Academic Year 2018-2019

The Urban Financial Metabolism Model: Quantifying the societal impact of residential energy poverty in Groningen, the Netherlands

Full Name of Student: *Cora Schouten*

Core Provider: *Hanze University of Applied Sciences*

Specialization: *Hanze University of Applied Sciences*

Host Organization: *New Energy Coalition; Nijenborgh 6, 9747 AG Groningen, Netherlands*

Academic Supervisor: *Prof. Han Brezet*

Submission Date: 30 November 2020

Acknowledgements

I would first like to thank J. Bekkering for supporting me from the beginning of the programme through months of trial and error and ensuring I found an internship fit for me. J. Scheepens-Hasek, G. Kuiken, and J. Fokkinga, thank you for your endless patience and for being my go-to for logistics and clarification leading up to this thesis. To P. Tamis, my company supervisor at the New Energy Coalition: without you, this project would not have been possible. I am very grateful for your guidance, support, and knowledge on the subject matter. My gratitude also goes out to H. Brezet and R. Veenstra, my academic supervisors from Hanze, for steering me down the path to success. Many thanks to J. Nauta from TNO for providing the framework for this project and expertise on the Urban Financial Metabolism model. Thank you to M. de la Vieter, for your behind-the-scenes mentoring and for always going the extra mile as my lecturer to prepare me for this venture. To N. Ortiz, N. Mendes, L.M Granja, Z. Chapidze, F. Acevedo, R. Hernandez, N. Kostakis and M. Lejeune: You may not have known it, but your persistence to help me through techno-economic modelling in Excel set me up for success during this project. Thank you for that. I am very grateful to B. Schouten for proof reading my drafts and offering insights for improvement. Finally, I am forever thankful to my incredible family. You took me in during the pandemic, let me use your home office for six months, and encouraged me every day. Thank you, thank you, thank you.

As the author of this paper, I would also like to acknowledge that the MAKING CITY project was funded in part by the European Commission via the Horizon 2020 programme, under grant agreement no. 824418. Please note that the information portrayed in this paper reflects the views and findings of the author's research. The European Commission is not responsible for any use of the content or information contained within this paper.

Originality Declaration

By this letter, I declare that I have written this thesis completely by myself, and that I have used no other sources or resources than the ones mentioned.

The sources used, have been stated in accordance with the EUREC Project Guidelines. I have indicated all quotes and citations that were literally taken from publications, or that were in close accordance with the meaning of those publications, as such. Moreover, I have not handed in an essay, paper or thesis with similar contents elsewhere. All sources and other resources used are stated in the bibliography.

In case of proof that the essay, paper or thesis has not been constructed in accordance with this declaration, the School of Engineering considers the essay, paper or thesis as negligence or as a deliberate act that has been aimed at making correct judgment of the candidate's expertise, insights and skills impossible.

In case of plagiarism the examiner has the right to exclude the student from any further participation in the particular assignment, and also to exclude the student from further participation in the MSc program at the School of Engineering of Hanze University of Applied Sciences, Groningen. The study results obtained in the course will be declared null and void in case of plagiarism (also see Article 14 of the Teaching and Examination Regulations).

Name: Cora Schouten

Place: Ottawa, Ontario, Canada

Date: 29/11/2020

Signature:

Cora Schouten

Executive Summary

The energy transition can be costly to those who are unable to make the switch to more sustainable energy sources or improve the energy efficiency of their homes. When people are unable to meet basic household energy needs without sacrificing other essential household expenditures, such as rent or groceries, they may be at risk of so-called energy poverty. Energy poverty can have impacts that spread beyond just the household, affecting the local economy and healthcare system as well. This paper identifies the number of households at risk of energy poverty in the neighbourhood of Paddepoel in Groningen, the Netherlands, and quantifies the impact that this has on society. The Urban Financial Metabolism (UFM) model is used to conduct this research. Six scenarios consisting of various technical interventions were studied using a cost-benefit analysis (CBA) to see if they could help mitigate the risks of energy poverty.

Various drivers of energy poverty were discussed, but the analysis focuses on three primary determinants in Paddepoel to determine which households are at risk of energy poverty: household income, energy label of household, and type of ownership. Three indicators were used to measure the societal cost of energy poverty: household spendable income, money spent in local economy, and money leaving the municipality.

The study identified that between 2020 and 2035, 310 households in Paddepoel are at high risk of becoming energy poor, costing society a total of € 806,587.16 over the 15-year period. Of the six scenarios studied in the CBA, none presented a positive business case, nor did they improve household spendable income or money spent locally. However, they did have a positive impact on the third indicator, because as the energy bills of the households decreased, the amount of money leaving the municipality to go to utility companies decreased. This analysis further emphasises the importance of this issue by revealing that households in energy poverty do not have the financial means to get themselves out of it.

The municipality of Groningen is advised to still consider technical interventions such as the ones proposed in the scenarios, even if they do not have a positive business case. In order for these households to successfully take part in the energy transition and help achieve Dutch climate targets, appropriate financing schemes will need to be implemented to aid in the initial investments and potentially in annual maintenance costs for the first few years. The benefits will have a larger impact that extends beyond the household, making these investments worthwhile.

This study also looked briefly at the potential of replicating the UFM model in another city or country. It is recommended that the municipality heavily involve stakeholders across domains to go through the required indicators and determinants of energy poverty within their own cities in order to successfully implement the model in this context.

Table of Contents

List of Figures & Tables

1. Introduction

Sustainable investments and policies are becoming increasingly popular amongst cities to combat the looming threat of climate change. This paradigm shift holds promise to aid countries in reaching their climate goals, including those set in the 2015 Paris Agreement, but can be costly to many stakeholders involved. For example, the energy transition from fossil fuels to renewable energy sources has the potential to exclude some households from this progression due to the associated costs of the transition. Rising energy prices and increasing carbon levies may not be an issue for many households, but for those in a lower income bracket this could be a barrier for meeting basic energy needs. Some households are resorting to renovation and upgrading their homes to be more efficient, installing smart metering systems, or even becoming prosumers of electricity (i.e.: installing solar panels), to help mitigate these costs. For low-income households however, these measures are simply not attainable due to the high capital costs of renovation and installation of new technologies. These households are at risk of so-called "energy poverty", and the effects of this extend beyond individual dwellings and into the local and national economy. Therefore, if to be executed successfully, a holistic approach to this energy transition must be taken to mitigate the risk of households falling into the energy poverty trap.

1.1 Energy Poverty

The term energy poverty is defined by the European Commission as "a situation where individuals or households are not able to adequately heat or provide other required energy services in their homes at affordable cost" [1]. However, a more specific, quantifiable definition does not yet exist on a wide scale, but rather is country specific. In fact, only four European countries (France, Ireland, Slovakia, and the UK) have specifically defined energy poverty [2]. The UK was the first to implement an official definition of energy poverty in 1991, which indicated that energy poverty exists when a household spends at least 10% of its income on fuel to "maintain an adequate level of warmth" [3]. Due to the lack of an overall European definition, the UK's definition is often unofficially adopted by other European countries. Using this metric can be problematic, however, as i) it is limited to energy use solely for heating purposes and ii), it does not necessarily reflect households that are truly experiencing energy *poverty*. For example, a high-income household may spend 10% or more of their income on energy, but not necessarily be in an impoverished situation because their earnings are high enough to accommodate these high costs. Due to these criticisms, the 2M metric is now used, which states that a household is in energy poverty when its total energy expenditure (both heat and electricity) to spendable income ratio is more than twice that of the national median ratio for that year [4].

There have been a multitude of studies that have been conducted on this topic and all tend to point to the same (or similar) indicators for what leads to energy poverty, as well as which indicators lead to greater negative impacts from said poverty. In general, low-

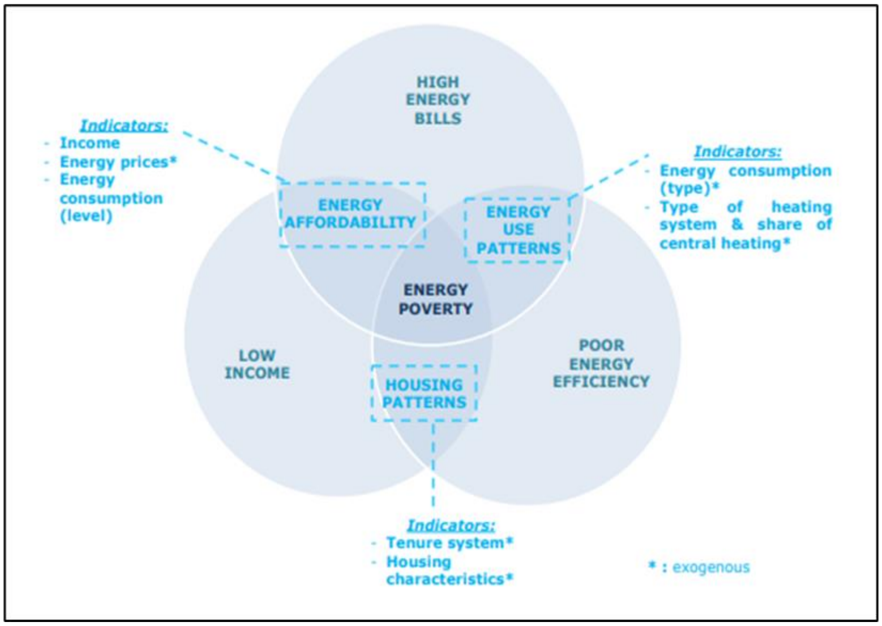


Figure 1: Drivers of Energy Poverty in Europe (Pye, 2015)

income households are more likely to experience energy poverty than moderate to high income households, especially those living in poorly insulated and energy inefficient homes, and when energy prices are high [3] [4] [5]. Figure 1 reveals how overlaps between these drivers results in energy poverty on a European scale.

Low-income households are often a result of other social and demographic indicators such as socio-economic status, education level, and race [6]. Coupled with these factors, households in extremely warm or cool climates are also at risk, as they require costly heating and cooling systems to combat uncomfortable indoor temperatures. Similarly, there are also various social and demographic indicators which can exacerbate the negative impacts of energy poverty on these households. Jessel et al. identify some of these factors which include age (children and the elderly are at higher risk of the impacts of energy poverty than other age groups due to their weaker immune systems), gender (women and girls in the Global South responsible for cooking with biomass fuels are more exposed to particulates causing respiratory illness) and health status (those with chronic illnesses and other mental and physical health conditions may be at increased risk of the adverse effects of energy poverty) [6].

It is important to consider all of these negative impacts associated with energy poverty when trying to navigate appropriate solutions. These adverse effects are not only detrimental to the households that experience them, but also to the local economy and to the structures in place to support them. For example, low-income households living in energy inefficient homes do not have the means to implement measures to make their homes more efficient or to become prosumers of renewable energy and therefore are consuming more energy than their moderate to high income counterparts. As displayed in Figure 2, this results in i) higher energy bills and therefore greater reliance on social assistance programmes to fund low-income households [4]; ii) higher emissions which subsequently increases the effects of climate change and outdoor ambient warming in these regions [7]; and iii), the household will have less available income to spend in the local economy because they will be spending too much on energy bills. Moreover, exposure to energy poverty puts vulnerable demographics at risk of adverse health conditions. Studies show that elderly people suffer from weaker immune systems which are affected by poor air quality and higher ambient temperatures, resulting in respiratory issues and sometimes even mortality [7]. Additionally, older, poorly insulated homes are at risk of exposure to higher concentrations of ozone that enter through ventilation systems and cracks in the house, which can have detrimental health impacts on its occupants [7]. While the elderly are particularly vulnerable, they are not the only ones who may suffer from the effects of energy poverty. According to a study by the Carnegie Mellon University, a reduction of the incidence of cold and flu of up to 50% was associated with improved indoor air quality in low-income households for people of all ages [7]. Another study reports the same reduction (up to 50%) in the incidence of depression and anxiety when a low-income household is retrofitted to be more energy efficient [7]. It is hypothesized here that by refurbishing and rehabilitating energy poor homes, money can be saved in the health care systems by reduction of mental and physical health occurrences. In the UK for example, it is estimated that for every £1.00 spent on energy rehabilitation, the National Health System (NHS) could save £0.42 [7].

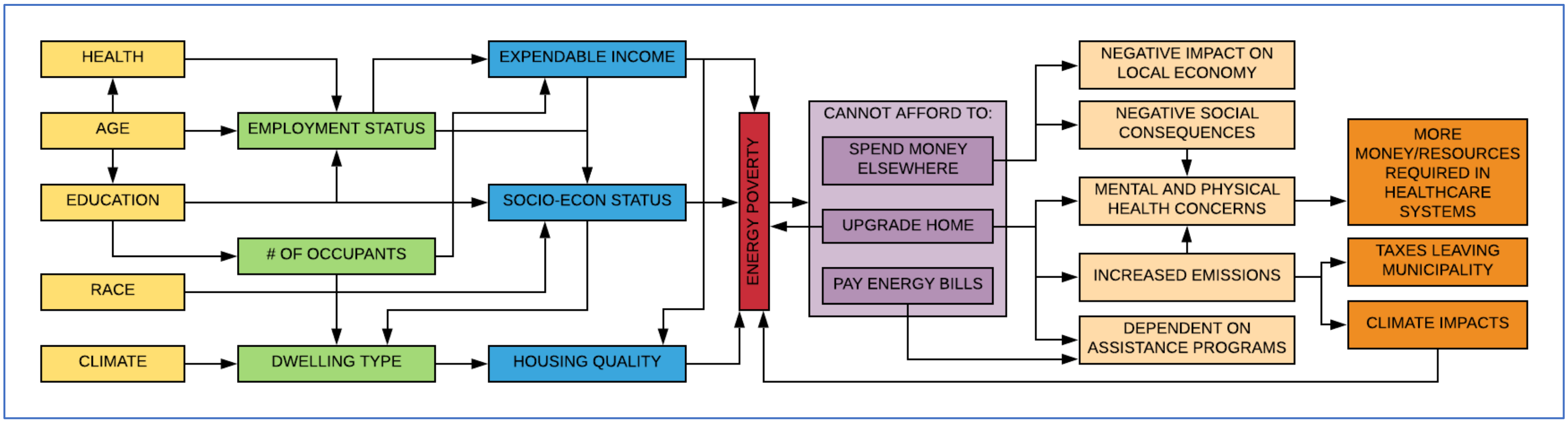


Figure 2: Indicators and Impacts of Energy Poverty

These elements of the energy poverty cycle are evident in the ongoing research being done in Groningen, the Netherlands. Researchers from the New Energy Coalition (NEC), TNO, and the Rijksuniversiteit Groningen (RUG) have partnered up to tackle energy poverty in the neighbourhood of Paddepoel in Groningen, NL, as part of Horizon 2020's *Making City* project.

1.2 Making City

The Making City project focuses on the implementation of sustainable interventions in Groningen, the Netherlands, using the positive energy district (PED) concept. This project is part of the larger Horizon 2020 Project, with the aim of re-vamping the energy system transition in urban settings to achieve low carbon cities, with minimal stress and congestion on the distribution system operator (DSO) [8]. Both Groningen and Oulu, Finland, are considered Lighthouse cities in the Making City project, where the PED concept is being developed and tested before implementing it in other European cities. While the PED concept of Making City is being used in a broad sense in both study regions to address a number of energy-related challenges, this paper will focus on the Lighthouse city of Groningen, as members from TNO and NEC are specifically investigating how the implementation of a PED can be used to mitigate the effects of residential energy poverty on individual households and the surrounding community.

1.2.1 Positive Energy Districts

In response to national climate goals, Regional Energy Strategies (RES) have been developed in 30 regions throughout the Netherlands in order to reduce carbon emissions. These climate goals include: generating 35 TWh of energy annually from renewable energy sources, producing 70% of all electricity in the Netherlands from renewable energy, and producing at least 27% of all energy, including gas, electricity, and heat, from renewable energy sources – all by the year 2030 [9]. The means to achieving these goals thus far has been the rapid installation of wind and solar fields in the country, creating a surplus of energy during peak consumption, which consequently results in congestion issues for the DSO (which is Enexis in the North-East part of the Netherlands). The PED concept is being introduced as an alternative to the RES for districts to still achieve national climate targets without the added stress the larger energy network.

A PED is “an urban area with clear boundaries, consisting of buildings of different typologies that actively manage the energy flow between them and the larger energy system to reach an annual positive energy balance” [10]. RES and PEDs have similar structures to reaching energy goals, but the updated PED concept goes a step further to make changes on a smaller scale in order to alleviate stress on the grid and keep certain energy cashflows within the municipality. In addition to energy efficiency within buildings and flexibility for energy consumption, PEDs also focus on the production of renewable energy on a small scale in order to minimize transport costs and grid overload, while also offering a clean supply of electricity that can be used to electrify residential heating and reduce dependency on natural gas.

1.2.2 Making City in Groningen

Making City in Groningen focuses on the North and Southeast districts of the city, as well as the city of Groningen as a whole, and analyses interventions required to achieve PEDs in each of these regions. Some of these interventions include the installation of roof-top solar panels on some buildings and car parks, a geothermal district heating system to support the use of heat pumps, biogas technology to utilize existing waste and waste water produced by public facilities, as well as a special focus on cycling and electric mobility [8].

Within their analysis, TNO and NEC have found that the North district – primarily the neighbourhood of Paddepoel – is comprised of many low-income households, thus increasing the risk of energy poverty in this district as the price of energy increases and the means to become more energy efficient are not accessible to all. The PED concept is intended to mitigate some of these risks by coming up with a combination of sustainable interventions to aid in the energy transition and assist with energy sovereignty within a district. However, before these interventions can be properly determined and designed, a better understanding of the cashflows running in, out, and through a neighbourhood is crucial for developing a viable business case for a PED. These cashflows will certainly differ from region to region, therefore quantifying the direct and indirect effects of energy poverty in a particular region is paramount for determining which holistic solutions can be implemented.

To address this, a tool for mapping cashflows developed by TNO, namely, the *Urban Financial Metabolism* (UFM) model, is used in the Making City context of Groningen to better understand the drivers and impacts of energy poverty in this Lighthouse city.

1.3 Urban Financial Metabolism Model

The UFM model is a tool designed to stimulate sustainable investments in the built environment by mapping current and future cashflows across domains and stakeholders. The goal of the UFM model is to quantify the impacts of a societal issue related to sustainability from beyond the directly impacted party to other actors as well. When added together, these impacts reflect the “cost of doing nothing” about the chosen societal issue, which can be used to incentivize policy makers and private partners to restructure cashflows so that resources may become available to address some of these challenges. It should be noted that the “cost of doing nothing” is not referring to the cost of doing nothing about the status quo per se, but rather what happens when society proceeds with the energy transition without taking into consideration the associated negative externalities that can impact a number of different stakeholders.

There is versatility within the UFM model as it can be used for the general purpose of mapping all of the cashflows within a city to see where “win-win” situations exist for sustainable investments (as can be seen in the pilot project conducted in Zwolle, NL[5]), or it can be used more specifically to address a particular societal challenge. In this study, the UFM model is used to identify the impacts of energy poverty in Paddepoel to better understand the reach of these impacts. These impacts are the negative externalities previously mentioned, or the so-called “costs of doing nothing” about the impending risk of residential energy poverty during the energy transition.

1.3.1 Levels of Cashflow Analysis

The UFM model is first used to analyse cashflows that run in and out of a household. This gives an indication of household expenditures, be they essential or leisure expenses, to understand the basic spendable income of a household. This determines an income to expenditure ratio which is later used to calculate what percentage of a household’s income is spent on energy. These cashflows will differ from country to country based on different policies, but the basic cashflows that flow in and out of households in Paddepoel can be seen in Figure 3 below:

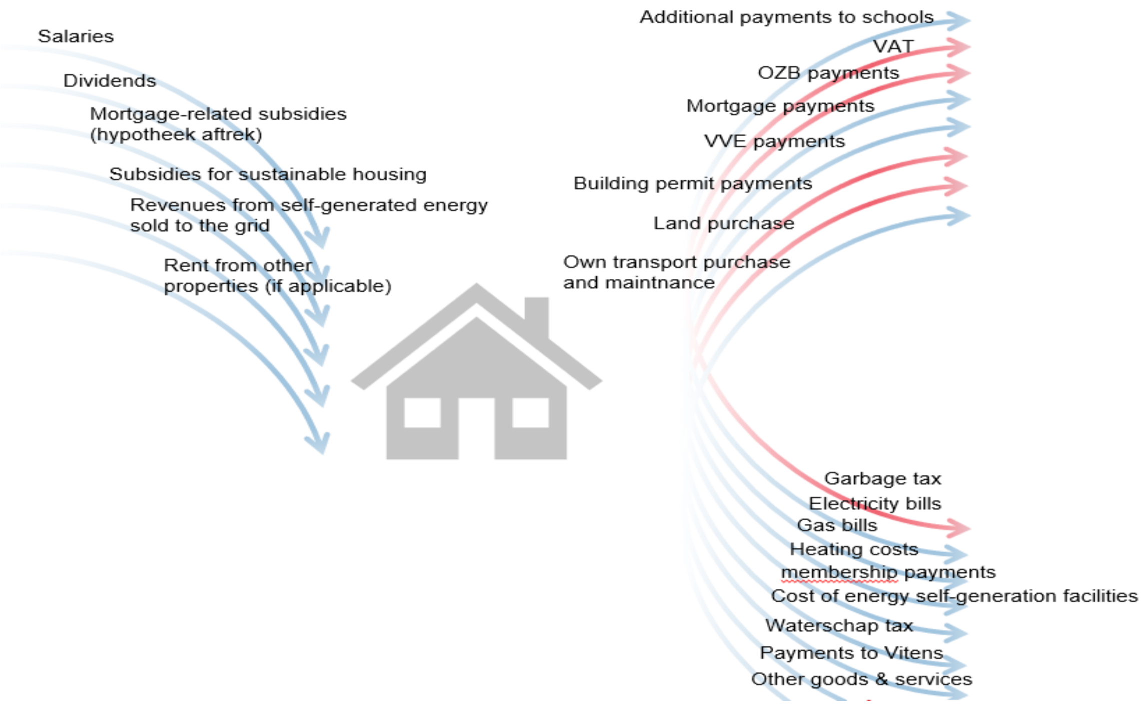


Figure 3: Household Cash Flows in Paddepoel (Nauta, 2020)

Once the household cashflows have been established, there is a better understanding of what kind of disposable income is available to be spent in the local economy and the UFM can be applied to wider scopes to determine the effects of reduced buying power on local businesses, the municipality, and even the federal government.

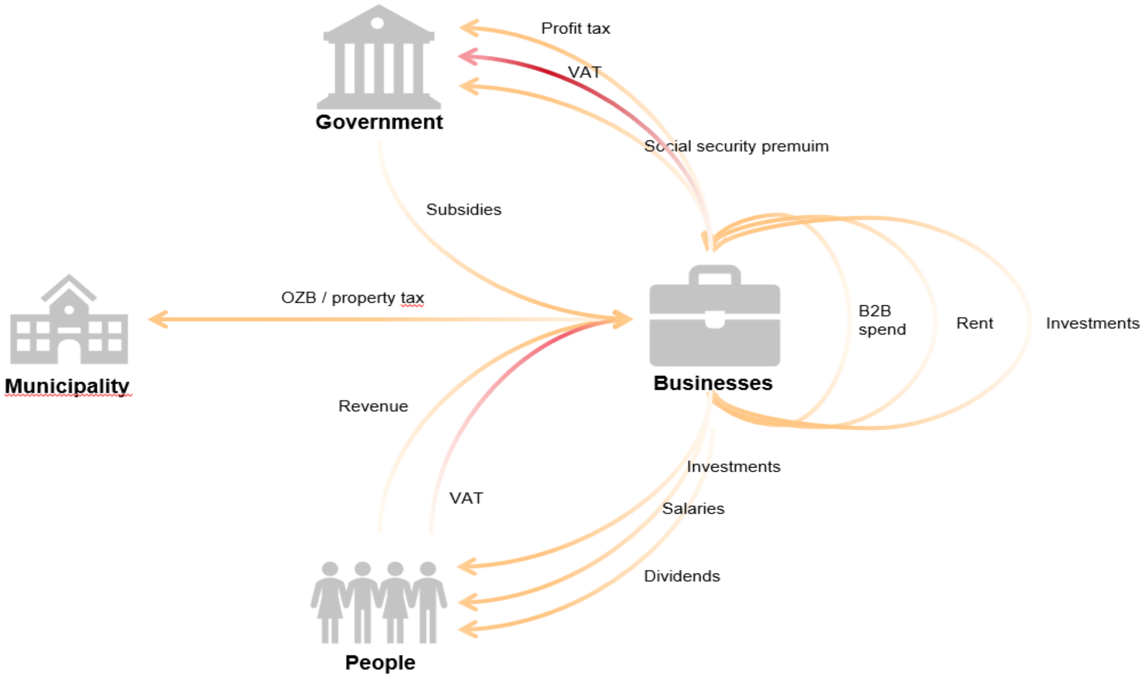


Figure 4: Cashflows Centred around Local Businesses (Nauta, 2020)

Figure 4 illustrates the cashflows that run in and out of local businesses in Paddepoel. Cashflows that run into businesses consist of business-to-business (B2B) spending, government subsidies, and revenue from people. The latter is of importance to the functioning of the UFM model because when households face the challenge of energy poverty, they have less money available to spend in the local economy, and local businesses subsequently experience this impact as well.

The UFM model is unique in that it addresses the financial challenges associated with the energy transition by engaging with stakeholders across many sectors and promoting collaboration and unlikely pairings between domains that may otherwise not work together. It can be used as a starting point to seek out mutual benefits between stakeholders and seize opportunities to share costs for a project or policy where these mutual benefits occur, otherwise known as “win-win” situations. However, this stage of creating “win-win” opportunities is still under development with TNO and cannot be fully implemented until data is available for all of the cashflows being studied. Due to this limitation, part of this study will be focusing on the first stage of implementing the UFM, which serves to quantify the societal impact of energy poverty in Paddepoel. This is valuable because it demonstrates to the municipality of Groningen how much money this issue is costing society as a whole to get them thinking about ways this money could be better used to implement sustainable interventions in these at-risk households instead. As such, this study is intended to be an important first step to identifying the extent of the issue so that in the future, colleagues at TNO and NEC can build off of this research to identify these aforementioned “win-win” situations.

1.4 Objective & Research Questions

As previously mentioned, this paper will be looking at the preliminary stages of the UFM model to quantify the societal impact of the “cost of doing nothing” about energy poverty in Paddepoel. The later stages of the model will likely be carried out by colleagues at TNO and NEC for future research. Besides quantifying these societal costs, it will also be interesting to explore potential interventions that the municipality may consider as a response to these costs. In this way, the UFM model is not being used to directly mitigate the risks of energy poverty, but rather is used to present to council members what the outcome would be if they do not take action on this issue. As such, the main research question that will be explored in this paper is as follows:

How can the preliminary stage of the Urban Financial Metabolism (UFM) model be used to stimulate sustainable investments within a municipality or neighbourhood and create a more inclusive energy transition, which mitigates the risk of energy poverty?

The term “inclusive” is used here to refer to an energy transition which includes all citizens, rather than leaving behind those who simply do not have the financial means to take part in this transition. The author will aim to answer this question by breaking it down into three sub-questions, as follows:

1. *What methods were used to estimate the number of households at risk of energy poverty in the neighbourhood of Paddepoel in Groningen, NL, and how has the preliminary stage of the UFM model been used to quantify the "cost of doing nothing" about these anticipated risks?*
2. *What sustainable interventions could be introduced into the neighbourhood of Paddepoel to combat the risks of energy poverty, and how might the costs of these interventions compare to the "cost of doing nothing" calculated in sub-question 1?*
3. *What aspects must be changed in the UFM methodology in order for it to be used effectively in another country/region?*

The first sub-question will be executed first to understand how the UFM model has been used in its early stages to calculate the number of households at risk of energy poverty in Paddepoel. Further analysis will then be done to understand how this number translates in monetary costs to society. Following this, a number of scenarios containing various sustainable interventions will be proposed to help to answer sub-question 2. A cost-benefit analysis (CBA) will be conducted to identify the economic viability of each scenario, and the costs of implementing each scenario will be compared to the "costs of doing nothing" that are calculated in sub-question 1. Finally, sub-question 3 will address things to think about when implementing the UFM model in another city or country so that other municipalities may benefit from this new methodology for addressing energy poverty within their own cities.

This paper will begin by discussing the different methodologies used to answer each of the sub-questions. Next, the execution and results of each of these methodologies will be explained with answers to each of the sub-questions provided. An overall discussion of these findings will be laid out and future suggested research will be offered, and finally, concluding remarks linking back to the main research question will be given.

2. Methodology

Answering these three sub-questions will require a number of combined methodologies and strategies. As such, each sub-question will have its own methodology/ies which are broken down in Table 1 and explained in the following sub-sections.

Table 1: Methodologies Used by Sub-question & Sub-section

Methodology	Sub-question	Sub-Section
Literature Review & Expert Interviews	1	2.1
Data Analysis	1, 2	2.2, 2.4
Cost-Benefit Analysis	2	2.3

2.1 Literature Review & Expert Interviews

Understanding how the UFM was used to quantify the cost of doing nothing about energy poverty in Paddepoel (SQ 1) required continuous dialogue with the experts who have been conducting this ongoing study. First however, a more general understanding of UFM was obtained through published literature by TNO. The first was a RESIN report funded by the European Union Horizon 2020 Project prepared by A. Woestenburg and H. Puts from TNO, explaining the challenges of other methodologies and why the UFM can be implemented to address a variety of societal issues related to climate adaptation [11]. The second was another report by A. Woestenburg and H. Puts, as well as A. Gavrilova from TNO, which outlines the use of UFM as a pilot project in the Dutch city of Zwolle [12]. Further literature review was done to gain a general understanding of energy poverty and its impacts to better grasp the concepts that TNO and NEC are working on. M. Santamouris was an important part of this review, as his work helped to gain an understanding of the impacts of energy poverty on human health [7]. Jessel et al. also expanded on this topic, while providing clarity on a number of social factors that can lead to energy poverty [6]. R. Holdsworth-Morris offered valuable insights on energy poverty in a Dutch context and elaborated on the different methodologies available to quantify it [4]. S. Pye et al. presented various indicators of energy poverty in Europe and discussed recommendations for addressing it [5]. These resources were fundamental in presenting the extent of energy poverty as a critical issue across different geographies and offered a variety of potential mitigation techniques. This study will attempt to add to existing literature by demonstrating the use of the UFM model as a new method for stimulating sustainable interventions from governments to address this issue.

P. Tamis, Project Manager at the New Energy Coalition and representative for the Making City Project, was the primary contact for understanding the processes in place to calculate the number of households at risk of energy poverty. Open discussions were held virtually twice weekly from June 2020 to November 2020 to understand the methodology and data obtained thus far, monitor progress, and ask questions about the project. He also walked through the data spreadsheet to explain the cashflow analysis of the UFM model.

J. Nauta was also consulted virtually four times throughout the research period as an expert in UFM from TNO. The first meeting consisted of a virtual presentation by Nauta, whereby he (supported by Tamis) explained the methodology of the UFM and the progress that they had made so far. The subsequent meetings were all follow-ups and semi-structured interviews whereby questions could be asked to gain more expert knowledge on the project.

These interviews were fundamental in understanding the process of calculating the number of households in energy poverty in Paddepoel.

2.2 Data Analysis

Once the number of households at risk of energy poverty was calculated, the next step was to quantify the societal impact of this. Nauta and Tamis came up with 4 indicators for quantifying the societal impact: i) spendable income of households, ii) money spent in the local economy, iii) money leaving municipality, and iv), money spent on health and welfare as a result of energy poverty. An analysis of the data collected by Nauta and Tamis was necessary for quantifying these impacts.

2.2.1 Impact on spendable income

In order to help meet climate targets, the Dutch government has set a goal for all residential buildings to be gas free by 2050 [13], causing an expected increase in natural gas price in the coming years to encourage residents to switch to more sustainable energy sources and/or make their homes more energy efficient. These increasing gas prices reduce the amount of spendable income a household has each year, and in low-income households, this can result in either arrears in their energy bills, or compromising another essential household expenditure in order to provide adequate warmth in their homes. This was calculated using the following formula:

$$\begin{aligned} &Spendable\ Income \\ &\quad = (Household\ income - essential\ household\ expenditures) \\ &\quad * no.of\ energy\ poor\ households\ per\ year \end{aligned}$$

In this formula, gas and electricity bills are considered “essential household expenditures”, alongside others such as rent or mortgage payments, food, water, insurance, phone, internet, and transportation, to name a few. The *difference* in spendable income was then calculated to show how much less spendable income households would have compared with 2020 levels. In other words, for the purposes of this project, the price increase was set to start in 2020, so all gas prices thereafter would be used to show the gap in what spendable income would be if these prices were not a barrier for households versus what it will be when they are forced to pay these costs. This was calculated by:

$$\begin{aligned} &Difference\ in\ Spendable\ income\ per\ year \\ &\quad = Spendable\ income\ per\ year - spendable\ income\ in\ 2020 \end{aligned}$$

2.2.2 Impact on money spent locally

When households experience a reduction in spendable income, that in turn also impacts the local economy. For every euro less a household has in spendable income, the local economy loses one euro also. It was assumed that most energy poor households do not have the means to go on holiday and spend money outside their municipality. Therefore, the impact on money spent locally which affects local businesses was assumed to be the same impact as the difference in spendable income. As such, the above formulas apply to this indicator as well.

2.2.3 Impact on money leaving the municipality

Gas and electricity bills are paid to utility companies outside the municipality. Therefore, as energy bills increase, the more money there is leaving the municipality. Ideally, the city of Groningen would prefer to keep cashflows within the municipality wherever possible, so that is why this is an important indicator for measuring societal impact. Since the difference in spendable income is based solely off of these two cashflows (gas and electricity payments), this indicator will also be equal to the previous two indicators for calculating the cost of doing nothing.

2.2.4 Impact on money spent on health and welfare

Studies have proven that people living in energy poverty are more prone to various physical and mental health issues, which puts a strain on the healthcare systems [7]. While these studies have looked in depth at the physical health consequences of energy poverty, few have found answers to what these physical conditions translate to in monetary terms. Among Nauta and Tamis' research, as well as further research done for this report, it was found that this indicator had insufficient findings for further consideration in this study. For this reason, it was decided that the analysis for the "cost of doing nothing" will omit the health and welfare indicator from the remainder of this study. More information on this decision will be offered in section 4.

The societal cost of doing nothing about energy poverty was then calculated by adding the costs for the first three indicators each year and taking the sum of all 15 years, making sure to only calculate the costs above the 2020 baseline threshold.

$$\begin{aligned} &Cost\ of\ doing\ nothing \\ &\qquad = Difference\ in\ spendable\ income + Difference\ in\ money\ spent\ locally \\ &\qquad + Difference\ in\ money\ leaving\ municipality \end{aligned}$$

2.3 Cost-Benefit Analysis

Once the cost of doing nothing about the energy poverty risk was calculated, a series of scenarios were proposed to address the issue:

- **Scenario 1:** Upgrade all homes at high risk of energy poverty in Paddepoel to Energy Label B.
- **Scenario 2:** Upgrade all homes at high risk of energy poverty in Paddepoel to Energy Label B, and install solar PV panels on rooftops.
- **Scenario 3A:** Upgrade all homes at high risk of energy poverty in Paddepoel to Energy Label B, and install all-electric heat pumps to replace natural gas
- **Scenario 3B:** Upgrade all homes at high risk of energy poverty in PED North to Energy Label B, and install hybrid heat pumps to replace 50% natural gas
- **Scenario 4A:** Upgrade all homes at high risk of energy poverty in Paddepoel to Energy Label B, install all-electric heat pumps and solar PV panels on rooftops
- **Scenario 4B:** Upgrade all homes at high risk of energy poverty in Paddepoel to Energy Label B, and install hybrid heat pumps and solar PV panels on rooftops

A cost-benefit analysis (CBA) was conducted for each scenario using a combination of data obtained from Nauta and Tamis as well as from other sources, using Microsoft Excel.

Table 2 contains certain technical and economic inputs that were used in this analysis for each scenario.

Table 2: Technical & Economic Inputs for CBA Scenarios

Scenario	Input	Value	Source	Notes
Upgrading Households to Energy Label B				
ALL	Upgrading to Label B	€12,000/house	[14]	Estimated €8,500 - €15,000
ALL	Reduction in heat demand from upgrade	50%	[15]	
ALL	Reduction in electricity demand from upgrade	15%		Assumption (see 2.3.1)
Installing Photovoltaic Panels to Rooftops				
2, 4A, 4B	PV Investment	€1,000/kW	[16]	
2, 4A, 4B	Installed Capacity PV	3.68kW/house	[17]	
2, 4A, 4B	PV Capacity factor	0.11		Standard NL
Implementing Electric Heat Pump to Replace Gas				
3A, 4A	Investment All-Electric Heat Pump	€12,000/house	[13]	Estimate: €9,000-19,000
3A, 4A	Subsidy – Electric Heat Pump	€1,100/house	[18]	
3A, 4A	Installed Capacity - Electric Heat Pump	40kW/house	[19]	Estimate 30-60kW
3A, 4A	Electricity Consumption – Electric Heat Pump	4000kW/house	[18]	
Implementing Hybrid Heat Pump to Replace 50% of Gas				
3B, 4B	Investment Hybrid Heat Pump	€4,000/house	[18]	Estimate: €3,600-4,600
3B, 4B	Subsidy- Hybrid Heat Pump	€1,650/house	[18]	Estimate: €1,500-1,800
3B, 4B	Electricity Consumption Hybrid Heat Pump	2000kWh/house	[18]	50% of electric heat pump
3B, 4B	Gas Consumption of Boiler w. Hybrid Heat Pump	50% of regular boiler	[18]	

Assumptions:

A number of assumptions and generalisations were used to conduct this CBA. The purpose of this analysis was not to calculate exact costs of each intervention, but instead to gather data to identify trends that could show which technical interventions would be most financially appealing and to understand how to implement financing schemes for the chosen interventions in the future. It should be noted that by using this approach, the CBA is rather oversimplified in some aspects, and that this should be used as the base for further research to build off of when more micro data is readily available. For all scenarios, it was assumed that yearly maintenance would amount to 5% of the capital expenditures. An internal rate of return (IRR) of 3% is assumed for all scenarios. Further assumptions will be outlined in the following sub-sections along with more detail on how the scenarios were conducted.

2.3.1 Scenario 1: Upgrade Homes to Energy Label B

This first scenario considers upgrading all households to energy label B. Poor insulation can be a huge factor when dealing with energy efficiency. For the remaining scenarios, there is not much sense in implementing other interventions such as PV panels or heat pumps if the energy is going to be wasted on an inefficient house. For that reason, it was decided that this should be the minimum technical intervention applied to all energy poor households in all scenarios. Of course, the costs for this will vary based on the size and age of the house, as well as by the current energy label. A estimation of €12,000 per household was used based on a report by RIGO and TNO which stated that the costs of upgrading a house to energy label B can cost anywhere from €8,500 -15,000 [14], to accommodate costs on both ends of this spectrum.

Calculating Costs: The capital expenditure (CAPEX) was calculated by multiplying this figure by the growing number of households in energy poverty each year. The operational expenditure (OPEX) was calculated by using an assumption of 5% of the CAPEX to cover annual maintenance costs of all interventions in all scenarios.

Calculating Benefits: The benefits were calculated by adding the money saved in gas and electricity expenditures from upgrading the houses. This was done using the following formulas:

$$Savings\ Gas = Reg.gas\ demand * 50\% * gas\ price$$

$$Savings\ Electricity = Reg.el.\ demand * 15\% * electricity\ price$$

Note that *Reg. gas & el. demand* refer to the gas and electricity demands of the household prior to upgrades. Information was available on 50% savings in gas demand when upgrading to energy label B by Gemeente Groningen [15], but this data was not available for electricity demand. It was assumed that most of the energy savings of this upgrade would be related to gas demand due to the insulation. Upgrades regarding electricity expenditure would presumably be more related to more energy efficient appliances and lighting, as an example. It was assumed that some of these may be involved in an upgrade to label B, but that most would be for upgrades to energy label A or higher. Therefore, a modest assumption of 15% was assumed for energy savings.

2.3.2 Scenario 2: Upgrade Homes to Energy Label B & Install PV Panels

This second scenario considers all the same upgrades from scenario 1, as well as installing solar PV panels on household rooftops. First, the changes in gas and electricity demand were calculated using the formulas from scenario 1. Then, the electricity produced by these panels was calculated by:

$$PV\ Production = \frac{3.68kW}{house} * 0.11 * No.of\ houses * 8760$$

Here, 3.68kW per house is the installed capacity [17], 0.11 is the PV capacity factor (CF) (standard CF for NL), *No. of houses* is the number of households with installed PV, and *8760* is the number of hours in a year.

The next step is to calculate how much of the electricity demand can be covered by the PV production. This is calculated using the "IF" function in Excel using the following formulas:

$$= IF(PV\ production > El.demand, THEN\ all\ demand\ covered)$$
$$= IF(PV\ production < El.demand, THEN\ only\ amt.produced\ by\ PV\ covered)$$

Calculating Costs: The CAPEX from scenario 1 is combined with the CAPEX of installing PV, which is calculated by the following formula:

$$CAPEX\ PV = \frac{3.68kW}{house} * \frac{€1{,}000}{kW} * No.of\ houses$$

Here, €1,000/kW is the assumed costs of the PV panels and installation [16]. The OPEX is again assumed to be 5% of the CAPEX.

Calculating Benefits: The money saved on gas expenditures was calculated the same way as in scenario 1. The money saved in electricity expenditure was calculated by reducing demand by 15% as was the case in scenario 1, and then subtracting the amount of demand that is met by PV production:

$$S2\ El.Demand = S1\ El.Demand - demand\ met\ by\ PV\ production$$

$$Electricity\ Savings = (Reg.el.demand - S2\ El.Demand) * electricity\ price$$

Note that *S1 El. Demand* and *S2 El. Demand* refer to the electricity demand of the houses for scenarios 1 and 2, respectively. Another benefit of this scenario is the profit from any surplus electricity that is sold back to the electricity grid, calculated as follows:

$$Earnings\ Surplus\ PV = (PV\ production - El.Demand) * Electricity\ Price$$

These benefits are then combined for each year.

2.3.3 Scenario 3: Upgrade Homes to Label B & Install Heat Pumps

Scenario 3 has two renditions. Scenario 3A is an analysis of installing an all-electric heat pump, Scenario 3B looks at installing a hybrid heat pump, and both A and B include the upgrades to energy label B. These two renditions were conducted very similarly, with the exception being that for scenario 3A, it is assumed that all of the gas demand is covered by the all-electric heat pump, while in scenario 3B, only 50% of the gas demand is covered by the hybrid heat pump.

Calculating Costs: The CAPEX for both scenarios is calculated by taking the investment costs of the heat pumps (€12,000 and €4,000 per household for electric and hybrid heat pumps, respectively) and multiplying it by the growing number of households at risk of energy poverty each year. This is combined with the CAPEX from scenario 1. The OPEX is comprised of two parts: the annual maintenance costs of 5% of the CAPEX, and the cost to run the heat pump, which was calculated as follows:

$$El.Expenditure\ Heat\ Pump = Consumption\ of\ heat\ pump * No.of\ houses * el.price$$

Calculating Benefits: Savings in electricity are calculated the same way as in scenario 1. Savings in gas are considered to be 100% in scenario 3A because the heat pump is replacing all gas demand. In scenario 3B, gas savings are calculated by:

$$Savings\ Gas\ Scenario\ 3B = S1\ Gas\ demand * 50\% * gas\ price$$

S1 Gas demand refers to the gas demand in scenario 1 after upgrades to label B have already been implemented. The third benefit to be calculated is the subsidy for the heat pump, which is a one-time payment of €1,100 and €1,650 for all-electric and hybrid heat pumps, respectively.

$$Subsidies = subsidy\ heat\ pump * No.of\ houses$$

These benefits are then combined for each year.

2.3.4 Scenario 4: Upgrade Homes to Label B, Install PV & Heat Pumps

Scenario 4 also has two renditions. Both look at upgrading houses to energy label B, installing PV and heat pumps. Scenario 4A uses all-electric heat pumps and scenario 4B uses hybrid heat pumps for the analysis.

Calculating Costs: The CAPEX in these scenarios is simply a combination of the CAPEX of all three interventions that have been calculated in the first three scenarios. The OPEX is again comprised of the maintenance costs being 5% of the CAPEX, as well as the expenditure of the heat pumps. The heat pump expenditure is calculated differently this time, as now there is PV production to offset these costs. First, the new electricity demand is calculated as follows:

$$S4\ el.demand = \left(reg.el.demand * (1 - 15\%)\right) + (Heat\ pump\ consump.* No.of\ houses)$$

Note that *S4 el. demand* refers to the electricity demand in scenario 4 which includes the 15% reduction from upgrades and the added demand of the heat pump. Then, the amount of electricity that is still required to be purchased from the grid is calculated by:

$$El.Expenditure = S4\ el.demand - PV\ production * electricity\ price$$

If the PV production is greater than the S4 electricity demand, then the earnings from the surplus is considered a benefit.

Calculating Benefits: In scenarios 4A and 4B, the savings in gas expenditure are calculated exactly as they were in scenarios 3A and 3B. The electricity savings are calculated as follows:

$$\begin{aligned}&Savings\ Electricity\\&\qquad = (S1\ el.demand + heat\ pump\ el.demand - PV\ production) * el\ price\\&\qquad * No.of\ houses\end{aligned}$$

These savings are combined with the subsidies as calculated in 2.3.3 for total benefits each year.

For each scenario, the net present value (NPV) is calculated as follows:

$$NPV = \frac{Cashflow}{(1-i)^t} - initial\ investment$$

Note that *i* refers to the IRR and *t* refers to the number of time periods, which in this case is 15 years. If the NPV is positive, the business case is positive. If it is negative, the business case is also negative and therefore the scenario is not recommended for implementation. Then, the cost-benefit ratio (CBR) is calculated as follows:

$$CBR = \frac{Total\ Benefits}{Total\ Costs}$$

If the CBR is greater than 1, then the benefits outweigh the costs. If it is less than 1 then the costs outweigh the benefits. If it is equal to 1, the costs and benefits are the same.

2.4 Data Analysis of Societal Impact Indicators

Once the CBA was completed, the impact of each scenario was measured using the three indicators discussed in section 2.2 and compared to the "cost of doing nothing" scenario. The impact on spendable income and money spent locally was calculated the same way, both using the following formula:

$$\begin{aligned}&Difference\ in\ spendable\ income\ (and\ difference\ in\ money\ spent\ locally)\\&\qquad = spendable\ income\ base\ case + Energy\ Savings - OPEX\end{aligned}$$

Note that "*spendable income base case*" refers to the spendable income in the "cost of doing nothing" scenario and that these are measured against 2020 levels of spendable income. The third indicator, money leaving the municipality, was calculated as follows:

$$\begin{aligned}&Difference\ in\ Money\ Leaving\ Municipality\\&\qquad = Money\ Leaving\ municipality\ base\ case - Energy\ Savings\\&\qquad + earnings\ from\ surplus\ PV\ production(if\ applicable)\end{aligned}$$

Here, scenario 1, 3A and 3B look simply at the energy savings that will no longer be leaving the municipality compared to the "cost of doing nothing" scenario. Scenario 2, 4A, and 4B also look at earnings coming from outside the municipality in the event that surplus PV production is sold back to the grid.

3. Results

3.1 Sub-question 1: Quantifying the “Costs of Doing Nothing”

In order to calculate the total “cost of doing nothing” about energy poverty, one must dedicate a set timespan to use as a metric for quantifying this. Nauta and Tamis set this timespan for 15 years: from 2020 – 2035. This is because most of the technical interventions proposed by Making City as a means to mitigate the risks of energy poverty have an approximate lifespan of 15 years.

To begin the execution of the UFM in Paddepoel, Nauta and Tamis first devised a system comprised of 4 parts to determine the actual risk of energy poverty in this neighbourhood. As demonstrated in Figure 5 below, by combining the demographic characteristics of Paddepoel with the key determinants of energy poverty, they were able to develop various household archetypes which could be separated into different levels of risk of energy poverty (i.e.: risk profiles). Only then could they conduct the UFM model by means of a cashflow analysis to determine how many households fall into the high-risk category, and the impact these households have on society.

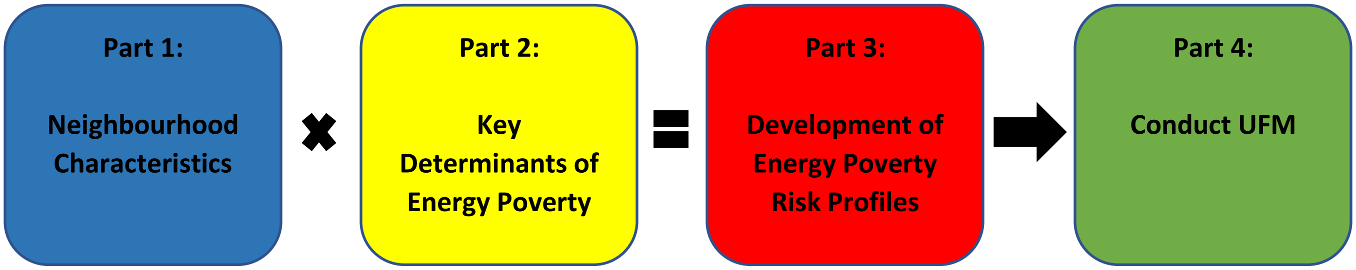


Figure 5: Four-Part Process of Executing UFM in Paddepoel (Nauta & Tamis, 2020)

3.1.1 Part 1: Neighbourhood Characteristics of Paddepoel

Part 1 required considerable data collection. Data on age of residents, dwelling type, number of occupants per household, year of house construction, house value, population density, income, and household expenditures were all relevant characteristics for better understanding the demographics of Paddepoel, but the latter two were of highest importance. Understanding income and expenditure, particularly *energy* expenditure, are essential for determining if a household is financially able to meet basic energy needs. However, obtaining this required data came with restrictions.

Income: Data on individual household income is not publicly available, but aggregate data on the different income brackets was obtained from the Dutch Central Bureau of Statistics (CBS). However, the CBS is forbidden by Dutch law to make projections on income, so Nauta and Tamis assumed an income inflation increase of 1% per year until 2035.

Energy Expenditure: Similarly, data on individual household energy expenditure is also not publicly available. However, data of energy expenditure by postal code is available from the Urban Data Centre (UDC). As such, Nauta and Tamis took the median expenditure for each street, as this was around the national average for a standard household. They assumed that the energy demand would stay the same for the 15-year period and then made their own forecasts based on expected changes in electricity and gas prices.

3.1.2 Part 2: Key Determinants of Energy Poverty

While many factors may similarly influence energy poverty in different regions as previously discussed in the section 1.2, it is important to identify which determinants have the greatest influence over the risk of energy poverty in the specific study area. Nauta and Tamis started the process of identifying these key determinants by doing a literature review, which indicated drivers of energy poverty on a European scale and a Dutch scale.

Referring back to Figure 1, they found that on a Europe-wide scale, low income, poor energy efficiency, and high energy bills make up the perfect storm for energy poverty, as discussed by Pye [5]. However, as they narrowed their search to a Dutch context, they found that different studies have found other determinants as well. A (soon to be published) PBL report found that house value, type of ownership, construction period, number of people per household, and average population density of the region to be the most important factors. Furthermore, a recent study in Amsterdam found that “low income, private-rented, single parent households, and those over the age of 65 are the main factors which increase the likelihood of energy poverty [in Amsterdam]” [4].

The findings of their literature review indicated to Nauta and Tamis that, not only are there many potential determinants that could lead to energy poverty, there was also a great deal of overlap amongst the studies. Together they analysed their findings and narrowed it down to 3 main determinants for energy poverty in Paddepoel: income, house energy label, and type of ownership (whether it be social, private, or rental housing). The following outlines their reasonings for selecting these determinants.

A) Income: This was found to be one of the more obvious determinants simply because if a household does not have sufficient income, they may not be able to meet basic energy needs for their home, or they may be required to sacrifice another expenditure in their life to meet these needs.

B) Energy Label: While house value and construction period may indeed influence the risk of a household falling into energy poverty, they do not necessarily accurately reflect the actual energy efficiency of the house. House value, for example, is an overall value which consists of many other elements that may not be related to energy at all. One house may be located in a great neighbourhood and have ample surface area, bringing up the total value of the house, but may not be very energy efficient. For construction period, it may be true that some old houses are less energy efficient than some newer houses, but this metric does not take into consideration whether a household has been renovated to be more energy efficient, and therefore, results using construction period as an input could be inaccurate.

Pye's analysis of energy efficiency as a key determinant seemed to be the most adequate for this study, but did not offer a metric of understanding what that looks like on a household basis. Moreover, energy expenditure was also an indicator that had repeatedly come up as essential in this energy poverty conversation, yet was not listed here as one of the key determinants. This is because Nauta and Tamis held that the Dutch energy labelling system adequately incapsulates both energy efficiency and expenditure in a system that already categorizes varying levels of each giving them a letter grade from A-G, making it simpler to quantify.

C) Type of Ownership: This determinant was mentioned by PBL and Holdsworth-Morris (when she indicates that private-rented households are the most at-risk of energy poverty) and was worth selecting as a key determinant for this study because it indicates the level of control the inhabitant has over the energy bills. The three types of housing that will be referred to here are social, rental, and private housing.
   - Social Housing: People who live in social housing are typically already in a lower income bracket. As such, various social assistance programmes and subsidies are in place to help support these households with living expenses, including energy bills. Therefore, the risk of not being able to meet basic energy needs based on this metric alone may not be as severe as it would be for people who do not receive these benefits.
   - Rental Housing: People who rent their home, regardless of their income bracket, are at the mercy of increasing energy prices. They may change certain behaviours in order to consume less energy, but ultimately, they are unable to implement most sustainable energy technologies or upgrade their homes to be more energy efficient because they are not the owners of the house. This could leave some tenants falling toward the energy poverty trap.
   - Private Housing: This refers to owner-occupied households. While these home owners may have more freedom to make certain sustainable upgrades to their homes, unlike tenants in the rental scenario, many of them still cannot afford to do so. Whether it be high mortgage payments or low income, people in private homes are also considered at risk of energy poverty because of the financial burden it may cause.

Now that the three main determinants for energy poverty have been determined for Paddepoel, the data collected in part 1 and part 2 are combined together to develop different risk profiles so one can better understand, based on the three determinants, which household types are at risk of falling into the energy poverty trap over the next 15 years.

3.1.3 Part 3: Energy Poverty Risk Profiles

As part of their research, Nauta and Tamis determined that the correlation between income and energy expenditure was the most robust way to determine the level of risk a household was at of becoming energy poor. The 2M metric has been a proven method for calculating this correlation, and is described by the following formula:

$$2M\ energy\ poverty\ ratio = \frac{Energy\ expenditure}{Income}$$

A household is considered to be energy poor when its energy poverty ratio is at least 2 times greater than the national median ratio for that year [4]. However, in order to make this calculation, data for individual household energy expenditure and income must be publicly available. Because the data available to TNO and NEC was aggregate, siloed data, they were unable to use this approach. In response to this barrier, Nauta and Tamis developed a matrix to produce 27 archetypes of varying risks of energy poverty using the determinants described in section 3.1.2. Each of the determinants was broken down into 3 levels of risk, as reported in table 3.

Table 3:Risk Categories of Key Determinants

	High risk	Risk	No Risk
Spendable Income /annum	< €22,600 (0%-20%)	€22,600 - €35,928 (20%-40%)	> € 35,928 (40%-100%)
Energy Label	E-G	C-D	A-B
Type of Ownership	Private Housing Rental Housing	Social Housing	N/A*

*All ownership types considered were found to have some degree of risk, therefore there is no “no risk” category for this determinant.

Based on these risk categories, 27 potential combinations were developed (Table 4).

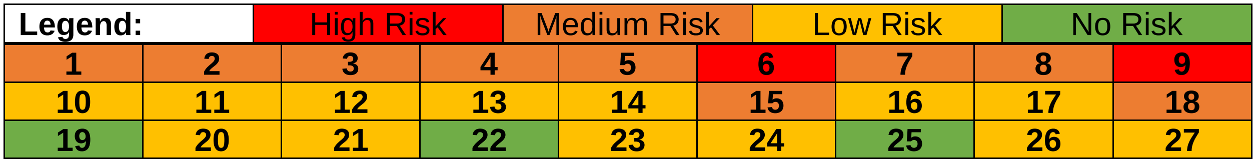
Table 4: Energy Poverty Risk Archetypes

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Income(%)	0-20	0-20	0-20	0-20	0-20	0-20	0-20	0-20	0-20
Ownership	Social	Social	Social	Private	Private	Private	Rental	Rental	Rental
E. Label	A-B	C-D	E-F	A-B	C-D	E-F	A-B	C-D	E-F
	10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Income(%)	20-40	20-40	20-40	20-40	20-40	20-40	20-40	20-40	20-40
Ownership	Social	Social	Social	Private	Private	Private	Rental	Rental	Rental
E. Label	A-B	C-D	E-F	A-B	C-D	E-F	A-B	C-D	E-F
	19	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Income(%)	40-100	40-100	40-100	40-100	40-100	40-100	40-100	40-100	40-100
Ownership	Social	Social	Social	Private	Private	Private	Rental	Rental	Rental
E. Label	A-B	C-D	E-F	A-B	C-D	E-F	A-B	C-D	E-F

After developing these 27 archetypes, Nauta and Tamis went through each one and discussed how each combination of determinants would impact the overall risk of a household becoming energy poor between 2020 and 2035.

Table 5 breaks down the archetype by severity of risk. Two of the archetypes (6 and 9) were found to be at “high risk” (red) because all three determinants of those combinations were ranked high-risk. Nine archetypes (1-5, 7-8, 25, 28) were found to be at “medium risk” (orange), thirteen archetypes (10-14, 16-17, 20-21, 23-24, 26- 27) were found to be at “low risk” (yellow), and just three archetypes (19, 22, 25) were found to have “no risk” (green).

Table 5: Severity of Energy Poverty Risk by Archetype



Legend:	🟥 High Risk	🟧 Medium Risk	🟨 Low Risk	🟩 No Risk				
🟧 **1**	🟧 **2**	🟧 **3**	🟧 **4**	🟧 **5**	🟥 **6**	🟧 **7**	🟧 **8**	🟥 **9**
🟨 **10**	🟨 **11**	🟨 **12**	🟨 **13**	🟨 **14**	🟧 **15**	🟨 **16**	🟨 **17**	🟧 **18**
🟩 **19**	🟨 **20**	🟨 **21**	🟩 **22**	🟨 **23**	🟨 **24**	🟩 **25**	🟨 **26**	🟨 **27**

Table 6: Number of households in risk categories within Groningen (Tamis, 2020)

Risk profile	**Paddepoel North**	**Paddepoel South**	**Groningen (municipality)**	**PED-North**	**Total share**
HIGH RISK	148	51	4051	199	3%
MEDIUM RISK	1409	1105	36914	2514	40%
LOW RISK	2021	1032	71480	3053	49%
NO RISK	243	277	19179	520	8%
Total	3821	2465	131624	6286	100%

Table 6 shows the breakdown of households in each risk archetype in 2020. The remainder of the analysis looks at just those households at *high risk* from 2020-2035. Figure 6 shows the increase over this time period for households at high risk of energy poverty only.

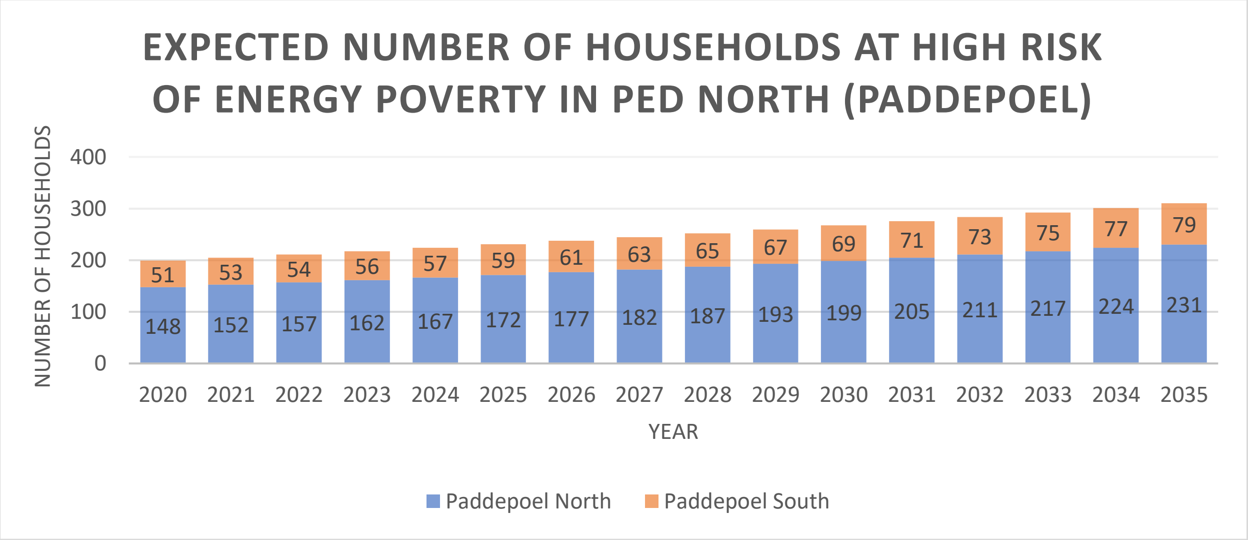


Figure 6: Households at High Risk of Energy Poverty in Paddepoel

This matrix approach for quantifying energy poverty was developed so that the number of households can be quantified in a neighbourhood even without publicly available micro data on income and energy expenditure. The assumption is that if the UFM model was to be offered as a solution for other municipalities to address energy poverty within their own cities, individual micro data on exact income and expenditure to use the desirable 2M metric would not be publicly available. Nauta and Tamis wanted to offer a different, yet still highly robust, alternative to the 2M metric.

Of course, the matrix still needs to be verified to ensure that it is indeed a robust and accurate means of calculating energy poverty. As such, this project with Making City is somewhat of a pilot project to test this method. The municipality of Groningen has agreed to take the results of this project and compare it to the private micro data and validate whether or not the estimates from this matrix approach are in line with the data they have at the UDC and CBS. This validation step will indicate the appropriateness of the matrix for further use.

3.1.4 Results of Part 1 to 3

By completing the first three parts of Nauta and Tamis' methodology, the "cost of doing nothing" can be quantified. Using the risk profile matrix, the number of households at high risk of energy poverty in Paddepoel has been calculated (Figure 6), so the impact that these homes have on society is also within reach. Using the approach outlined in section 2.2, "cost of doing nothing" about houses being at high risk of energy poverty in Paddepoel was calculated and the results are presented in Figure 7.

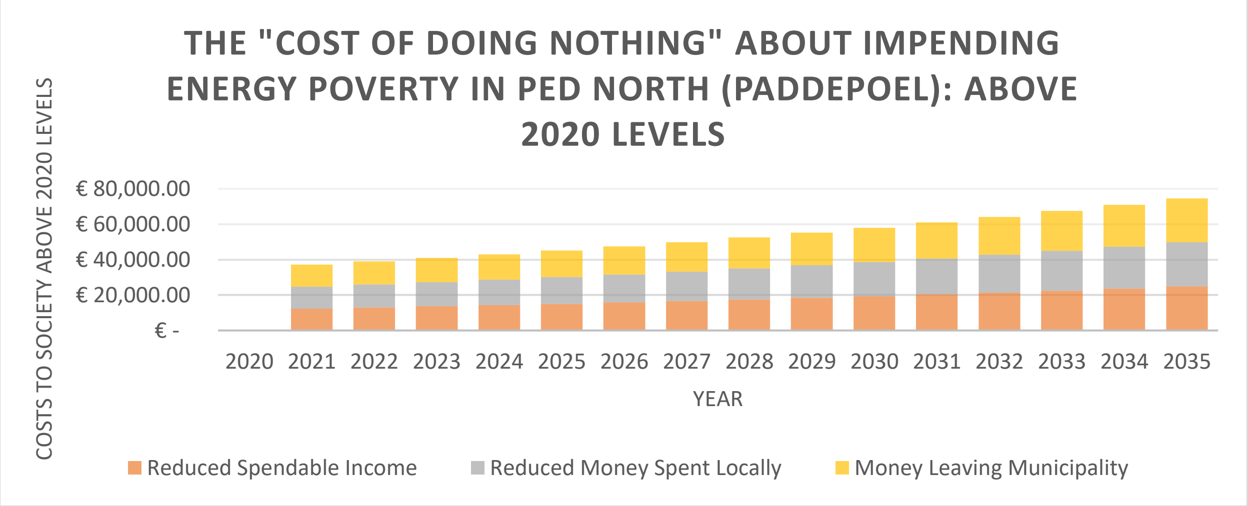


Figure 7: Societal "Cost of Doing Nothing" about Energy Poverty, by indicator

As discussed, these costs shown in Figure 7 are divided by the chosen indicators for this study and calculated above 2020 levels. Each of these indicators are contingent on gas and electricity bills. As energy bills increase, spendable income and money spent locally decrease, while money leaving the municipality increases. Because of this, the impact on each of these indicators is exactly equal, and grows each year as energy expenditure increases and the number of energy poor households also increases.

According to these results, each indicator will be impacted by a total of €12,375.65 for all 199 energy poor households combined in 2021. This number is projected to increase to €24,882.36 for each indicator for all 310 energy poor households by 2035. It is important to note that, while this amount (€12,375.65, for example) is only spent once in the form of energy bills, it is calculated three times to show that its impact extends beyond just the household paying those bills. This is also €12,375.65 less that households can spend in the local economy, which subsequently affects local businesses adversely, and it is €12,375.65 more leaving the municipality. Because one of the goals of the municipality of Groningen is to keep cashflows within the municipality as much as possible, this is considered another societal impact. The total societal impact calculated for the entire 15-year period is estimated to be ***€ 806,587.16***.

In summary, the number of households at high risk of energy poverty in Paddepoel was calculated by first determining the neighbourhood characteristics and key determinants of energy poverty, and then implementing these into the energy poverty risk matrix developed by Nauta and Tamis. The cost of society was then determined by obtaining data on spendable household income and energy prices, and multiplying this by the number of at-risk households.

3.1.5 Part 4: Conduct UFM Cashflow Analysis

Part 4 of this process consists of the cashflow analysis that is done once all of the characteristics, key determinants, and energy poverty risk profiles have been determined. It should be noted that this section covers the ongoing process of using the UFM model to discover these so-called “win-win” situations and to align cashflows that can help to save money across different domains while also mitigating the risk of energy poverty. As discussed, the results of this part of the UFM model have yet to be completed by Nauta and Tamis, so this section is more of an overview of what is to come in future research.

Step 1: Level of detail and mapping of cashflows: Nauta and Tamis began with 120 different cashflows which they obtained from the UFM pilot project in Zwolle [12]. Together, they decided on the level of detail required for delivering the requested outcomes to the municipality of Groningen. Then they reviewed the list of 120 cashflows during a 2 to 3-hour workshop with relevant stakeholders and categorised them as relevant and not relevant, and added any others that were missing from this list. These were then ranked on level of impact (high, medium, low) on energy poverty and categorised by domain (i.e.: energy, health, economic, education, mobility, etc.).

Step 2: Organise cashflows: Once the cashflows were determined they were organised by the following indicators:

- <u>Direction of cashflow:</u> Where/who is the cashflow coming from and where/who is it going to (i.e.: households, municipality, energy companies, businesses, corporations, national government, non-profit organisations, etc.)?
- <u>Type of cashflow:</u> What kind of cashflow is it (i.e.: payment, salary, subsidy, tax, etc.)?

- Frequency of cashflow: How often does this cashflow occur (incidentally, weekly, bi-weekly, monthly, annually, etc.)?
- Effect of the cashflow: Which of the four impact indicators does this effect (spendable income, money spent locally, money leaving municipality, health and welfare)?
- Assignment/Label of cashflow: Is this cashflow restricted to one stakeholder or domain, or is their flexibility for it to be directed elsewhere?
- Operation or Capital Expenditure: Is this cashflow an operational or capital cost?
- Municipality "middle man": Does this cashflow run through the municipality before it gets to its destination, or is it a direct cashflow (i.e.: garbage tax runs via municipality to waste disposal service)

Step 3: Verify Cashflows: Once the cashflows were organised, another 2 to 3-hour workshop was held with the municipality to verify the accuracy of the chosen organisational structure.

Step 4: Data Collection: Once all of the cashflows have been organised and verified, Nauta and Tamis began collecting data values for each. This has been an extensive process that is still ongoing. Some data was found from a number of online resources, while others were found from approaching different stakeholders and conducting interviews.

Step 5: Quantify Cashflows & Projections over 15-year period: The next step is to take the data that has been collected in Step 5 and extrapolate it over a 15-year period. Some of the data sources offer these projections, but in other cases Nauta and Tamis did their own calculations to determine the future trends of each cashflow.

Step 6: Execution: In this step, the actual cashflow analysis will take place. The data obtained will be plugged into a model that is still under development to identify overlaps in cashflows and identify opportunities for collaboration amongst stakeholders. Further information on how this model will run will be a topic for further research.

3.2 Sub-question 2: Technical Interventions for Households at Risk of Energy Poverty

This section will review the results of the CBA for the six proposed scenarios of technical interventions outlined in section 2.3. These scenarios will then be measured against the base scenario of the "cost of doing nothing" for the three chosen indicators: spendable income, money spent locally, and money leaving the municipality. Finally, a brief overview of potential financing schemes will be presented.

3.2.1 Results of Cost-Benefit Analysis

The costs and benefits for each scenario 1 were totalled for the whole 15-year project period and the results are presented in Tables 7-12.

Table 5: CBA Results for Scenario 1

Scenario 1: Energy Label B			
Costs – 15 Year Period		**Benefits – 15 Year Period**	
CAPEX	€ 3,720,426.19	Savings Electricity	€ 250,771.17
OPEX	€ 2,220,710.32	Savings Gas	€ 2,226,302.49
Total Costs	**€ 5,941,136.51**	**Total Benefits**	**€ 2,477,073.66**

Scenario 1 did not make for a positive business case. Due to the high capital costs of upgrading these homes to energy label B, the benefits are not substantial enough to make this a financially appealing project. The NPV of this scenario is ***€ -3,158,190.86*** with a CBR of 0.42. In other words, for every euro invested in this project, there is €0.42 in benefits created.

Table 6: CBA Results for Scenario 2

Scenario 2: Energy Label B & PV Panels			
Costs – 15 Year Period		**Benefits – 15 Year Period**	
CAPEX	€ 4,861,356.89	Savings Electricity	€ 1,421,036.63
OPEX	€ 2,901,728.15	Savings Gas	€ 2,226,302.49
Total Costs	**€ 7,763,085.04**	Earnings - Surplus PV	€ 1,311,392.18
		Total Benefits	**€ 4,958,731.30**

Scenario 2 also proved not to be a positive business case. In this scenario, the PV covered all of the electricity demand with added surplus that could be sold back to the grid. Still, the benefits did not outweigh the costs. This suggests that the high capital costs of this scenario do not justify the 50% savings in gas and 100%+ savings in electricity. This scenario has a NPV of ***€ -2,801,405.54*** and a CBR of 0.69.

Table 7: CBA Results for Scenario 3A

Scenario 3A: Energy Label B & All-Electric Heat Pumps			
Costs – 15 Year Period		**Benefits – 15 Year Period**	
CAPEX	€ 7,440,852.38	Subsidy	€ 341,039.07
Maintenance	€ 4,441,420.64	Savings reg. Electricity	€ 243,467.16
Heat pump expend.	€ 3,082,224.28	Savings Gas	€ 4,322,917.45
Total Costs	**€ 14,964,497.30**	**Total Benefits**	**€ 4,907,423.67**

Scenario 3A is very costly. The price of all-electric heat pumps is not yet competitive enough for the rewards to be worth the investment. A low-to-midrange value of €12,000 for an all-electric heat pump was used for this analysis, but prices can be as high as €19,000 [13], which would make this even less financially appealing. Moreover, the electricity expenditure of the heat pump is nearly as much as the savings in gas, so while replacing natural gas with a heat pump may reduce carbon emissions (depending on the electricity source), this scenario does not make sense financially. The NPV is ***€ -5,329,074.47*** and the CBR is 0.33.

Table 8: CBA Results for Scenario 3B

Scenario 3B: Energy Label B & Hybrid Heat Pumps			
Costs – 15 Year Period		**Benefits – 15 Year Period**	
CAPEX	€ 4,960,568.25	Subsidy	€ 511,558.60
Maintenance	€ 2,960,947.09	Savings reg. Electricity	€ 245,710.49
Heat pump expend.	€ 1,541,112.14	Savings Gas	€ 3,498,156.21
Total Costs	**€ 9,462,627.48**	**Total Benefits**	**€ 4,255,425.31**

Scenario 3B still does not result in a positive business case, but the capital costs decrease considerably from scenario 3A due to the much lower price of €4,000 for the hybrid heat pumps [18] compared to the all-electric ones. The hybrid heat pumps only replace 50% of the gas demand [18], so their electricity expenditure also decreases, but then the savings in gas are not substantial enough to make this an economically attractive option. The NPV is ***€ -4,617,066.17*** and the CBR is 0.45.

Table 9: CBA Results for Scenario 4A

Scenario 4A: Energy Label B, All-Electric Heat Pumps & PV Panels			
Costs – 15 Year Period		**Benefits – 15 Year Period**	
CAPEX	€ 8,581,783.08	Subsidy	€ 341,039.07
Maintenance	€ 5,122,438.47	Savings reg. Electricity	€ 2,732,428.81
Heap pump expend	€ 1,729,442.68	Savings Gas	€ 4,322,917.45
Total Costs	**€ 15,433,664.23**	**Total Benefits**	**€ 7,396,385.33**

Scenario 4A is similar to 3A because the capital costs are very high due to the high price of the all-electric heat pumps, with the added investment of the PV panels included in scenario 4A. In this scenario, there are significant savings in electricity due to the solar PV, but it is not enough to cover the additional electricity expenditure of the heat pumps. Therefore, this scenario is still not positive due to the high capital costs and the electricity expenditure of the heat pumps. The NPV is ***€ -5,943,091.14*** and the CBR is 0.48.

Table 10: CBA Results for Scenario 4B

Scenario 4B: Energy Label B, Hybrid Heat Pumps & PV Panels			
Costs – 15 Year Period		**Benefits – 15 Year Period**	
CAPEX	€ 6,101,498.95	Subsidy	€ 511,558.60
Maintenance	€ 3,641,964.92	Savings reg. Electricity	€ 1,623,114.37
Heat pump expend.	€ 188,330.54	Savings Gas	€ 3,195,221.76
Total Costs	**€ 9,931,794.42**	**Total Benefits**	**€ 5,329,894.73**

Scenario 4B combines all three technical interventions the same as in scenario 4A, with the exception being that hybrid heat pumps are used instead of all-electric ones. While the capital costs are considerably less than in scenario 4A, and the heat pump expenditure is minimal, the benefits of the subsidies and energy savings are still not enough to outweigh the costs. The NPV is ***€-4,237,723.77*** and the CBR is 0.54.

This CBA of the proposed scenarios has revealed that none of the proposed technical interventions are financially interesting to explore, which is yet another indication of the challenges that households in energy poverty face when confronted with the costs of the energy transition. This outcome further highlights the importance of implementing adequate financing schemes to help these households reduce their energy costs.

3.2.2 Societal Impact of Scenarios vs. the "Cost of Doing Nothing"

Because none of the proposed scenarios resulted in a positive business case, the impact on spendable income and money spent locally was negligible for all scenarios (see Annex 7.1). However, the implementation of these interventions did reduce energy bills in all cases, resulting in less money leaving the municipality.

Figure 8 shows how these interventions reduce the amount of money leaving the municipality from energy bill savings, which is a societal impact that the municipality of Groningen was interested in. The 3 scenarios which include the implementation of PV panels, scenarios 2, 4A and 4B, have the largest savings in money leaving the municipality due to the fact that these households would be producing the majority of their own electricity, so that cashflow would not be going to utility companies outside of the municipality. Scenarios 1, 3A and 3B also have reductions in money leaving municipality, albeit not as high as the PV scenarios. These savings are on account of the energy savings from making the households more energy efficient.

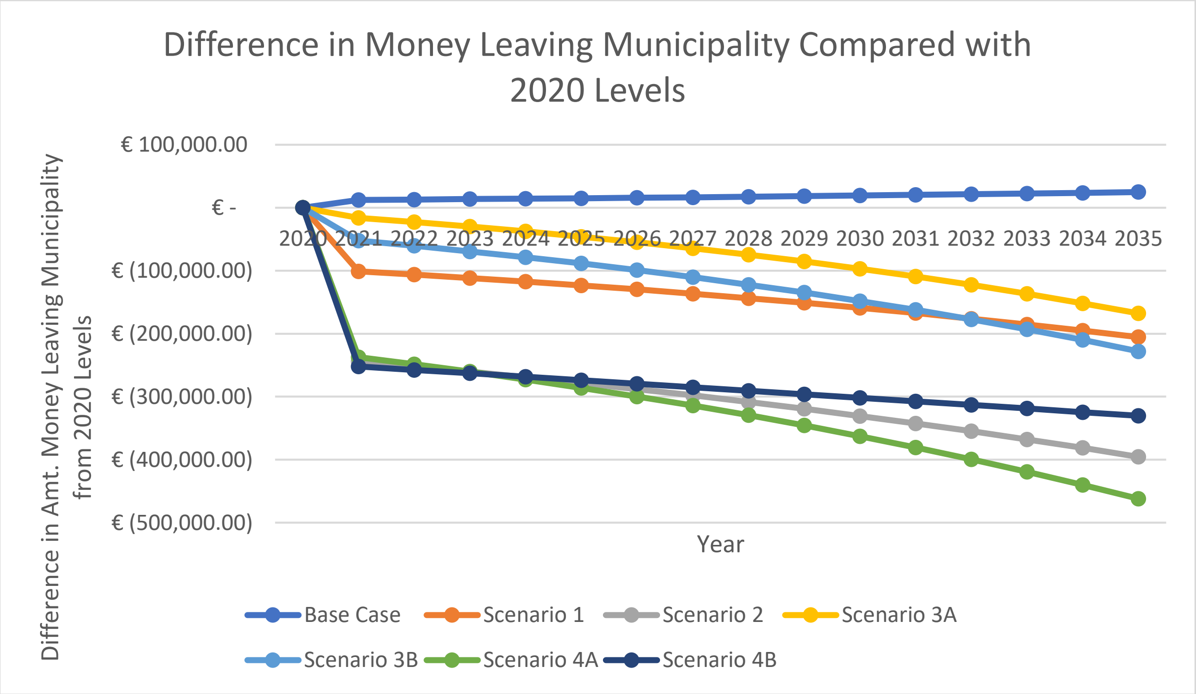


Figure 8: Difference in Money Leaving Municipality Compared with 2020 Levels

While none of the proposed sustainable interventions resulted in a positive business case, nor did they have a positive impact on spendable income or money spent locally, these scenarios should not be dismissed by the municipality altogether. The very fact that they make households more sustainable is a step towards achieving Dutch climate targets, which makes them interesting to explore further. With appropriate financing schemes to assist these households, there may be sustainable interventions that can succeed in both improving energy efficiency and mitigating the risk of households falling into the energy poverty trap.

Scenario 2, while still having a negative business case, had the highest CBR of 0.69. This indicates that of all the scenarios, scenario 2 offers the highest benefits for the costs that go into it. Moreover, even though the costs outweigh the benefits, they are among the lowest costs of all the scenarios (with the exception of scenario 1). This makes scenario 2 interesting for the municipality to explore further because with the proper financing schemes, this could be something worth investing in to address the risk of energy poverty in Paddepoel, without costing too much to the municipality. When looking at the impact that this scenario has on spendable income and money spent locally, it is evident that the annual maintenance costs of the technologies are the competing factor with the energy savings, which is why the difference on these indicators was negligible. A financing scheme that assists households financially with these ongoing costs (rather than just the upfront capital costs) could be an interesting approach to take. This would allow households at risk of energy poverty to improve the energy efficiency of their homes without compromising other expenditures and contributing to the local economy.

3.3 Sub-question 3: Calculating Energy Poverty in Other Regions

In the event that a municipality would like to carry out the same approach for calculating energy poverty that was done in Paddepoel, the four-part approach devised by Nauta and Tamis and explained in section 3.1, should be implemented. The steps within each of these parts will differ in each region, so adaptations should be made where applicable. Stakeholder workshops were fundamental for determining which characteristics to focus on in Paddepoel, and this should be no different in any other region. Council members of a municipality should be advised to invite technical and finance experts in the field of energy and sustainability, as well as other involved stakeholders such as those from housing corporations, local business, infrastructure, etc. Together, they should decide on relevant characteristics that should be used for the study in their region and determine where to obtain this data from.

The decision tree in Figure 9 can be used as a tool during these stakeholder workshops to determine if certain determinants or cashflows should be used in the study region. Some determinants may be just a suitable in another city as they are in Paddepoel, while others may be less important in the energy conversation or not even exist in the new context.

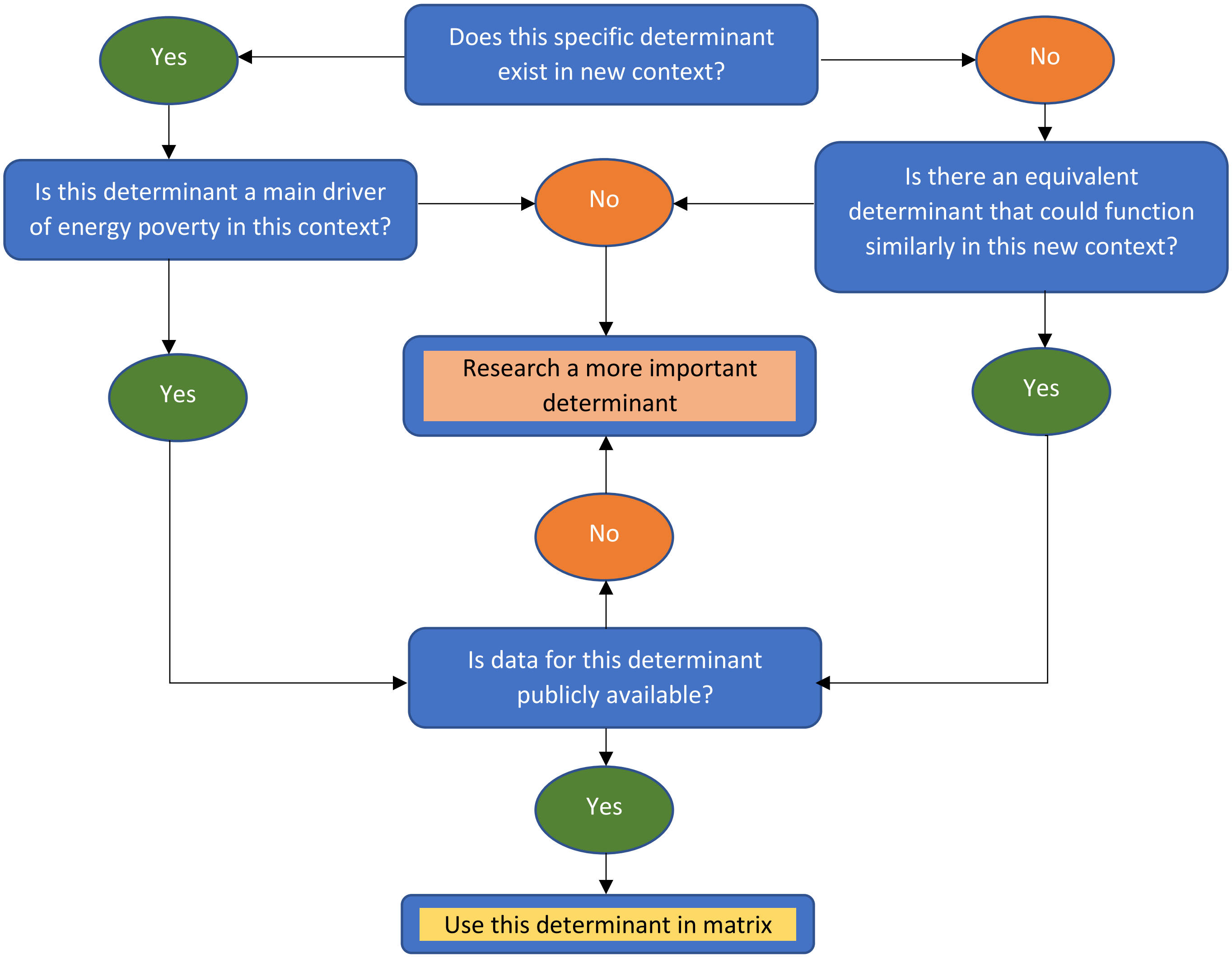


Figure 9: Decision Tree for Key Determinants of Energy Poverty

As an example, if the UFM model were to be introduced to a municipality in Ontario, Canada, some of the key indicators used in Paddepoel may still be valid. Income, for example, is a determinant that has been mentioned in many different studies for energy poverty in many different countries [3] [6] [7] [5], including Canada [20]. Therefore, this determinant does exist in the Canadian context and it is a main driver of energy poverty in Ontario. Data for individual household income may not be publicly available, but a similar approach using aggregate data could be a possibility to explore.

Energy label, however, is not a determinant that exists in the Canadian context. A similar determinant does exist that can be used instead, called EnerGuide. This metric scores households' energy efficiency on a scale of 1-100 based on a home evaluation and coaches residents on how to improve their score to become more energy efficient and save money [21]. Therefore, following the decision tree, the EnerGuide score could be used as a key determinant that replaces energy label in a Canadian context.

The third determinant used in the Paddepoel study is type of ownership. This determinant exists in Canada but is not necessarily a main driver of energy poverty. It could be used for this analysis, but the municipality should research other important factors that drive energy poverty in Ontario before making the final decision.

Once three determinants are decided, they can implement them into the risk profile matrix to determine the number of households at risk of energy poverty in their region.

This decision tree can also be used for deciding on which cashflows to analyse for part 4 of Nauta and Tamis' approach. While this may be a time-consuming task, it could be an effective way to organise cashflows and challenge the municipality to come up with alternative ones where applicable. For example, certain cashflows regarding taxes may be structured differently in a different country or even be different types of tax altogether. This approach allows the municipality to use the appropriate alternative to fit the context of their own city.

To answer the third sub-question, it is recommended that municipalities maintain strong stakeholder engagement throughout the implementation process and host regular workshops to discuss how the UFM model can be applied in their own cities. The decision tree in Figure 10 can be used as a tool for deciding which characteristics, determinants, and cashflows remain the same in their municipalities and which should be changed for something more relevant or impactful.

4. Discussion

The results of this study not only reaffirm that the energy transition has negative consequences for households who cannot afford to implement sustainable interventions, but it also indicates that this issue is expected to worsen overtime. The fact that none of the scenarios turned out to have a positive business case from the CBA that was conducted shows just how difficult it is for at-risk households to part-take in the energy transition, which is why it is so important for governments to take action.

4.1 Considerations and Limitations

One very important consideration to take away from this analysis is the fact that the “health and welfare” indicator was omitted from the analysis. There is extensive literature that exists stating that energy poverty has negative impacts on human health [6] [7] [5], but this literature does not yet quantify what that looks like in monetary terms. Because of this, the author did not feel that the data available was substantial enough to make any claims on the financial impact this would have on society. However, the literature that does exist is assurance that it is indeed, a very important indicator. If more data on this subject was available, and a societal business case were to be conducted, it is possible that the results would have been very different. That is why it is important that this be suggested for future research so that municipalities may see the true costs that energy poverty has on society.

The CBA also took a general approach and used a number of assumptions as discussed. One consequence of this is that the projections up to 2035 did not consider a change in price for the various proposed technologies. It is plausible that once these technologies (i.e.: electric heat pumps) scale up, their investment costs may go down. It would be interesting to see how the results of the CBA might differ if a proper analysis of future technology pricing was included.

Another assumption that was made during this analysis for scenarios 2, 4A and 4B is that all of the households at risk of energy poverty would install solar PV panels to their rooftops. This does not take into consideration housing types, such as apartments, that do not have rooftops to install solar PV. A solution to this that could be explored is the “postcode rose” project, where residents can rent rooftop space from other households within their postal code or neighbouring postal code to install solar panels if they do not have their own rooftops [22].

4.2 Recommendations for Municipality

Despite these elements not being included in the analysis, the municipality should not dismiss the proposed scenarios altogether simply because they do not have positive business cases. They may not be financially attractive scenarios at this point, but the following are positive impacts that arise from these technical interventions:

- By making households more efficient and in some cases producing their own electricity, there is less money leaving the municipality in the form of energy bills, which is one of the indicators that was important to the municipality of Groningen.
- Upgrading these houses makes the living environment more comfortable for residents, which can improve overall health and productivity. This can have subsequent positive impacts on the healthcare system and in the workplace.
- Upgrading homes to use less natural gas and produce renewable energy reduces carbon emissions and helps achieve Dutch climate targets.

For these reasons, the scenarios should still be considered. Future research on this topic could include an analysis on various financing schemes that have been implemented to help mitigate energy poverty in other countries. If residents have some assistance with the financial hurdles involved with making their homes more energy efficient, then municipalities should consider options to alleviate this burden. This might include low-interest loans for capital investments or subsidies for ongoing maintenance costs of the technologies. Other interesting options include co-investment in renewable energy projects, where residents can choose to invest in a portion of a solar or wind farm, for example, and in turn receive a discounted rate for their energy bills at home.

As discussed in section 3.2.2, scenario 2 would be interesting for the municipality to explore because it has the highest CBR and relatively low capital and operational costs compared to the other scenarios (barring scenario 1). Further research on financing schemes by TNO and NEC can act as a guide for the municipality of Groningen to implement the most suitable scheme that will help lift households out of energy poverty while making their homes more efficient. A financing scheme that alleviates some of the annual operational costs, such as subsidies, would be recommended in order to improve spendable income and money spent locally on a year-to-year basis. Meanwhile, a more generous scheme, such as a low-interest loan, would be suggested for some of the more burdensome upfront costs.

4.3 Suggestions for Future Research

The intention of using the UFM model to calculate the societal costs of energy poverty is so that it can capture costs across many different domains and not just the costs to the household in energy poverty. However, by not including health and welfare in this analysis, the results are preliminary, and further analysis is strongly recommended to produce more robust and insightful results. Therefore, it would be beneficial to the municipality if they collaborated with research institutes and universities, and not only with experts in energy poverty, but in public health as well. A thorough analysis on the monetary costs of energy poverty on the healthcare system will be invaluable to the continued research by TNO and NEC.

Another interesting piece that should be included in future studies is a carbon emissions analysis. This is a broad category, but monetising the impacts of a household's carbon footprint would likely increase the societal impact in this analysis – the question is by how much? Therefore, it is recommended that this be included in future societal business cases for sustainable interventions in Paddepoel, and could be interesting an interesting research topic for students with backgrounds in emissions modelling to explore.

Due to time constraints and the delay in the full development of the UFM model, the results for sub-question 3 regarding replication are very high-level and preliminary. Once the UFM model is complete and there is a better understanding of how the cashflow analysis works, it would be very interesting to test this model in another country so that a step-by-step user guide can be developed for municipalities to implement it around the world.

4.4 The Implications of COVID-19 for this Study

This study took place at the same time that the global coronavirus (COVID-19) pandemic substantially started to change the way people live, work, and recreate around the world. While this study did not include any elements related to COVID-19, it is estimated that this pandemic will have a major impact on energy poverty. Many people have been forced to work and study from home, meaning their household energy bills are very likely to increase. Moreover, many people were also unemployed due to the pandemic which, depending on the financial aid response by respective governments, will likely result in more households falling into the low-income bracket as the pandemic progresses. With the combination of higher energy bills and more people earning low-income, it is hypothesised that the number of households in energy poverty would be much greater if this was included in the analysis. This would be another interesting topic to explore in future research, once more data on these patterns becomes available.

5. Conclusions

In summary, this paper analysed the use of the UFM model in its beginning stage to identify approximately how many households are high risk of energy poverty between 2020 and 2035 in the neighbourhood of Paddepoel. It also addressed the societal impacts that this energy poverty has on household spendable income, money spent locally, and money leaving the municipality, and proposed a number of different scenarios for technical interventions to undergo a CBA. This CBA found that none of the proposed scenarios yielded a positive business case, nor did they have any meaningful impact on spendable income or money spent locally, but they did reduce the amount of money leaving the municipality, which was one of the impact indicators that the municipality was interested in. Finally, it gave a high-level analysis of how this model might be used in another country, but more research must be done before it is ready to be fully replicated elsewhere.

The main research question for this study was:

“How can the preliminary stage of the Urban Financial Metabolism (UFM) model be used to stimulate sustainable investments within a municipality or neighbourhood and create a more inclusive energy transition, which mitigates the risk of energy poverty?”

This question was answered by demonstrating how the impacts of energy poverty extend beyond just the household itself. By highlighting the impacts that this issue has on the local economy as well, this helps to stimulate sustainable investments by incentivising the municipality to take action that will positively impact society as a whole. It brings awareness to the reach of energy poverty and highlights the urgency of doing something about it. In the later stages of the UFM model, it is also expected to reveal “win-win” opportunities amongst stakeholders across domains so they, too, can benefit from a more inclusive energy transition.

This study adds value to existing research because it uses a holistic approach to identify the impacts of energy poverty. However, certain limitations must be addressed in future research to make these findings more robust and reflective of the impact that energy poverty has on health and welfare. For now, recommendations for future research on this topic, as well as on carbon emission projections, financing schemes, and replicability were all discussed to help TNO, NEC, and the municipality of Groningen move forward with addressing the issue of energy poverty in Paddepoel.

6. References

[1] H. Thomson and S. Bouzarovski, “Addressing Energy Poverty in the European Union: State of Play and Action,” *European Commission,* pp. 1-54, 2018.

[2] European Commission, “Energy: Introduction,” [Online]. Available: https://ec.europa.eu/energy/content/introduction-5_en. [Accessed July 2020].

[3] European Commission, “Energy Poverty,” [Online]. Available: https://ec.europa.eu/energy/eu-buildings-factsheets-topics-tree/energy-poverty_en?redir=1. [Accessed July 2020].

[4] R. Holdsworth-Morris, “Energy Poverty on the Map: Assessing the Suitability of Energy Poverty Indicators for use in Local Area-Based Targeting of Policies in Amsterdam,” Amsterdam, 2020.

[5] S. Pye, A. Dobbins, C. Baffert, J. Brajkovic, P. Deane and R. De Miglio, “Addressing Energy Poverty and Vulnerable Consumers in the Energy Sector Across the EU,” *L'Europe en Form,* vol. 378, no. 4, p. 64, 2015.

[6] S. Jessel, S. Sawyer and D. Hernandez, “Energy, Poverty, and Health in Climate Change: A Comprehensive Review of an Emerging Literature,” *Frontiers in Public Health,* vol. 7, 2019.

[7] M. Santamouris, “Chapter 5 - Defining the Synergies Between Energy Consumption–Local Climate Change and Energy Poverty,” in *Minimizing Energy Consumption, Energy Poverty and Global and Local Climate Change in the Built Environment: Innovating to Zero,* Sydney, AU, Candice Janco, 2019, pp. 169-194.

[8] Making City, “Making City Groningen,” 2020. [Online]. Available: http://makingcity.eu/groningen/.

[9] Naiontaal Programma : Regionale Energie Strategie, “RES Region Groningen,” 2019. [Online]. Available: https://www.regionale-energiestrategie.nl/res+regio+groningen/default.aspx.

[10] P. Tamis, Interviewee, *Ongoing Consultation re: Urban Financial Metabolism and Energy Poverty with Philo Tamis.* [Interview]. 2020.

[11] A. Woestenburg and H. Puts, “D6.8_ RESIN District Financial Metabolism _TNO_2018-10-31,” 2018.

[12] A. Woestenburg, H. Puts and A. Gavrilova, “Urban Financial Metabolism: 4.1.2 Flagship: SSD_UFL_Guidelines and Final Report,” The Hague, 2018.

[13] E. van den Ende, “A revolution: The Netherlands kisses gas goodbye - but will it help the climate?,” Energy Post EU, 07 June 2017. [Online]. Available: https://energypost.eu/a-revolution-the-netherlands-kisses-gas-goodbye-but-will-it-help-the-climate/. [Accessed 24 November 2020].

[14] K. Leidelmeijer, R. de Wildt, Borsboom and M. van Vliet, *Energy Leap Modelling: Costs of making homes more sustainable,* 2017.

[15] Gemeente Groningen, *Neighbourhood Vision: Aardgasvirj Paddepoel,* Groningen, 2019.

[16] IRENA, “Hydrogen from Renewable Power: Technology Outlook for the Energy Transition,” 2018. [Online].

[17] E. Bellini, “Netherlands PV market expanded by 46% in 2018,” PV Magazine, 30 January 2019. [Online]. Available: https://www.pv-magazine.com/2019/01/30/netherlands-pv-market-expanded-by-46-in-2018/. [Accessed 24 November 2020].

[18] Milieu Centraal, “Subsidy for Heat Pumps,” [Online]. Available: https://www.milieucentraal.nl/energie-besparen/energiezuinig-huis/financiering-energie-besparen/subsidie-warmtepompen/.

[19] R. Nordman, M. Lindahl, K. Andersson, M. Miara, M. Ceovet, O. Kleefkens, W. Planje, A. Zottl, O. Polyzou, A. Benou and C. Karytsas, “D2.1 Survey of completed and ongoing field measurements of heat pumps with hydronic heating systems,” 2012.

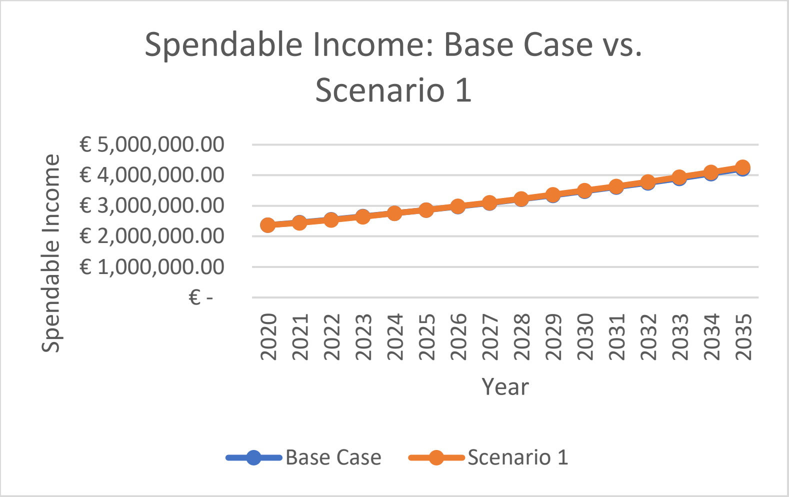
[20] Homeless Hub, “Poverty Hub,” 2016. [Online]. Available: https://www.homelesshub.ca/povertyhub/basic-needs/energy-poverty.

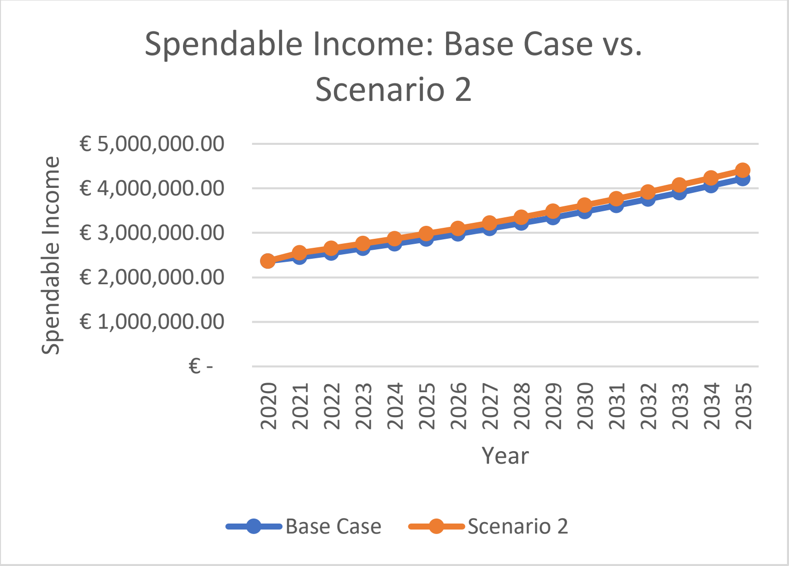
[21] Government of Canada, “EnerGuide energy efficiency home evaluations,” 10 March 2020. [Online]. Available: https://www.nrcan.gc.ca/energy-efficiency/energuide-canada/energuide-energy-efficiency-home-evaluations/20552.

[22] Canadian Urban Sustainability Practicioners Network, “Equity Implications of Energy Poverty in Canada: A preliminary analysis of energy poverty trends in racialized, recent immigrant, and Indigenous households using the Energy Poverty and Equity Explorer,” 2019.

7. Annex

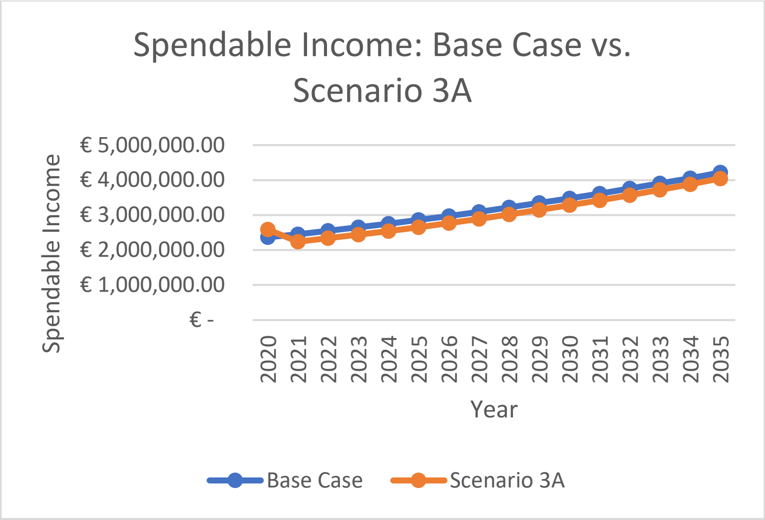
Annex 7.1: Spendable Income of Scenarios vs. “Cost of Doing Nothing”[1]

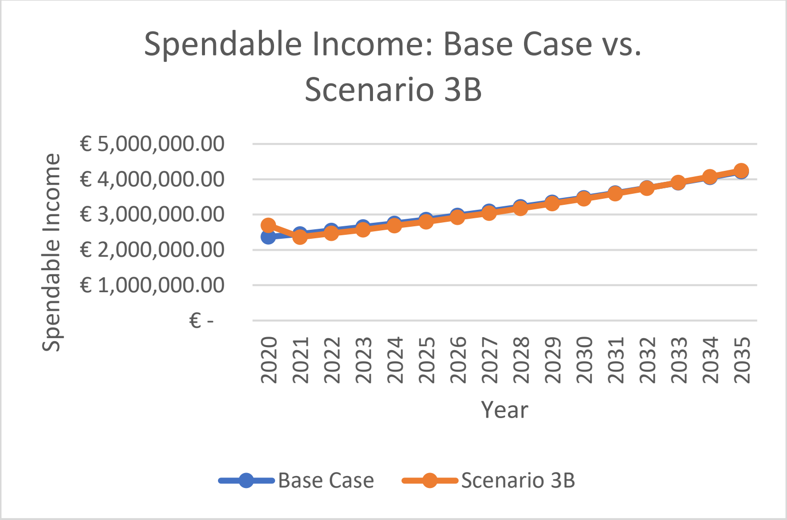


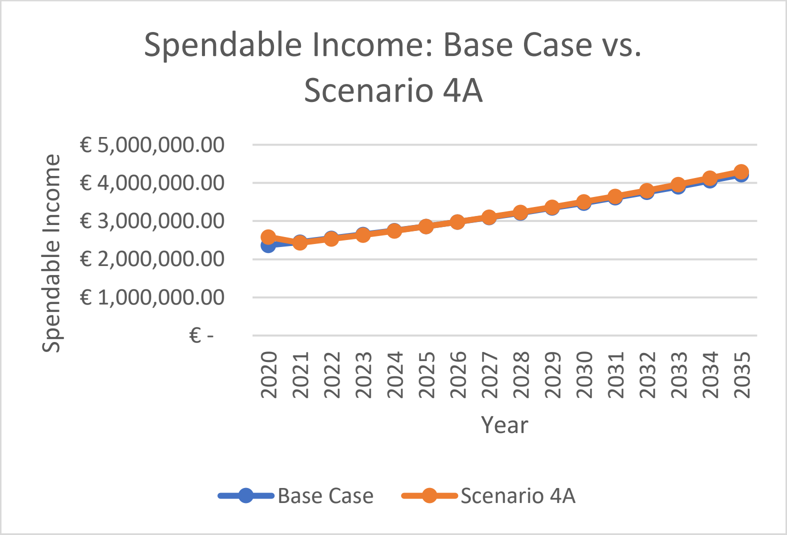


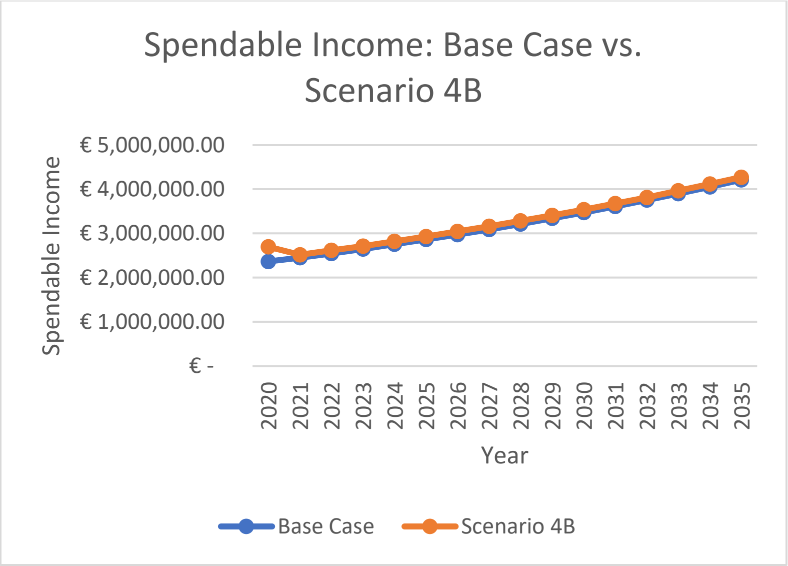
---

[1] The results for “Money spent locally” are identical to the results for “spendable income”, therefore, the graphs would be the same.


Spendable Income: Base Case vs. Scenario 3A
Spendable Income
€ 5,000,000.00
€ 4,000,000.00
€ 3,000,000.00
€ 2,000,000.00
€ 1,000,000.00
€ -
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
Year
Base Case
Scenario 3A


Spendable Income: Base Case vs. Scenario 3B
Spendable Income
€ 5,000,000.00
€ 4,000,000.00
€ 3,000,000.00
€ 2,000,000.00
€ 1,000,000.00
€ -
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
Year
Base Case
Scenario 3B


Spendable Income: Base Case vs. Scenario 4A
Spendable Income
€ 5,000,000.00
€ 4,000,000.00
€ 3,000,000.00
€ 2,000,000.00
€ 1,000,000.00
€ -
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
Year
Base Case
Scenario 4A


Spendable Income: Base Case vs. Scenario 4B
Spendable Income
€ 5,000,000.00
€ 4,000,000.00
€ 3,000,000.00
€ 2,000,000.00
€ 1,000,000.00
€ -
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
Year
Base Case
Scenario 4B