Smart energy solutions for Anand Jyoti

A feasibility study of different pathways towards a sustainable energy community

Course: Transdisciplinary case study - GEO4 2302
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Executive summary

By signing the 2015 Paris climate accords, the Netherlands have committed to drastically reduce greenhouse gas emissions, by up to 80-90% by 2050. This will require an energy transition, in which patterns of energy use are altered, and dependence on fossil fuels is reduced. At the same time, Dutch society is becoming increasingly participatory; civilians are expected to bear some responsibility in solving societal problems. These two concurrent trends suggest that small-scale, local initiatives will play a large role in achieving the Netherlands' climate goals.

The Anand Jyoti community is an example of such a small-scale, local initiative. The Anand Jyoti residential complex is situated in Amsterdam's Holendrecht municipality and is home to 24 households of Hindustani elders (i.e. over 50 years of age). Additionally, there is a large communal area where the inhabitants frequently cook together and organize communal activities. A social analysis, based on individual interviews and group discussions, revealed that the residents have a strong sense of community and are willing to work together towards making their residence more sustainable in terms of energy.

In this report, a variety of options have been considered that may allow the community to do so. According to the Trias Energetica concept, energy sustainability options can be categorized in three broad groups. In descending order of preference these are: 1) reducing energy demand; 2) replacing fossil fuels with renewable sources of energy; 3) use fossil fuel where necessary, but as efficiently as possible. Different energy sustainability options were selected to represent all categories of the Trias Energetica. In the first category, energy-saving options were considered in the form of improving (heat) insulation of the housing complex, and also replacing old lamps with LED lights. For the second category, various technologies that generate renewable energy on a residential scale were examined. These included three options utilizing solar energy; photovoltaic panels that convert light into electricity, solar boilers that use thermal energy to generate hot water, and hybrid PVT panels that combine the two. The fourth renewable energy option was the Biomeiler, a structure that harnesses the heat released during composting organic material to generate hot water. For category three, heat pumps were investigated. Heat pumps provide a very efficient way of heating a house by transferring heat energy from a cold environment to a warmer one (i.e. from outside to inside the building) by using mechanical energy, but consume electricity in order to do so. They may be used as a stand-alone feature, or combined with an existing boiler. The impacts of these options were considered for low-energy households, high-energy households, the communal area, or all of the above.

Each of the options was evaluated by 5 criteria: technical feasibility, economic desirability, environmental impact, social desirability and legislative feasibility. Bar legislative feasibility, each of those criteria was graded on the basis of one or various indicators. These indicators were then compared across all options to assign each sustainability option with a 1 to 5 score for every criterion. The relative importance of each of each criterion has been based on interviews with Anand Jyoti's residents; the criteria deemed more important by them carried more weight in the final verdict. This process resulted in a final overall score for each technology that indicated how suitable it would be for implementation at the Anand Jyoti residential complex.

Rather than simply selecting the option with the highest score, various possible pathways (i.e. combinations of options with high scores) were formulated, along with an indication of the associated costs, savings and environmental impacts.

Our analysis revealed that solar panels were overall the best option for the Anand Jyoti residential complex. These could easily be combined with LED-lighting, in order to use the generated electricity more sparingly. In addition, either a heat pump could be installed to heat the communal area (it could run, in part, on electricity generated by the panels), or a Biomeiler could be built to do so instead. While the end-result is a solution tailored specifically to the Anand Jyoti community, our methodological framework is suited for evaluating sustainability options for similar, small residential communities.

Samenvatting

Met het tekenen van het klimaatverdrag in Parijs, heeft Nederland zich toegewijd aan het fors verminderen van de uitstoot van broeikasgassen; een vermindering van 80-90% tegen 2050. Dit vereist een energietransitie; een verandering in patronen van energieverbruik alsmede een verminderde afhankelijkheid van fossiele brandstoffen. Tegelijkertijd wordt Nederland een participatiesamenleving, waarin een grotere bijdrage van burgers verwacht wordt voor het oplossen van maatschappelijke problemen. Samen bekeken suggereren deze trends dat kleinschalige, lokale initiatieven een belangrijke rol zullen spelen om de Nederlandse klimaatdoelen te verwezenlijken.

De Anand Jyoti-gemeenschap is een voorbeeld van een dergelijk lokaal, kleinschalig initiatief. Anand Jyoti is een wooncomplex voor Hindoestaanse 50-plussers met 24 individuele huishoudens in de Amsterdamse gemeente Holendrecht. Er is een grote gemeenschappelijke ruimte waar de bewoners dikwijls samen koken en allerlei gemeenschappelijke activiteiten organiseren. Een sociale analyse, gebaseerd op individuele interviews alsmede groepsdiscussie, liet blijken dat de bewoners van Anand Jyoti een sterke gemeenschapszin hebben, welke ze ook zouden willen toepassen op het verduurzamen van het energieverbruik van hun wooncomplex. De bewoners wilden graag weten welke opties het meest geschikt zijn voor hun situatie.

In dit verslag zijn verscheidene mogelijkheden onderzocht om deze vraag te beantwoorden. Volgens het Trias Energetica-concept vallen de opties voor het verduurzamen van energiegebruik van gebouwen in 3 brede categorieën, in afnemende volgorde van voorkeur: 1) het energieverbruik verminderen; 2) fossiele energie vervangen met hernieuwbare energie; 3) waar nodig, fossiele brandstoffen zo efficiënt mogelijk gebruiken. Hier zijn verschillende opties uitgekozen om elke categorie van de Trias Energetica te vertegenwoordigen. In de eerste categorie is er gekeken naar opties die het energieverbruik van de bewoners zou verminderen, middels verbeterde isolatie alsmede het vervangen van de huidige lampen door LED-lampen. Voor de tweede categorie zijn verschillende technologieën in beschouwing genomen die op kleine schaal hernieuwbare energie opwekken. Drie van deze technologieën benutten de energie van de zon: photovoltaische panelen zetten licht om in elektriciteit, de zonneboiler gebruikt thermische zonne-energie om water op te warmen, en de hybride PVT-panelen combineren de twee. Een vierde optie om hernieuwbare energie op te wekken was de Biomeiler, een met houtsnippers gevulde structuur die de hitte die vrijkomt bij het composteringsproces gebruikt om water te verwarmen. Voor de derde categorie werden hittepompen overwogen. Hittepompen zijn een zeer efficiënte manier om een woning te verwarmen; ze gebruiken mechanische energie om hitte van een koudere naar een warmere omgeving (zeg maar; van buiten naar binnen) te verplaatsen, maar verbruiken elektriciteit om dit te kunnen doen. Een hittepomp kan ofwel op zichzelf staan, ofwel gecombineerd worden met een bestaande boiler. De uitwerking van deze opties werd gekwantificeerd voor huishoudens met een laag energieverbruik, huishoudens met een hoog energieverbruik, de gemeenschappelijke ruimte, of al het bovenstaande.

Elke optie werd geëvalueerd aan de hand van 5 criteria: technische haalbaarheid, economische wenselijkheid, impact op het milieu, sociale wenselijkheid en juridische haalbaarheid. Met de uitzondering van juridische haalbaarheid werd elk criterium getoetst aan de hand van een of meerdere indicatoren. Deze indicatoren werden vervolgens over alle opties vergeleken, waarna elke optie voor elk van de 5 criteria een score van 1 tot 5 kreeg toegewezen. De weging van de criteria is gebaseerd op interviews met de bewoners van Anand Jyoti; de criteria die zij belangrijk achten

werden zwaarder meegewogen in het uiteindelijke oordeel. Dit proces resulteerde in een eindscore voor elke optie, die aantoont hoe toepasselijk en wenselijk de optie is voor Anand Jyoti. In plaats van de zomaar de optie met de hoogste score aan te raden, werden ook verschillende combinaties van opties geformuleerd, alsmede de daarmee samengaande kosten en baten.

Uit onze analyse bleek dat zonnepanelen over het algemeen de beste optie waren voor het Anand Jyoti wooncomplex. Zonnepanelen zouden echter gemakkelijk gecombineerd kunnen worden met het installeren van LED-lampen, opdat de door de zon opgewekte elektriciteit spaarzamer gebruikt wordt. Daarnaast zou een hittepomp geplaatst kunnen worden in de gemeenschappelijke ruimte (deze zou dan door de zon opgewekte elektriciteit kunnen gebruiken) om deze te verwarmen, of een Biomeiler zou voor dat doeleind gebouwd kunnen worden. Het eindresultaat van dit verslag is een oplossing specifiek voor het Anand Jyoti wooncomplex. Desalniettemin zou de gebruikte methodologie ook kunnen worden toegepast op soortgelijke, kleine woongemeenschappen die hun woonomgeving wensen te verduurzamen.

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1. Introduction

The vast majority of energy production and consumption in the Netherlands relies on finite, fossil fuels, which produce a large share of greenhouse gas (GHG) emissions. For a sustainable future, a transition towards renewable and sustainable energy is necessary (Boon and Dieperink, 2014). By signing the Paris climate agreement in 2015, the Dutch government has agreed to reduce the amount of GHG emissions by 20% in 2020 and by 80-90% in 2050. In this energy transition, local initiatives are considered essential for reaching these goals (Ministry of Infrastructure and Environment, 2011).

The aimed energy transition takes place in a context where a move from a top-down organized welfare state towards a more participative society ('participatiesamenleving') is taking place in the Netherlands, where public services (such as healthcare) are increasingly being decentralized (Putters, 2014). It is in this context that the residential community of 33 Hindustani elders, Anand Jyoti, located in neighbourhood Holendrecht in the Southeast of Amsterdam as from the 1990s, is willing to take initiative considering a shift towards their own independent sustainable energy production and consumption. Recently, the residents of Anand Jyoti have indicated to be open to the challenge of sustainable energy for their communal space and individual houses, with the possibility of sharing a surplus of energy with the neighbours in the direct environment in the project 'Anand Jyoti BIEDT buurtwarmte' as part of wider cooperative SAMENredzaam.

The residents have consulted our team to research the possible pathways for creating a (more) energy sustainable community in the near future. Therefore, this research aims at performing a transdisciplinary analysis on different potential sustainable energy solutions for Anand Jyoti. It also serves as a case study for potential technologies for such residential communities as part of the wider transition towards sustainable energy consumption in the Netherlands on a local, bottom-up level. The main question of this research is:

Which pathways are feasible for making the Anand Jyoti community more energy sustainable?

Different types of strategies can be applied in order to locally produce renewable energy, while also reducing energy demand from external (often fossil-based) energy sources. In this report, four types of technologies are analyzed, using the structure of 'Trias Energetica', a three-step framework developed by Duijvenstein (1993) in order to rank measures for sustainable housing construction. In this model, the most favorable measures are placed in step one, which consist out of the reduction of energy demand (Entrop, 2010). In this report, several energy savings methods are assessed; insulation and LED lights. The second step in the model is to produce renewable energy sources instead of using external fossil sources. In this regard technologies based on solar power are examined; solar panels, solar boilers and PVT panels. Another renewable energy source considered in this report is biomass and the corresponding technology that is examined is the Biomeiler. The third step is to produce and use (fossil) energy as efficiently as possible. In this step, three types of heat pumps are elaborated; air sourced heat pumps, hybrid heat pumps and ground source heat pumps.

In order to assess the feasibility of these technologies in a transdisciplinary manner, five interrelated elements are taken into account: technical, environmental, economic, legislative and social. In order to emphasize the desire of the residents as it considers a bottom-up project, the social desirability score (which incorporates technical, environmental, and economic elements to the extent the residents find these important) indicates the feasibility of each technology. The feasibility analysis is carried out on two different levels: community level and individual level. On the community level, technological propositions for sustainable energy production and consumption for the communal space are included. On the individual level, technological propositions for the individual residential units is analyzed both for households with high and low energy demand. A combination of the above mentioned technologies is made in order to create the most feasible pathways for the residents of Anand Jyoti.

In the next chapter, the conceptual framework of this report are elaborated. Here, the concepts of sustainable development, Trias Energetica and the feasibility criteria are explained. In the third chapter, the baseline situation is described, based on the five feasibility criteria. The results of the analysis of the technologies is compared with the baseline situation. Next, in the fourth chapter - Reducing energy demand - the results of the energy savings methods are presented. In chapter five - Renewable energy supply - the results of the technologies based on solar power and biomass are explained. Then, in the sixth chapter - Efficient energy supply - the results of the analysis of the heat pumps are presented. In the seventh chapter, a combination is made of the most feasible pathways for respectively the communal and individual areas is presented. In the final chapter, propositions are made for the community Anand Jyoti, describing the future steps that have to be taken in order to achieve the most feasible pathway according to our analysis, followed by a discussion and conclusion.

2. Conceptual framework

2.1 Sustainable Development

In order to develop a methodological framework for researching this case study, the basic concepts need to be defined. First and foremost, the term sustainability needs to be defined as this term is used in the research question posed. According to Brundtland (1987) sustainable development is *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*. The present need of the Anand Jyoti community is to reduce their dependency on fossil fuels. Currently the majority of the warm water and electricity that is used by the residents of Anand Jyoti is produced through fossil fuels. Being aware of the environmental problems associated with burning fossil fuels, the residents want to switch to more sustainable patterns of energy use for their communal space as well as their individual houses. Moreover, the residents have expressed a great willingness to not be dependent on third parties for their warm water and electricity supply. They are motivated to be as self-sufficient as possible while reducing their impact on the environment so that future generations will live in a more sustainable world.

There are different possible technological options and behavioural strategies that can help the Anand Jyoti in becoming a more sustainable energy community. A framework, named the Trias Energetica, is a three step design to make buildings sustainable in term of energy production and consumption. This framework is explained in the next section of this chapter.

2.2 Trias Energetica

As mentioned above, the majority of the heat and electricity in the residential community of Anand Jyoti is generated by fossil fuels which are finite and polluting sources of energy. However, different types of strategies can be applied for the reduction of both the energy demand and fossil-based energy supply (Rafindadi et al., 2014; CBS, 2014). In order to analyse the technological solutions, it is important to apply a sound strategy and to take into consideration the combinations of the different measures. For example, a building without insulation requires more heat and thus a bigger heat pump or more solar panels. This can be inefficient in terms of costs and energy (Rijksdienst voor Ondernemend Nederland, 2013). In order to take such inefficiency into account, the framework of 'Trias Energetica' is used. Duijvenstein (1993) has introduced this three-step scheme to rank measures for sustainable housing construction. The most favorable measures are part of the first step and the least favorable measures form the last step (Entrop, 2010). These steps range from energy reduction, to renewable energy production and energy efficiency and are described in the figure below.

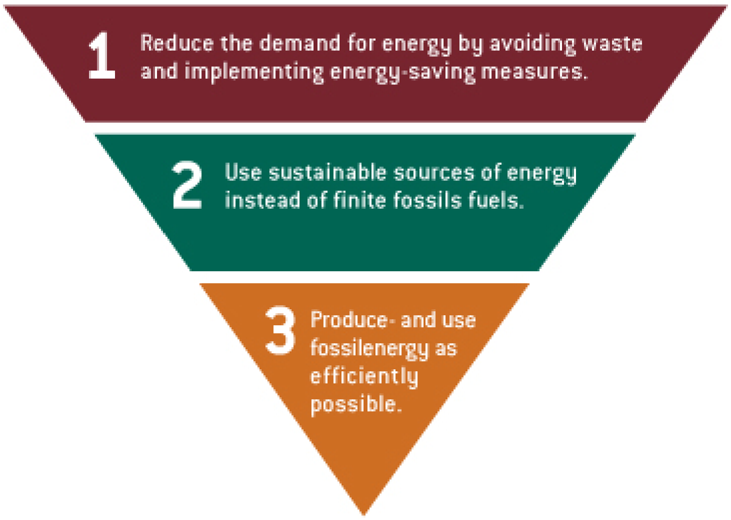


Figure 1. Trias Energetica (source: Euremia, 2011)

Various technologies can be applied in order to make the residential community Anand Jyoti more energy sustainable. The technologies that are elaborated in this report have been selected based on the above mentioned framework and on the criteria of customer accessibility, obtainability, and presumed technical achievability. Hereby, only the most widely applied private energy technologies (in densely populated areas like Amsterdam) and successful examples from other neighborhoods were considered (Rijksoverheid, 2016; Gemeente Amsterdam, 2011). In addition, orientation meetings and discussions with the residents were held in order to identify their personal preferences, thresholds and boundaries. On the basis of this, it has been determined which technologies could be excluded, considering these to be socially undesirable or technically problematic. Moreover, technologies that have already proven its value elsewhere have been preferred during the selection process. This has finally resulted in a selection of most desirable technologies ready to be analyzed and investigated further, in order to assess an ideal pathway for sustainable energy for the residential community. Following the structure of the Trias Energetica model, the selected technologies are elaborated below.

1. Reduction of energy demand

There are different strategies of energy-saving measures that reduce energy demand, such as technical improvements, different use of products, and shifts in consumption. According to Poortinga et al (2003), technical improvements are often more efficient over behavioural measures and especially the change of consumption depending on the year a building was built. However, as a consequence of the improved quality of the insulation of buildings due to energy regulations, the final energy use associated with building characteristics is decreasing, making the impact of the behavior of the occupant more important (Santin et al., 2009). Santin et al therefore concluded that behavior regarding energy consumption in households increasingly plays a significant role. Their study on the effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock, determined that the behavior accounted for 4,2% of the energy use. This shows that the behavior of Dutch residents indeed play a role in the energy consumption. However, the extend of this behavioural influence is not studied into quantitative detail, because it is for the timespan of this research difficult to isolate behavioural effects on energy consumption from the variety of effects on the apartments in Anand Jyoti such as the sun heating up some houses more than others, the different elevation levels (ground, first and second floor), and in-between or corner apartments. To get a qualitative indication however, the current energy consumptive behaviour and flexibility therein to change, hence to reduce energy demand, is studied.

The potential of reduction in energy demand through technological implementations is analyzed, focusing on the following two energy saving techniques:

- Thermal insulation: techniques used to reduce the rate of heat transfer.
- Change to LED lights: highest energy efficiency class for high-energy consumptive lights.

2. Renewable energy production

Two types of renewable energy sources are taken into account; solar power and biomass. The following technologies are analyzed:

Solar power:

- PV panels
- Solar boiler
- PVT panels

Biomass:

- Biomeiler: a system that can harness the energy present in discarded plant material.

3. Efficient energy supply

Finally, it is useful to consider measures for the most efficient and effective way of energy use. The following technologies are included:

- Air sourced heat pump
- Ground sourced heat pump
- Hybrid heat pump

Moreover, here the option of changing to a green energy provider is examined too. This is not a more efficient way of fossil energy use, it can however be seen as more efficient in terms of CO_2 emissions of energy. The Trias Energetica model serves as a framework for the analysis of the above mentioned techniques. In the following methodological chapter, the criteria and their respective indicators are elaborated on which these techniques are assessed.

3. Methodological framework

In order to have a clear picture about which technology or combination of technologies is most feasible for the Anand Jyoti community, this chapter elaborates upon the methodological approach. Boon and Dieperink (2014) have identified five elements (i.e. technical, environmental, economic, legislative and social) that are important to take into account when establishing local renewable energy initiatives. As the Anand Jyoti community is aiming for such a local renewable energy initiative, these elements have been chosen to be the most relevant to take into account.

First, in this chapter is clarified how these five elements - from now on called criteria - are methodologically determined. Accordingly, five sub-questions have been formulated (sections 3.1-3.5). In each section below is clarified how each criterion is determined by using several indicators. For each indicator it is specified how they are calculated so that this study is transparent in its scoring process and replicable for other communities who wish to achieve a similar sustainability transition. As this case study is conducted in a transdisciplinary manner, both qualitative and quantitative indicators are used. Hence, the data that is collected and analysed is both quantitative and qualitative. The criteria determined by quantitative indicators - economic, environmental, technical - are complemented with a social criterion determined with qualitative indicators. Finally, the scoring process for final desirability of each proposed technology is described (3.6). Second, the methodological process of integrating the most desirable technologies into the most feasible pathways is described (3.7). Third and finally, the methodological framework described in this chapter is summarized into a flow chart (3.8).

3.1 Feasibility from a technological perspective

To what extent are the technologies feasible from a technological perspective?

First, the technical feasibility of each proposed technology is assessed. All the technologies undergo a technological assessment to determine what technical adjustments need to be made for the implementation and maintenance of the technology. For each technology, an interpretation and explanation of the technical issues, relevant for the implementation process, is given (e.g. cable routes, technical integration in the meter box). For this, it is important to make an assessment of the difficulties and constraints concerning the technology. Furthermore, it must be determined what type of technology brand has the highest price/quality (power) ratio and can be taken as default for further calculations. Subsequently, an evaluation can be made according to these components, by appointing a score in terms of technical feasibility. Because the technologies considered compose dissimilar issues, we use time for installation and upkeep (or ‘work’) as a measure of technical feasibility. Specifically, we use the total number of hours worked required for saving 1000 kWh of primary energy. Each technology is assigned a score ranging from 1 to 5. Three of such scores are given for each technology, based on communal, high and low individual usage. The scores are based on the scale presented below:

Score	Hours/1000 kWh saved
1	4+
2	3-4
3	2-3
4	1-2
5	0-1

Table 1. Technological scoring scale

3.2 Desirability from an environmental impact perspective

To what extent are the technologies desirable from an environmental impact perspective?

Secondly, the environmental impact of each of the technological solutions is assessed. Human interference with the climate system, of which greenhouse gas emissions is the largest contributor, causes high risks for all natural systems and thus humans (IPCC, 2014). Reducing emissions is necessary to mitigate potentially harmful consequences. Of all CO_2 emissions, 42% are caused by electricity and heat production (IEA, 2015). The environmental impact of the current energy use in Anand Jyoti will therefore be conceptualized through the amount of CO_2 that is emitted because of the energy use. Moreover, the amount of primary energy use is taken into account, however is not used to compare as environmental consequences (i.e. CO_2 reduction) for energy savings is dependent on how the energy is produced.

CO_2 reduction is calculated both from the communal energy use and the average individual energy use. Because the communal area and all but one of the households use ‘grey’ electricity the emission factor of Dutch ‘grey’ electricity is used to calculate how much CO_2 can be reduced by implementing each of the technologies. As a general rule, 1 kWh of electrical energy releases about 0,526 kg of CO_2 (CO2emissiefactoren, 2015). The efficiency of the total Dutch electricity mix production is assumed to be 45% (CBS, 2012). This means that for every kWh electricity produced, 2,22 kWh of primary energy is used. Burning gas directly releases 1,88 kg of CO_2/m^3 on average (CO2emissiefactoren, 2016). For the substituting technologies, the CO_2 emissions reductions are calculated based on the same electricity use and heat supply as in the baseline.

For the energy savings technologies the CO_2 emissions are based on the savings on electricity and heat supply while maintaining an acceptable level of comfort. The amount of primary energy use is calculated using the amounts of kWh electricity and m^3 gas consumed by the residents derived from energy bills. It is assumed that 1 m^3 of gas has a net caloric value of 31,65 MJ/M^3 and the gas boiler has an efficiency of 108% when used for heating purposes and 88% for tap water heating (Intergas-verwarming, 2016). In an average household 72% of the gas is used for space heating and 23% for tap water heating, the rest is used for cooking (RVO, 2016b). In the communal area we assume 95% is used for space heating and 5% for tap water as it is a large space that needs to be heated and water is not excessively used. The assumptions for energy use and CO_2 emissions which are only relevant for a specific technology are discussed within the section of the specific option. Based on this, each technology is assigned a score ranging from 1 to 5. Three of such scores are given for each technology, based on communal, high and low individual usage. The classification for each environmental score is displayed below (low and high energy demand scenarios are merged as CO_2 emissions are similar):

Score	**Communal** In kg CO_2/year saved	**Individual: low and high energy demand** In kg CO_2/year saved
1	0-700	0-100
2	700-1400	100-200
3	1400-2100	200-300
4	2100-2800	300-400
5	2800+	400+

Table 2. Environmental scoring scale

3.3 Viability from an economic perspective

To what extent are the technologies viable from an economic perspective?

Thirdly, the costs and benefits of the technological solutions are considered in the economic viability. It is necessary to know what the costs and benefits of the different technological solutions are (Boon & Dieperink, 2014). To see whether an investment is profitable over a certain lifetime, a discount rate must be included in the costs and benefits analysis of a project. It is called the net present value (NPV) of a new implemented technology (Blok, 2007).

Net Present Value (NPV) > 0 (source)

$$NPV = - I + (B-C) / \alpha$$

where:

I = Initial investment
B = Benefits (annual)
C = Costs (annual, excluding capital costs)
α = capital recovery factor (annuity factor)

$\alpha = r / (1 - (1+ r)^{-L})$ for calculating the annuity factor

r = discount rate
L = lifetime of the technology

When considering one of these investments one must keep in mind that the net present value is an absolute number and when positive, is profitable over the expected lifetime. However, it does not provide much information about the project's profits in relation to the initial investment. Therefore, this paper also provides the pay-back-period (PBP) of the considered technologies in order to indicate how profitable a technology is (Blok, 2007).

Pay Back Period (PBP) < lifetime (source)

$$PBP = I / (B - C)$$

where:

I = Initial investment
B = Benefits (annual)
C = Costs (annual, excluding capital costs)

The PBP is seen as of great importance, especially considering the average age of the Anand Jyoti residents. Considering the income level and financial situation of the residents chances are high no large personal investments can be made, the Amsterdam Sustainable Energy Loan are used to cover the investments where possible. To be able to measure the difference in costs of the heat and electricity from the new technologies compared to the costs of the current situation, the costs per year are calculated. In the comparison of technologies we leave out the potential loan and because loan structures will differ per technology and not all technology need a loan for investment(e.g. LED lights). Technologies will thus be compared on the basis of the yearly costs savings over the lifetime of the technology. This is done according to the following formula;

Yearly costs savings over the lifetime (Blok, 2007, p.295).

Cost savings (p.area.p.y.) = α * I + annual costs heat/electricity - annual benefits

The current variable energy price is used for the calculation of annual costs and benefits. This average price is derived from energy bills of the residents and amounts 0,065 euro/kWh for electricity and 0,30 euro/m3 natural gas. The tax is based on the 2016 energy tax as set by the Dutch government and amounts 0,122 euro/kWh electricity and 0,305 euro/m3 natural gas (Rijksoverheid, 2015). This comes to a total of 0,187 euro/kWh and 0,605 euro/m3.

Based on the yearly savings over lifetime, each technology is assigned a score ranging from 1 to 5, based on the scales presented below:

Score	**Communal** Yearly savings over lifetime	**Individual: low and high energy demand** Yearly savings over lifetime
1	Not feasible	Not feasible
2	0 - 250	0 - 20
3	250 - 500	20 - 40
4	500 - 750	40 - 60
5	750+	60+

Table 3. Economic scoring

3.4 Feasibility from a legislative perspective

To what extent are the technologies feasible from a legislative perspective?

Fourth, the Dutch legislation needs to be investigated concerning the technological solutions to figure out what the barriers and opportunities are for implementation (Allen, Hammond, & McManus, 2008). The legislative issues connected to the implementation of the different technologies is briefly pointed out. No score is connected to legal feasibility, as this considers a decision based on legal restrictions: each option will receive a *go* (if there are no legal restrictions), *preconditions* (when some legal adjustments have to be made) or a *no go* (if there are legal restrictions).

3.5 Desirability from a social perspective

To what extent are the technologies desirable from a social perspective?

Fifth, it is important to take into account the social desirability of the proposed technologies. In order for a local sustainable energy project to succeed, substantial involvement of the community is needed (Boon & Dieperink 2014). Therefore, it is important to include the residents of Anand Jyoti in the choice for the technologies that are analysed and the possible pathways that will result from this analysis. Inclusion is ensured by determining the social desirability of each proposed technology, where social desirability is defined as the coherence between desires from the residents on the one side, and the implications each proposed technology on the other side. In order to make such desires and implications comparable, these are defined as the required changes in energy consumptive behaviour and nuisance associated with installing and maintaining each technology. Behavioural changes and nuisance are chosen as indicators, because it became clear from exploratory conversations with the residents that these two are seen as relevant for social desirability by them.

In order to describe the desires of the residents, first a social 'baseline' is established. In this methodological section, first the indicators used for the analysis of social baseline are discussed. Second, the methods for collecting data needed for this baseline are briefly explained. Third, the analytical method for comparing the social desires to the implications of each technology is discussed, ultimately determining social desirability.

3.5.1. Indicators for the social baseline

First, the social baseline is determined. The social baseline includes a description of (1) how the residents currently consume energy, (2) to what extent they are willing to change this energy consumptive behaviour, and (3) what they find important motivations and obstacles to participate in the sustainable transition. Current energy consumptive behaviour, determined by analyzing what and how high energy consumptive devices are used (and whether they have an energy label) is also important for the analysis of energy saving potential in the "reducing energy demand" analysis (see chapter 5). The used indicators are listed below:

Indicator 1: Current energy consumptive behavior

- Amount of high-consumptive devices per household (Washing Machine, Dryer, TV, Computer, Refrigerator, Freezer, Lights)
- Frequency of use of these devices
- Energy label of the devices (A++, B etc.)
- Energy supplier

Indicator 2: Willingness to change consumptive behavior

The flexibility for a change in behavior regarding energy consumption is determined by using the indicators related to lower consumptive behavioural aspects.

- Willingness to change aspects of consumptive behavior
- Willingness to share high-energy consumptive devices
- Willingness to change energy supplier

Indicator 3: Priorities of motivation and obstacles

Motivations and obstacles to participate in the sustainable transition – and how these are prioritized – are the final indicators for the social baseline, and have a strong influence on determining final desirability of each technology (see section 3.6 below) in order to ensure inclusion of the residents in the scoring process. Based on early observations in the Anand Jyoti community, it is evident that the motivations listed below are the most relevant for the community to eventually be involved in a renewable energy transition. Additionally, it is determined to what extent nuisance, changing behavior and sharing of devices are viewed as obstacle for the transition. The actual ranking of these motivations is determined in this social baseline.

- Ranking of important motivations for renewable transition
    - (Financial) / Environmental / Social)
- Obstacles for cooperation in a sustainable energy transition
    - Behavioural / Social (sharing) / Nuisance

3.5.2 Methods for collecting data on social baseline

The required data to establish the social baseline is retrieved by conducting a focus-group discussion and individual interviews. The aim of a focus group is "not to infer but to understand, not to generalize but to determine the range, not to make statements about the population but to provide insights into how people perceive a situation" (Parker and Tritter, 2006). Focus group discussions have some important benefits. The residents are elderly Hindustani with a "group mentality", meaning that respondents are more comfortable with providing information in group atmosphere. Indeed, according to Sim (1998), group processes can help people to explore and clarify their views in ways that would be less easily accessible using other methods (1998). Sim argued that a greater degree of spontaneity in the expression of views is encouraged and participants may feel supported and empowered by a sense of group membership, which is likely to be the case for Anand Jyoti due to the group mentality. One focus group discussion is held with nine residents, representing eight households. In addition to the focus group discussion, six individual interviews with residents of Anand Jyoti are held to collect more specific data on current consumptive behavior and flexibility in changing this behavior. Four of these individual respondents also participated in the focus group discussion, so the data below represents information of ten different households.

3.5.3 Analysis of social desirability for the proposed technologies

Second, once the social baseline is determined, these are compared to the social implications of each proposed technology. The social implications of each technology are qualitative in nature, defined as the required changes in energy consumptive behaviour, and the amount of nuisance in the living space (both private and communal) when implementing and maintaining the technology. These implications are then compared to the willingness to change consumptive behaviour by the residents, as analyzed in the baseline above. It results in the score on the social desirability indicator, which is the coherence between the willingness to change energy consumptive behaviour and the extent of requirements of each respective technology to do so.

In order to determine social desirability, required changes in behavior of each technology are compared relatively with each other. A score between 1 and 5 is given. The higher the coherence (i.e. the smaller the difference) between willingness to change consumptive behavior and the required change in consumptive behavior of each technology, the higher the score for social desirability (1-5). For example, if the willingness to change consumptive behavior is high and required changes in behavior is also high, while relative nuisance is low while tolerance for this is also low, the social desirability scores 5 out of 5.

3.6. Final Desirability scoring process

As this study focuses on a bottom-up sustainable energy initiative, the desires of the community itself have a decisive influence on the final desirability score of each technology. The final desirability score represents the score for each technology, in which all five are incorporated and have been weighted according the priorities of motivations and obstacles indicated by the community in the social baseline. It therefore represents the most desirable option in a bottom-up, transdisciplinary manner: the importance of each criterion which influence final desirability (economic, technical, environmental, social) is largely weighted according to the priorities in motivations and obstacles of the community and not by the researchers themselves. The legislative criterion is not used as this has no scaled scoring, but a dichotomous decision of go or no-go.

In order to determine a numerical score (1-5) for final desirability, a linear ranking is used on which the weight of each indicator is based. For example, when the economic motivation is seen as most important by the residents (e.g. a low payback time of a technology), the score of the economic parameter is weighted times 4. And when the technical indicator is seen as second most important (e.g. a low amount of time for installing the technology), its score is weighted times 3, and so forth. Accordingly, final desirability is determined using the following formula:

Final Desirability = (Economic (*weight) + Environmental (*weight) + Technical (*weight) + Social (*weight)) /10

3.7 Method of integration

Once the final desirability of each technology is determined, the final stage of this report considers the description of the optimal pathway for the residents of Anand Jyoti to achieve their goal to become more energy sustainable. This pathway will entail the optimal combination of the different technologies according to the used indicators, with a step-by-step plan on how to achieve it.

The promising technologies are then integrated following the Trias Energetica to form a pathway. The energy savings (step 1) will thus be 'implemented' after which the remaining energy demand is substituted with our proposed technologies (step 2). If there is still a residual of fossil energy needed, this is taken care off by the options for a more efficient supply (step 3). First, the pathway for the Communal area is created, this is because the substitution energy of certain technologies (PV Panels) is firstly designated for the communal area, after which the remaining electricity would be divided among the apartments.

Figure 2 below summarizes the methodological framework as described in this chapter. The five criteria (vertical, left side) are tested for several technologies associated with energy savings in red (insulation, LED lights), renewable energy supply in green (solar such as PV panels and biomass such as a Biomeiler), and efficient energy supply in orange (heatpumps such as air-water heatpumps).

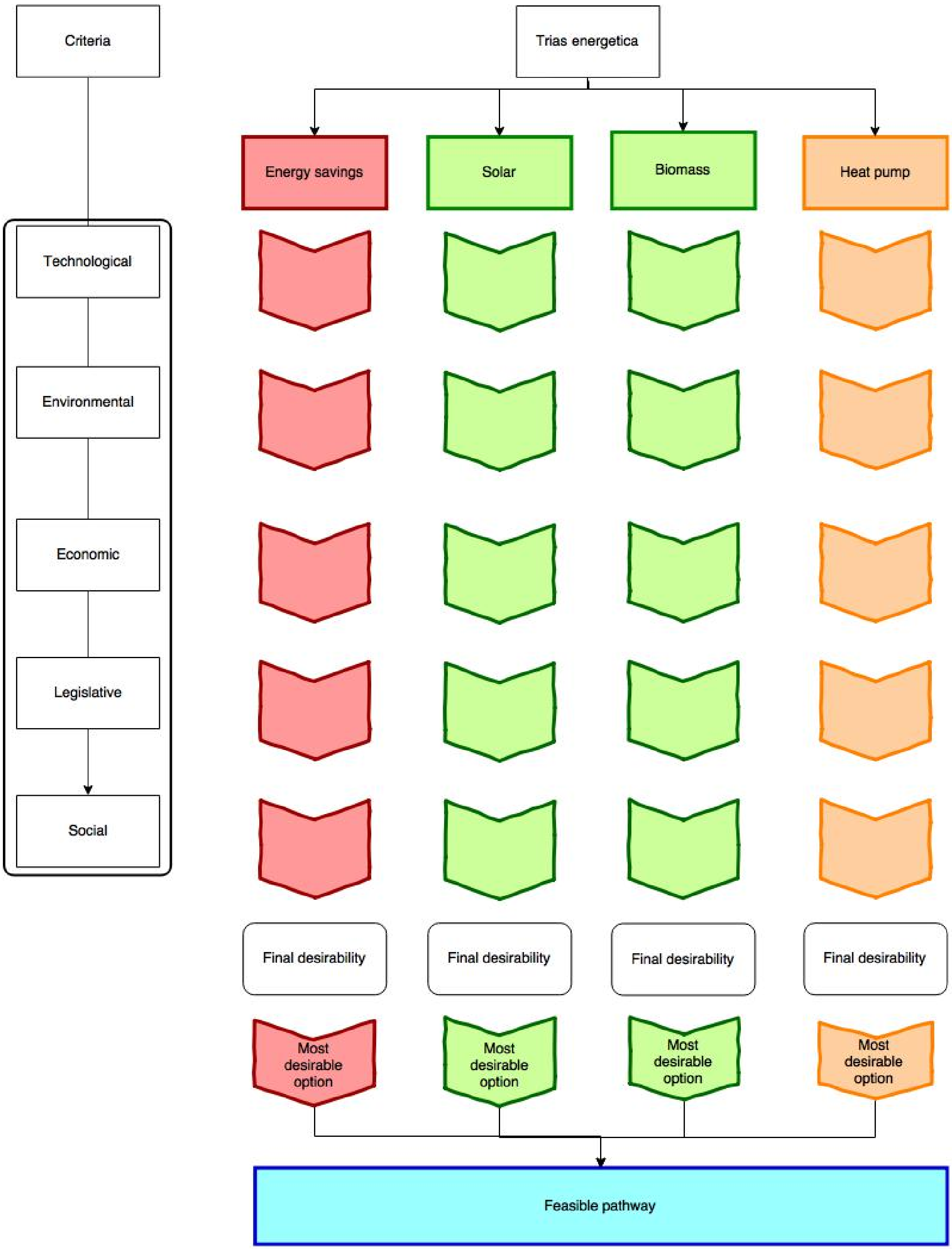


Figure 2. Methodological framework

4. Baseline

The residential community of Anand Jyoti is located in the South East of Amsterdam, in the neighborhood of Holendrecht. Here, a total of 33 Hindustani elders live in a residence with 24 individual houses, which are either two- or three-room apartments. They share a communal space, which is provided with a (new) kitchen. This communal space is mainly used for activities such as computer classes, shared meals and yoga lessons. In this chapter, the current situation regarding the residential community and the building is described according to the five categories (technical, economic, environmental, legislative, social).

4.1 Technical

Relevant areas/surface:
The communal area has a glass window surface of 44 m^2, the walls have a surface of 58 m^2 and the floor and ceiling of 108 m^2. The total volume of the communal space is 216 m^3.
An apartment in the North or South building is approximately 11 by 7 meters and has a total window surface of 11 m^2. Moreover, the total volume of these apartments is 154 m^3.
The dimensions of the Northern roof of the residential complex are 11 meters by 28,6 meters, length to width. The dimensions of the middle roof are approximately 14 by 7,4 meters. And finally, 11 by 20,8 are the dimensions of the Southern roof.

Electrical grid:
All households have their own electricity meter and own electricity contracts with their energy supplier. As a result, energy prices vary among the different households. Also the community space has a separate electricity meter and meter box, which is collectively used and paid.

Heat system:
In all apartments and the communal space a high efficiency gas boiler (Intergas Compact, 22 kW) is installed. This gas boiler has recently been replaced throughout the building.

Insulation:
According to Dutch 1990 Building Regulations, external barriers of heated buildings, such as roofs and walls, are required to have a thermal resistance of at least 0,5 W / m^2 x Kelvin. Doors and windows may have a thermal resistance of no more than 4,2 W / m^2 x Kelvin. These values were assumed to apply to the Anand Jyoti residential complex.

Defects in houses concerning energy:[1]

- The floor is cold (ground floor).
- Ventilation above windows release a lot of heat.
- It depends a lot on the location of the house. There is one side where there is a lot of sun, and another side where there is almost no sun, this is much colder. Also, apartments on the first floor are warmer.

[1] Based on the group discussion

4.2 Environmental

Based on seven energy bills of the residents of Anand Jyoti, two scenarios for current CO_2 emissions are calculated, based on a high and a low energy consumption.

High energy consumption:
The high-energy households on average use 2622,9 kWh of electricity on a yearly basis. This amounts to a primary electricity use of 5828,7. On top of this, the high-energy household consumes 1187,1 m^3 of gas, amounting to 10.228,2 kWh of primary energy for central heating and warm water. The total primary energy used is 16056,9, which corresponds to the emission of 3611,4 kg of CO_2 per year.

Low energy consumption:
The low-energy households use about half the amount of energy of the high-energy ones. On average, they consume 1.013,4 kWh of electricity per year. This amounts to a primary electricity use of 2252 kWh. The low-energy household consumed 478,5 m^3 per year, which amounts to 4.122,6 kWh of primary energy for heating and warm water. The total amount of primary energy consumed for these households on a yearly basis is 6374,6 kWh. This amounts to 1432,6 kg of CO_2 emitted per year.

Communal space:
Unlike the high and low-energy households, which were based on energy bills, the energy consumption of the communal space was based on estimates. This was because none of the individual residents had access to its consumption data. Based on average consumption patterns for medium households, we assumed electricity consumption to be 6000 kWh; or 13.333,3 in primary energy. Gas consumption was estimated at 1500 m^3, or 14.110,6 kWh per year. Annual primary consumption totalled 27.443,9 kWh, or 5982 kg of $CO_{2.}$

4.3 Economic

Based on the same energy bills as were used for the CO_2 emission scenarios, two economic baseline situations are calculated for the individual households, also based on high and low energy consumption.

High energy consumption:
The high-energy households spent on average €672,17 per year on gas, of which €413,19 in base costs and €258,98,- is in taxes. They spent €489,03 on electricity, of which €183,56 in base costs and €305,48 in electricity tax. In addition to this, they also pay a network fee of €342,-. Their total average yearly bill is €1550,26.

Low energy consumption:
The low-energy households consumed €293,75 worth of gas, divided in €179,50 in base costs and €114,25 in energy tax. Their electricity consumption amounted to €206,69 of which €95,48 in base costs and €111,21 in energy tax. Despite these large differences in consumption with the high-

energy group, they paid a similar amount on network costs; €310,87. In total, they spent €567,15 per year on energy.

Communal space:
While bills were not available for the communal space, costs can be inferred from the assumed energy use. While different providers may charge different rates, on average gas in the Netherlands costs €0,30 per m^3, with an additional €0,30 per m^3 in energy tax. Electricity costs €0,065 per kWh with an additional €0,1218 per kWh in energy taxes. This would bring the communal electricity bill to €653,80 and their communal gas bill to €900,-. Combined with a network bill of about €340, this amounts to a grand total of €1893,80.

4.4 Legislative

The legislative situation is conceptualised through ownership of assets and contracts between residents and third parties. The residents of Anand Jyoti rent the apartments from the housing corporation Stadgenoot, the owner of the building. Stadgenoot is responsible for the maintenance of the gas boiler and radiators in the apartments. Aliander is responsible for the electricity grid and gas piping system. All residents have their own energy supplier and meter system. The costs for the energy consumption in the communal space is included in the rent they pay to Stadgenoot.

4.5 Social

The social baseline in this section considers a description of the current energy consumption behaviour, the willingness to cooperate and the priorities of motivation and obstacles of the Anand Jyoti residents.

4.5.1 Current energy consumption behavior

In a focus group discussion with nine residents, representing eight households, and in six individual interviews, the residents have been asked what high-energy consumptive devices they have, how often they use them and whether they have energy labels. The results for both the collective space and individual households are displayed below. The results of the individual households are based on the six individual interviews (See Appendix D) and the results of the communal space are based on the focus group discussion.

In the group discussion, the residents of Anand Jyoti indicated to already be quite considerate with the environment. A majority of the residents have already taken considerable technological and behavioural steps towards reducing their energy usage. For example, some residents use LED lights, switch the lights off when they are not in a room, and shut the doors. However, a minority of households in the use devices with energy savings labels (see table 1). Most residents have Nuon as their energy supplier (6/8), and a few use Essent (1/8) and Greenchoice (1/8)

Anand Jyoti is a social community; they organize a lot of activities for the residents but also for their neighbors. However, the devices in the collective space (kitchen devices and a computer) are not used much: only once a week. One resident confirmed this, but also said that she is certain that it will be used more in the near future as the kitchen has only been installed recently.

4.5.2 Willingness to change consumptive behavior

In this regard there seems to be a division between the younger residents (aged roughly 50) and older residents (aged 70+). Two younger women, who participated in the group discussion, are more open to change their behavior and for example share devices like a washing machine and dryer, whereas the elder residents are more reluctant towards sharing devices. One elder resident explains: "*We are used to have our own things for years, sharing is not going to work. I do not want to be dependent on others.*"

More specifically, in the six individual interviews, residents have been asked to indicate their flexibility in changing certain aspects of their behavior. The results are presented in the table below:

	Baseline	**Flexible for change**
Change temperature in house	19°C: 2 20°C: 3 22°C: 1	No: 2 Little: 3 Yes: 1
Wear warm clothes instead of heating	Does this already: 6 Doesn't do this: 0	No: 4 Little: 1 Yes: 1
Switch lights off when not in the room	Does this already: 4 Doesn't do this: 2	No: 4 Little: 1 Yes: 1
Close the doors	Does this already: 5 Doesn't do this: 1	No: 5 Little: 0 Yes: 1
Switch TV/Laptop off instead of standby	Does this already: 1 Doesn't do this: 5	No: 1 Little: 1 Yes: 4
Share devices	Currently, all residents have their own devices which are not shared.	No: 4 Maybe: 1 Yes: 1

Table 4. Flexibility in changing certain aspects of behavior

As the table above shows, there is generally no to little flexibility in changing behavior or sharing high-energy consumptive devices. A concern raised in the focus group discussion is when not all residents are prepared to use devices that are shared in the collective space, while all households contribute to the costs in energy use of this collective space through their rent equally. For example, if a washing machine is placed in the collective space which would be used by 5 or 10 households, this results in an unfair situation considering costs for the collective space. Therefore, introducing shared devices in the collective space is only possible if the costs of these devices are somehow transmitted to only those who use it. This is however not worth the effort, as only a minority (2 out of 6 interview respondents, and 1 out of 8 people in the group discussion) were prepared to be involved in sharing devices. The low flexibility in changing consumptive behavior (with exception of switching off TVs and laptops) and sharing of devices demonstrates a low potential for lowering energy demand through behavioural change in energy consumption. Therefore, such issues are not examined in the analysis on reducing energy demand (chapter 5). Flexibility in changing energy supplier is however high: there is not a lot of confidence in current energy suppliers because of disappointments in costs. However this should not entail more costs nor significant effort.

4.5.3 Priorities of motivation and obstacles

The most important reason for cooperating in this project is in order to reduce energy costs. Reducing environmental costs are considered as an extra motivation to cooperate, however remain subordinate to the financial benefits of the transition. In fact, when solutions would cost more (or even the same amount of) money than they spend now on their energy bill, they would not be willing to cooperate. The social incentive of the project is also appealing, as it would lift the reputation of the Anand Jyoti community in the wider neighborhood. However, this is also subordinate to the financial incentives of a transition.

Roughly half of the residents view some obstacles regarding a transition towards more sustainable energy, whereas the other half does not. Obstacles that have been identified are: difficulty to grasp the financial consequences of an energy transition, nuisance tolerance is low as many residents want minimal disturbance from the installation and use of the new technologies because of their old age. Importantly, the residents are not prepared to reduce energy consumption if it is “at the cost of their comfort”. For example, heating and a high frequency of showering (one/twice a day) are valued as important routines that are not flexible for change. Openness to change consumptive behaviour is therefore low.

Based on these motivations and obstacles, a linear ranking is used for the quantification of final desirability on which the weight of each criterion is based:

- The economic criterion is considered as most important by the residents of Anand Jyoti so in the calculation of the social desirability score, the weight of the economic score for each technology is 4.
- The residents have indicated that they do not want to give in comfort or change their behavior, and nuisance tolerance is low. Therefore the social desirability is weighted 3.
- The disturbance of installation and maintenance should be minimal. Accordingly, the technical score is weighted 2.
- The residents do value the environmental criterion, however the economic, social and technical criteria are considered more important, so the environmental criterion is weighted 1.

Final desirability = (Economic (*4) + Environmental (*1) + Technical (*2) + Social (*3)) /10

5. Reducing energy demand

The first step in the Trias Energetica model is the reduction of energy demand. This step is considered to be most important in making buildings more energy sustainable. The decline in energy intensity has been driven mostly by the enhancement of energy efficiency within the key and end-uses such as space heating (IEA, 2005). Projections for the energy efficiency potential and the use of renewable energy sources predict a key role in reaching the global CO^-_2 targets. By implementing energy efficiency improvements within the demand and supply sectors a reduction of 48% can be reached in 2050, compared with the primary energy supply of the IEA baseline scenario globally (Krewit et al., 2009). In other words: A large role for residential energy savings is predicted for reaching the global CO^-_2 targets and thus energy savings within the Anand Jyoti community can contribute to reach the targets.

In order to reduce the amount of energy of the Anand Jyoti community, energy saving measures can be adopted within their current energy system to decrease their energy demand. Energy saving methods can be decomposed in terms of volume effects (e.g. population per house), structural effects (e.g. insulation or LED lights) and energy efficiency measures (e.g. conventional boiler, solar boiler or heat pump). In this case, several structural energy-saving measures that could possibly contribute reduce energy demand in the Anand Jyoti community were considered. The following techniques are considered and get a score on the five criteria as described above: insulation and changing towards LED lighting.

5.1 Insulation

According to a study based on the KWR database from the Ministry of Housing in the Netherlands building characteristics determine 42% of the energy consumption in a dwelling (Santin et al., 2009). Insulation can improve the heat demand of a dwelling because less heat is lost to the environment through walls, windows, floors and roofs. Because the Anand Jyoti complex is built according to the "Bouwbesluit 1992", the wall, roof and floor insulation has a thermal transmittance, or U-value of roughly 0,4 W/m^{2}K. This value is according to standards and can only be improved slightly. These measures would be expensive and are therefore not considered as cost-effective they are therefore left out of the scope of the insulation study. The windows, window frames, and doors are permitted to have a thermal transmittance of up to 4,2 W/m^{2}K. High efficiency window glazing with far lower thermal transmittance are currently manufactured. Changing the glazing of the houses in the Anand Jyoti complex could lower the heat demand.

Insulation Assumptions

Current window frames are made of wood, which has an average thermal transmittance of 2,4 W/m^{2}K. Double glazed windows and have an average thermal transmittance of double glazed windows is 2,7 W/m^{2}K (Ekbouwadvies, 2016; Milleucentraal, 2016d). Triple glazed windows have the lowest U-value; between 0,5 and 0,9 W/m^{2}K. However, because of their heavy weight they may not be applicable in windows that can open (Milieucentraal, 2016d). If that is the case HR++ glass may be considered, which has a U-value of 1,2 W/m^{2}K. The results is this section are based on the average windows surface area in the houses of about 11,75 m^2 glass, of which 4,75 m2 can be opened. The communal space is assumed to have 44m^2 of glazing of which 8 m^2 can be opened. The energy savings per m^2 window are based on an average inside temperature of 18 degrees celsius and compared with the current double glazing. For this calculation an apartment on the top floor in the middle is considered. The walls and floor area which neighbors other apartments is assumed to have a thermal transmittance of 0,1W/m^2K. The surfaces bordering outside are considered to have a thermal transmittance conform the Bouwbesluit. The volume and surface of the communal space and the apartment are described in the baseline. The heat loss of the spaces yearly is calculated with the following formula (Blok, 2007):

$Q = k \cdot A \cdot 3600 \cdot 24 \cdot D + cp \cdot \rho \cdot V \cdot N \cdot 24 \cdot D$

Q	= total heat loss of a building in a year in [J]
k	= average thermal transmittance [W/m2K]
A	= surface are [m2]
D	= Heating Degree days: 2496 in Amsterdam (DegreeDays.net, 2016)
cp	= specific heat of air (1.0kJ/kgK)
ρ	= specific mass of air (1.20 kg/m3)
V	= volume inside building [m3]
N	= ventilation rate (1 time/h)

This formula is based on Heating Degree Days, and thus the assumption that the heating will always be in use if the outside temperature is lower than 18 degrees. However, in the real situation this might not be the case, causing the energy use for heating to be lower than expected from the annual heat loss calculation. Because of this, the heat loss savings of new glazing is converted to percentages to be able to apply on the real energy use of the residents.

The costs of HR++ is assumed to be 80 euros/m2 and triple glazing to be 120 euro/m2, excluding labour. Labour costs are expected to be 70 euro/m2 including the needed appliances and scaffold (Dubbelglas-weetjes, nd). The lifetime of glazing is expected to be 50 years.

Insulation results

Technical

Changing to windows of the complex will require some technical adjustments. The window frames have to be widened to fit in the slightly thicker insulating glazing. The estimated installation time per m2 of glass is 1 hour. This will thus be 44 hours for the communal area and 11 hours for individual apartments.

Environmental

The new insulating glazing will save 9,5 % of natural gas for heating in an apartment and 18,6% of natural gas in the communal area. This equals a primary energy saving for heating of 9059 MJ/year (2516 kWh/year) for the communal area and for the high and low heat demand apartment subsequently 2776 MJ/year (770 kWh/year) and 1118,7 MJ/year (310 kWh/year). The associated emission savings are listed in table 6.

Economic

The measure will save annual costs due to the lower heat demand and thus savings on energy for heating. These savings after the PBP are subsequently 160,5 euro/year, 49 euro/year and 19,7 euro/year for both the communal area, high heat demand house and low heat demand house. However, the investment costs of new glazing are so high, 2042,5 euro for the apartments and 8420 for the communal area, that the PBP would be very long. Although it does not exceed the lifetime of 50 years in the case of the high heat demand apartment, the NPV is negative for all cases. Which means this measure is not cost effective. The score on economical feasibility will therefore be 1.

Legislative

For improving window insulation and thereby changing the structure of rental housing, a written permission from the owner is needed. This means that Stadgenoot, who is the owner of the housing complex Anand Jyoti, has to authorize the request of the residents (Rijksoverheid, 2016). Stadgenoot has to respond within eight weeks can only reject the renovation if the structural change has a negative effect on the attractiveness of the rental house or when the value of the house drops due to the renovation (Rijksoverheid, 2016). Because insulation increases the value of the apartments, this measure is expected to be approved by Stadgenoot.

Social

Insulation of the individual apartments and communal area do not require any changes in energy consumption, which is positive for the social desirability score - as the community prefers no required changes therein. However, the relatively short installation would take place in the appartments and therefore, there would be some nuisance. This is relevant as the nuisance tolerance is low (see social baseline). Combining both issues, the social desirability scores 4 out of 5

Final desirability

The final desirability score, however, scores 1 since this option is not economically feasible and this is a precondition.

According to a study based on the KWR database from the Ministry of Housing in the Netherlands building characteristics determine 42% of the energy consumption in a dwelling (Santin et al., 2009). Insulation can improve the heat demand of a dwelling because less heat is lost to the environment through walls, windows, floors and roofs. Because the Anand Jyoti complex is built according to the “Bouwbesluit 1992”, the wall, roof and floor insulation has a thermal transmittance, or U-value of roughly 0,4 W/m^2K. This value is according to standards and can only be improved slightly. These measures would be expensive and are therefore not considered as cost-effective they are therefore left out of the scope of the insulation study. The windows, window frames, and doors are permitted to have a thermal transmittance of up to 4,2 W/m^2K. High efficiency window glazing with far lower thermal transmittance are currently manufactured. Changing the glazing of the houses in the Anand Jyoti complex could lower the heat demand.

	High insulation glass		
	Communal	**High heat demand**	**Low heat demand**
Technical	Installation time: 44 hours **17 [hrs work /1000 kWh]** **Score:** 1 out of 5	Installation time: 11 hours **14 [hrs work/1000 kWh]** **Score:** 1 out of 5	Installation time: 11 hours **35 [hrs work/1000 kWh]** **Score:** 1 out of 5
Environmental	Primary energy savings: 2516 kWh **-500,124 kg CO_2/year** **Score:** 1 out of 5	Primary energy savings: 770 kWh **-152 kg CO_2/year** **Score:** 2 out of 5	Primary energy savings: 310 kWh **-61 kg CO_2/year** **Score:** 1 out of 5
Economic	Initial investment: €8420 PBP: 52,47 years NPV: -5890,69 **Score:** 1 out of 5	Initial investment: €2042,5 PBP: 41,65 years NPV: -1269,67 **Score:** 1 out of 5	Initial investment: €2042,5 PBP: 103,35 years NPV: -1731 **Score:** 1 out of 5
Legislative	*Preconditions*	*Preconditions*	*Preconditions*
Social	**Score:** 4 out of 5	**Score:** 4 out of 5	**Score:** 4 out of 5
Final desirability	**Score: 1**	**Score: 1**	**Score: 1**

Table 5: Score high insulation glass

5.2 Change to LED Lighting

In the interviews with the residents of Anand Jyoti, energy use and the use of equipment and lighting has been discussed. It became clear that many households have incandescent light bulbs or halogen lighting (see Appendix A and C). Changing to LED lighting is a simple energy saving method and expected to be cost effective. This section shows the potential for LED lighting in the Anand Jyoti community.

LED Assumptions

For the communal area and individual apartments, the calculations on the shift towards more sustainable lightning is based upon a baseline of 9 incandescent lights (60 W). These will be replaced with with 9 LED lights (AH Led Standard 470 lm). The fluorescent lighting will remain in place, because fluorescent tubes are already quite efficient. Incandescent lights are the least efficient light sources (Milieucentraal, 2016d; Blok & Nieuwlaar, 2016).

To calculate the average electricity consumption from lighting of the individual households, an online tool called the 'ScenarioTool', was used (BDH, 2016). No clear trend could be derived from the individual data analysis that related the number of lamps and the energy consumption of one apartment (See Appendix D). For this reason, there is no division in low and high electricity demands regarding the individual households in this section.

It is assumed that the data analysis of the 6 chosen residents is representative for the whole community. The ScenarioTool is used to provide insight in the energy consumption for lighting in the Anand Jyoti community. For the calculation of energy savings for the individual electricity demand, first a calculation of all the apartments was made by using the ScenarioTool. For a representative housing of the Anand Jyoti apartments, 24 mid-terraced houses are used as input for the ScenarioTool. Within the tool, incandescent lights and the halogen lights are seen as 'Conventional' light sources, the CFL lights were counted as 'CFL', whereas the fluorescent tubes were counted as 'LED' because of its high efficiency. This reasoning is fairly consistent with the efficiency of different light sources according to Blok & Nieuwlaar (2016, p. 194). Figure 3 shows the input of the abundance of the various light types that are used in the ScenarioTool. The reference year is covered by 2020 and the final year is covered by 2025. The values under 2013 are representative for the average lightning type abundance in The Netherlands.

Conventional	Light bulb	Halogen		Total		Percentage
	6	54		60		54%
CFL	CFL			Total		Percentage
	37			37		33%
LED	LED	Fluorescent beam		Total		Percentage
	7	7		14		13%

LED lighting

Lighting type	2013	2020	2025
Conventional	40 %	54 %	0 %
Fluorescent	56 %	33 %	0 %
LED	4 %	13 %	100 %

Figure 3: The abundance of different light types according to the 'Individual data analysis' for the reference year (2020) and the switch towards 100% LED in the final year (2025) that is used in the ScenarioTool simulation (BDH, 2016).

Furthermore, the price of the LED light considered (AH Led Standard 470lm) is 8 Euro. The power of this light is 7W and a lifetime about 15 years (AH, 2016). The average light hours per bulb in the communal area is assumed to be 15 hours a week.

<u>**LED Results**</u>

Technical

For the change towards more sustainable lightning, no technical barriers are considered. As stated before, the fluorescent beams will not be replaced in both the communal area and the individual apartments. The installation time of the new LED's is assumed to be 1 hour per area. To save 1000 kWh for the communal area, 1,23 hours of installation time is needed (1000 kWh / 814,67 kWh x 1hr). To save 1000 kWh for the individual apartment 1,31 hours of installation time is needed (1000 kWh / 761,84 kWh x 1 hour).

Environmental

For the communal area the primary electricity savings are 814,67 kWh/year which corresponds to 192,5 kg CO_2 per year. The total electricity savings of all apartments are 8.228 kWh. For the average apartment this means that the 'LED change' saves 342,83 kWh final energy per year (See Appendix B), this corresponds to 761,84 kWh primary electricity. This is equivalent with the saving of 180,32 kg CO_2 per year.

Economic

For the communal area an investment of €72 (9 x €8) is needed. The benefits per year can be calculated by the difference in power use of the 9 lights multiplied with the average burning hours per light per year. The difference in power for the 9 lights is 477W (9 x (60W - 7W))and the average burning hours are 780 hours per year (15 x 52). The total energy saved by switching to LED lights is 366,6 kWh per year (generated by 780 hrs x 477W / 1000). Consequently, the costs for the electricity saved is €68,55 per year after the PBP (366,6 x 0,187). The PBP of this investment is about one year and the NPV is positive. Both are calculated as:

PBP = 72 [Euro]/ 68,55 [Euro/ year] = 1,05 year
$\alpha = r / (1 - (1 + r)^{-L}) = 0{,}06 / (1 - (1 + 0{,}06)^{-15}) = 0{,}103$ (with a lifetime of 15 years)
NPV = - I + (B - C) / α = - €72 + €68,55/ 0,103 = 593,53
Finally, the yearly saved costs over the lifetime are:
α x I - B = 0,103 x €72 - €68,55 = -€61,13

According to Appendix A, 87,4% of the lighting of the individual apartments can be changed to LED's, which corresponds with 16,2 lights for the average apartment. This means, the average individual apartment needs an investment of €129,33 (16,2 x 8). The total final energy savings for the average apartment equals 342,83 kWh per year (See Appendix B). Consequently, the electricity costs saved are €64,11 per year after the payback time (342,83 kWh x 0,187 cents/kWh). The PBP of this investment is around two years and the NPV is positive. Both are calculated as:

PBP = 129,33 [Euro]/ 64,11 [Euro/ year] = 2,02 year
$\alpha = r / (1 - (1 + r)^{-L}) = 0{,}06 / (1 - (1 + 0{,}06)^{-15}) = 0{,}103$ (with a lifetime of 15 years)
NPV = - I + (B - C) / α = - €129,33 + €64,11/ 0,103 = 493,10

Finally, the yearly saved costs over the lifetime are:
α x I - B = 0,103 x €129,33 - €64,11 = -€50,79

Legislative
There are no legislative barriers for the implementation of LED lighting.

Social
Important for implementing LED lighting is knowledge on the desired color temperature. In general: the higher the color temperature the brighter the light, and the lower the color temperature the more atmospheric the light. Light with a color temperature above 3000K is noticeable brighter and can influence the atmosphere of the light (Consumentenbond, 2015). The LED in this study (AH Led Standard 470lm) has got a color temperature of 2700K does not change the atmosphere negatively. Moreover, changing to LED lights does not require any changes in behavior or any major adjustments. For these reasons, the social desirability scores 5.

Final desirability

The final desirability is scored: (Economic*4) + (Environmental*1) + (Technical*2) + (Social*3) /10
Communal = (2*4)+(1*1)+(4*2)+(5*3) /10 = 3.2
Individual household = (4*4)+(2*1)+(4*2)+(5*3) /10 = 4.1
(both high and low demand)

	Changing to LED lighting	
	Communal	**Individual household**
Technical	Installation time: **1,23 hr/ 1000kWh** **Score:** 4 out of 5	Installation time: **1,31 hr / 1000kWh** **Score:** 4 out of 5
Environmental	primary energy savings: 814,67 [kWh/yr] **CO2 savings: 192,5 [kg/yr]** **Score:** 1 out of 5	primary energy savings: 761,84 [kWh/yr] **CO2 savings:** 180,32 **[kgCO_2/yr]** **Score:** 2 out of 5
Economic	Initial investment: €72 PBP: 1,05 year NPV: 593,53 **Cost savings: €61,13/year** **Score:** 2 out of 5	Initial investment: €129,33 PBP: 2,02 year NPV: 493,10 **Cost savings: €50,79/year** **Score:** 4 out of 5
Legislative	*Go*	*Go*
Social	**Score:** 5 out of 5	**Score:** 5 out of 5
Final desirability	**Score: 3.2**	**Score: 4.1**

Table 6: Score Changing to LED lighting

6. Renewable energy supply

The second step in the Trias Energetica model is to move from fossil fuel-based energy supply to renewable energy sources. In this report, two renewable energy sources are taken into consideration: solar power and biomass.

6.1 Solar

The infinitude and possible efficiency of solar energy can be seen as a solution for the sustainability issues addressed in this report (Rafindadi et al., 2014; CBS, 2014). Solar panels (or PV-panels), solar boilers and PVT panels are the most prominent and practicable technologies within the spectrum of solar energy that are applied in the Netherlands to provide households with renewable energy. More specific, these technologies could contribute to a permanent solution with regard to the sustainability and self-sufficiency of the living environment within the residential community Anand Jyoti.

Figure 4: Roof of the community building from top view (left) and side view (right). (Cyclomedia, 2016)

The Netherlands is not the first country you think of when you think of sun and solar energy. Nevertheless, the Dutch weather is in general particularly suitable for a profitable PV, boiler, or PVT installation. Be it in some cases with the help of subsidies of the national government. Amsterdam (location of Anand Jyoti) has between 1500 and 1600 hours of sun per year, this means Anand Jyoti receives this impressive amount of hours of free energy on its roof (Figure 4) which is unfortunately not captured at this moment (zonnepanelen.info, n.d.). The total roof surface area of the Anand Jyoti community building amounts 650 m^2. Taking into account the chimneys, other obstacles, shadow zones and safety margins, the available effective roof area is approximately two third of this, dependent on the practical design of the technology. This means that this area has been continuously available for generating 'free' and sustainable electric power and heat. The quantity of energy that can be generated within this area by means of the application solar-technologies, and the associated cost-benefit analysis is assessed in this section. In addition, all aspects which have to be taken into account in order to achieve a successful implementation these technologies is described on the basis of the outlined research questions.

6.1.1 Solar panels

PV-panels work on the basis of so-called photovoltaic (PV) cells. These cells consist of two layers of silicon. These cells absorb the radiation of the sun, resulting in the development of an electrical current between the layers and subsequently the generation of DC-power (direct current power) (Fahrenbruch & Bube, 2012). This power is transported to the inverter, which converts it into AC-power (alternating current power). This AC-power is the ‘normal’ power that all power outlets provide, and is thus suitable to transfer into the meter box for one’s own daily use.

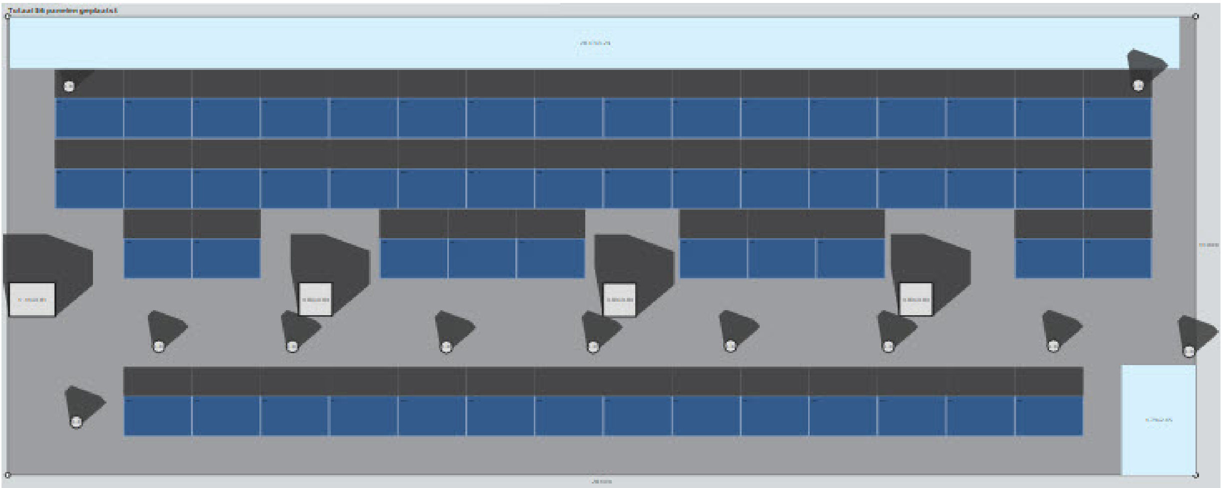
PV Assumptions

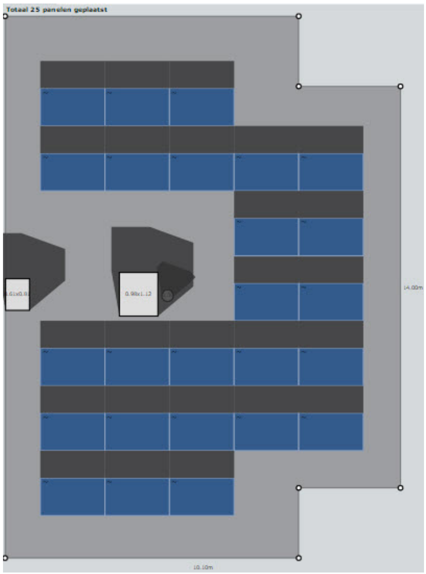
For the assessment regarding Anand Jyoti, it is most advisable to choose a polycrystalline solar panel, since these panels are cheapest (lowest price per Wp) and aesthetics do not have to be taken into account considering the horizontal roof of the building. Considering that the community lives in a flat, the mean effective roof area per resident is relatively low. This means that the efficiency of the panels has to be relatively high, still retaining a low price per square meter. In addition, the quality of the panel and the reliability of the manufacturer have to be consistent. The 265 Wp solar panel of the Canadian Solar brand is one of the panel types that satisfies these criteria reasonably and scores relatively high on price, quality and performance, assuming a lifespan of 25 years (zonnepanelenkennis.nl, n.d.; Consumentenbond, n.d.; SolarNRG, n.d.). Moreover, this panel has one of the highest power/price ratios and is commonly often used in the Netherlands (Vereniging Eigen Huis (VEH), n.d.). It has therefore been selected as the default panel and calculations will be made on the basis of the characteristics this panel. It is very important to note that the final decision of the exact type and brand of the solar panel is dependent on the time of acquisition and specifications in tenders. This means that the choice of selecting Canadian Solar as the brand for this study is not specifically propagated for the actual decision Anand Jyoti eventually has to make, it could only be one of the possibilities.

The Canadian Solar panel has a capacity of 265 Wp (Wattpeak). Wattpeak is a unit which expresses the maximum amount of power that can be generated by the panel, per second and under ideal laboratory conditions. Wattpeak indicates the power or capacity of a solar panel, while kWh indicates the yield (generally per year). Accordingly, one panel generates 265 Wh (Watt hour) after being tested in the laboratory during one hour (Wp x h = Wh). In this sense, this measure is not realistic and applicable for this practical calculation under the Dutch climate conditions. Moreover, the amount of kWh per year cannot just be calculated according to the number of sun hours per year in Amsterdam, because these hours do not correspond with the lab hours in terms of intensity. Therefore, one could use a relevant climate radiation curve in order to convert the sun hours into an amount of optimal laboratory hours. On the basis of this, a conversion factor for Wp towards kWh per year has to be determined. For the Dutch climate, a commonly valid factor of 0,85 is considered (Da Graça et al., 2012; Azzopardi & Mutale, 2010; Fahrenbruch & Bube, 2012; zonnepanelen.net, n.d.). This means the default panel of this study generates 265 Wp x 0,85 ≈ 225 kWh per year in an optimal position on a Dutch roof.

In Figure 5, the configuration of the roof has been illustrated. The roof has been filled with solar panels with dimensions of 100 cm by 165 cm, taken into account the obstacles, consequent shadow, eave margins and mutual spacing. As a result, 124 solar panels have been drawn on the roof, containing possibilities of installing them on a frame under an optimal angle of incidence, which is between 20° and 25° (Gunerhan & Hepbasli, 2007; Li & Lam, 2007). Besides the constraints of the climate regarding the actual energy production per year, more issues are involved that can limit the generated energy. For the Anand Jyoti case, the orientation of the solar panels is 150° south. This means a maximum of 5% power would be lost as a result of this 30° deviation of the optimal orientation (EVO Energie, n.d.). Altogether, one solar panel on the roof of Figure 5 will generate 225 x 0,95 ≈ 214 kWh per year. The whole package 214 x 124 = 26536 kWh per year.

Assuming an average consumption of 6000 kWh per year for the communal space only, a surplus of 20536 kWh (26536 – 6000) is left to divide among the residents within the community. With a number of 24 households, this will come down on approximately 856 kWh of solar energy per household.





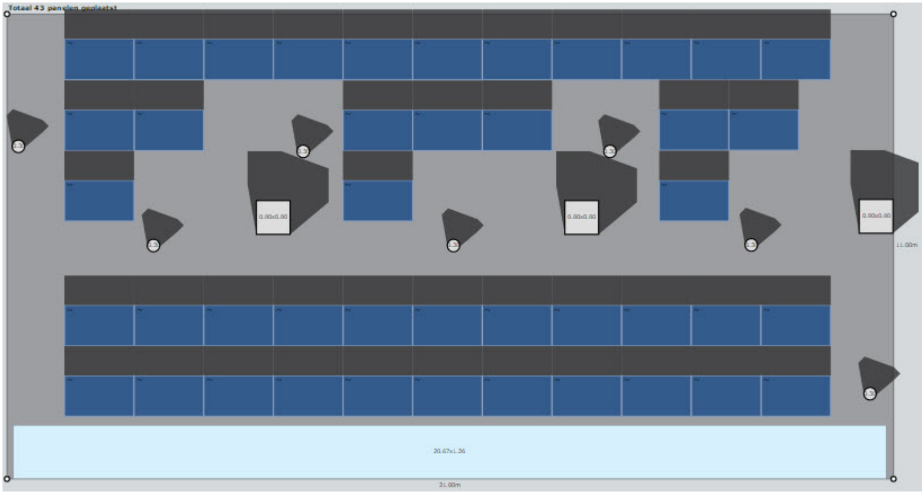


Figure 5. Roof configuration of the Northern roof (top), the middle roof (middle), and the Southern roof (below).

Results:

Technical

All technical issues within the community building satisfy the technical preconditions for installing solar panels. There is an adequate area on the roof suitable for installing solar panels, even taken into account the high number of obstacles on the roof. In addition, there are no limitations regarding the possibilities of installing a proper cable route and there is more than enough space in the communal room for the implementation of the inverters. Via the meter box, the generated energy can easily be conducted to the grid, albeit with minor adjustments. The total installation duration will probably be around 16 hours (two working days). This means the time/power proportion is approximately 2 seconds per kWh (16 hours / 26536 kWh x 3600 seconds). In conclusion, the technical feasibility of the implementation of solar panels can be considered 5 on a level of 1 to 5.

Environmental

The solar panel system on the roofs of the Anand Jyoti community building generates 26536 kWh in total per year. According to the general rule determined in the baseline, this amount of energy saves approximately 13957 kg of CO_2 per year (26536 kWh x 0,526 kg per kWh) in total. For the communal area this is (6000 kWh x 0,526 kg per kWh =) 3156 kg of CO_2 per year. For the rest of the individual households this is (856 kWh x 0,526 kg per kWh ≈) 450 kg of CO_2 per year. This impressive amount is considered a key indicator for the assessment of overall feasibility of the solar panel technology. The amount of primary energy that would have been needed to generate the energy amount that is now saved with the technology can be calculated according to a factor of 0,45. Consequently, this total amount of primary energy is (26536 kWh / 0,45 ≈) 58969 kWh. For the community this is (6000 kWh / 0,45 ≈) 13333 kWh. Lastly, for the rest of the individual households this is (856 kWh / 0,45 ≈) 1902 kWh.

Economic

One solar panel costs approximately €350,- (SolarNRG, n.d.). Within this amount, the relative price of the inverter, cables and the total installation has already been taken into account. This means the total price of the installation will amount to 124 x €350 = €43400,-. In the Netherlands, there is a subsidy in the form of deduction of the 21% tax that has been paid for the purchase of the solar panels. Meanwhile, also a tax for the generating capacity must be paid (Belastingdienst, n.d.). All this results in the following net price: €43400 x 0,79 + €600 = €34886,-. The purchase of the solar panels can be covered with a municipal loan via the sustainability fund of the Amsterdam municipality. This loan has an interest rate of 2% (Gemeente Amsterdam, 2016). This means that the total costs of the project will amount (€34886 x 1,02 ≈) €35584,-.

Approximately 6000 kWh will be used within the communal space every year, this means this amount of kWh can directly be netted every year over the energy bill. Assuming an an actual energy price of €0,187 per kWh, an amount of €1122,- can be considered as the communal saving per year. By means of the so called 'postcoderoosregeling', it is possible to collectively own and maintain the solar panels through the communal space and meter box, while virtually selling and distributing the surplus of the generated power to individual customers within the same postcode zone. This means 20536 kWh per year must be sold the energy supplier for on average €0,07 per kWh electricity rate. This amount is dependent on the energy supplier and can thus be selected targeted and smart. Subsequently, per generated kWh that has been sold to customers within the postcode zone, the community (Samen Redzaam) receives an additional €0,10 from the tax authorities (RVO, n.d.; Hier opgewekt, 2016; postcoderoosregeling.nl, 2016). This means that the community receives an accumulated €0,17 per kWh of the generated energy surplus from the solar panels (20536 kWh in total). The individual customers have their own contract with their energy supplier and pay the regular energy price on their energy bill. Because of the loan construction, nobody will notice anything from the purchase in financial terms, i.e. in the payback period no changes in energy bills will occur. Although, alternatively one can choose to extend to period to pay back the loan, then users will directly notice some relief in their electricity costs.

Summarizing, the community gains (6000 kWh x €0,187) + (20536 kWh x €0,17) = €4613,12 per year. This means the payback time of the solar panel technology in this context will be roughly 7 years and 9 months (€35584 / €4613,12). In this sense, one can conclude that after 7 years and 9 months, the loan has been repaid and the technology will start bringing money. From that point, individual customers within the postcode zone will receive their own discount per consumed kWh and there will be no financial contribution for the energy of the communal space left. Accordingly, the energy that can be saved per household is 856 at max, in monetary terms this amounts to (856 kWh x €0,17 =) €145,52 per year. In addition, the NPV is positive which means this technology is cost effective and thus economically feasible.

For the purpose of comparison, the total investment costs are divided by the percentage of kWh produced which is used by an individual household or the communal area. This implies that households invest themselves. This will not be the case in the real situation, however this method makes it possible to compare technologies in which loan constructions are not taken into account. Yearly cost savings are based on the amount of electricity used by the individual households or the communal area from the solar panels multiplied with the average electricity costs of 0,187 euro. The results are shown in table 8.

Legislative

In legislative terms, implementation of solar panels is commonly known way forward to both financial and economical improvements. Governments respond to the trend and various practical and economical possibilities are offered in order to stimulate solar energy. Unless the fact that the organization and structure concerning the Anand Jyoti community is not very common, there are entries to effectively implement an efficient plan and solar system within the limits of the law. An important factor herein is that governments and municipalities are willing to cooperate and accommodate in order to increase opportunities of sustainable solar energy. Examples of this are subsidies, loans and broader legislation, e.g. the postcode zone arrangement. The only obstacle that must be overcome, is getting permission from 'Stadgenoot' in order to install solar panels by means of this construction, on their property.

Social

Residents do not have to change their behavior when solar panels are installed, which is positive for the social desirability score as the community prefers no required changes therein. Also, the nuisance is quite low since installation will take place on the rooftops and not in the apartments. Therefore, the social desirability scores 5 out of 5.

Final desirability

The final desirability: (Economic*4) + (Environmental*1) + (Technical*2) + (Social*3) /10
Communal = (4*4)+(5*1)+(5*2)+(5*3) /10 = 4.9
Individual (low/high heat demand) = (5*4)+(5*1)+(5*2)+(5*3) /10 = 5

	Solar panels	
	Communal	**Individual households**
Technical	Installation time: 16 hours 0,27 [hrs /1000 kWh] **Score:** 5 out of 5	Installation time: 16 hours 0,27 [hrs /1000 kWh] **Score:** 5 out of 5
Environmental	Yearly primary energy savings: 13333 kWh **Yearly CO_2 savings: 3372 kg CO_2** **Score:** 5 out of 5	Yearly primary energy savings: 1902 kWh **Yearly CO_2 savings: 450 kg CO_2** **Score:** 5 out of 5
Economic	PBT: 7,75 years NPV: €235588,56 Savings after PBT: €1122,- per year **Yearly savings over lifetime =** **€506,70 per year** **Score:** 4 out of 5	PBT: 7,75 years NPV: €235588,56 Savings after PBT: €145,52 per year **Yearly savings over lifetime =** **€72,30 per year** **Score:** 5 out of 5
Legislative	*Preconditions*	*Preconditions*
Social	**Score:** 5 out of 5	**Score:** 5 out of 5
Final desirability	**Score: 4.9**	**Score: 5**

Table 7: Scores solar panels

6.1.2 Solar boiler

A solar boiler, other than solar panels, makes use of the heat of the sun. A solar boiler system captures the heat of the sun by means of a sun collector panel with an incorporated liquid. The panel warms up the water by means of the heat exchange between the heated liquid and the passing water. A pipeline system transports the heat into the water boiler, here the heated water is stored and subsequently distributed for warm water usage. From the boiler, the heated water can be used for daily consumption (zonnepanelen.info, n.d.). Once the water on the bottom of the boiler is cold, the water is transported through the sun heater and ends up in the boiler again. In this way, a sustainable water cycle is created. One can save significant amounts of gas for warming up water and therewith lower CO_2-emission.

Solar boiler assumptions

Since storage and distribution of energy is in technical terms much easier and more obtainable than that of water, it would not be feasible to install a solar boiler system for every household separately within the community building. The electrical infrastructure makes it possible to conduct power through single cables into a central grid and net the usage virtually after distributing energy through the existing distribution system in the community building. However, this methodology is not possible regarding the distribution of heated water. There is no central grid existing for communal collection of heated water and subsequent distribution of it. Creating one would have a huge impact on the costs, occupied space, and therewith efficiency of the technology in this context. Therefore, in the Anand Jyoti case the solar boiler system is only assumed as a technology option for the facilities within the communal space of the building. The roof above the communal space has an approximate effective area of 100m2.

The most appropriate type of solar heater is the one that is directly attached to the storage tank of the boiler. This allows the heater to serve as a kind of pre-heater for the regular existing boiler. In this way, the heat of the sun can also partly be used for the central heating system of the communal area in case of overproduction of common heated water use (Zonnepanelen-weetjes, n.d.). However, the periodic operation mechanism of the technology must be taken into account, i.e. low heat demand in summer. Heating energy is most needed in winter while a solar boiler system will generate most heat in summer. Therefore, covering the required energy for heating the building will cause a major energy surplus and thereby heat losses in summer.

Under the same intentions and conditions as with the solar panels, one of the most profitable and reliable type of solar boiler installation is selected as the default brand. The RemehaSol type solar boiler has been selected accordingly, assuming a lifespan of 25 years (Consumentenbond (2), 2016; Remeha, 2016)._One collector of 2,5 m^2 generates approximately 4700 Mega Joule (MJ) per year (Remeha, 2016; Zonnepanelen-weetjes, n.d.). The warm water usage of the communal space amounts approximately 2089 MJ per year. In addition, the central heating in the sunniest months of the year requires about 20% of the total heating demand, which is (0,2 x 48709 MJ ≈) 9742 MJ (energiesite.nl, n.d.). Together, there can be concluded that the capacity of the solar boiler system must not exceed 11831 MJ in order to prevent energy losses and inefficient financial payback. In this sense, 2 collectors (9400 MJ) would be sufficient to cover the warm water usage and .

Results:

Technical

A solar boiler system is a very common and widely applied sustainability measure in the Netherlands. Moreover, technical implementation of the system is, under normal circumstances, commonly feasible. However, in the case it concerns a community residential building, water infrastructure in terms of storage and distribution limit the possibilities of individual and/or extensive application of the solar boiler technology. Therefore, heat generation only for collective use in the communal space of the building can be accounted as feasible. Considering this, all technical issues concerning the communal space satisfy the technical preconditions for installing solar panels. Although, this is more comprehensive in comparison to the installation of a solar panel system. The installation duration of the complete solar boiler system would be around one working day (8 hours). This means the time/power proportion is approximately 11 seconds per kWh (8 hours / 2611 kWh x 3600 seconds). In conclusion, the technical feasibility of the implementation of solar panels can be considered 5 on a level of 1 to 5.

Environmental

The solar boiler system implemented at the Anand Jyoti community building generates 9400 MJ or 297 m^3 gas in total per year. 9400 MJ can be expressed in 2611 kWh. According to the general conversion rule determined in the baseline, this amount of energy saves approximately 496 kg of CO_2 per year (2611 kWh x 0,19 kg per kWh). The amount of primary energy that would have been needed to generate the energy now produced by the solar boiler system, has a total amount of (2611 kWh / 0,45 ≈) 5802 kWh.

Economic

A solar boiler system with two collectors and all related equipment costs approximately €4000,- (Remeha, 2016; Zonnepanelen-weetjes, n.d.; Consumentenbond (2), 2016). Within this price, the expected installation costs have already been taken into account. However, there is a subsidy available in the Netherlands with regard to the purchase of a solar boiler system. Although the subsidy is dependent on the brand, the RemehaSol boiler is incorporated in the conditions. The granted subsidy amounts €937,- (Milieucentraal, n.d.; RVO, n.d). This completes the full costs of the solar boiler system at €4000 - €937 = €3063,-.

The purchase of the solar boiler system can be covered with a municipal energy loan of the Amsterdam municipality. This loan has a fixed term of 10 years and an interest rate of (0,8 + 0,9 =) 1,7% (Gemeente Amsterdam (2), n.d.). As a result, the repayment per month will be (€3063 / 120 ≈) €25,53 without interest, and (€25,30 x 1,017 ≈) €25,96 with interest included.

The solar boiler system on the community building generates 9400 MJ per year. Since the net caloric value of dutch natural gas is as stated 31,65 MJ/m^3, the system equivalently generates (9400 / 31,65 ≈) 297 m^3 gas per year. The price per m^3 gas is €0,60. This means the community gains (297 x €0,60 =) €178,20 per year and (€178,20 / 12 =) €14,85 per month. This causes a negative balance of (€14,85 - €25,96 =) -€11,11 per month. Furthermore, the payback time of the solar boiler technology in this context is roughly 17 years and 6 months ((€25,96 x 120) / €178,20 euro). Only after this period, the solar boiler system could in theory start to bring money. Yet, the financial construction is loss making as a result of the 10 year term loan. In this sense, we can conclude that the technology is not effective nor efficient in economic terms.

Legislative

Refer to explanation of previous legislative section (solar panels).

Social

Similar to the PV panels, no behavioural changes are required for the installation of the solar boiler in the communal area. Nuisance is also low as installation would take place outside the houses. Social desirability therefore scores 5 out of 5.

Final desirability

The final desirability of this technique scores 1, since it is not economically feasible.

	Solar boiler
	Communal
Technical	Installation time: 8 hours **3 hours/1000 kWh** **Score:** 2 out of 5
Environmental	Yearly primary energy savings: 5802 kWh **Yearly CO_2 savings: 496 kg CO_2** **Score:** 1 out of 5
Economic	PBT: 17,5 years NPV: -€830,58 **Score:** 1 out of 5
Legislative	*Preconditions*
Social	**Score:** 5 out of 5
Desirability	**Score: 1**

Table 8: Score solar boiler

6.1.3 PVT panels

The PVT panel combines both technologies within the surface of 1 panel. This can be considered area-efficient. Although, relative energy conversion-efficiency is lower with respect to other technologies (Alius Solar, n.d.; Ten Brinck, 2016). Taking into account the earlier reasoning regarding the infrastructure, storage and demand of heated water, it would not be logical to install PVT panels throughout the roof. Also regarding the communal area, it would be inefficient to install PVT panels for energy and heat generation, since both individual PV panels and solar boiler systems have a higher efficiency. In this sense, PVT panels are only effective and efficient for private use in case there is a limited area available and there is substantially equivalent demand for energy and heat. As a result, the PVT-panels are no longer considered an appropriate technology in this case study and will not be further analysed in this report.

6.2 Biomass

Biomass is organic matter derived from living or recently living plants. Biomass contains large amounts of chemical energy that can be utilized as fuel, or bioenergy. Unlike fossil fuels, biomass is renewable. Moreover, as living plants incorporate carbon from the atmosphere during their lifetime, they essentially compensate for the CO_2 that is emitted when they are later used as a source of energy. This effectively makes bioenergy carbon-neutral. Still, using biomass for generating energy remains a controversial option. This is because land, water, energy and nutrients -which could be used to grow food crops- have to be sacrificed to grow energy crops, which are often themselves edible (Field, Campbell, & Lobell, 2008). For this reason, it is more sustainable to use plant waste, as opposed to first-generation energy crops, for generating bioenergy (Naik, Goud, Rout, & Dalai, 2010). For biomass as a source of energy, two technologies were considered; the Biomeiler, which produces heat through composting; and bio fermentation, which produces natural gas through fermentation. Initial desk research revealed that the biofermentation technology would not be feasible for the Anand Jyoti case, because a large amount of organic waste is required to produce just a small amount of biogas. Additionally, the infrastructure that is needed for biofermentation on such a small scale, is not yet available in the Netherlands. Therefore, only the Biomeiler is taken into consideration in this analysis.

6.2.1 Biomeiler

The Biomeiler is a system that can harness the energy present in discarded plant material. It is a large structure that harvests the heat released when biomass (usually in the form of woodchips, but other kinds of plant material may be used as well) degrades in the presence of oxygen, a process known as composting. Microbial activity in the Biomeiler steadily generates heat, which is tapped by a system of pipes leading water through the structure. While the Biomeiler needs to be exposed to sunlight, its energy output is relatively stable and does not depend (much) on the weather (Stichting Biomeiler, n.d.).

Whatever amount of heat energy is utilized from the Biomeiler, will not have to be produced by burning carbon-intensive natural gas. Biomeilers come in different shapes and sizes and the amount of heat produced by a Biomeiler depends primarily on its volume. Here we investigate what the minimal dimensions are for a Biomeiler capable of heating Anand Jyoti's common area year-round (only the water for the heating system, not tapwater).

Biomeiler assumptions

The energy savings of a Biomeiler can be said to equal the total heating costs of a building if it is capable of supplying sufficient heat during the months when heat demand is highest (i.e. winter). Since the gas use of the common area is not known on a month-to-month basis, inferences were made using general patterns of gas use during the year. Generally, january is the month in which the largest amount of energy, about 17% of annual use, is used for heating (energiesite.nl, n.d.).

The rate of energy use for heating (in kW) in januari was taken as the minimum amount that the Biomeiler needs to be able to generate. This estimate was obtained by multiplying the total amount of energy, in kWh, used in the year multiplied by 0.17, the fraction that is estimated to be used in January. This number was divided by the number of hours in january to calculate the minimum amount of heat that a Biomeiler must generate in order to fully cover heating costs during the time that demand is highest, and therefore the entire year.

The size calculator on the website of the company Native Power (Native Power, n.d.), which is involved in constructing Biomeilers, was then used to calculate the minimum size dimensions of a Biomeiler capable of generating the necessary amount of heat. As such, the total amount of natural gas saved by installing a Biomeiler of that size was then taken to be equal to current demand. Using the previously mentioned conversion factor, the amount of natural gas saved in this way (in m^3) was converted to energy savings (in kWh), CO_2-reduction and monetary savings (in €). Many of the economic costs are based on estimates given by Stichting Biomeiler on their website, as well as on correspondence with people involved in the Biomeiler project.

Results:

Technical

The heat output of a biomeiler depends mostly on its size and age. Larger Biomeilers generate more heat (though not necessarily higher temperatures), and heat output declines as the biomass degrades over time. As the biomeiler produces heat continually and without a storage vat, there is no way to store excess heat. While it is possible to install an underground vat to store excess heat for later use, Arie van Ziel of stichting Biomeiler pointed out that they are usually so costly that they are not worth it (personal correspondence, October 19, 2016).

Younger Biomeilers are mostly unaffected by weather fluctuations, but older ones may cool down after heavy rains. Tapping too much water at the same time can also cause the Biomeiler to cool down. Since the bacteria inside the biomeiler are themselves sensitive to temperature, such declines in temperature may not be reversible unless a fresh batch of bacteria is added. This may become a problem if the Biomeiler is being used in a communal setting where people do not know how much it has recently been used (Stichting Biomeiler, n.d.).

It takes roughly a day to build a Biomeiler. After a period of 18 months it needs to be deconstructed and rebuilt. The overall lifetime of the materials is around 10 years (Native Power, n.d.; Stichting Biomeiler, n.d.). Here we assume that the Biomeiler can be filled and refilled a total of 7 times. This amounts to 7 days of work in a period of 10.5 years of operation.

Environmental

The energy used to heat the communal area in january amounts to about 2300 kWh. Assuming constant heating through the month (i.e. also at night-time), the rate of energy use for heating would be around 3.1 kW.

A Biomeiler of approximately 6 meter in diameter and 2.1 meters in height generates 3.2kW and would thereby be sufficient to fully cover their communal heating needs (Native Power, n.d.) This saves about 1425 m^3 of gas per year, corresponding to 270.8 kg of CO_2.

Economic

The biomeiler does not require any hard-to-acquire or expensive materials. A large vat is required, as is tubing and a pump to keep water flowing throughout the structure. These materials costs between €600-€1200, depending on the size of the biomeiler. In addition to this, a barrier surrounding the biomeiler needs to be built. Depending on the material, this can cost between €15-€30 per meter. When the Biomeiler's heat output starts to decline after around 18 months, these materials can be reused or recycled and a new Biomeiler can be constructed from them. These materials need to be replaced after roughly 10 years (Native-power, n.d.). For people with the necessary skill, it is possible to construct a DIY Biomeiler. This is however very unlikely to be a possibility for the residents of Anand Jyoti and consequently contractors will have to be hired to set the Biomeiler up. This entails a one-time cost of about €1200,-.

Costs of integrating the Biomeiler to an existing boiler system can vary widely, ranging between €500 - €2500, depending on the Biomeiler's distance from the boiler and the amount of time needed to install it (Arie van Ziel, stichting Biomeiler, personal correspondence by e-mail, 19/10/2016). As the inhabitants of Anand Jyoti indicated that they did not want the Biomeiler directly in their communal outside area, but preferably in an adjacent green strip, costs will be at the higher end of the spectrum. Here the conservative estimate of €2500 is chosen.

Finally, the Biomeiler runs on large amounts of organic material, usually in the form of woodchips. Assuming a Biomeiler with a base diameter of 6 meters and a height of 2.1 meters, the volume of woodchips needed to fill the Biomeiler amounts to about $52m^3$. Crude (i.e. un-chipped) garden waste is often available for free, but it must be processed by a large, industrial wood chipper at about €10 per 1000 kg. Based on personal correspondence with Stephan Beentjes, who manages waste collection services in Amsterdam, about 19500 kg of 'crude' garden waste is required to generate $52m^3$ of woodchips that may be used in the Biomeiler. This would put fuel costs at about €195,- per 18 months, or €130 per year. Stichting Biomeiler estimates that woodchips, bought directly, cost around €15 per m^3. This would amount to a fuel cost of €780 per 18 months, or €520 per year. In the best case scenario, woodchips are available for free, for instance by donations from farmers. Each of these scenarios is considered.

When the Biomeiler no longer generates sufficient heat, the entire structure needs to be deconstructed and built anew. When the Biomeiler is first set up, stichting Biomeiler provides a workshop teaching participants how to build a Biomeiler themselves. The idea is that the participants are subsequently able to rebuild it when it is necessary. Unfortunately, due their advanced age, it is unlikely that the Anand Jyoti inhabitants are able to rebuild the structure by themselves. If young volunteers are not available to assist the community, the labour costs for rebuilding the Biomeiler would make this solution prohibitively expensive. It is here assumed that some volunteers are willing to periodically assist in rebuilding the Biomeiler.

Material costs	~€700,-
Set-up costs	~1200,-
Fence costs	€15* 6π ~= €282,-
Integration with existing boiler (estimate)	€2500,-
Total initial costs	**€4682,-**
Fuel costs	€520,- / year (buying woodchips) €195,-/ year (crude garden waste) €0 (free woodchips)
Savings	€861,- / year
Total costs	€4682 + 520*year (buying woodchips) €4682 + 195*year (crude garden waste) €4682 (free woodchips)
Payback period	4682/(861-520) = ~13.7 years (buying woodchips) 4682/(861-195) =~ 7 years (crude garden waste) 4682 / 861 =~ 5.4 years (free woodchips)
Annuity and Net Present Value	$\alpha = r / (1 - (1 + r)^{-L}) = 0{,}06 / (1 - (1 + 0{,}06)^{-10.5}) = 0{,}13$ €4682 + (861-520) / 0,13 = -2058.92 (buying woodchips) -4682 + (861-195) / 0,13 = 441.07 (crude garden waste) -4682 + (861-0) / 0,13 = 1941,07 (free wood chips)

Table 9: The NPV reveals that a Biomeiler is not economically viable if the woodchips have to be bought. However, in both other cases it can make a profit, albeit a moderate one.

Legislative

As Biomeilers are a relatively obscure technology, they are not eligible for a sustainability loan. The residents would themselves be the owners. However, while the Biomeiler would be their own, the same is not true for the area it occupies. As the inhabitants prefer not to put this structure in their own garden, it would have to be placed in the adjacent green strip (which belongs to the municipality). In this case, installing the Biomeiler will need to be negotiated in advance with the local municipality. Additionally, integration with the existing heating system (which the residents do not own) must be agreed upon by Stadgenoot.

Social

The Biomeiler has some serious drawbacks in an urban residential setting. Because of its size and lack of aesthetic appeal, from the group discussion became clear that residents are unwilling to put it directly in their communal garden. Instead, it would need to be placed in the adjacent park which might upset the neighbours who do not benefit directly from the Biomeiler. Moreover, periodically hiring people to reconstruct the Biomeiler would make this option too expensive. Therefore, it is important that there are volunteers willing and able to assist with this task. Because of these drawbacks, the social desirability score for the Biomeiler is 3 out of 5.

Final desirability

The final desirability = (Economic*4) + (Environmental*1) + (Technical*2) + (Social*3) /10 (based on the option of free wood chips)

Communal = (3*4)+(4*1)+(1*2)+(3*3) /10 = 2.7

	Biomeiler
	Communal
Technical	Installation time: 56 hours **4,14 hours/1000 kWh** **Score:** 1 out of 5
Environmental	Yearly primary energy savings: 13530.4 kWh **Yearly CO2 savings: 2679 kg CO2** **Score**: 4 out of 5
Economic	Initial investment: €4682,- PBT: 5.4 - 7 year (depending on fuel source) NPV: 441.07 - 1941,07 (depending on fuel source) **Yearly cost savings: €258.3 - €430.5** (depending on fuel source) **Score**: 3 out of 5
Legislative	*Preconditions*
Social	**Score:** 3 out of 5
Final desirability	**Score: 2.7**

Table 10: Score biomeiler

7. Efficient energy supply

The third step in the Trias Energetica model is to use the energy supply that is needed when the above steps are taken, in a most efficient way. In this chapter, two possible technologies of heat pumps are discussed.

7.1 Heat pump

In the recent years heat pumps have become increasingly popular for energy saving for water heating and spatial heating. This is because heat pumps are very efficient in transferring heat from a colder environment, outside, into a warmer environment, a building. This is done through a refrigeration cycle (Andrews & Jelley, 2013). There are multiple types of heat pumps; the most common are air sourced heat pumps and ground sourced heat pumps. The later could be water sourced or rock/soil sourced. Both types have proven to have potential for energy saving even in colder climates such as the Netherlands, however especially the air sourced heat pump should be examined site specific (Sarbu, I. & C. Sebarchievici, 2014; Vieira et al., 2015). The ground sourced heat pump is not feasible from an individual perspective. The use of a ground source heat pump would be problematic from a legislative and social perspective and will therefore be left out of this research.

Heat pump assumptions

Key to the analysis of the CO2 emission reduction and costs is the Coefficient of performance of a heat pump (COP). The principle of a heat pump is based on the Carnot cycle, which describes the ratio of heat Q and work W, which is called coefficient of performance (COP). An optimal ratio would result in a COP of 10. In practice, however, COPs are typically in the area of 3 to 4.5 (Andrews & Jelley, 2013). Usually ground source heat pumps (GSHP) are much more efficient than ambient air heat pumps because of the more constant temperature level of water compared to air. For an air source heat pump (AWHP) different COP apply to different temperatures. Because the outside air temperature differs greatly through the year a more suitable factor is used for performance; the seasonal performance factor (SPF). The SPF would be higher a hybrid system in which a boiler is used when the AWHP's efficiency is too low because of low outside air temperature (COPmin = 2,05). In this study average SPF's of earlier studies are used; SPF of 3,5 for a hybrid system and a SPF of 2,75 for a AWHP only system (Klein et al., 2014; Mattinen et al., 2015). According to most studies the COP for a GSHP varies between 3 and 6, for this study it is chosen to be the average 4,5 (Self et al., 2013). The lifetime of both heat pumps in this study is assumed to be 25 years. The assumed lifetime differs among authors from 30 years (e.g. Badescu, 2007; Garber et. al, 2013) and 20 years (Greening & Azapagic, 2012), an average is used.

A study of Klein et al. combined a 3kW capacity AWHP in combination with the old gas boiler (Klein et al., 2014). In the case of a hybrid system the 3 kW heat pump is considered too. The current 22kW boiler is overdimensioned according to this study. Based on the assumptions mentioned in the insolation section the heat specific heat loss of the apartment is little more than 100W/K and 240W/K. The capacity needed when a minimum outside temperature is reached (C=-10) equals 2800W for the apartment and 6720 W for the communal room. In the communal area, the capacity of the 3kW AWHP in the hybrid system will not be sufficient on these days, however also in due to efficiency loss of the AWHP the heat demand would be fulfilled by the gas boiler. This would be the case in the apartments too. Based on this estimation and according to Klein et al. (2014) the 3 kW AWHP should be able to provide enough capacity for heating almost all year and provide tap water in warmer months. Because the AWHP in a hybrid system will only be in operation when efficient enough a load factor of 0,57 will be used according to a study with a heat demand similar to the communal area (Klein et al., 2014). This an even higher heat demand than the heat demand of the apartments, it is therefore expected that the real load factor will be higher. The AWHP and GSHP only system would be installed with a capacity of 13 kW in the apartments and 16 kW in the communal area. This to overcome heat demand differences between apartments located in different areas of the buildings (the specific heat loss will differ) and to provide enough capacity for tap-water heating.

Insulation is vital for the output of a heat pump system, better insulated houses give a higher SPF (Klein et al., 2014). Moreover, heat pump systems are the most efficient in combination with low temperature heating systems. The temperature difference between the input and output becomes smaller and makes the heat pump more efficient. However, higher investments would be needed thus this is only considered feasible when combined with planned renovations. Because this is not the case at Anand Jyoti, this has been taken out of the scope of this study. Heat pumps can also be used for cooling purposes; this study only considered heating because the current radiator system is not suitable for cooling purposes. This should be further investigated.

7.1.1 Air-water heat pump (AWHP)

The air to water heat pump is a heat pump which uses the energy in the heat in the outside air to heat up water for heating and/or tap water. The performance of the AWHP is therefore dependent on the fluctuating outside temperature.

Results:

Technical

An AWHP system consists of an outside unit, an inside unit which should be within a distance of 10 meters from the outside unit and a buffer tank. Two pipes will connect the outside and inside units. Installing the AWHP system is relatively easy since little adjustments have to be made (Dutchheatpump, 2016). The expected amount of hours for installation will be 4 hours[2].

Environmental

Instead of gas, electricity would be used to produce hot water from the heat in outside air. Because of the relatively high efficiency compared to a gas boiler, the AWHP will save 20% of primary energy used to meet the heating demand in the communal area and the houses. Based on the calculations and assumptions in our methods the primary energy savings of the AWHP in the communal area will be 2708kWh a year, the high and low heat demand houses can save 1963kWh and 791kWh subsequently. All emission savings per area are given in Table 11. Interesting to notice is that an heat pump in the communal area has the highest energy primary savings but saves less CO_2. This is due to

[2] Based on telephone consult with heat pump installer

the fact that the reduced gas use is proportionally more displaced by electricity, which has a higher emission factor than only natural gas because we use a ‘grey’ electricity mix including e.g. coal. Thus the CO2 savings potential could be larger when this option would be combined with green electricity, this will be further elaborated upon in the integration section.

Economic

The investment costs of a 12 and 16 kW AWHP are between 6500 and 10500 euro and subsidies of between 2150 and 3400 can be obtained (Millieucentraal, 2016; Dutchheatpump, 2016). For this study an averaged investment of 6000 euro will be taken in which the subsidies are already incorporated. the depreciation costs of the current gas boiler are not taken into account because this boiler is owned by Stadgenoot and is assumed to be returned to Stadgenoot. The cost savings per year are 9 euro’s for the apartments with a low heating demand, 22 euro’s for the high heating demand houses and 98 euro’s for the communal area. However, when taking into account the investment costs, the heat pump system the annual savings are negative. The system is more expensive than the current system. The NPV is negative and the PBP is longer than the lifetime of the heat pump. The economic feasibility is therefore scored 1, not feasible.

Legislative

The most important issues from a legislative perspective are the right of the residents to make changes to the heating system of their house owned by Stadgenoot and the need for potential new residents to cooperate and adopt the loan from the former residents when residents move out or die. Both issues need to be addressed.

Social

A major social concern for this type of system could be the esthetics. A heat pump looks like a air conditioner from the outside. Residents in the neighborhood of Anand Jyoti might feel that their view is polluted. Moreover, if a heat pump is situated in the garden of Anand Jyoti to provide the communal area, residents of Anand Jyoti themselves could be bothered by the looks and the slight noise it makes. The room where the current gas boiler is located could fit a buffer tank, this reduces the storage space of residents and may therefore be unwanted. Accordingly, the nuisance of this technology is relatively high, so the social desirability scores 3 out of 5.

Final desirability

The final desirability score is 1 since this option is not economically feasible.

Air water heat pump (AWHP)			
	Communal	High heat demand	Low heat demand
Technical	Installation time: 4 hours **1,4 [hrs work/1000 kwh]** **Score**: 4 out of 5	Installation time: 4 hours **2 [hrs work/ 1000 kwh]** **Score:** 4 out of 5	Installation time: 4 hours **5 [hrs work/1000 kWh]** **Score:** 1 out of 5
Environmental	primary energy savings: 2708 kWh/year **-127,0 kg CO_2/year** **Score:** 1 out of 5	Primary energy savings: 1963 kWh/year **-280,2 kg CO_2/year** **Score:** 3 out of 5	Primary energy savings: 791 kWh/year **-112,9 kg CO_2/year** **Score:** 2 out of 5
Economic	Initial investment: €6000 PBP: 61 years NPV: -4743,9 **Score:** 1 out of 5	Initial investment: €6000 PBP: 262 years NPV: -5707,8 **Score:** 1 out of 5	Initial investment: €6000 PBP: 651 years NPV: -5882,3 **Score:** 1 out of 5
Legislative	*Preconditions*	*Preconditions*	*Preconditions*
Social	**Score:** 3 out of 5	**Score:** 3 out of 5	**Score:** 3 out of 5
Final Desirability	**Score: 1**	**Score: 1**	**Score: 1**

Table 11: Score AWHP

7.1.2 Hybrid heat pump (AWHP + existing gas boiler)

In a hybrid heat pump system the gas boiler is still used when the efficiency of the heat pump becomes too low. This system ensures a high efficiency heat production also during cold days in winter. The capacity of the heat pump can be much lower because it does not have to be able to produce the heat demand at peak times. This saves costs and space.

Results:

Technical

The same technical conditions apply as with the AWHP only system. However, this system needs to be connected to the current gas boiler. This should be done by an installer with expertise. For the installation process 5 hours is estimated because of this extra step.

Environmental

Because of the higher efficiency of this system the overall energy and therewith CO_2 savings are much higher than in the AWHP system discussed above. Here 21% of primary energy can be saved using this system, subsequently 2936kWh, 2128kWh and 958kWh for the communal area, high heat demand house and low heat demand apartment. This is only slightly more than the AWHP only system however the CO_2 savings are much higher than in the AWHP only system. This is due to the fact that less electricity is used which has a higher emission factor because of the fossil fuel mix than the when the gas boiler is used. The amounts of CO_2 saved yearly can be found in Table 12. In this study an equal load factor is used for all three spaces, the communal area, the low heat demand apartment and the high heat demand apartment, however in reality the load factors will differ, this will potentially lead to even higher CO2 savings in the low heat demand apartment.

Economic

Because this system combines an AWHP with a gas boiler, low capacity heat pumps which are cheaper can be used. Moreover, no buffer tank is needed in this system. The costs are therefore lower than an AWHP only. Prices are between 2.500 and 4.500 euro and subsidies up to 1.500 euro can be obtained (Millieucentraal, 2016; Dutchheatpump, 2016). The total investment costs used in this study are 2.600 euro including the subsidies (Dutchheatpump, 2016).

The saved costs per year based on the assumptions on use and performance vary from 43 euro (low heat demand household), 123 euro (high heat demand household) to 237 euro per year in the communal area. Taking into account the investment costs, investing in a hybrid heat pump for the communal area would be an economic feasible option. The NPV is positive and the PBP is 11 years while the lifetime of the heat pump is 25 years. The heat demand for the individual houses is too low to ensure enough savings per year to make the investment viable. The 'duurzaamheidslening' of the municipality is only lasting 10 years, because of the longer PBP it is advisable to find a loan with a longer pay-back time to ensure savings from the beginning. The yearly costs savings over the lifetime would be 37,18 euro.

Legislative

Again the same conditions apply as with the above described AWHP system. However, the issue of ownership could become complicated in the case on a hybrid system. Stadsgenoot owns the current gas boiler system and the new AWHP, owned by the residents, would be connected to the boiler.

Agreements should be made on the responsibilities of both parties in the event of a leakage or malfunction of the system. This could potentially be a problem.

Social

The same conditions apply to the hybrid system as to the AWHP system. However, because no buffer tank is needed, this system would have a slightly less negative impact on the comfort of the residents - scoring a 4 out of 5.

Final desirability

The final desirability = (Economic*4) + (Environmental*1) + (Technical*2) + (Social*3) /10
Communal = (3*4)+(1*1)+(1*2)+(3*3) /10 = 2.4
High heat demand = 1
Low heat demand = 1

	Hybrid heat pump (AWHP + existing gas boiler)		
	Communal	**High heat demand**	**Low heat demand**
Technical	Installation time: 5 hours 1,7 [hrs work/1000 kWh] **Score:** 4 out of 5	Installation time: 5 hours 2,5 [hrs work/1000 kWh] **Score:** 3 out of 5	Installation time: 5 hours 5,8 [hrs work/1000 kWh] **Score:** 1 out of 5
Environmental	primary energy savings: 2936 kWh/year -402,064 kg CO_2/year **Score:** 1 out of 5	primary energy savings: 2128 kWh/year -479,562 kg CO_2/year **Score:** 5 out of 5	primary energy savings: 958 kWh/year -174,423 kg CO_2/year **Score:** 2 out of 5
Economic	Initial investment: €2600 PBP: 11 years NPV: 437 Cost savings: -€34,18/year **Score:** 3 out of 5	Initial investment: €2600 PBP: 21 years NPV: -1016,87 **Score:** 1 out of 5	Initial investment: €2600 PBP: 59 years NPV: -2039,3 **Score:** 1 out of 5
Legislative	*Preconditions*	*Preconditions*	*Preconditions*
Social	**Score:** 4 out of 5	**Score:** 4 out of 5	**Score:** 4 out of 5
Final desirability	**Score: 2.4**	**Score: 1**	**Score: 1**

Table 12: Score AWHP

7.1.3 Ground source heat pump (GSHP)

The option of providing individual households with heat from a shared ground source heat pump is considered not to be feasible after the pre study. This is because it would require substantial technical adjustments such as change of piping through the whole building. The total costs of these adjustments would be very high and not cost effective, especially because not all residents are willing to change their heating system which means two systems of piping (gas and hot water) would still be in place[3]. Moreover, all these adjustments would be difficult from a legal perspective. The ownership situation of the Anand Jyoti complex forms a constraint for this technology.

However, ground source heat pumps are found in different variations. Providing the communal area with a GSHP may still be feasible, on which the analysis below is conducted. In this study a closed circuit GSHP of 16kW is taken into account for the communal area.

Results:

Technical

Installing a GSHP would be a time consuming and comprehensive project. Piping has to be buried in the garden or other outside area. This means the time needed for installing would be much higher than in the case of the AWHP. The installation time is assumed to be 1 week, 40 hours (5,6h/1000kWh).

Environmental

The ground source heat pump has the highest potential for energy and CO_2 savings because of the higher efficiency than air sourced heat pumps. The primary energy savings are 49%, 7142 kWh/year and total emission savings are 1176,62 kg a year.

Economic

The energy savings also result in yearly cost savings of 471 euro. Although this seems like a good investment, the total investment costs are too high to be able to pay itself back over the lifetime. The total investment costs are between 10.000 and 15.000 euro and subsidies range from €500-2.500 (RVO, 2016b). Even though the PBP is shorter than the lifetime of the technology (21,23 years), the NPV is negative which means that investing in this technology is more expensive than saving the money. This technology is therefore scored as not feasible from an economic perspective.

Legislative

Similar to legislative implications of the other heat pumps analyzed above.

Social

No behavioural changes in energy consumption are required. However, due to high intensity and time of required installation which would considerably cause nuisance, the GSHP scores 3 out of 5 for social desirability.

Final desirability

The final desirability scores 1 since this technology is not economically feasible.

[3] Based on phone interview with expert

	Ground source heat pump (GSHP)
	Communal
Technical	Installation time: 40 hours **5,6 [hrs work/1000 kWh]** **Score:** 1 out of 5
Environmental	Primary energy savings: 7142 kWh/year **-1176,62 kg CO2/year** **Score:** 2 out of 5
Economic	Initial investment: €10.000 PBP: 21 years NPV: -3516,73 **Score:** 1 out of 5
Legislative	*Preconditions*
Social	**Score:** 3 out of 5
Final desirability	**Score: 1**

Table 13: Score GSHP

7.1.4 Changing to green energy

All but one household in the Anand Jyoti community have energy contracts with 'grey' electricity producers. A simple option for emission savings would be changing the contracts to a 'green' energy company.

Changing to green energy assumptions

Green energy emits 0 kg of CO_2 per m^3 or kWh. Here, life cycle emissions are not taken into account. The chosen energy provider could be Qurrent, Greenchoice or another company which provides green electricity and compensates the emissions for natural gas burning. The standard costs and variable cost difference are assumed to be negligible.

Results:

Technical

This option would not require any technical or physical changes. The given score for technical feasibility is therefore 5.

Environmental

This option will not reduce the primary energy for natural gas. It does however reduce the primary energy needed for electricity production because this will be wind/solar or another green energy source. According to the general rule determined in the baseline, a high electricity demand household would save approximately 1474 kg of CO_2 per year for electricity. For a low demand household this is 569,5 kg of CO_2 per year and 3372 kg CO_2 for the communal area. They will also save CO_2 for gas use, subsequently 2237 kg, 901 kg and 2826 kg.

Economic

Changing provider has no effect on the economics. No investment costs are needed and no costs savings are present.

Technical

Since residents are free to chose their energy provider this would not cause any problems with their contracts with Stadgenoot. Changing energy provider is free in between contracts and contracts are normally 1 year length. However, if residents have chosen a longer term contract, changing during the contract might be fined. If this is the case it is advised to wait until the current contract finishes.

Social

The social desirability for this option scores high, since the residents already indicated to be flexible in changing energy supplier (see social baseline). This would not entail behavioural change or nuisance, so the social desirability scores 5.

Final desirability

The final desirability of changing to green energy scores a 5 out of 5 since the residents already indicated to be open to change energy supplier, this would not entail costs or technical installation and the amount of CO_2 that would be saved is relatively high.

	Changing to green energy		
	Communal	**high energy demand**	**low energy demand**
Technical	**Score:** 5 out of 5	**Score:** 5 out of 5	**Score:** 5 out of 5
Environmental	Electricity: 2826 kg of CO_2 Gas: 3372 kg CO_2 Total: 6198 kg CO_2 **Score:** 5 out of 5	Electricity: 1474 kg CO_2 Gas: 2237 kg of CO_2 Total: 3711 kg of CO_2 **Score:** 5 out of 5	Electricity: 569,5 kg CO_2 Gas: 901 kg CO_2 Total: 1470,5 kg CO_2 **Score:** 5 out of 5
Economic	-	-	-
Legislative	*Go*	*Go*	*Go*
Social	**Score:** 5 out of 5	**Score:** 5 out of 5	**Score:** 5 out of 5
Final desirability	**Score: 5**	**Score: 5**	**Score: 5**

Table 14: Scores changing to green energy

8. Integration: proposed pathways

8.1 Integration of different technologies

In this section all the different technologies, which have been analysed and assessed accordingly, are integrated towards a suitable and combined solution for Anand Jyoti. This means a combination of the different technologies are discussed in order to generate an optimized plan for sustainable electricity and heat use within the living community. To come to the optimal combination the Trias Energetica is followed; the best options per step from the trias energetica are chosen and combined. These options are derived from the total given score per technology.

8.1.1 Technologies and the Trias Energetica for communal area

Here the ideal combination of technologies proposed in this paper for energy savings in the communal area is presented. The scores per technology are presented in table 15 below.

	Energy savings		Renewable energy supply			Efficient energy supply			
	Insulation	LED	PV Panels	Solar Boiler	Biomeiler	Heatpump	Hybrid heatpump	Ground heatpump	Green energy
Technical	1	4	5	2	1	4	4	1	5
Environmental	1	1	5	1	4	1	1	2	5
Economic	1	2	4	1	3	1	3	1	-
Legislative	Pre-conditions	go	Pre-conditions	Pre-conditions	Pre-conditions	Pre-conditions	Pre-conditions	Pre-conditions	go
Social	4	5	5	5	3	3	4	3	5
Final desirability	**1**	**3.2**	**4.9**	**1**	**2.7**	**1**	**2.4**	**1**	**5**

Table 15: Technology scores for the communal area

Step 1: Energy saving
As can be seen, the only feasible option for energy savings presented in this paper is the option of switching to LED lighting. This technology will save the communal area money, it will save energy and thus CO_2 emissions and LED lights are very easy to install.

Step 2: Substitution with renewables
For renewable energy substitution both the PV panels and Biomeiler show positive results and a promising overall score. These technologies can be combined because the PV panels will substitute electricity and the Biomeiler will substitute natural gas.

Step 3: Efficient use of fossil energy
The hybrid heat pump shows potential in the third step of the Trias Energetica, this is due to its higher efficiency on energy use, and therefore savings of primary energy. The highest score however is given to changing to a green energy provider. The latter does not save energy, but it does replace fossil energy with green energy; reducing the total carbon emissions of energy use to zero.

Proposed pathway for the communal area

Following the Trias Energetica, the proposed pathway is combining LED lighting with PV Panels and a Biomeiler. The hybrid heat pump also showed positive results, however this technology is not included in the combined pathway. This is because the Biomeiler will substitute all energy needed for heating and this reduces the gas demand dramatically. The heat pump will therefore not be cost effective after implementation of the Biomeiler. However, if the community decides not to implement the Biomeiler, the heat pump will become an interesting option. This alternative pathway is included in Appendix C. Cost savings per year might differ from the individual result section in the proposed pathway because of the integration and thus different energy inputs.

Current final energy demand: 1500 m^3 natural gas 6000 kWh electricity Current CO_2 emission: 5982 kg	Energy and CO_2 savings	Cost savings
Step 1	LED lighting -366 kWh electricity -192,5 kg CO_2 emissions	€61,13
Step 2	PV Panels substitution: -5634 kWh electricity -2963,48 kg CO_2 Biomeiler Substitution: -1425 m^3 gas -2684,7 kg CO_2 emissions	€474,14 €258,3 - €430,5
Step 3	Changing to green energy: -141,3 kg CO_2 emissions (75 m3 gas)	
Total savings	1425 m^3 gas 6000 kWh electricity 5982 kg CO_2 emissions	€793,57 - €965,77

Table 16: Pathway steps for the communal area

8.1.2 Technologies and the Trias Energetica for low and high energy demand

The desirability scores per technology are presented in table 17 and 18 below. The only major difference between the scores for the high and low demand households are the potential for primary energy savings of the LED and heat pumps. The scores for environment and technical feasibility therefore differ.

low energy demand	Energy savings		Renewable energy supply			efficient energy supply			
	Insulation	LED	PV Panels	Solar Boiler	Bio-meiler	Heatpump	Hybrid heatpump	Ground heatpump	Green energy
Technical	1	4	5	-	-	1	1	-	5
Environmental	1	5	5	-	-	2	2	-	5
Economic	1	5	5	-	-	1	1	-	-
Legislative	Pre-conditions	go	Pre-conditions	-	-	Pre-conditions	Pre-conditions	-	Go
Social	4	5	5	-	-	3	4	**-**	5
Final desirability	**1**	**4.1**	**5**	**-**	**-**	**1**	**1**	**-**	**5**

Table 17: Technology scores for the low energy demand individual houses

high energy demand	Energy savings		Renewable energy supply			efficient energy supply			
	Insulation	LED	PV Panels	Solar Boiler	Bio-meiler	Heatpump	Hybrid heatpump	Ground heatpump	Green energy
Technical	1	4	5	-	-	4	3	-	5
Environmental	2	5	5	-	-	3	5	-	5
Economic	1	4	5	-	-	1	1	-	-
Legislative	Pre-conditions	go	Pre-conditions	-	-	Pre-conditions	Pre-conditions	-	go
Social	4	5	5	-	-	3	4	-	5
Final desirability	**1**	**4.4**	**5**	**-**	**-**	**1**	**1**	**-**	**5**

Table 18: Technology scores for the high energy demand individual houses

Step 1: Energy saving
The only feasible option for energy savings presented in this paper is switching to LED lighting. This technology will save energy and CO_2 emitted, for the high as well as the low-energy households. Also, LED lights are very easy to install.

Step 2: Substitution with renewables
PV panels are the only desirable option for generating renewable energy. This option is fairly easy to implement and has high cost reductions and CO_2 savings.

Step 3: Efficient use of fossil energy
The use of heat pumps for efficient energy use is not feasible from an economic perspective. The only positive score in this step is thus given to changing to a green energy provider. This is the option that is included in the integrated pathway.

Proposed pathway for individual households

The remaining electricity production of the PV Panels from the communal is be divided among the 24 households. substituting the total electricity demand of low energy demand households (assuming 50% of the apartments is a low energy demand households) and providing the high energy demand households with almost half of their electricity. In the integration the possibility of combining insulation and a heat pump system have been evaluated because these technology influence each other and could therefore have a positive effect on the cost effectiveness of both technologies. This is however found not to be the case for the individual households of Anand Jyoti. Both options are therefore not included in the pathways.

Low energy demand houses

Current final energy demand: 1013,38 kWh 478,49 m^3 gas Current CO_2 emission: 1434,51 kg CO_2	Energy and CO2 savings	Cost savings
Step 1	LED lighting[4] -137,13 kWh -72,13 kg CO_2	€20,31
Step 2	PV Panels substitution: -856 kWh -450,26 kg CO_2	€72,80
Step 3	Changing to green energy: - 11,18 kg CO2 (21,25 kWh electricity) - 901,48 kg CO2 (478 m3 gas)	-

4 The calculated amount of potential electricity savings from LED is relatively high compared to the total electricity demand of the low energy demand apartments (342,83 kWh savings and 1013,38 kWh total demand). This amount of savings is taken as the potential for high energy demand houses. high energy demand households have a factor 2,5 higher electricity demand than the low energy demand households. The potential LED savings are therefore also expected to be a factor 2,5 lower for the low energy demand houses (137,13 kWh)

Total savings	993,13 kWh electricity 0 m^3 gas 1435,05 kg CO_2 emission	€93,11

Table 19: Pathway steps for the low energy demand individual houses

As a result, for low energy demand households 478 m^3 gas demand is left, 0 kg CO_2 is emitted, and 20,25 kWh demand is left.

High energy demand houses

Current final energy demand: 2622,89 kWh electricity 1187,14 m^3 gas Current CO_2 emission: 3621,9 kg	Energy and CO_2 savings	Cost savings
Step 1	LED lighting -342,83 kWh electricity -180,32 kg CO_2	€50,79
Step 2	PV Panels substitution: -856 kWh electricity -454,99 kg CO_2	€72,8
Step 3	Changing to green energy: -749,58 kg CO_2 (from 1425,06 kWh electricity) -2236,57 kg CO_2 (from 1187,14 m^3 gas)	
Total savings	1198,83 kWh electricity 0 m^3 gas 3621,9 kg CO_2 emissions	€123,59

Table 20: Pathway steps for the high energy demand individual houses

As a result, for high energy demand households 1187 m^3 gas demand is left, 0 kg CO_2 is emitted, and 1424,06 kWh demand is left.

8.2 Future steps

In this section, a plan is presented in which all the steps, that have to be undertaken in order to achieve the outlining of the pathway, are incorporated. All technical, environmental, economic, legislative and social aspects that have to be taken into account in order to achieve the final purpose are presented in this section.

General

- Come to a common understanding and consensus within the Anand Jyoti community on the way forward.
- Retrieve data on the energy use of the communal area from Stadsgenoot.
- Gather various price offers from providers of the proposed feasible technologies. Their experts will conduct a thorough inspection and are able to give an accurate price and impact overview.
- Seek expert advice on loan structures and payment structures for investments made by a community.
- Negotiate with Stadsgenoot about the legal aspects of the proposed changes of ownership.

Biomeiler

- Ask for permission of the municipality for placing a Biomeiler near Anand Jyoti. Seek approval of neighbours first.

9. Discussion and Limitations

In this section both the strong points and the limitations of our research regarding Anand Jyoti are discussed. An important part herein is the evaluation of the research process. In our methodology we have proposed use indicators to score the different technologies on economic, environmental, technical and legislative feasibility. Scoring options is a good way of comparing technologies, but there is always the risk of simplifying the matter too much. In this study it has been tried to balance this by giving the specific numbers and score them afterwards. Moreover, the background of the scores are given in the results sections per technology. Furthermore, choosing right indicators to score the technologies on a scale becomes very important in this way of presenting results. For technical feasibility this proved to be a challenging, because technical feasibility is a condition for implementation to be possible at all (therefore a dichotomous decision, not a scaled value).

However, the difficulty of installation is not equal between the different technologies. This is closely interlinked with the economic aspect of investment costs and the social aspect of having to deal with 'hassle'. To avoid overlap our indicator of installation time/1000 kWh saved yearly was chosen. The importance and value of this indicator and what it measures is however debatable, as installation methods diverge. Another indicator which could be improved in further research is environmental impact. CO_2 emissions of energy savings are used in this study, but the environmental impact of the technology itself is not included. This could be done through a Life Cycle Analysis.

The chosen technologies are all scientifically proven, except the Biomeiler. This technology is relatively new, looks promising however is little studied by scholars. The used references are mostly from non-scientific sources. This does not necessarily have lo lead to problems, however this technology should be handled with caution. Moreover, changing the current equipment to A+++ equipment has not been included in the energy savings analysis due to time constraints. The current situation has been measured, see Appendix D, it is however not included in the results. At least 2 out of 6 apartments where measurements have taken place use appliances older than 15 years. The potential for energy and cost saving is therefore major. Changing to A+++ equipment should be addressed in further studies.

Early in the process data collection has started, however not all data needed has been retrieved. This was partly due to the lack of planning of the authors. This was the case for accurate measurements of the dimensions of the property. However, for some other important inputs, such as data on the energy use of the communal area, coordination for data gathering between the residents and Stadgenoot appeared to be impossible. Many assumptions have therefore been made, which decreases the accuracy of the results. Moreover, assumptions are made on 'average' energy demands of households in the Anand Jyoti community. In real life the 'average' house does not exist. We have tried to overcome this by using a low and high energy demand average. This makes our results more applicable but they remain an average. Furthermore, assumptions on energy prices are made in over to calculate potential savings. Energy prices however differ greatly and might change in the near future. This too is the case for energy tax. For all other unknown factors assumptions are used as close as possible to the real situation. Presenting results would not have been possible without these assumptions, however they also undermine the accuracy of the results.

10. Conclusion

Changes need to be made to our whole society if GHG emissions need to be reduced by 2050 in accordance with the Paris climate agreement. A large amount of the GHG emissions are released through the burning of fossil fuels for energy production. In order to cut back on the amount of fossils fuels needed, our energy consumption and production should be altered. More and more individuals and small local communities are making considerable efforts to change the way they consume but also produce energy. Different measures and technologies can be implemented that will reduce the amount of energy consumed or produce one's own renewable energy.

A community that also wanted to become more energy sustainable and seeked for our help is the Anand Jyoti. This a group of elderly Hindustani who have organised themselves to live in a more participatory manner. They use a communal kitchen, do activities together and have a system where their scootmobiles are shared among the inhabitants. A next step in their participatory manner of living would be to produce renewable energy for communal and individual use but also it is important from an environmental perspective to reduce the energy consumption of the inhabitants. Therefore we have done extensive research into the most feasible manners in which the Anand Jyoti can become a more energy sustainable community.

From the results it has become clear that a combination of different options is most optimal for the Anand Jyoti. First, it has been determined that the installation of solar PV panels is the most desirable option. By generating electricity through PV panels, the communal areas are completely supplied with green energy and no fossil energy is needed anymore. The rest of the energy production can be shared with the wider community through the *postcoderoos* policy. This first option can be ideally combined with energy saving measures, in particular installing LED lighting in all the individual apartments. Within the current situation of the Anand Jyoti it has been evaluated that individual energy consumption is relatively high. By installing efficient LED lights the energy consumption of the people can be reduced. Finally, in order to reduce the amount of natural gas needed for the communal space, the biomeiler is evaluated to be a feasible option. A biomeiler would all year long provide a stable source of heat to the building in a sustainable manner. A combination of these three individual measures is concluded to be the most feasible pathway for the Anand Jyoti to take in order to become more energy sustainable.

Although these results and most feasible technological options are specific for the Anand Jyoti case, it needs to be stressed that the methodology can be replicated and used for other cases. In this sense the report has not only been beneficial for the Anand Jyoti but can guide other initiatives to become more energy sustainable.

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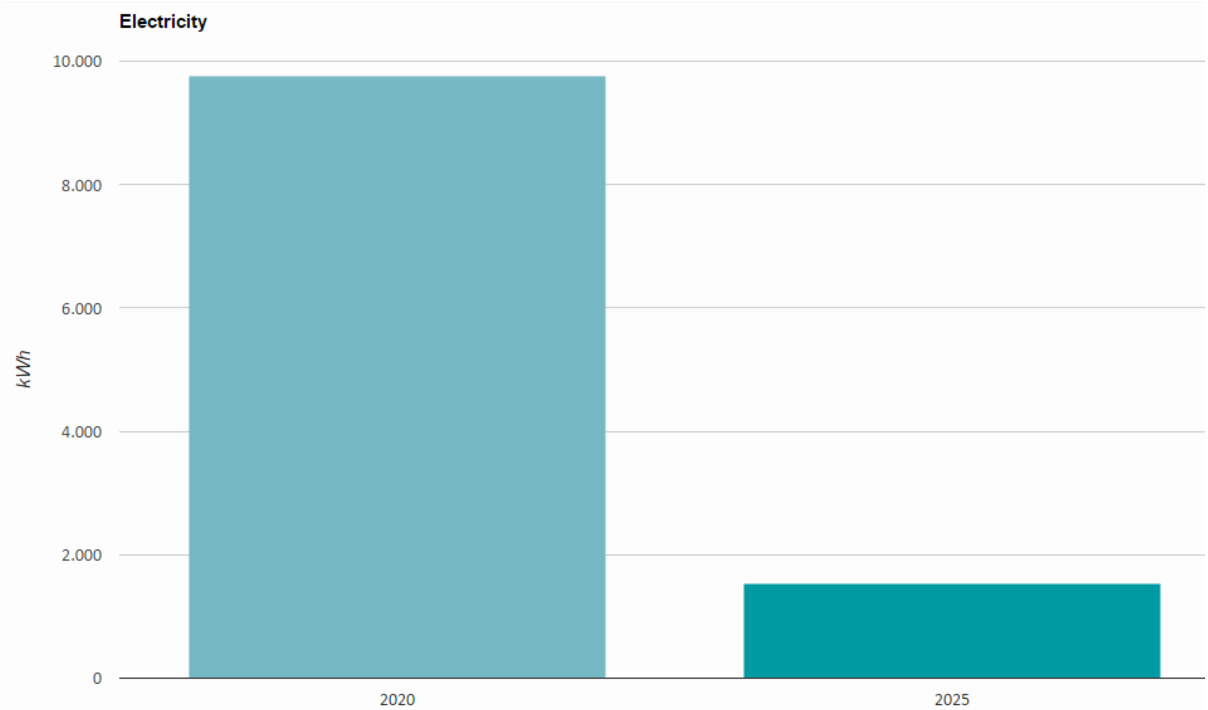
Appendix A - Abundance lighting types Anand Jyoti complex

	LED	CFL	Halogen	Light Bulb	Fluorescent beam	Total
9E	0	6	5	0	0	11
5D	3	0	16	3	3	25
5B	1	3	9	2	0	15
5M	1	13	9	0	0	23
9F	0	3	7	0	4	14
7B	2	12	8	1	0	23
Total	7	37	54	6	7	111

Data analysis of different lightening types from 6 apartments of the Anand Jyoti community.

Appendix B - Final energy consumption ScenarioTool



The simulated amount of final energy (electricity) saved between the reference year (2020) and the final year (2025) is 8.228 kWh per year for the 24 Anand Jyoti apartments together (BDH, 2016).

Appendix C - Alternative Pathway

Current final energy demand: 1500 m^3 natural gas 6000 kWh electricity Current CO_2 emission: 5982 kg	Energy and CO_2 savings	Cost savings
Step 1	LED lighting -366 kWh electricity -192,5 kg CO_2 emissions	€61,13
Step 2	PV Panels substitution: -7932 kWh electricity -4172,23 kg CO_2	€669,9
Step 3	Heat pump: -855 m3 gas +2298 kWh electricity -402,06 kg CO2 Changing to green energy: - 1215,18 kg CO_2 emissions (655 m3 gas)	€34,18
Total	855 m^3 gas 6000 kWh electricity 5982 kg CO_2 emissions	€765,21

Appendix D - Data analysis of the individual apartments

	Collective Space			***Individual households***				
Devices		***Frequency of use***	***Energy label***	***Number of households***	***Frequency of use***	***Number of households***	***Energy label***	***Number of households***
Dryer	*0*	*-*	*-*	*4*	*1 time a week:* *3 times a week:*	*2* *2*	*A++:* *None:*	*1* *3*
Washing	*0*	*-*	*-*	*6*	*1-2 times a*	*4*	*A++:*	*1*

machine					*week:* *3-4 times a week:*	*2*	*A+:* *None:*	*3* *2*
TV	*0*	*-*	*-*	*6*	*3-4 hours per day:* *6 hours per day:* *Never:*	*4* *1* *1*	*LED:*	*6*
Computer	*1*	*1-2 hours a day*	*LED*	*0*	*-*	*-*	**-**	*-*
Laptop	*0*	*-*	*-*	*5*	*3 hours a day:* *1 hour a day:*	*4* *1*	*Old:* *New:*	*3* *2*
Microwave	*1*	*1 time a week*	*New*	*5*	*2 times a day:* *1 time a week:* *Rarely:*	*1* *2* *2*	*New:* *Old:*	*2* *3*
Dishwasher	*1*	*1 time a week*	*New*	*2*	*1 time a week:* *1 time a day:*	*1* *1*	*A+:* *Old:*	*1* *1*
Fridge	*1*	*Fulltime*	*New*	*6*	*Fulltime*	*6*	*A++:* *None:*	*2* *4*
Freezer	*1*	*Fulltime*	*New*	*6*	*Fulltime*	*6*	*None:*	*6*
Lights	-			*6*	*5-10 hours:* *10-15 hours a day:* *Unknown:*	*1* *2* *3*	*Some LED:* *No LED:*	*2* *4*

Data analysis 9E

General data	Equipment	Amount	Label	Frequency	Watt
9E	Dryer	1	A++	0,5x pw	
Mevrouwe Hoeba	Washing machine	1	A+	1x pw	
Corner house	TV	1	LED		
Sun sided	Computer	0			
3-room apartment	Oven	1	new	1x pm	
1 person	Microwave	0	new	1x pw	
63 Euro pm	Dishwasher	0			
level 1	Refrigerator (combi)	1	A++	fulltime	0
	Freezer	1		fulltime	
	Laptop	1	10 yrs	3 hrs/day	
	Lightening*	11		5-10 hrs	
	Kettle	1			1950

Lightening*	LED	Fluorescent beam	halogen	CFl	light bulb
11	0	0	5	6	0

Energy sharing

Possibly	yes	no
X		

Opinion
In the mood for new sustainable incentives

Behaviour

	Reference	Adaptable?
Temperature	19 degrees Celsius	little lower
Clothing	warmer clothing when colder	impossible
Lights off	yes	impossible
Doors closed	yes	impossible
Stand-by	TV/ laptop	yes
Total impression	energy efficient	almost impossible

Insulation

inside wall	plaster walls	
ouside wall	brick	double glass
doors	weather strips	
floor	laminate	isolated + damping
Weak spots	none	

Data analysis 5D

General data	Equipment	Amount	Label	Frequency	Watt
5D	Dryer	1	18 yrs	3x pw	
André Bhola	Washing machine	1	A++	3x-4x pw	
Corner	TV	1	LED	6 hrs pd	38 / 50
Shadow side	Computer	0			
3-room apartment	Oven	1	new	rarely	
2 persons	Microwave	2	6 yrs / 2 yrs	1-2x pw	715
105 Euro pm	Dishwasher	1	6 yrs / 2 yrs	0,5x pd	
ground floor	Refrigerator (combi)	1	A++	fulltime	0
Essent	Freezer	1	8 yrs	fulltime	
	Laptop	1	3 yrs	3 hrs / day	
	Lightening*	25		10-15 hrs pd	
	Kettle	1			1326
	Senseo	1			1412
	Sandwich iron	1		1x pd	675

Lightening*	LED	Fluorescent beam	halogen	CFl	light bulb
25	3	3	16	0	3

Energy sharing

Possibly	yes	no
		X

Opinion
Couples don't like sharing; Singles do like sharing

Behaviour

	Reference	Adaptable?
Temperature	22 degrees Celsius	little lower
Clothing	warmer clothing when colder	little
Lights off	2 small ones always on	yes
Doors closed	most of the time	not possible
Stand-by	tv / laptop	yes
Total impression	not energy efficient	yes

Insulation

inside wall	plaster walls	
ouside wall	brick	double glass
doors	no weather strips	
floor	wood	isolated + damping
Weak spots	windows and lattices	

Data analysis 5B

General data	Equipment	Amount	Label	Frequency	Watt
5B	Dryer	1	18 yrs	1x pw	
xxx Bhola	Washing machine	1	1 yr	1-2x pw	
Midden	TV	1	LED	4 uur pd	
Schdawkant	Computer	0			
3-kamer	Oven	2	18 yrs	zelden	
2 persons	Microwave	1	18 yrs	3-4x pw	1164
105 Euro pm	Dishwasher	1	18 yrs	1x pw	
Ground floor	Refrigerator (combi)	1	18 yrs	fulltime	0
	Freezer	1	6 yrs	fulltime	
	Laptop	1	4 yrs	3 uur/wk	
	Lightening*	15		10-15 uur pd	
	Kettle	1			1765
	Senseo + Nespresso	1	6 yrs	1-2x pd	1062 + 1296
	Sandwich iron	0			675

Lightening*	LED	Fluorescent beam	halogen	CFl	light bulb
15	1	0	9	3	2

Energy sharing

Possibly	yes	no
		X

Opinion
Couples don't like sharing; Singles do like sharing

Behaviour

	Reference	Adaptable?
Temperature	20 degrees Celsius	little lower
Clothing	warmer clothing when colder	little
Lights off	yes	not possible
Doors closed	indoors closed	yes
Stand-by	tv	yes
Total impression	average	yes

Insulation

inside wall	plaster walls	
ouside wall	brick	double glass
doors	no weather strips	
floor	wood	isolated + damping
Weak spots	windows	

Data analysis 5M					
General data	**Equipment**	**Amount**	**Label**	**Frequency**	**Watt**
5M	Dryer	0			
M Hiralall	Washing machine	1	A+	1x pw	
Middle apartment	TV	1	LED	3 hrs pd	
Sun sided	Computer	0			
3-room apartment	Oven	1	3 yrs	0,5x pw	
1 person	Microwave	1	5 yrs	rarely	1594
	Dishwasher	0			
Nuon	Refrigerator (combi)	1	4 yrs	fulltime	0
Level 2	Freezer	1	5-10 yrs	fulltime	
	Laptop	0			
	Lightening	23			
	Kettle	1	2 yrs	2x pd	1765
	Senseo	0			
	Sandwich iron	1	4 yrs	1x pm	

Lightening*	LED	Fluorescent beam	halogen	CFl	light bulb
23	1	4	9	13	0

Energy sharing

Possibly	yes	no
		X

Opnion
Appreciates own privacy

Behaviour

	Reference	Adaptable?
Temperature	19 degrees Celsius	niet mogelijk
Clothing	slightly warmer clothing when colder	trui + verwarming
Lights off	yes	niet mogelijk
Doors closed	indoors closed	niet mogelijk
Stand-by	none	niet mogelijk
Total impression	very energy efficient	niet mogelijk

Insulation

inside wall	plaster walls	
ouside wall	brick	double glass
doors	weather strips	
floor	laminate	isolated + damping
Weak spots	windows and lattices	

Data analysis 9F					
General data	Equipment	Amount	Label	Frequency	Watt
9F	Dryer	0			
C. Ramsanjal	Washing machine	1	12 yrs	1x pw	
Corner	TV	1	LED	never	
Sun sided	Computer	0			
3-room apartment	Oven	2	10 / 5 yrs	1x pm	
1 person	Microwave	1	5 yrs	rarely	
104 Euro pm	Dishwasher	0			
Energie Direct	Refrigerator (combi)	1	8 yrs	fulltime	0
level 2	Freezer	1	4 yrs	fulltime	
	Laptop	1	2yrs	5 hours pw	
	Lightening*	14			
	Kettle	1		3x pd	1863
	Senseo	0			
	Sandwich iron	1		1x py	

Lightening*	LED	Fluorescent beam	halogen	CFl	light bulb
14	0	4	7	3	0

Energy sharing

Possibly	yes	no
	X	

Opinion	
In the mood for new sustainable incentives	

Behaviour

	Reference	Adaptable?
Temperature	20 degrees Celsius; 19 during night	not possible
Clothing	warmer clothing when colder	not possible
Lights off	1 always on	little
Doors closed	yes	not possible
Stand-by	tv / dvd	yes
Total impression	Average	little

Insulation

inside wall	plaster walls	
ouside wall	brick	double glass
doors	weather strips	
floor	linoleum	damping
Weak spots	windows	

Data analysis 7B					
General data	Equipment	Amount	Label	Frequency	Watt
7B	Dryer	1		3x pw	
S. Nohar	Washing machine	1	A+	3x pw	
Corner	TV	1	LED	4 hours / day	
Shadow / Sun	Computer	0			
2-room apartment	Oven	2	20 yrs	1x pm	
1 person	Microwave	1	3 yrs	2x pd	
104 Euro pm	Dishwasher	0			
Essent (3-yrs contract)	Refrigerator (combi)	1	25 yrs	fulltime	many
Level 1	Freezer	1	15 yrs	fulltime	many
	Laptop	1	5 yrs	3,5 hours pw	
	Lightening*	23			
	Kettle	1	2 yrs	3x pd	1898
	Coffie machine	1		rarely	
	Grill iron	1	new	1x pj	

Lightening*	LED	Fluorescent beam	halogen	CFl	light bulb
23	2	0	8	12	1

Energy sharing

Possibly	yes	no
		X

Opinion
Allows sharing options others, when it doesn't cost more
Appreciates own privacy
Privacy of clothes in shared washmachine?

Behaviour

	Reference	Adaptable?
Temperature	21 degrees Celsius; 18 night	based on feeling
Clothing	slightly warmer clothing when colder	Not possible
Lights off	yes	timer
Doors closed	yes	Not possible
Stand-by	tv / dvd	Little
Total impression	Average	Little

Insulation

inside wall	plaster walls	
ouside wall	brick	double glass
doors	weather strips	
floor	laminate	damping
Weak spots	none	

The individual data analysis of 6 apartments within the Anand Jyoti community in which *General info*, *Electrical Equipment, Energy sharing, Behavior and Insulation* are summarized (Personal communication, 2016).