildings in Sweden where it represents more than half of total heating of buildings. In 2020 in Sweden, waste heat supplied 8,3 % of the total heat distributed through district heating (Energi Företagen website, 2021).

Sweden is considered a world leader in heat recycling with its well-developed district heating networks, reusing nearly half of the 9.5 TWh of available industrial waste heat (not including the considerably larger waste heat streams from nuclear power) - Parker and Kiessling, 2016.

In a report commissioned by the Swedish energy agency the preconditions for and challenges of using industrial waste heat in district heating networks are explored. It finds that the payback time for waste heat cooperation projects between industry and district heating often are relatively long and thus that long term contracts for the heat supply are important. It finds that this is not without its problems, since it may limit flexibility to adapt to changing economic conditions. It also identifies a critical question for the industrial companies, which is the potential risk that added equipment needed to export waste heat may potentially increase the risk for operational problems in their industrial processes. The report provides an overview of the literature where the viewpoints of industry representatives on waste heat cooperation projects are investigated (Grönkvist et al., 2008).

In a study from 2005 the consultancy firm ´Profu´ interviewed representatives for industry and district heating companies at three locations in Sweden and identified three key reasons for why waste heat is not utilized more in district heating.

- First, the heat demand from the district heating network might not be sufficient, especially during summer. Further, because other heat sources may compete for this demand, such as heat from burning waste.
- Second, the associated investment costs to enable the waste heat to be used might be too high.
- Third, disagreement about how to value and price the supply of waste heat existed. The study also finds that their interviewees have different views on which project party should be responsible to bear the risk of financing the investments.

One viewpoint was that the district heating company should make the investments so that the management of the industry need not get approval from their board, and because the district heating companies generally have lower return requirements than the industrial party. A second viewpoint was that the industrial party should make the investments in order to keep full control of its industrial processes and to avoid outside parties gaining insight into their industrial processes.

Moreover, the study finds that another problem is that there are no widely accepted valuation principles for how to value and price the waste heat supply – while a district heating company may argue for sharing the profits from the project the industrial company may argue that the price of the heat should be slightly below the alternative cost for the district heating company. A counter argument from district heating companies may be that if the waste heat is not utilized it has a value of zero for the industry (Profu report, 2005).

In a later study Profu investigates the valuation principles in existing waste heat cooperations and finds that a general valuation method is not recommendable as the local circumstances differ substantially. It argues that these local preconditions must guide the valuation principles (Johnsson and Sköldberg, 2005).

Other authors have suggested a profit-sharing pricing system to achieve contractual efficiency for exchange of heat between owners of waste heat and district heating companies. They have analysed exchange of waste heat from a data centre that is upgraded using heat pumps and then distributed through district heating, and suggest an approach based on mathematical modelling where the heat price varies depending on factors such as heat demand, heat pump efficiency, electricity price, end user price of heat, and the fixed and variable costs of the investment (Wheatcroft et al., 2021).

How to value the waste heat and how to split profits between the industry and district heating company are identified in the report by Profu as key questions to enable cooperation. A set up where the parties split the investment and share profits pro rata in relation to their share of the investment cost was identified as a frequently occurring type of contract. In other cases, it was identified that the parties agreed on a contract where the district heating company financed the whole investment and received all of the profits from the set up until the investment had been recovered/paid-back (Grönkvist and Sandberg, 2006). The authors of this study note that in the majority of cooperation projects which they have studied the leading people behind the projects had a will to also do something good for the local industry, people and environment, indicating that non-financial considerations also might play an important role. Profu, in their study, similarly find from their interviews that utilizing the waste heat generates goodwill for the companies, not least given the environmental benefits.

In another study of waste heat cooperation in Sweden the authors find that the project risk for the industry is relatively low since the district heating network provides a stable and predictable heat demand over time. They argue that a bigger source of uncertainty is whether the industry supplying the waste heat will remain on that location, as it is subject to risks from the industrial market it operates in. They argue that industries have higher return requirements than the district heating companies, especially for waste heat projects which they view as a side business. Their conclusion is that waste heat cooperation requires large upfront investments with long pay back times and that this disincentivizes such projects, even though the risk for the industrial company is low (Program Energisystem, 2001).

Industrigruppen återvunnen energi (IÅE) is a Swedish industry association that has as its main agenda to support a development where more waste heat is recycled through the district heating network. It has large industrial members such as steel producer SSAB, chemical company Kemira, and the oil refinery Preem.

According to Anders Ydstedt, spokesperson at IÅE, the key obstacle for using more industrial waste heat for district heating is not technical or economical but rather legal. Specifically, §37a in the Swedish district heating law ´fjärrvärmelagen´ (2008:263) which makes it easy for the district heating companies, typically owned by the local municipalities, to reject industrial waste heat flows from gaining access to their heating network. It also enables district heating companies to first accept industrial waste heat and then being free to change that decision, bringing a significant uncertainty to the industry contemplating making the necessary investments for exporting the heat. This law enables district heating companies to stop external heat from gaining access to the network and protects other heat sources, such as burning of biofuels, or burning of household waste. The same local municipalities have often made large investments in waste-burning and bio-burning plants, not seldom having it on balance sheet of companies controlled by the local government. IÅE questions both the economic and environmental rationale of importing household waste from other countries to generate heat while there is several TWh´s of industrial waste heat available, and currently being wasted. They argue that Swedish industry would benefit from having better opportunities to export their residual heat to the district heating network, and that this could significantly improve competitiveness of Swedish industry, while improving its environmental profile. Moreover, they argue that if more industrial waste heat was used less bio-fuel and bio-material, for example from the forestry industry, could be burned and hence greenhouse gas emissions could be reduced and more bio-material be made available for other purposes such as producing furniture and paper products. In essence, IÅE argues that this specific law supports an inefficient use of resources and has a negative effect on the competitiveness of Swedish industry.

In those cases where industrial heat is connected to the district heating network pipelines and pumping systems are often the main capital expenditures needed to facilitate the heat recycling. Anders comments that the industries typically have significantly higher internal rate of return (IRR) requirements for their investments compared to district heating companies which are often owned by local municipalities. Anders therefore argues that there could be a strong case for a specialized intermediary to take on the role of project planning for heat recycling, investing in the required capital expenditures, and standardizing the economic contracts for transactions of waste heat. And that this could make it easier for industries and district heating companies to come to agreements for recycling more of the industrial waste heat.

Regarding the potential for industrial heat to be used in greenhouse projects Anders comments that the heat volumes required are much lower compared to the large heat volumes required for district heating, adding that large volumes of the total waste heat is in a temperature range that is too low for district heating but could be sufficient for greenhouses. If more industrial waste heat was utilized in greenhouse and aquaculture projects IÅE views it as potentially also benefitting the opportunities for more waste heat to be used in district heating, since it could boost the interest and attention for waste heat recycling in general. Moreover, Anders comments that there are also many other use cases for waste heat, such as drying and processing of different products such as for example bio-material. He also adds that for industries with waste heat that are located far away from district heating networks it might be especially interesting to use the heat for greenhouses and other projects. And that the transition towards hydrogen in industries such as steel means that the amount of available industrial waste heat will likely increase significantly, for example waste heat from the process of electrolysis, which converts electricity to hydrogen. Such fossil free steel projects are being planned in northern Sweden, an area where the district heating systems are already well supplied with heat, and hence alternative uses for heat, such as greenhouses, might be especially interesting in such areas. (Anders Ydstedt, 2021-10-28)

## 4.3. Usage of heat in greenhouse operations

Greenhouses, especially in northern latitudes, depend on external heating for large parts of the year to achieve high enough temperatures for plant growth and hence the production of foods such as tomatoes and cucumbers. Between 2002 and 2017 the share of fossil fuels used for Swedish greenhouses declined from 77% to 18% and today different bio-based heat sources such as wood chips play a dominant role (Jordbruksverket Report 2018:05).

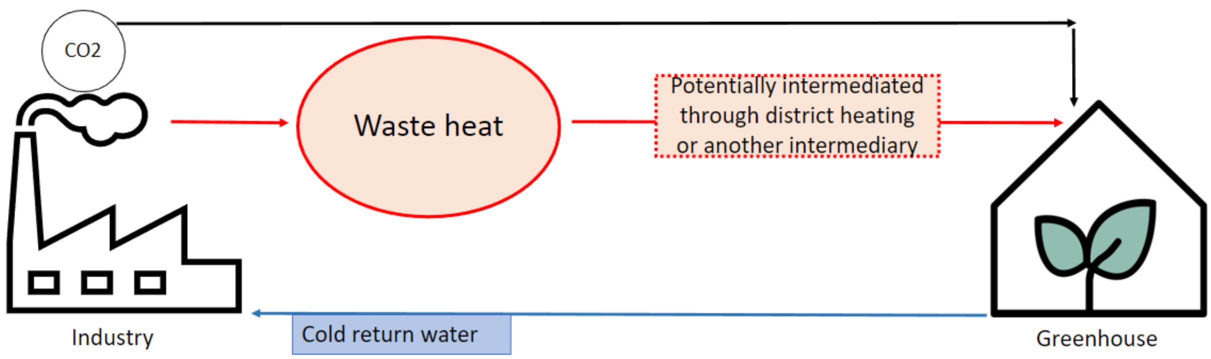


*Figure 1: Process flow showing exchange of waste heat between an industry and greenhouse*

## 4.4. Monetization of waste heat through greenhouses

In 2009, only 10% of the Swedish greenhouse area for production of tomatoes utilized waste heat (Jordbruksverket Report 2011:17). As a large part of the available waste heat is currently being wasted this raises the question if more of this heat can be used for the heating of new and existing greenhouses. If so, the environmental footprint of existing greenhouses could be lowered, and cost savings could be achieved. According to input data collected for this study and further presented in the appendix section, between ca 15-30 per cent of total cost of goods sold for a greenhouse operation relate to heating costs, depending on the price of the heat.

In Sweden, the majority of fruits and vegetables are being imported, for example the self-sufficiency rate of tomatoes is below 20 per cent (Jordbruksverket 2021). If more of these fruits and vegetables could be grown in greenhouses in Sweden the need for imports could be reduced and food security could be improved. Moreover, such greenhouses may create many new relatively low-skill employment opportunities.

Since greenhouses need heat, this raises the question of how the exchange of residual heat between industries and greenhouses can be structured and financed.

A number of greenhouses using waste heat are in operation in Sweden and abroad.

For example, in the region of Kirchweidach, Germany, where residual heat from a geothermal power plant combined with residual heat from a biogas plant and local district heating network is used to heat a 12ha (120,000 square meters) greenhouse growing vegetables (FG Geothermie website, 2021).

In the Netherlands there are also examples of greenhouses supplied with waste heat. For example, in the area of Zeeuws-Vlaanderen where residual heat and CO2 from fertilizer company Yara is supplied to local greenhouses (Warmco website, 2021).

In general, the greenhouse industry plays a significant role in the Dutch economy. Although it´s a relatively small country, it is the second biggest exporter of agricultural produce in the world by value, after the United States. Its exports of agricultural products accounts for 17,5% of its total exports. The Dutch government aims to reduce energy and gas consumption in the sector and identifies geothermal energy as well as biogas and bioenergy as promising technologies for achieving that goal. As of 2020 all new greenhouses need to be climate-neutral (Department of Agriculture, Netherlands, 2021). An area of 10,000 ha, roughly the size of Paris, is covered by greenhouses in the Netherlands, many of them using natural gas as a source of not just heating but also electricity and excess CO2 which is pumped into greenhouses to boost growth. In one sense, the heat that is co-produced when generating power out of natural gas can be considered waste heat, as it is a by-product of the main product, electricity. Up to 3 billion cubic meters of natural gas, or more than 8% of the country´s natural gas consumption, are used by the greenhouses annually. During the spike for natural gas prices in 2021 this has put pressure on the industry as it has faced severe increases in its costs for heating and electricity (Bloomberg, 2021). A greenhouse company that is dependent on natural gas for its heat and power could mitigate its financial risk exposure to higher gas prices by utilizing hedging strategies on the natural gas futures market.

For greenhouses using industrial waste heat the risk is instead centered around the dependance on the industry providing the heat. If that industry were to shut down the greenhouse would need to invest in a new source of heating to be able to continue its operations. This risk could potentially be mitigated by certain clauses in the supply contract stipulating the terms of agreement between the greenhouse and the industry supplying the heat. Slite Växthus on the island of Gotland exemplifies this risk. It utilizes waste heat from the nearby cement factory and is able to grow both cucumbers and bananas (Slite Tidningen, 2021). Cementa, part of Heidelberg Group, a major cement producer, is facing some uncertainties around its long-term permits of operation (Government Press Release, Sweden, 2021). If the cement factory generating the waste heat for the Slite greenhouse changes this naturally also has consequences for the greenhouse, in the worst case forcing it to invest in a replacing heating source. This example highlights one of the inherent operational risks of operating greenhouses with waste heat.

## 4.5. Additional synergies between greenhouses and aquaculture

Plants need nutrients such as phosphorus and nitrogen to grow and in agriculture these nutrients are often supplied through the application of artificial fertilizers, produced with natural gas. In fish aquacultures the fish leave behind manure which is rich in those same nutrients, and this can be used as a natural fertilizer. The greenhouse can be designed to use such fish wastewater, in the process purifying it so it can be circulated back to the fish aquaculture. This forms the basis for a symbiotic relationship between greenhouse plantations and fish aquaculture operations. A symbiosis that has been shown to be able to facilitate environmental benefits while generating cost savings for greenhouse plants, and an additional source of revenue in the form of fish (Hocham et al., 2018).

# 5. The Cases

In this section a range of greenhouse and aquaculture projects with varying sources of heat and project finance structures are explored. First, a greenhouse heated with biofuel through its own heat burner is explored, since this is the most common way of heating of Swedish greenhouses. Then, a range of greenhouses and aquaculture operations using different types of waste heat are explored.

## 5.1 Svegro

This is an example of a greenhouse operation using a bio-based heating system and having the heating equipment on its own balance sheet.

Svegro is a Swedish company operating an organically certified 5,5ha (55,000 sqm) greenhouse operation on the island of Färingsö, close to Stockholm, producing for example salads and herbs. It utilizes bioenergy for heating the greenhouse (Svegro website, 2021).

Supply chain director Kristin Orrestig, responsible for production, purchases, deliveries, and sustainability at Svegro, comments that Svegro´s greenhouse has been built stepwise, with the first section being completed in 1983. The greenhouse was designed for using relatively high water temperatures of well above 80 degrees Celsius. The heat is distributed through a network of pipes. Originally diesel oil was burned to generate heat and throughout the years fossil oil input was replaced step by step with bio-based oil. In recent years one important focus area has been to continuously improve the environmental profile of the operation. This led to the decision in 2018 to invest in two pellet fuel burners to fully replace the oil burners. Besides improving the environmental footprint, operational reliability was another key consideration for deciding what heating source to transition to. The combination of a high degree of operational reliability, attractive cost profile, and ability to buy fuel pellets made in Sweden, as well as the ability to easily store pellets at the site, motivated the decision to invest in transitioning to bio-heat.

Kristin explains that there is no industrial waste heat available in the area and hence that was never an option, although she sees it as potentially interesting had there been a source of waste heat nearby. The main benefit would have been to be able to use already existing heat instead of producing new heat, thereby potentially making the production even more environmentally friendly. She views the operational reliability of waste heat as a potential obstacle, given the importance of having access to a stable and reliable supply of heat to be able to operate the greenhouse efficiently. She comments that if she was evaluating waste heat as an option, she would view the risks of a varying heat flow as well as the risk of the waste heat owner closing its operations as the major risks. Hence, it is questionable if Svegro would have been willing to rely solely on an industrial waste heat source, without having internal control over a back-up heat source. Had waste heat been available a combination of having access to waste heat and having a bio-fuel heat generator as back-up might have been a preferred option, given that the cost of waste heat had been lower compared to the bio-heat source so that cost savings could be made by having to burn fewer biofuels. If the waste heat supply contract was relatively long term, say around 10 years, and the contracted heat supply was stable enough, it might be possible that the capital expenditures for the complementary bio-fuel-burners could be reduced, making the combined option even more attractive.

Regarding the pricing of the waste heat in such a contract Kristin comments that Svegro would have compared it to their alternative cost, and that a discount to that alternative cost would be necessary to motivate the potential risk inherent in not having internal control over the heat supply. On the topic of fixed vs variable heat prices for potential use of waste heat Kristin comments that a long-term contract with stable and predictable heat prices would be important for it to be attractive. Some degree or variability within given boundaries would be seen as feasible, noting that in many other supply contracts Svegro works with index adjustments. (Kristin Orrestig, 2021-10-28)

## 5.2 Trollåsens Tomato plantation

This is an example of a greenhouse operation using industrial waste heat, sourced directly from a neighboring pulp and paper mill.

Susanne Andersson founded the operation with her brothers in 1986 and has run the 1ha tomato plantation located outside of the city of Varberg since then. She comments that the background of the project was that Södra Cell, a forestry company with several pulp and paper mills in southern Sweden, was together with the local municipality investigating new ways to utilize its waste heat in order to improve its environmental performance. Her dad owned a piece of land and grew vegetables just 500 meters away from the pulp and paper mill and she was asked if she wanted to utilize the waste heat to start a larger greenhouse operation. Södra Cell made the investment in a 500-meter pipeline to transport the heat to the site, and Trollåsens Tomat AB made the investments in the greenhouse and required heat exchange equipment to utilize the heat. The waste heat is purchased directly from Södra cell according to a contract. The heat was initially of relatively low temperatures, of around 40-50 degrees, and hence it required Trollåsens to build a heating system in the greenhouse using relatively more pipes to successfully transfer the heat, compared to if they had for example used an oil burner which at that time in the 1980´s would have been the major alternative source of heat. To hedge against the risk of reduced waste heat flows during malfunctions or maintenance of the pulp mill Trollåsens also invested in an oil burner as a back-up heating system. These extra pipe and back-up investments were reflected in the price at which Trollåsens was able to purchase the heat, I.e. If Södra had been able to contractually promise slightly higher temperatures and guarantee a non-interrupted heat flow Trollåsens would have been willing to pay more per unit of heat.

Susanne adds that for a greenhouse operation it is critically important to have a continuous and predictable steady flow of heat to make the growing system operate smoothly and efficiently. She views this as a general challenge for greenhouses using waste heat, since there is always the risk that the waste heat supplier needs to perform maintenance work or might change its operation, resulting in a possibly volatile or non-continuous heat flow. Hence a back-up heat system is important, adding that in her case the cooperation with Södra Cell has worked well with relatively minor disruptions, typically due to planned maintenance of the pulp mill. She also comments that greenhouses are labor intensive operations and it´s enough of a challenge to find, train and keep skilled employees. If the heat supply is volatile the operations also get more unpredictable, and this poses further challenges for the employee situation.

Recently Susanne sold her greenhouse to Södra Cell, commenting that it could be potentially interesting for a forestry company to have access to a greenhouse of their own to be able to grow new tree plants before planting them in the forests. (Susanne Andersson, 2021-11-26)

## 5.3 Elleholm´s Tomato Plantation

This is an example of a greenhouse operation using industrial waste heat, sourced indirectly through the district heating network.

Elleholms tomatodling AB is Sweden´s second largest tomato greenhouse and the largest one utilizing industrial waste heat. Covering an area of ca 6ha it produces 2700 tons of tomatoes per year (Elleholms website, 2021).

A large pulp mill of the company ´Södra´ is located ca 2km away from the greenhouse, generating large amounts of industrial waste heat. Much of this heat is fed into the local district heating network of local energy company Karlshamn Energi which then distributes the heat to local households and other buildings. Thomas Lilja, CEO and chairman of Elleholms, explains that the Elleholm greenhouse can access this heat through a connection to the district heating infrastructure, and consumes around 13% of the total heat distributed through the district heating network. Once the hot water fed into the district heating network has heated up the buildings it is returned as cooling water to the pulp mill, and the cycle can begin again. For the pulp mill it is beneficial to get as cold cooling water as possible, since that supports a more efficient cooling process. The set-up of supplying the greenhouse with this heat source has its origins in the realization of the local energy company that the greenhouse is more efficient than the households in reducing the temperature of the water, which in turn is attractive to the pulp mill. The hot water fed into the system is typically around 104 degrees Celsius. After heating up the households the return temperature is typically around 55 degrees, while the greenhouse is able to reduce the temperature down to between 27-30 degrees. At the core, this is what made the set-up attractive. In that sense a win-win is facilitated, as the pulp mill gets cooler cooling water, and the greenhouse gets access to a price competitive and environmentally sustainable heating source. While not being able to comment on the exact cost of the heat Thomas comments that it is cost efficient compared to his alternative cost of producing own heat from burning wood chips. From Elleholm´s point of view it was beneficial that they could connect to an existing infrastructure of pipelines and thus did not need to make large capital expenditures in pipelines to transport the heat to its facility.

Elleholms has a long-term contract for the heat supplied by Karlshamn energy and were the pulp mill to close down the district heating company would make the necessary investments to replace the heat from the pulp mill, thereby reducing the financial risk of having to make new CAPEX investments in a replacing heat source. A risk that Elleholms would have been exposed to had it sourced its heat directly from the pulp mill. This set-up also entails the benefit that Elleholms does not need to have a back-up heat production source on its own balance sheet.

Thomas sees a large potential for more greenhouses in Sweden, arguing that Sweden has large resources of heat and fresh water available. The major risk he sees for new such operations is that greenhouse operations are personnel intense and access to employees can be limited, absent of the right political support. He also identifies access to cheap electricity as an important risk, noting the recent increase in electricity prices during the fall of 2021, especially in southern Sweden.

Going forward Thomas has plans to expand his operation with an additional 8ha of greenhouses, as well as adding an on-land fish production facility which would use some of the remaining heat that his greenhouse is not able to absorb, while generating a circular and sustainable source of natural fertilizer from the fish waste products for his tomato plantation. Furthermore, he sees an opportunity in the future to utilize some of the more low-grade heat generated by the pulp mill. He comments that this lower grade heat has a too low temperature for district heating but is warm enough for a greenhouse. (Thomas Lilja, 2021-11-11)

## 5.4 Peckas Naturodlingar

This is an example of a greenhouse operation using heat from the local district heating network.

Peckas is a 1,35ha aquaponic greenhouse operation located in the city of Härnösand and produces 600 tons of vegetables and 60 tons of fish per year. The produce is grown in a symbiotic aquaponic system, where fish waste products are fed as nutrients to the vegetable plants.

Co-founder Daniel Brännström explains that when they initiated the project they considered possibilities of utilizing industrial waste heat but that it was not accessible in close enough proximity to the site of the greenhouse. Moreover, the risk of the heat supply disappearing, would the industry supplying it shut down or change its operations, was identified as a major risk, disincentivizing this option. Instead, they opted for connecting to the local district heating network of Härnösand, owned and operated by the local energy company HEMAB. Thus, the capital expenditures needed to gain access to the heat had already been made, by HEMAB. The risk that the district heating system would shut down was considered minimal. This meant that they were willing to make the greenhouse investment without also investing in their own back up heat supply, thereby reducing the need for capital expenditures.

The heat in the district heating network is in turn sourced partly from the wood pellets factory Bionorr, owned by pulp and paper company SCA, and partly from a biomass combined heat and power plant. Thus, some of the heat used by the greenhouse has its origins in waste heat. Daniel adds that the lights used by the greenhouse to support plant growth also emit a significant amount of the needed heating.

Daniel comments that since HEMAB is owned by the local municipality the heat prices were not directly negotiable but instead subject to standard prices, although offered with a discount since Peckas could buy relatively large volumes. The contract is a rolling 1 year contract and no significant capital expenditures were needed from Pecka´s side in order to connect to the heating network.

On a more general note, when asked about the potential for utilizing waste heat in greenhouses Daniel comments that the major risk from a financial standpoint is the risk of necessary new investments in a replacing heat supply, would the industry supplying the waste heat decide to close, move or scale down its operations. According to Daniel it is likely quite complex to negotiate a long-term financial contract for purchasing waste heat from an industrial company, not least because of possibly conflicting views about who should make what investments, and because of differing time horizons. In his experience, many industries operate with quite short-term strategic targets, and greenhouses with a more long-term horizon.

He adds that in some regions close to major cities the electrical grid is quite stretched in terms of capacity and the financial risk of delayed start of operation should therefore be considered, given that large greenhouses consume significant amounts of power and the local grids might not always be able to support such an increase in demand from one site.

In addition to operating the greenhouse and fish cultivation Peckas also invested resources into product development, eventually leading to the rebranding of the company, now called Agtira, and a shift in strategy. Agtira is now focusing on developing modular hardware and software for combined greenhouses and fish cultivation, that can be installed in direct proximity to food retail stores. (Daniel Brännström, 2021-11-09)

## 5.5 Agtira

This is an example of a greenhouse system designed to be installed right next to food retail stores and utilizing residual heat from those stores, potentially combined with additional heat from district heating or other sources.

Building on the experience of Peckas, Agtira has developed modular systems for aquaponic greenhouses, that can be combined with on-land fish cultivation (Agtira website, 2021). In a press release it was announced in October of 2021 that Agtira had signed a contract and will deliver one of its systems to food retailer Ica Maxi in the city of Östersund, to be installed in 2022 and start operations in September that year, delivering fresh and sustainable vegetables and salmon to be sold to Ica Maxi´s customers (Cision News, 2021).

Co-founder Daniel Brännström explains that food stores generate heat from its different machines and the people working and shopping in it, and that this heat supply is often sufficient to provide the necessary heating for their modular systems. When investigating a case Agtira looks at the available heat supply generated by the store and takes this into account. If more heat is needed a feasible option in many cases is to also connect to the local district heating network. In the case with Ica Maxi in Östersund the customer makes the investment to finance the system supplied by Agtira. In that case, the associated company Ica Fastigheter (Ica Real Estate) which rents the food store to Ica Maxi Östersund makes the necessary capital expenditures. Agtira supports them with their operational expertise and a team that can manage production and take care of maintenance if needed.

Daniel adds that one of the reasons for Agtira´s change in strategy to sell these systems to be installed right next to food stores was the realization that consumers are increasingly demanding locally and sustainably produced foods, and by growing the food right next to the store so the customers can see the food being grown the food stores are able to charge a higher price for it. It also reduces the need for a food wholesaler since the food is grown right next to the store, thereby enabling higher margins and forming the basis for a profitable business case that can motivate its customers to make the CAPEX investments. Another motivation for developing this smaller modular system, he adds, was the realization that, compared to having a large plant in one location, many smaller plants in many locations would entail lower risk for difficulties with getting permission to access the electrical grid. In many densely populated areas, his experience is that being able to connect to the electrical grid is far from certain, creating a big risk for the project development. But connecting a smaller greenhouse to the grid is typically not a problem at all. In sparsely populated areas this is less of a problem. But the big food retailers of course tend to be situated close to the major cities (Daniel Brännström, 2021-11-09).

In Germany, similar projects are under way, for example through the food retailer REWE (Dagligavarunytt, 2021).

## 5.6 BigAkwa

This is an example of an aquaculture pilot project using waste heat from the pulp and paper industry, and in return providing resources for the paper factory´s biofilter.

Hugo Wikström, who previously co-founded Peckas Naturodlingar, is the founder of BigAkwa AB, a start-up developing on-land fish cultivation technology that aims to work in symbiosis with the pulp and paper industry, and thereby produce fish in a cost-competitive and environmentally efficient way. By growing more fish on land BigAkwa aims to address the environmental problems associated to overfishing and in-ocean fish farming, in the process generating valuable and sustainable inputs in the form of nutrients needed by the pulp and paper mills (BigAkwa website, 2021). In a press release from early 2021 a pilot project with SCA, a large Swedish forestry and pulp and paper company, was announced. The project aims to lead to a symbiotic cooperation between the two companies whereby excess heat from one of SCA´s plants is to be fed into the aquaculture operation and excess fish waste is to be fed into SCA´s biofilter, thereby reducing the need of externally bought chemicals for that process (Press Release, BigAkwa, 2021).

Hugo comments that during 2021 BigAkwa has been validating the processes and tested them through a pilot project in close cooperation with industry to simulate a full-scale project. They have found that their fish cultivation plant is able to utilize low-grade heat of around 37 degrees Celsius at a cost competitive price, heat that is difficult to utilize in other ways. And the rest-products from the fish cultivation, which is rich in nutrients such as nitrogen, can supply the biofilter of the pulp and paper factory with nutrients. This in turn reduces costs for the pulp and paper factory´s cleaning process, as it reduces its needs to buy nutrients from other sources.

Hugo adds that they are currently evaluating several different sites for a full-scale operation. At one of those sites a pipeline able to transport the heat already exists since before, thereby reducing the necessary capital expenditures needed to facilitate a full-scale project. Moreover, if the fish plant can access the electricity connection of a large paper mill there could be significant electricity cost savings for the fish plant.

Hugo expects that a full-scale project would entail ca 250 MSEK of capital expenditures and a net working capital need of ca 60 MSEK. Such a facility could produce 13,000 tons of fish per year, which would double the Swedish aquaculture production, albeit from low levels. In terms of financial returns, he expects that such a project would generate a payback period of 5-7 years in terms of discounted free cash flows.

Hugo identifies access to land near the pulp and paper plant as a challenge for enabling this type of project. He explains that large pulp and paper companies are very unlikely to be willing to sell land for such an operation to base its activity on, but that a land lease agreement is more feasible. And if the waste heat recovery activity, in this case a fish cultivation plant, can be housed in a building that also has other alternative use cases, such as a machine hall, it becomes more feasible for a large industrial company to make such an investment in a building. Therefore, BigAkwa has developed its hardware equipment in a modular way that can be moved to a different site if needed, and so that it fits well into a more general-purpose building.

Hugo furthermore comments that to make this type of project financeable it is of high importance to ensure that the contracts for the symbiotic exchange of heat and nutrients are long term. He identifies the Achilles heel of this type of symbiotic projects as the interdependency between the project parties and stresses the importance of stress testing for different scenarios when performing the financial due diligence. For example, investigating potential extra costs or lost revenue that could occur if the biofilter closes for maintenance and thus has no demand for purchasing nutrients from the fish plantation. The ongoing pilot project is an important part of this due diligence process and helps with evaluating the financial potential of the project. He comments that to structure the financial contracts for this type of project it is important to understand the synergistic value that it enables, before agreeing on how to share that value between the parties. By quantifying the symbiosis and then pricing the waste streams of heat and nutrients in such a way that both project parties save costs, i.e., below the alternative costs for the respective parties, a good deal can be structured, and this is fundamental to the investment willingness of both parties. (Hugo Wikström, 2021-11-12)

## 5.7 Söderlinds

This is an example of an existing greenhouse project using waste heat from a nearby biogas facility.

Marcus Söderlind, the owner of Söderlinds ekologiska grönsaker, operates a 1,500 square meter greenhouse. The heat is being sourced from Rånghult Biogas AB, the neighboring farm business which is equipped with a biogas plant run by Dan Waldemarsson. The biogas is used to produce ca 40 kW of renewable electricity, in the process generating ca 60 kW excess heat, which is then led through a pipeline to the greenhouse where organic vegetables are being produced. Dan comments in an article about the project, published by the Swedish farmers´ association, that having a reliable customer for the heat was a critical factor for making the biogas investment, the revenue from the heat being around 43% of the total revenues from the biogas plant. The decision of Marcus to invest in a new greenhouse was in that sense enabling the biogas investment, and Söderlinds got access to purchase a stable source of heating at a price slightly below the alternative cost of producing the heat with pellet fuel (LRF, 2016).

Marcus comments that neither the biogas plant nor his greenhouse would have been practically possible without the other, and that the two businesses therefore operate in symbiosis with each other. Marcus and Dan cooperated during the process, for example to get approval from the local government to build the biogas plant, a system that requires an environmental permit. They agreed that Marcus would only pay for the heat he actually used in the greenhouse and that they would not need an actual written contract to formalize the terms. Instead, they decided that an oral agreement would be sufficient, and they promised each other to cooperate long term as neighbors to make their joint project work, for example meaning that they would help each other with operations and maintenance as required. The heat price, they agreed, would be set so that it would be below the alternative cost for Marcus, in practice meaning below what it would cost him to heat his greenhouse with pellets fuel.

Marcus goes on to explain that Dan made the investment in the capital expenditure related to the biogas plant and associated equipment to produce the biogas, while Marcus made the investments in the ca 70-meter-long pipeline transporting the waste heat from the biogas plant to his greenhouse. Marcus adds that the bank providing the loan for financing the greenhouse was initially very skeptical and that it put a very conservative valuation on the greenhouse, arguing that if the business were to fail there would be limited alternative use for his farm once covered with a large greenhouse. But eventually he was able to raise the required bank loan and financed the remainder with agricultural investment grants.

Regarding financial risks for his greenhouse operation Marcus comments that, given the good relationship and historically good cooperation with his neighbor, the risk of losing access to the waste heat was considered very limited. He views the challenges of finding and keeping good employees as a significantly greater risk, explaining that his greenhouse has a cyclical demand for staff and that it is therefore challenging to offer full-time employment contracts. He adds that it is time-consuming for him to train new staff and that he runs the risk of losing good employees once a growing season is over, potentially implying that he needs to commit time and expenses to train new staff once the next season starts. Historically he has been fortunate to find good employees but to limit this risk he views support from local government employment agencies as important, adding that greenhouse work can be a good opportunity for junior professionals and newly arrived immigrants to get into the labor market.

On the revenue side of the operation, he adds that there are also important risks for him to consider. He has worked continuously for many years to build up a strong local customer base that is willing to pay a good price for his produce, thanks to it being organic, locally produced and arguably of high quality. But during the peak season he runs a risk of supply outstripping local demand. Compared to some of the much larger greenhouses that have more stable output throughout the year it is relatively more difficult for a smaller greenhouse like Söderlind´s with a more cyclical production, peaking during early summer, to establish sales contracts with large buyers such as retail chains who demand more stable supplies throughout the year (Marcus Söderlind, 2021-11-08).

## 5.8 RePro Food

This is an example of a greenhouse operation using waste heat that never materialized.

ReproFood was a development project with eight partners, initiated by Swedish food production company “Findus”, and funded by VINNOVA (Swedish governmental agency for innovation systems) that ran from 2015 to 2017. It was envisioned to create a system with greenhouses and fish farms re-using waste heat and carbon dioxide from one of Findus´s food processing plants in Bjuv, Sweden (RePro Food website, 2021). The project manager was Thomas Parker, founder of WA3RM AB, a Swedish company that today has several projects in its pipeline, including greenhouses and land-based fish farming using residual flows, for example waste heat, from industries (Wa3rm website, 2021).

The outcome of the ReproFood project was a set of reports, including a detailed investment calculus and a financial report in which the business structure was tested and evaluated between the project partners who would build, finance and operate the food production facilities. The project was designed to be useful as templates for future rollouts of similar projects.

The original plan of constructing the greenhouse at the location in Bjuv was cancelled when Findus made the decision to close the plant towards the end of the project and thus the heat supply was cancelled. Therefore, the project changed location to investigate using waste heat from Saint-Gobain Isover in Billesholm, Sweden. Ultimately, the project never materialized though, because of difficulties with securing a high and stable enough flow of waste heat (RePro website, 2021).

The project demonstrated that combined greenhouse and fish farm operations, where industrial waste heat is used for heating, CO2 is recycled to boost plant productivity, and fish waste product is used as fertilizer, can generate attractive returns to investors while providing substantial environmental and social benefits in the form of recovered energy and new job creation.

It also identified two important barriers to waste heat recycling.
The first barrier is the risk connected to the waste heat supply contract. To manage this risk, it was identified that careful qualification studies are important and that a back-up heating solution is important to provide investors with the confidence that capital can still be returned, if the waste heat supply were to be lost, as in the case with Findus´s plant.
The second barrier is the quality of the waste heat, its temperature, intermittency and carrier medium being key parameters. For example, Veolio, one of the eight project partners in ReproFood, investigated heat recycling from the Saint-Gobain Isover facility and found that the heat source was insufficient, partly due to a new decision of Isover during the project to start utilizing some of the waste heat for internal purposes, thereby lowering the amount of waste heat available for the greenhouse.

The ReproFood study demonstrates that large upfront Capex investments are needed to enable waste heat to be used for a greenhouse, but that the supply of waste heat is sensitive to the internal decisions of the industrial company supplying the waste heat. The risk is that once the pipes for the heat and the greenhouse is installed the supply of the heat diminishes or vanishes, making it uneconomical to operate the greenhouse, and hence difficult for the investors to recover the capital. The ReproFood project also showed that while there are back-up solutions for heat for such occasions, they typically imply a higher cost of heat, lowering the returns for investors. The study also showed that the cost of heat and cost of capital are key variables for the financial viability of such projects.

## 5.9 Regenergy Frövi

This is an example of a greenhouse operation that has been signed and is now to be constructed. Once in operation it will utilize low grade industrial waste heat.

In 2019 the Swedish company Billerud Korsnäs, a producer of products such as paper and cardboard, and their project partner company, WA3RM AB, announced a letter of intent that they plan to develop a project to recover waste heat from the pulp and paper production site in Frövi for heating of a large-scale greenhouse and aquaculture facility. Improved resource efficiency was expected to facilitate an economically attractive project for the parties involved (BillerudKorsnäs Press Release, 2021). The press release from Billerud Korsnäs states that both the local municipality and local energy company Linde Energi, which distributes waste heat from the factory through its district heating network (Linde Energi website, 2021), participated in the initial discussions.

In 2021 the same parties announced that a contract had been signed to develop the project (BillerudKorsnäs Press Release, 2021). The project vehicle is called ´Regenergy Frövi AB´ and includes three project parties, a heat supplier, a project developer and owner, and a greenhouse operator. Initial construction work is planned to start during Q1 2022. The total investment is budgeted for 754 MSEK and includes a 10ha greenhouse and 10ha aquaculture facility. It will enable 50 GWh of energy to be recovered on an annual basis, enabling production of 15,000 tons of vegetables and 4,000 tons of fish per year. The project will also lead to avoided and reduced emissions of almost 20,000 tons of CO2 per year through avoided transport and sustainable heating and create 220 new full-time employments. A combination of a green fund vehicle and bank loans will finance the project (Regenergy Frövi webpage, 2021).

As of 2021 WA3RM had several co called ´Regenergy´ projects in planning phase in Sweden and two projects, including ´Regenergy Frövi´ that had been initiated. They define a ´Regenergy´ project as green industrial projects that enables circular and regenerative production of products such as vegetables and fish, in symbiosis with industries that have significant residual flows of waste heat and other biproducts such as CO2. The stated motivations for these projects are to support the environmental goals, create new green jobs, and help strengthen the competitiveness of Swedish industry (Regenergy website, 2021).

Fredrik Indebetou, Thomas Parker and Michael Wiegert are the co-founders of WA3RM. The background to the company is that they were working with energy related questions, including heat recovery, at the European spallation source (ESS) and then founded WA3RM as a spin-off from their work at the ESS energy division. Their business concept is summarized as “waste-to-X" - capturing residual flows such as, but not excluded to, heat and CO2, and enabling these flows to be used in business models such as food production in greenhouses (Wa3rm website, 2021).

Fredrik comments that during their time at ESS they had contact with ´Findus´, a major food producer with a large facility not far from the ESS location in Lund Sweden, and that this eventually led to the start of the ReproFood project. The ReproFood project never materialized due to the decision of Findus to move their production to Germany. However, the results and financial budgeting from the ReproFood study proved to be rather representative of Wa3rm´s current projects and their learnings from that project greatly contributed to the later success with new projects. Since executing the ReproFood project their business model has evolved from renting out a greenhouse plus selling the heat into one where WA3RM can provide greenhouse operator partners with a more complete concept that includes financing, construction and heating of a greenhouse. In other words, the heating cost is now included in the rent. This concept enables the operator to focus on its core competence of operating a greenhouse. Wa3rm takes care of the heat supply, designing the greenhouse according to the operator´s specification, and financing the project. Thus, the operator can rent a heated greenhouse, hence not having to finance the capital expenditures and negotiating the heat contract with another heat supplier.

Fredrik likens it to a phone subscription, arguing that just as most consumers prefer a monthly fixed fee instead of financing their phone themselves upfront, many greenhouse operators might prefer a fixed rent fee for a greenhouse they can operate. In that sense, WA3RM can be seen as an intermediary between industries with residual flows such as waste heat, and off-takers of residual flows such as greenhouse operators. By specializing in construction and financing of projects that enable such industrial symbiosis to be monetized WA3RM supports market efficiency by enabling the industry and greenhouse operator to focus on their core business instead of having to engage in the details of facilitating the exchange.

Fredrik comments that industrial companies typically view heat recovery as a non-core business activity and that it therefore might be a preferred option from their point of view to have a project partner taking care of the required planning and investments for recovering the heat. Adding that industries with waste heat are naturally interested in monetizing their heat but that such projects often have too long pay-back periods (too low IRR´s) for them to motivate it. When WA3RM can step in as an intermediary making the necessary capital expenditure investments and offering the industries to instead simply sell their excess heat, instead of making the capex investments internally, this time-perspective friction can be resolved. For WA3RM to be able to make the investments it is critical that they can both buy and sell the heat through long-term contracts, ranging from 10 to 20 years.

While not being able to comment specifically on the heat price or negotiation process Fredrik comments that the heating cost is a very significant cost item for any greenhouse operator and that the heat price is a key motivator for industries to engage in these projects. The greenhouse which will be built in Frövi is furthermore dimensioned for using heat source temperatures of 45 degrees Celsius instead of 70-80 degrees which is typical for greenhouses, an important aspect as it broadens the scope of total waste heat volumes available for recycling. The Dutch project partner ´Lokal Harvest´ which will rent and operate the heated greenhouse was involved in the project at an early stage and the greenhouse is designed in accordance with their specification.

A key part of the due diligence during the pre-study and investment phase was to thoroughly evaluate the greenhouse operator´s competence and long-term economic viability. This included evaluating both the ability to grow greenhouse crops as well as the distribution channels and market demand for the crops. One of the other key risks evaluated during the due diligence was the risk that the heat supply would be reduced or disappear, and that the investment budget should have room for recovering necessary reinvestments in a new heat supply for such a case. The location of the greenhouse was another key factor being evaluated since investments in the necessary piping infrastructure for the hot water is a large item in the investment budget. The closer between the industry and the greenhouse site the better, ideally within 1 or 2 kilometers, as in the case of Regenergy Frövi. (Fredrik Indebetou, 2021-11-05)

### 5.9.1. Billerud Korsnäs - Waste heat project partner in Regenergy Frövi

Billerud Korsnäs is a Swedish forest industry company that is listed on OMX Stockholm Large Cap and has several plants in Sweden and Finland, producing for example consumer board and packaging paper. The company is working actively with sustainability related questions and was assessed to be among the top 10 per cent of companies within the sector in the S&P Global Sustainability assessment of 2021 (BillerudKorsnäs website, 2021).

Ingrid Engström is senior director of technology at BillerudKorsnäs and previously worked as factory manager at the plant in Frövi. Her responsibilities include working with sustainability related questions on a company group strategic level. She comments that this type of project is right in line with the company strategy of positioning itself as a sustainable supplier of sustainable products, e.g., for consumer packaging. According to Ingrid, the main motivation for them to participate in this project is not purely financial but rather that contributing to this type of project brings about social and environmental benefits, in extension strengthening their local presence in the community, as well as supporting its brand positioning of being a sustainable company. Many of their products are used as packaging for consumer products and she expects that engaging in this type of energy recovery project will strengthen the sustainability profile of those products, which has a value since consumers increasingly demand sustainably produced products. She adds that the Regenergy Frövi project had strong top-level support given how well it aligned with the company strategy of contributing to a more sustainable development. Ingrid also comments that that although the project will generate some extra profits through the sale of residual heat, which would otherwise have been wasted, these cashflows are a marginal bonus, fairly insignificant compared to cashflows from the existing business. That the greenhouse can lower temperatures of the waste heat flows and return cold water to the industry is also a bonus, mostly because the flow of cold return water becomes less volatile.

Today, BillerudKorsnäs sells high grade waste heat to district heating companies at many of its locations. The Regenergy Frövi project is a way to increase the scope of such win-win cooperations, by also making lower grade waste heat available for value creating projects.

Ingrid explains that without the opportunity to work together with the project partner WA3RM to develop this project it would most likely not have happened. It would have been much more difficult for BillerudKorsnäs to develop such a project themselves, for several reasons.
First, their strategic focus and core expertise lies in their core business, and not in developing greenhouse projects with all the niched competences which that entails. While being more than able to contribute to an efficient exchange of waste heat it would simply have been unfeasible for them as an organization to commit resources to a large project outside of their core business focus.

Second, since WA3RM could take care of most of the needed capital expenditures it simplified the decision to sell waste heat considerably. BillerudKorsnäs was able to commit significant resources, mainly in the form of time and effort from their engineers, but had the project entailed larger internal capital expenditures, it would have been a more complicated process, and likely not feasible to commit to as it is outside of their core business. She sees a conflict in that as an industrial group they have a high degree of discipline for committing to capital expenditures and that such projects need to show quite a high and more immediate return on capital. While waste heat projects such as Regenergy Frövi requires more patient long-term capital with different return requirements. She also comments that for capital expenditures the decision mandates depend mainly on the size of investment, with large projects requiring approval from the top level, while smaller decisions can be made on factory management level.

Third, she confirms that there is a fair degree of information asymmetry between a greenhouse operator and an industrial company like BillerudKorsnäs. Working with a project partner that is knowledgeable within both these domains and can align the interests of all parties involved was therefore fundamentally important. Not least since WA3RM could bridge the information asymmetry and effectively analyze the project risks and design the project structure to handle those risks, for example by analyzing the competence of the greenhouse operator project partner. In this type of project, she adds, it is important for BillerudKorsnäs to minimize risks for something going wrong, and hence it is critical to cooperate with a knowledgeable partner such as WA3RM.

Going forward, she expects that the concept of industrial symbiosis can play an important role in realizing the green transition. Regarding financial risks for such projects she views it as fundamental that such projects do not threaten the operational stability of industries core business areas. Since such projects are typically very long-term it is also important that local municipalities provide their support. She also expects that intermediaries will need to play an important role to bring together project parties and align everyone´s interests (Ingrid Engström, 2021-12-02).

# 6. Results

In this section we synthesize and analyze the interviews.

## 6.1. What are the major financial risks in such projects, and how have they been mitigated?

A set of specific financial challenges of waste heat greenhouse projects were identified, as compared to greenhouse projects utilizing their own heat source:

### 6.1.1. Uncertainty around financial returns for investments in heat recovery Capex

In essence, interviewees perceived uncertainty around recovery of invested capital in pipelines and related capital expenditures as significant. It was also viewed as a financial challenge to negotiate what party should be responsible for making what parts of the investments, and how that should be reflected in the terms for which the heat should be bought.

For waste heat owners it was viewed that the IRR of such projects may be too low to motivate internal capex investments, depending on the funding sources and cost of equity attributed to such an investment. There is always a market risk that the greenhouse project operator may be unsuccessful, which would lead to loss of demand for waste heat and threaten the recovery of the invested capital.

### 6.1.2 Inherent risk of potentially having to make extra capital expenditures in a replacing heat source

There is an operating risk that the waste heat supplier will reduce, shut down or move its operations, leading to the loss of the needed heat supply to operate the greenhouse. If that risk materializes there is a need for new capital expenditures in a replacing heat supply, threatening the expected financial returns and repayment capacity. Moreover, the risk of volatility in the supply of waste heat, for example due to maintenance work on the side of the waste heat supplier. These were perceived as major risks with utilizing waste heat. For a greenhouse operator it is already a large financial risk to have a large greenhouse on its own balance sheet and extra uncertainty around the heat supply adds to that risk.

### 6.1.3. Strategic priority mismatch

It was identified that the heating source is a key priority for greenhouse companies, but that waste heat utilization is a relatively less important priority for industrial companies with excess waste heat, competing with other capital investments.

### 6.1.4 Risks and opportunities associated with access to electricity

It was found that in densely populated areas greenhouse operators had experienced the risk of being denied access to the electrical grid, or getting delayed access, as a major risk. It was also found that there was a potential benefit in placing greenhouse operations close to industrial sites with waste heat, due to the possibility of connecting to the electricity access of that industry, as it enables reduced grid fees and hence a lower electricity price.

### 6.1.5 Information asymmetry

It was identified that there is a significant information asymmetry between waste heat owners and greenhouse owners and that this complicates the preconditions for effective negotiation around potential financial contracts for the exchange of waste heat. Planning, budgeting, raising the capital for, and constructing necessary investments to transport and process the waste heat is a complex task. One that is generally outside of the core competence of greenhouse operators who are often more focused on the operational aspects of growing crops.

### 6.1.6. Risk of project rejection due to decision mandates

It was identified that it can be a long process to get approval from the people responsible within industrial organizations for internal capital expenditures and that this adds financial uncertainty to all parties involved. Similarly, approval from the local government and other government agencies can be uncertain and take a long time, contributing to some extent of regulatory risk. In essence, this complicates the project planning and due diligence process and adds uncertainties. The risk is that time and capital may need to be invested before there is certainty around project approval, and thus that there can be sunk costs.

It may be added that for greenhouse projects in general the overall balance sheet risk of owning and financing the construction of a large greenhouse was viewed as a significant balance sheet risk. Would the operation be unsuccessful there is high uncertainty around finding a buyer for the greenhouse at a good price, or alternatively finding a tenant to rent the greenhouse. Hence, there can be uncertainty around being able to repay the debt that was required to finance the construction of the greenhouse.

## 6.2. How have waste heat transactions between waste heat owners and greenhouses been financed and structured?

It was found that the structure of the heat supply contract is an important project financing aspect for greenhouse projects utilizing waste heat. Three different transaction structures for exchange of heat between waste heat owners and greenhouses were identified.

1. Direct exchange between waste heat producer and greenhouse. A possible disadvantage of this structure is that it may be difficult for the project parties to agree on what party should make what parts of the necessary investments to transport the heat. An advantage could be that if successful, profits from the project can be split without having an intermediary charge part of the profit.

2. District heating (DH) indirect exchange between waste heat producer and greenhouse through district heating companies effectively acting as an intermediary. This intermediary, however, has as its primary objective not to facilitate exchange of waste heat between industry and greenhouses, but rather between industry and households. An advantage with this structure is that the greenhouse may be able to access existing infrastructure, mitigating the potential difficulties around constructing and financing necessary infrastructure to transport the waste heat. Should the waste heat supply disappear, the district heating company may also be responsible for investing in a replacing heat source.
3. Exchange of waste heat between waste heat producer and greenhouse through a specialized SPV intermediary. The intermediary purchases heat from the industry and then sells it further to the greenhouse operator. In this specific case the intermediary also makes the investment in the greenhouse and the heat cost for the greenhouse is included in the rent which the greenhouse operator pays the intermediary. Advantages and disadvantages of this structure are further discussed in the discussions section.

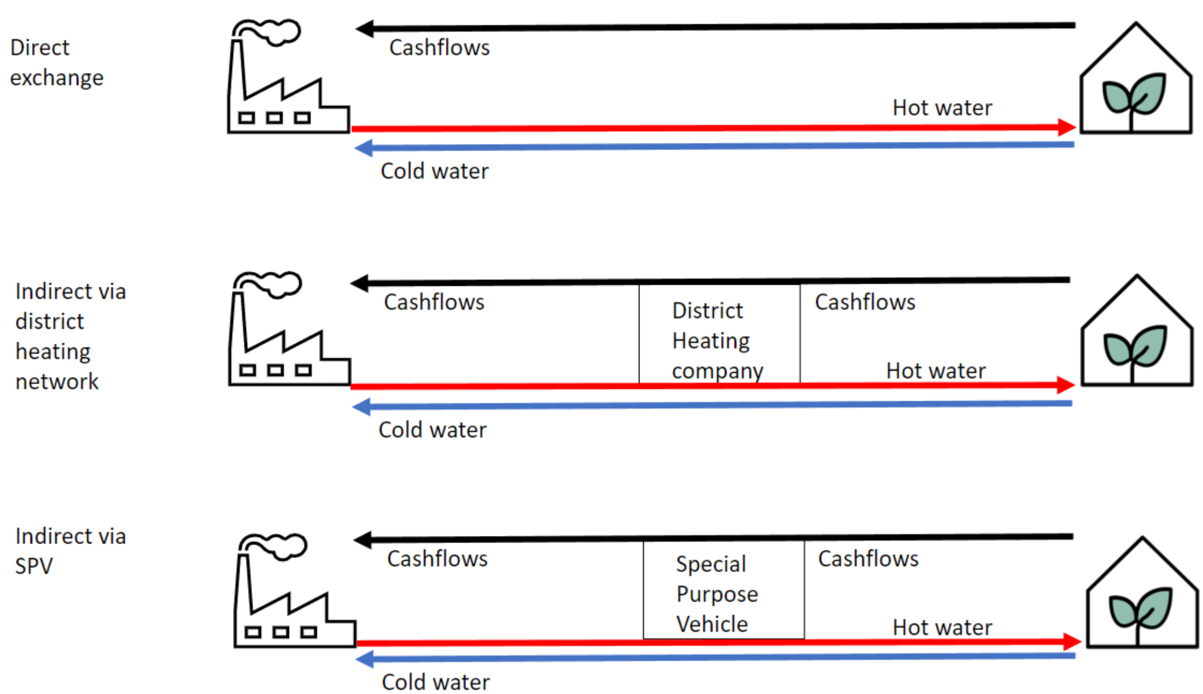


*Figure 2: Simplified illustration showing the three different identified transaction structures.*

| Case/Factor | Type of exchange | Investment in heat related capex | Investment in greenhouse/ aquaculture | Operator of greenhouse/ aquaculture | State of project |
|---|---|---|---|---|---|
| Trollåsens | Direct | Waste heat owner Södra Cell | Trollåsens | Trollåsens | In operation |
| Elleholms | District heating Indirect | District Heating company | Elleholms | Elleholms | In operation |
| Peckas Härnösand | District heating Indirect | District heating company | Peckas | Peckas | In operation |
| Agtira Östersund | Direct | Ica fastigheter, customer of Agtira. And district heating company | Ica fastigheter | Ica Maxi | Signed, construction during 2022 |
| BigAkwa | Direct | Waste heat owner SCA | BigAkwa | BigAkwa | Pilot phase |
| Söderlinds | Direct | Söderlinds and waste heat owner | Söderlinds | Söderlinds | In operation |
| ReproFood | SPV Indirect | SPV | SPV | Project partner | Cancelled |

| | | | | | |
|---|---|---|---|---|---|
| Regenergy Frövi | SPV Indirect | WA3RM SPV | WA3RM SPV | Project partner “Lokal Harvest” | Signed, construction during 2022 |

*Table 2: Illustrating a summary of investment related factors for those of the investigated cases where exchange of waste heat is included.*

## 6.3. What are the financial motives for the project parties to engage in and invest in enabling waste heat transactions?

From the point of view of greenhouse owners and operators motivation was found to be two-fold. First, to get access to a heat source below the alternative cost of other heat sources. Second, to get access to a heat source with low, or arguably zero, environmental footprint, and thereby potentially increase the payment willingness for its produce, based on the assumption that some customers are willing to pay a premium price for environmentally friendly produce.

From the point of view of waste heat owners, the motivation was found to be three-fold. First, to generate additional revenue from heat that would otherwise have been wasted. Second, to get access to a colder return flow of cooling water, in turn enabling a more cost-effective cooling process. Third, to improve environmental performance of its overall business. Contributing to a positive local development with new job and business opportunities was also found to be a motivating factor.

## 6.4. Estimated financial viability of a 10ha greenhouse project with waste heat

Based on financial data supplied by one of the interviewees and complemented with data from the Swedish agricultural agency, a discounted cash flow (DCF) model was produced. It is presented in further detail in the appendix section. The results from the model should be viewed as rough estimates, given the many assumptions that were used for estimating input data values. For example, input values for yields, crop prices, personnel expenses, energy costs, and cost of input goods should not be seen as absolute. Moreover, assumptions around investment costs, financing, and return requirements of fund providers had to be made.

Given the input values presented in the appendix section the DCF demonstrates that a 10ha greenhouse projects using waste heat can be financially viable and that the heating cost is a significant variable for the profitability of such operations. It was found that an internal rate of return (IRR) of 19% could be generated with a heat cost of 0,5 SEK/kWh. And all else equal that the IRR increases with 3 percentage points to 22% at a heat cost of 0,2 SEK/kWh. 0,2 SEK/kWh being significantly below the alternative cost for a greenhouse. The alternative may have been to invest in a heating system based on burning of, for example, wood chips.

It was similarly found, also subject to similar assumptions, that a project to intermediate waste heat between a waste heat owner and greenhouse was financially viable. Generating an expected internal rate of return of 17%. This scenario assumes that the intermediary makes the necessary capital expenditures to recover and transport the heat, and then purchases waste heat at 0,05 SEK/kWh and sells it further for 0,2 SEK/kWh.

# 7. Discussion

To the best knowledge of the authors of this paper, no previous study has investigated the different financial transaction structures for exchange of waste heat between industries and greenhouses. A main contribution of this thesis has been to establish and distinguish between three different such transaction structures. Since the interviewees represent a limited sample of the total universe of projects of this type, there could likely be other structures as well, however. Nevertheless, it suggests that the transaction structure, either direct or through different forms of intermediation, can play a key role in managing the financial risks inherent in this type of project. And that a specialized intermediary can be more efficient in handling those risks that are associated to both the project planning and due diligence process, as well as the balance sheet risk of owning the equipment needed for waste heat exchange, and the risk of necessary re-investments.

## 7.1. The potential benefits of a specialized entity intermediating the exchange of waste heat

At present the process of facilitating an economic exchange of waste heat from industries against cashflows from greenhouses is relatively inefficient. By reducing this market inefficiency more such transactions could be enabled. Utilizing waste heat for the heating of greenhouses holds the potential to help a broad range of industries to improve both their environmental as well as financial performance, while enabling more greenhouses to be constructed, supporting a more local and sustainable food production.

Intermediaries play an important role in many financial settings, for example financial markets and banks which facilitate more efficient exchange of financial assets and credit compared to if such exchanges were made directly between buyers and sellers or debtors and lenders. This study has indicated that an intermediary can have a key role as an enabler of more efficient exchanges of waste heat, a relatively abundant yet largely "hidden" asset of a broad range of industries.

In the results section a number of financial difficulties for exchange of waste heat were identified. An intermediary could potentially resolve these problems and provide a solution that enables a more efficient exchange of resources between industries and greenhouse operators, thereby facilitating a symbiotic effect. Relating to the results in 6.1., the role of the intermediary could be to:

- Plan, finance and construct an infrastructure, including pipelines for the heat, and hold this on its balance sheet, thereby resolving the return requirement issue for the other project parties. Thus, the greenhouse operator gets access to a heat source and the industry gets access to an off-taker of its residual heat. In essence, transferring the financial project risk to the intermediary. From the industries, i.e., heat owner´s point of view it can be easier to agree on letting an intermediary make the investments and just sell heat, instead of investing in capital expenditures. The intermediary could also be well suited to find a new greenhouse operator to rent the greenhouse, should the first one be unsuccessful. From the greenhouse´s point of view it can be easier to simply buy heat at a certain price from an intermediary, instead of having to negotiate directly with the waste heat owner. The intermediary can play an important role by enabling long term supply and off-take agreements for the waste heat.

- Bear the risk of providing a back-up heating source would the industry shut down, thereby removing a significant overhanging reinvestment risk from the point of view of the greenhouse operator. The intermediary could also mitigate the problem of intermittency, i.e., by supplying an additional heat source over and above the waste heat, so that it can balance out the potential mismatches of supply and demand of heat between the industry and greenhouse. This would be especially important in such projects where the nature of the industrial production is intermittent or cyclical, i.e., such that it produces varying amounts of waste heat during different times of the day or year.
- Reduce the strategic priority mismatch. In essence, by allowing waste heat owners to simply sell heat that they currently waste, the decision to do so becomes more strategic compared to considering making large upfront investments to be able to sell the heat.
- Simplify electricity connectivity. By having more in-depth understanding about industrial companies, compared to greenhouse operators in general, the intermediary could simplify the process for the greenhouse of getting access to the electrical grid in a smooth way and at good terms. In turn reducing a significant project risk for the greenhouse operator. In principle, the intermediary could also invest in electricity generating assets, such as solar panels or ORC-machines, and sell this directly to the greenhouse operator.
- Reduce information asymmetry between waste heat owners, which are typically large industrial firms with strong internal knowledge about heat flows, and greenhouse operators, which are typically small and entrepreneur-led organizations with limited expertise in heat flows.
- Reduce the risk for sunk costs due to slow decision making. By having niched expertise in waste heat and developing knowledge around decision making processes within relevant industrial organizations with waste heat, the intermediary could shorten the time to decision. Moreover, by offering the waste heat owner to simply sell the heat,

the financial decision also becomes simpler for the waste heat owner to make. The distinction between operational and investment decisions in industrial firms may also bear relevance here. While a large capital expenditure decision might be subject to decisions on a higher organizational level, an operational decision might only be subject to approval from an operations manager level. I.e., if a waste heat intermediary offers an operations manager to simply purchase the waste heat, it may be an easier decision to make, compared to if a greenhouse owner suggest the operations manager to make significant capital expenditures, in turn necessitating the operations manager to suggest such an investment project to his or her seniors.

  An intermediary could also reduce this problem by developing a strong understanding of the relevant relationship building processes with local governments and application processes to relevant government agencies.

- Lastly, to plan, finance and construct a greenhouse, and thereby remove the significant balance sheet and financing risk for the greenhouse operator. When it comes to raising project finance it may also be argued that a specialized intermediary could be better suited to raise project finance for such heat recovery greenhouse projects, compared to industrial firms, because of their more niched focus area. If the intermediary has a proven track record of executing similar projects successfully in the past it might also enable better access to financing.

The signing of the Regenergy Frövi project where WA3RM AB largely fulfills this role as an intermediary may be seen as a signal for that an intermediary can play an important role for the realization of such projects. It may indicate that such an intermediary is able to more efficiently manage the financial risks inherent in this type of project.

The role of such an intermediary could be viewed as lowering the threshold for both industries and greenhouse operators to engage in projects which utilize currently wasted heat sources. It can take on and manage certain financial risks experienced by heat owners and greenhouses in more efficient ways.

Industrial companies, such as pulp and paper plants, generally keep a strict focus on their core businesses, such as producing consumer board. Investing in a project to sell waste heat to a greenhouse may from that point of view be seen as a side question of lesser importance. If a waste heat intermediary on the other hand offers to take care of the necessary project planning and investments and simply purchase the waste heat from the steel mill, it simplifies the decision of recovering waste heat, as it allows the steel mill to maintain its core focus. Similarly, the core business of a greenhouse entrepreneur is to grow food and not engage in waste heat recovery project planning and investments.

Taking a broader perspective, the intermediary need not be limited to intermediating heat only to greenhouses, there could be many other off-takers or bidders to such heat, for example district heating companies, ORC-companies, and food processing industries. Importantly, there should be long-term off-take agreements for such waste heat, to minimize project risk. Moreover, there are other residual flows from industry that could potentially be monetized and intermediated as well, for example carbon dioxide which greenhouses can use to boost plant growth.

### 7.1.1. Learnings related to the transaction structures for utilization of waste heat in district heating networks

Intermediaries in the form of local district heating companies play an important role for the exchange of waste heat between waste heat owners and households. In the studies and investigations on the topic of waste heat utilization through district heating companies, and through the interview with IÅE, it was found that one of the reasons for why not more waste heat is utilized was the relative complexity for waste heat owners and district heating companies to agree on mutually beneficial terms and prices. According to the interviewee at IÅE this issue could be mitigated through a specialized entity with more in-depth knowledge about industrial waste heat. This could be viewed as evidence supporting the rationale for the concept of a specialized entity intermediating waste heat between waste heat owners and greenhouses.

## 7.2. Potential for win-win-win effects

Industrial firms are under pressure from shareholders to decarbonize in financially profitable ways. Food production needs to increase while reducing its environmental footprint. Local economies need to create new green jobs. Institutional investors need access to large green investment projects that can yield stable returns. By recovering industrial waste heat and using it to heat greenhouses these problems can be addressed at the same time. If Swedish industries operating in a global competitive market can engage in more waste heat recovery projects, it could potentially contribute to improved competitiveness. At the same time, Swedish greenhouses would get access to a price competitive source of heat which could spur a positive development with improved food security and increased supply of sustainably produced vegetables.

## 7.3. The greening of financial markets

In recent years the issue of climate change has risen on the agendas of different stakeholders in the economy. Asset managers are increasingly being requested by regulators to report on their portfolios´ climate impact. And investors are pivoting towards greener investments.

In some markets greenhouse gas emissions are already being priced, for example through the emission rights trading scheme in Europe, and some analysts are expecting a higher carbon price in the future.

This gives incentives for and puts pressure on companies and industries to engage in projects which can reduce their carbon footprint. Waste heat recovery through greenhouse and aquaculture projects fits well into that narrative, since it is a way for industrial heat owners to generate extra cashflows while improving their energy efficiency, and at the same time contribute to more sustainable food production.

### 7.3.1. The investment case for long term financial asset managers

Food demand is relatively stable and predictable compared to many other products and services. Many of the crops suitable for cultivation in greenhouses, such as tomatoes, cucumbers and salads, meet a stable demand from consumers who are increasingly shifting to a more plant-based diet. This demand forms the basis of the investment opportunity as it can generate a stable stream of cashflows from consumers buying vegetables. Cashflows which can in turn be used to repay the greenhouse financiers or pay rent to the external greenhouse owner. And a greenhouse typically has a long economic lifetime, of well above 20 and up to 50 years. Moreover, food demand is rather non-cyclical and food prices are an important factor in consumer price inflation indices. For investors looking for alternative commercial real estate assets with long-term predictable yields, that are insensitive to the business cycle and have some degree of natural inflation hedge, it may be argued that greenhouse projects possess attractive characteristics worthy of further research.

Moreover, if a portfolio consisting of several waste heat greenhouse projects can be constructed, with projects spread out in different geographies and producing a varied set of crops, diversification benefits can be achieved, thereby reducing financial risk and hence possibly enabling lower cost of capital. A heat intermediary that owns greenhouses and rents them out to greenhouse operators could potentially build such a portfolio. This might prove to be an important competitive advantage over its potential competitors with fewer greenhouse projects. A larger portfolio of greenhouse projects might also enable access to a broader base of potential investors, given that many of the larger institutional investors prefer to make significantly larger transactions than for example the 754 MSEK ´Regenergy Frövi´ project.

## 7.4. Potential to combine electricity production and heating of greenhouses

With the technology of Organic Rankine Cycle (ORC) it is possible to generate electricity out of industrial waste heat as well as geothermal heat. This process typically requires a heat temperature of 90 degrees Celsius or more as inflow, and after extracting some of that energy for electricity production there is still heat energy over, heat that is too low temperature for electricity production, yet sufficient to heat a greenhouse. Combining ORC with heating of greenhouses thus has the potential to utilize more of the total available heat energy than with ORC alone. Moreover, the greenhouse can lower the return temperature, and as ORC builds on extracting electricity from a temperature difference between a hot and a cold source, this lower return temperature may be beneficial for the ORC process.

### 7.5. Potential symbiotic effect with green hydrogen production

Hydrogen is widely expected to play an important role as an energy carrier in a decarbonized future global economy, for example for fossil free steel production and heavy transportation. In Sweden, H2 Green Steel and HYBRIT are examples of large-scale projects that plan to use large amounts of green hydrogen for steel production. One of the processes for production of green hydrogen is electrolysis where electricity is used to split water molecules into hydrogen and oxygen, in the process releasing residual heat. But not all of the energy input is converted to hydrogen, a significant amount of up to 40% of the energy input is lost as waste heat (Burton et al., 2021). In a competitive environment, if one green hydrogen producer has the ability to monetize its waste heat, for example by selling it to a greenhouse, while its competitors have not, this could potentially prove a significant competitive advantage.

### 7.6. Limitations of the thesis

Limitations of this thesis include:

- While the study does present multiple cases, it can be argued that it is not exhaustive enough to facilitate wide reaching generalizations. It might have been useful to study more projects and particularly those outside of Sweden, given the limited sample size of existing projects within the country. This would have also helped provide a broader overview of the landscape for waste heat exchange projects.
- It is also to be noted that Regenergy Frövi is a non-completed project and hence the conclusions drawn herein are advised to be taken with caution. It is, however, a case that has been signed after years of planning and preparation.
- It could also be argued that the thesis falls short in its focus on the industries providing the waste heat since they are a key stakeholder in the ecosystem. Better understanding their perspective, by interviewing more representatives of waste heat owners, would have rounded the discussion quite well.
- When performing the calculations in the DCF a number of simplified and uncertain assumptions were made, for example around yields and sales prices for vegetables, as well as investment costs for transporting waste heat. Much of the input data was

sourced from interviewees, although second checked against accounting statements and data from the Swedish agricultural agency to reduce some uncertainty. Hence, the results should be treated with a fair degree of caution and be interpreted as indicative rather than absolute. More thorough research related to these input value assumptions would have been preferable. Still, it serves the purpose of demonstrating the risks and opportunities with the transaction structure to intermediate heat and expected returns that could be achieved through this type of project.

# 8. Conclusion

This thesis suggests that, based on findings from data collection from interviewees, that a specialized entity acting as a waste heat intermediary plays a key role in enabling an efficient financial transaction of waste heat between industries and greenhouse operators. It was found that such an intermediary among other things reduces information asymmetry, can handle the major financial risks more effectively, and eases the process of negotiating contracts for the exchange of heat, and thereby facilitates a more efficient transaction.

## 8.1. Suggestions for future research

To further investigate the role of specialized waste heat intermediaries it could be of interest to research and develop a fair, transparent and more standardized pricing model which such an intermediary can apply to its projects. This would be relevant as it might enable a more efficient mechanism for establishing a fair price between the bid price of the heat purchasers and ask price of the waste heat owners. This in turn might support the development of more waste heated greenhouse projects. It could also be relevant to conduct a more in depth single-case based study to quantify the financial risks and benefits from the point of view of such an intermediary.

The potentially symbiotic relationships between electrolysis and greenhouses, as well as ORC and greenhouses could also be worthy of further investigation.

Also, if a greenhouse is complemented with fish cultivation the return temperature to the waste heat provider can be lowered further. To quantify the financial benefit of this would be a relevant topic for future research, i.e., quantifying what value in terms of reduced cooling costs that could have for the industry producing the waste heat, and in extension if that could motivate a discounted heat price for the greenhouse buying the heat.

Lastly, another topic worthy of further exploration is heat storage connected to waste heated greenhouse projects. In essence, greenhouses have limited heat demand during the warmer summer months while industrial waste heat tends to be generated in similar quantities throughout the year. Hence, the supply of waste heat would outstrip demand during summer. Therefore, if excess heat during summer can be stored, even more of the total annual waste heat can be monetized. Investigating the associated investments and financial returns of such heat storage projects could therefore be of interest.

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Phone interview with Henrik Strängh, CFO and co-founder, Zelk Energy AB, 2021-11-10

# 10. Appendix

## 10.1. DCF calculations and input values for combined greenhouse owner and operator

| **input data assuming greenhouse area of 10ha** | | |
|---|---|---|
| **(SEK)** | | |
| **item** | **unit** | **amount** |
| | | |
| greenhouse area | square meters sqm | 100000 |
| | | |
| greenhouse investment including water pipes, | SEK/Square meter (sqm) | 4000 |
| land investment | SEK/sqm | 200 |
| employees needed | persons | 100 |
| employee cost | per person and year | 300000 |
| yield tomatoes | kg/sqm/year | 45 |
| yield cucumbers | kg/sqm/year | 120 |
| selling price for tomatoes | SEK/kg | 30 |
| selling price for cucumbers | SEK/kg | 24 |
| Average heat demand | Watt per sqm | 60 |
| Average electricity demand | Watt per sqm | 10 |
| heat consumption | kWh/year | 52560000 |
| electricty consumption | kWh/year | 8760000 |
| weighted average heat price | SEK/kWh | 0,2 |
| weighted average electricity price | SEK/kWh | 0,9 |
| | | |
| input goods total | SEK/year | 10000000 |
| insurance and other | SEK/year | 10000000 |
| sales costs | SEK/year | 3000000 |
| | | |
| | | |
| economic lifetime | years | 40 |
| depreciation greenhouse | years | 20 |
| depreciation land | | none |
| annual maintenance | per cent of investment (excl | 2% |
| annual inflation (all sales and costs) | per cent | 2% |
| time from investment to full operations | years | 1 |
| year 1 increased working capital need when o | SEK | 10000000 |
| years 2-39 change net working capital | SEK | 0 |
| year 40 change working capital | SEK | -10000000 |
| | | |
| tax rate | | 20,60% |
| | | |
| cost of debt | | 4% |
| cost of equity | | 10% |

Table A1: DCF input values, subject to assumptions and uncertainties.

| (SEK) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **1. income statement projection** | | | | | | | | | | |
| | year | 0 | 1 | 2 | 3 | 4 | 37 | 38 | 39 | 40 |
| Net sales | | | | | | | | | | |
| | Tomatoes | 0 | 67500000 | 68850000 | 70227000 | 71631540 | 137692395,7 | 140446243,6 | 143255168,5 | 146120271,9 |
| | Cucumbers | 0 | 144000000 | 146880000 | 149817600 | 152813952 | 293743777,5 | 299618653 | 305611026,1 | 311723246,6 |
| | TOTAL | 0 | 211500000 | 215730000 | 220044600 | 224445492 | 431436173,2 | 440064896,7 | 448866194,6 | 457843518,5 |
| Cost of goods sold (COGS) | | | | | | | | | | |
| | input goods total | 0 | 10000000 | 10200000 | 10404000 | 10612080 | 20398873,44 | 20806850,91 | 21222987,92 | 21647447,68 |
| | insurance and other | 0 | 10000000 | 10200000 | 10404000 | 10612080 | 20398873,44 | 20806850,91 | 21222987,92 | 21647447,68 |
| | employees | 0 | 30000000 | 30600000 | 31212000 | 31836240 | 61196620,31 | 62420552,72 | 63668963,77 | 64942343,05 |
| | heat | 0 | 10512000 | 10722240 | 10936684,8 | 11155418,5 | 21443295,76 | 21872161,67 | 22309604,91 | 22755797 |
| | electricity | 0 | 7884000 | 8041680 | 8202513,6 | 8366563,87 | 16082471,82 | 16404121,25 | 16732203,68 | 17066847,75 |
| | maintenance | 0 | 8000000 | 8000000 | 8000000 | 8000000 | 8000000 | 8000000 | 8000000 | 8000000 |
| | TOTAL COGS | 0 | 76396000 | 77763920 | 79159198,4 | 80582382,4 | 147520134,8 | 150310537,5 | 153156748,2 | 156059883,2 |
| | Gross profit | 0 | 135104000 | 137966080 | 140885401,6 | 143863110 | 283916038,4 | 289754359,2 | 295709446,4 | 301783635,3 |
| | Gross margin | | 63,88% | 63,95% | 64,03% | 64,10% | 65,81% | 65,84% | 65,88% | 65,91% |
| | sales, general and administrative costs (SG&A) | 0 | 3000000 | 3060000 | 3121200 | 3183624 | 6119662,031 | 6242055,272 | 6366896,377 | 6494234,305 |
| | depreciation | 0 | 20000000 | 20000000 | 20000000 | 20000000 | 0 | 0 | 0 | 0 |
| | EBIT (operating profit) | 0 | 112104000 | 114906080 | 117764201,6 | 120679486 | 277796376,4 | 283512303,9 | 289342550 | 295289401 |
| | interest pmts | 0 | 26880000 | 12640000 | 11840000 | 11040000 | 0 | 0 | 0 | 0 |
| | EBT | 0 | 112104000 | 88026080 | 105124201,6 | 108839486 | 277796376,4 | 283512303,9 | 289342550 | 295289401 |
| | Tax | 0 | 23093424 | 18133372,48 | 21655585,53 | 22420934 | 57226053,54 | 58403534,61 | 59604565,3 | 60829616,61 |
| | Net income | 0 | 89010576 | 69892707,52 | 83468616,07 | 86418551,6 | 220570322,9 | 225108769,3 | 229737984,7 | 234459784,4 |

Table A2: Income statement projection. For readability not all years are included in this snapshot. Depreciations continue until year 20.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2. Investment and financing** | | | | | | | | | | | | | | | |
| Investments | | | | | | | | | | | | | | | |
| | Land | 20000000 | | | | | | | | | | | | | |
| | Greenhouse incl. equipment | 400000000 | | | | | | | | | | | | | |
| | TOTAL | 420000000 | | | | | | | | | | | | | |
| Depreciation | | | | | | | | | | | | | | | |
| | Greenhouse incl. fittings, equipment etc (years, straight amortization) | 20 | | | | | | | | | | | | | |
| | Depreciation per year | 20000000 | | | | | | | | | | | | | |
| Financing | | | | | | | | | | | | | | | |
| | Source | Share | Amount | Cost of capital | cost of capital | Comment | | | | | | | | | |
| | Equity | 20% | 84000000 | 10% | | | | | | | | | | | |
| | Debt | 80% | 336000000 | 4% | 3,18% | Assumes: Debt raised beginning of year 0. Amortizations equal depreciation and are made at end of year, starting year 1 | | | | | | | | | |
| | WACC initial | | | 4,5408% | | | | | | | | | | | |
| | annual amortization (straight) paid on 31/12 and equal to depreciation | | 20000000 | | | | | | | | | | | | |
| Asset side | year (31/12) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| | land+greenhouse valued at aqcuisition price minus depreciation | 420000000 | 400000000 | 380000000 | 360000000 | 340000000 | 320000000 | 300000000 | 280000000 | 260000000 | 240000000 | 220000000 | 200000000 | 180000000 | 160000000 |
| | TOTAL | 420000000 | 400000000 | 380000000 | 360000000 | 340000000 | 320000000 | 300000000 | 280000000 | 260000000 | 240000000 | 220000000 | 200000000 | 180000000 | 160000000 |
| Financing side | | | | | | | | | | | | | | | |
| | equity | 84000000 | 84000000 | 84000000 | 84000000 | 84000000 | 84000000 | 84000000 | 84000000 | 84000000 | 84000000 | 84000000 | 84000000 | 84000000 | 84000000 |
| | debt | 336000000 | 316000000 | 296000000 | 276000000 | 256000000 | 236000000 | 216000000 | 196000000 | 176000000 | 156000000 | 136000000 | 116000000 | 96000000 | 76000000 |
| | TOTAL | 420000000 | 400000000 | 380000000 | 360000000 | 340000000 | 320000000 | 300000000 | 280000000 | 260000000 | 240000000 | 220000000 | 200000000 | 180000000 | 160000000 |
| | share equity | 20,0% | 21,0% | 22,1% | 23,3% | 24,7% | 26,3% | 28,0% | 30,0% | 32,3% | 35,0% | 38,2% | 42,0% | 46,7% | 52,5% |
| | share debt | 80,0% | 79,0% | 77,9% | 76,7% | 75,3% | 73,8% | 72,0% | 70,0% | 67,7% | 65,0% | 61,8% | 58,0% | 53,3% | 47,5% |
| | WACC for period | 4,5% | 4,6% | 4,7% | 4,8% | 4,9% | 5,0% | 5,1% | 5,2% | 5,4% | 5,6% | 5,8% | 6,0% | 6,4% | 6,8% |
| | check balance (0=balance) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table A3: WACC increases over time as the project debt financing is continuously amortized and an increasing fraction of project assets become equity-financed. For readability only years 1-13 out of total 40 years are included. Simplified assumption that market value of financed assets equals book value of financed assets.

**4. DCF valuation**

| year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| EBIT | 0 | 112104000 | 114906080 | 117764201,6 | 120679486 | 123653075,3 | 126686137 | 129779860 | 132935457 | 136154165,9 | 139437249,2 |
| less tax | 0 | -23093424 | -18133372,48 | -21655585,53 | -22420934 | -23198293,5 | -23987904,2 | -24790011 | -25604864 | -26432718,2 | -27273833,3 |
| plus depreciation | 0 | 20000000 | 20000000 | 20000000 | 20000000 | 20000000 | 20000000 | 20000000 | 20000000 | 20000000 | 20000000 |
| less change in net working capital | 0 | 10000000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| less capex | -420000000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Free Cash Flow (FCF) | -420000000 | 119010576 | 116772707,5 | 116108616,1 | 118258552 | 120454781,8 | 122698233 | 124989849 | 127330593 | 129721447,7 | 132163415,9 |
| Discount factor | 1 | 0,956564327 | 0,913821911 | 0,871672429 | 0,83000549 | 0,788698071 | 0,74761127 | 0,7065862 | 0,6654386 | 0,623951947 | 0,581868924 |
| Present value of FCF | -420000000 | 113841271,5 | 106709458,7 | 101208679,4 | 98155247 | 95002454,07 | 91730582,1 | 88316100 | 84730685 | 80939949,87 | 76901784,66 |
| | | | | | | | | | | | |
| Net present value of project | 1215,25 | MSEK | | | | | | | | | |
| IRR | 22,18% | | | | | | | | | | |

Table A4: DCF valuation of project. For readability only years 1-10 are included. According to this model, with a heat price of 0,2SEK/kWh, project IRR is 22,18% with net present value of 1215 MSEK.

## 10.2. DCF calculation and input values for waste heat intermediary

| input data assuming greenhouse area of 10ha (SEK) | | | |
|---|---|---|---|
| **item** | **unit** | **amount** | **description** |
| connection to heat source | | 5000000 | factory internal pipe modifications |
| piping | SEK/m | 6000 | needed to transport the hot water |
| distance | m | 1500 | distance between waste heat owner and greenhouse |
| piping total | 1 | 9000000 | |
| heat pump | | | not needed in this case |
| pump stations | 1 | 1000000 | to pump the water |
| back up heat boiler | | 3000000 | emergency solution if the waste heat supply isn´t there e.g. due to maintenance, not able to cover full demand but enough to protect against some losses |
| construction | 1 | 1000000 | |
| heat accumulator tank | 1 | 3000000 | |
| | | | |
| | | | |
| Investment Total | | 22000000 | |
| depreciation | 10 | 2200000 | SEK/year over 10 years |
| | | | |
| | | | |
| cost and revenue items to operate the service of intermediating the heat below | | | |
| | | | |
| sales price for the heat | SEK/kWh | 0,2 | |
| purchase price for heat | SEK/kWh | 0,05 | |
| quantity of heat bought an | kWh/year | 52560000 | |
| | | | |
| land lease for pipes | SEK/year | 100000 | |
| maintenance for pipes | SEK/year | 90000 | 1% |
| running the pumps | SEK/year | 1839600 | |
| running the back up boiler | SEK/year | 300000 | |
| other | SEK/year | 80000 | |
| | | | |
| | | | |
| COGS texcl heat total | | 2409600 | |
| | | | |
| | | | |
| tax rate | | 20,60% | |
| | | | |
| cost of debt | | 4% | |
| cost of equity | | 10% | |

Table A5: Input values for heat intermediation DCF, subject to assumptions and uncertainties.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (SEK) | | | | | | | | | | | | |
| 1. income statement projection | | | | | | | | | | | | |
| | year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Net sales | | | | | | | | | | | | |
| | Heat | | 10512000 | 10722240 | 10722240 | 10722240 | 10722240 | 10722240 | 10722240 | 10722240 | 10722240 | 10722240 |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| Cost of goods sold (COGS) | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | heat | | 2628000 | 2680560 | 2680560 | 2680560 | 2680560 | 2680560 | 2680560 | 2680560 | 2680560 | 2680560 |
| | other COGS | | 2409600 | 2457792 | 2457792 | 2457792 | 2457792 | 2457792 | 2457792 | 2457792 | 2457792 | 2457792 |
| | | | | | | | | | | | | |
| | TOTAL COGS | | 5037600 | 5138352 | 5138352 | 5138352 | 5138352 | 5138352 | 5138352 | 5138352 | 5138352 | 5138352 |
| | | | | | | | | | | | | |
| | Gross profit | | 5474400 | 5583888 | 5583888 | 5583888 | 5583888 | 5583888 | 5583888 | 5583888 | 5583888 | 5583888 |
| | Gross margin | | 0,520776 | 0,520776 | 0,520776 | 0,520776 | 0,520776 | 0,520776 | 0,520776 | 0,520776 | 0,520776 | 0,520776 |
| | | | | | | | | | | | | |
| | sales, general and administrati | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | depreciation | | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 |
| | | | | | | | | | | | | |
| | EBIT (operating profit) | | 3274400 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 |
| | interest pmts | | 704000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | EBT | | 2570400 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 |
| | Tax | | 529502,4 | 697080,9 | 697080,9 | 697080,9 | 697080,9 | 697080,9 | 697080,9 | 697080,9 | 697080,9 | 697080,9 |
| | Net income | | 2040898 | 2686807 | 2686807 | 2686807 | 2686807 | 2686807 | 2686807 | 2686807 | 2686807 | 2686807 |

Table A6: Income statement projection for heat intermediation project, years 0-10, out of total 40 year project lifetime.

| | | | | | |
|---|---|---|---|---|---|
| 2. Investment and financing | | | | | |
| Investments | | | | | |
| | TOTAL | 22000000 | | | |
| | | | | | |
| Financing | | | | | |
| | Source | Share | Cost | Cost after | Amount |
| | Equity | 0,2 | 10% | | 4400000 |
| | Debt | 0,8 | 4% | 3,18% | 17600000 |
| | WACC | 0,045408 | | | |

Table A7: Investment and financing table. A simplified assumption was made that the WACC remains constant throughout the project lifetime.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4. DCF valuation | | | | | | | | | | | | |
| | year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | | | | | | | | | | | | |
| | EBIT | 0 | 3274400 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 | 3383888 |
| | less tax | 0 | -529502 | -697081 | -697081 | -697081 | -697081 | -697081 | -697081 | -697081 | -697081 | -697081 |
| | plus depreciation | 0 | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 | 2200000 |
| | less change in net working capital | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | less capex | -22000000 | | | | | | | | | | |
| | Free Cash Flow (FCF) | -22000000 | 4944898 | 4886807 | 4886807 | 4886807 | 4886807 | 4886807 | 4886807 | 4886807 | 4886807 | 4886807 |
| | Discount factor | 1 | 0,956564 | 0,915015 | 0,875271 | 0,837253 | 0,800886 | 0,766099 | 0,732823 | 0,700993 | 0,670545 | 0,641419 |
| | Present value of FCF | -22000000 | 4730113 | 4471503 | 4277281 | 4091494 | 3913777 | 3743780 | 3581166 | 3425616 | 3276822 | 3134491 |
| | | | | | | | | | | | | |
| | Net present value of project | 62,75 | MSEK | | | | | | | | | |
| | IRR | 17% | | | | | | | | | | |

Table A8: DCF valuation of project. For readability only years 1-10 are included. According to this model, with a heat purchasing price of 0,05 SEK/kWh and sales price of 0,2 SEK/kWh, the expected project IRR is 17% with net present value of 62 MSEK.