DECENTRALIZED AND SUSTAINABLE WATER AND ENERGY SUPPLY FOR PERI-URBAN INDUSTRIAL AREAS IN BANDUNG, INDONESIA

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ABSTRACT

Can a decentralized, circular system be used to provide energy and water to a industrial peri-urban neighborhood of 26,000 people in Bandung, Indonesia? How can a textile factory provide a positive impact to its surroundings? This research paper will provide an answer in three parts. Firstly, the current energy and water usage of both the factory and the residents in the area will be calculated. Secondly, a review of potential water and energy engineering solutions will be made, to determine which technical solutions will be suitable for the area. Finally, the paper will recommend four facilities that could provide services to the area: a solar and rainwater collection roof, a public laundry, a public toilet, and a constructed wetland rice field.

KEYWORDS: *Decentralized water and energy system, waste water treatment, Peri-urban Kampung, Textile factory, water and energy flows*

I. INTRODUCTION

1.1. Context

Industrial Peri-urban Kampungs in Bandung, Indonesia

The area of focus for this research paper is a neighborhood, Cigondewah, next to a vertically integrated textile factory, PT Kahatex, a facility with 26,000 employees. The neighborhood is situated in the peri-urban area of Bandung, which is the second largest metropolitan area in Indonesia. 90% of the textile and clothing industry of Indonesia is concentrated on the island of Java (where Bandung is situated), and there are more than 150,000 people working in the textile industry per district in Bandung. (Smit, 2016, p. 43)

The project site is a typical example of a peri-urban industrial area in Bandung. Although factories are the main source of income for many residents in the area, Kampung residents directly suffer from its environmental effects.

1.2. Problem statement

Water Pollution

Because of lack of policies, factories often dump industrial waste directly into the river water, including waste water containing heavy metals and textile dyes (Greenpeace Indonesia, 2013). The sewage of local residents is also directly disposed into the river without any treatment. Polluted water is then used to irrigate the rice fields in the area. (Magister Arsitektur ITB , 2015) This affects the health and safety of the Kampung residents, because they are directly exposed to the water when farming, and children also play in and around the water sources. (Asia Development Bank, 2013)

Resource depletion

Water**:** Textile factories and the neighborhoods surrounding it are depleting energy and water resources in an unsustainable manner. In Bandung, groundwater levels have been lowered due to overdrafting - water is being extracted from the ground faster than it can be replenished. In the future, this will lead to problems with land subsidence and flooding. (Chaussard, et al., 2012)

Energy **:** Electricity for the area is provided by the national grid, which generates 95% of its electricity by using non-renewable resources - oil, coal, and gas. (Ministry of Energy and Mineral Resources, Republic of Indonesia , 2016) At a global scale, these resources will be depleted in 50-80 years, and burning them releases carbon dioxide into the atmosphere, accelerating the process of global warming. (Hook & Tang, 2013) There is an urgent need to find alternatives to supplying energy with renewable alternatives. The neighborhood also uses non-renewable resources for fuel: the factory uses coal as a direct source of heating, and the local residents buy liquid petroleum gas (LPG) cans to use for cooking.

1.3. Opportunities

Sustainability initiatives of large clothing companies

Large clothing companies from developed countries, such as C&A, have recently started initiatives to explore more sustainable alternatives to the manufacturing of clothing. (C&A Foundation , 2016) Not only does this improve the environment, it also gives a positive image to the clothing company. Although some may call this 'green washing', it presents an unprecedented opportunity to take advantage of the capital of textile factories to not only minimize the negative impacts of the factory on the surrounding environment, but to also provide infrastructure that benefits the local residents.

Decentralized, circular infrastructure

Since the neighborhood currently has limited access to energy and water provided at a national scale, there is an opportunity to provide these services in a de-centralized manner, at a neighborhood scale, utilizing renewable resources found in the area.

There is also an opportunity to change the current energy and water system using ideas of the circular economy. The Ellen MacArthur Foundation defines the circular economy as, "Looking beyond the current "take, make and dispose” extractive industrial model, the circular economy is restorative and regenerative by design. Relying on system-wide innovation, it aims to redefine products and services to design waste out, while minimizing negative impacts". (Ellen MacArthur Foundation, 2017)

1.4. Research question

Taking into account the problems and opportunities of the site, the purpose of this paper is therefore to explore a decentralized and circular energy and water infrastructure as an alternative to the current energy and water system in the area. The research question of this research paper is:

Can a decentralized, circular system be used to provide energy and water to a industrial peri-urban neighborhood of 26,000 people in Bandung, Indonesia?

In order to answer the main research question, the following sub-questions will also be explored:

1. *what are the environmental potentials of the site?*
2. *what are the decentralized technologies available to harness these potentials?*
3. *what are the spatial and architectural impacts of these technologies?*

1.5. Method

The findings of the sub-questions above will also form the structure of this research paper. In the section on environmental potentials, the energy and water usage for the neighborhood of 26,000 people is calculated based on existing survey of water and energy usage in the area conducted by a local university, Institut Teknologi Bandung (Magister Arsitektur ITB , 2015). The survey was conducted on two villages next to the factory that have the combined population of 4,300. In order to estimate the energy and water usage of 26,000 people, the results found in the ITB survey were multiplied by 5.9.

Because it was impossible to access data on the water and energy usage of PT Kahatex, an interview was conducted with another nearby textile factory. The name of the textile factory cannot be named in this paper because of a non-disclosure agreement signed with the management of the facility. In this paper, this un-named factory will be referred to as "factory A". Factory A is at a smaller scale compared to PT Kahatex, so the results obtained from the interview is multiplied by 7.2 in order to estimate the water and energy usage of Kahatex. The scale factor of 7.2 was used because the output of PT Kahatex is 7.2 times larger than the output of Factory A.

In the sections on decentralized energy and water providing technologies and their spatial and architectural impacts, findings are based on literature review on scientific papers introducing technologies that have the potential to be applied to the neighborhood.

1.6. Defining site boundaries - "Kahatex and Kahaville"

Because PT Kahatex has a working population of 26,000, I decided that the size of the population that could potentially be served by a new, decentralized system could also be 26,000. This newly defined neighborhood is called 'Kahaville'. Thus, all calculations within this paper will assume that the services will be provided to:

1. PT Kahatex, which has a working population of 26,000
2. 'Kahaville', a residential neighborhood of 26,000 people

Based on the population density of the area (Magister Arsitektur ITB , 2015), the area of Kahaville is around 0.6km^{2}, shown as the white dotted circle on the map. The purpose of this paper is therefore to explore different ways water and energy can be supplied to people living within the white dotted circle, and how realistic these alternatives are.

The calculations for Kahaville is based a survey conducted on two villages next to the factory, RW12 and RW02 (Magister Arsitektur ITB , 2015), shown as the black dotted line on the map. Since Kahaville's population is 5.9 times larger than RW12 and RW02, the results of the ITB survey was scaled by the same factor. It is also important to note that only 15% of the population work in the textile factory (Magister Arsitektur ITB , 2015). So, Kahaville may have a population of 26,000, but only around 4,000 of the residents are factory workers.

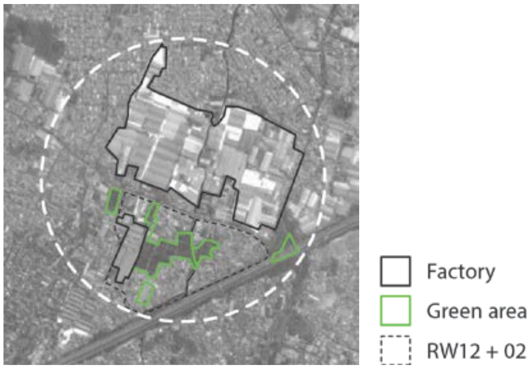

Figure 1. Map of site boundaries of 'Kahaville' (own illustration)

II. EXISTING FLOWS OF WATER AND ENERGY

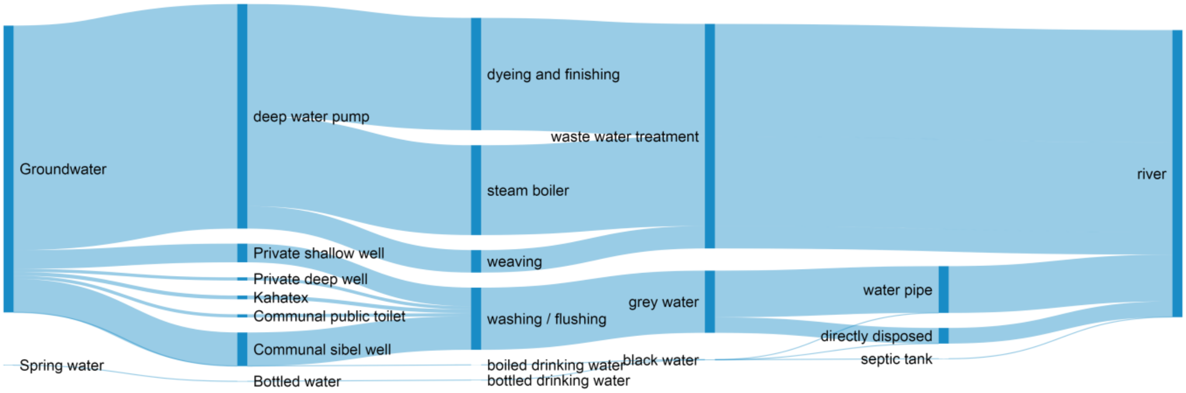

Figure 2. Sankey diagram of current water usage of Kahatex and Kahaville (own illustration)

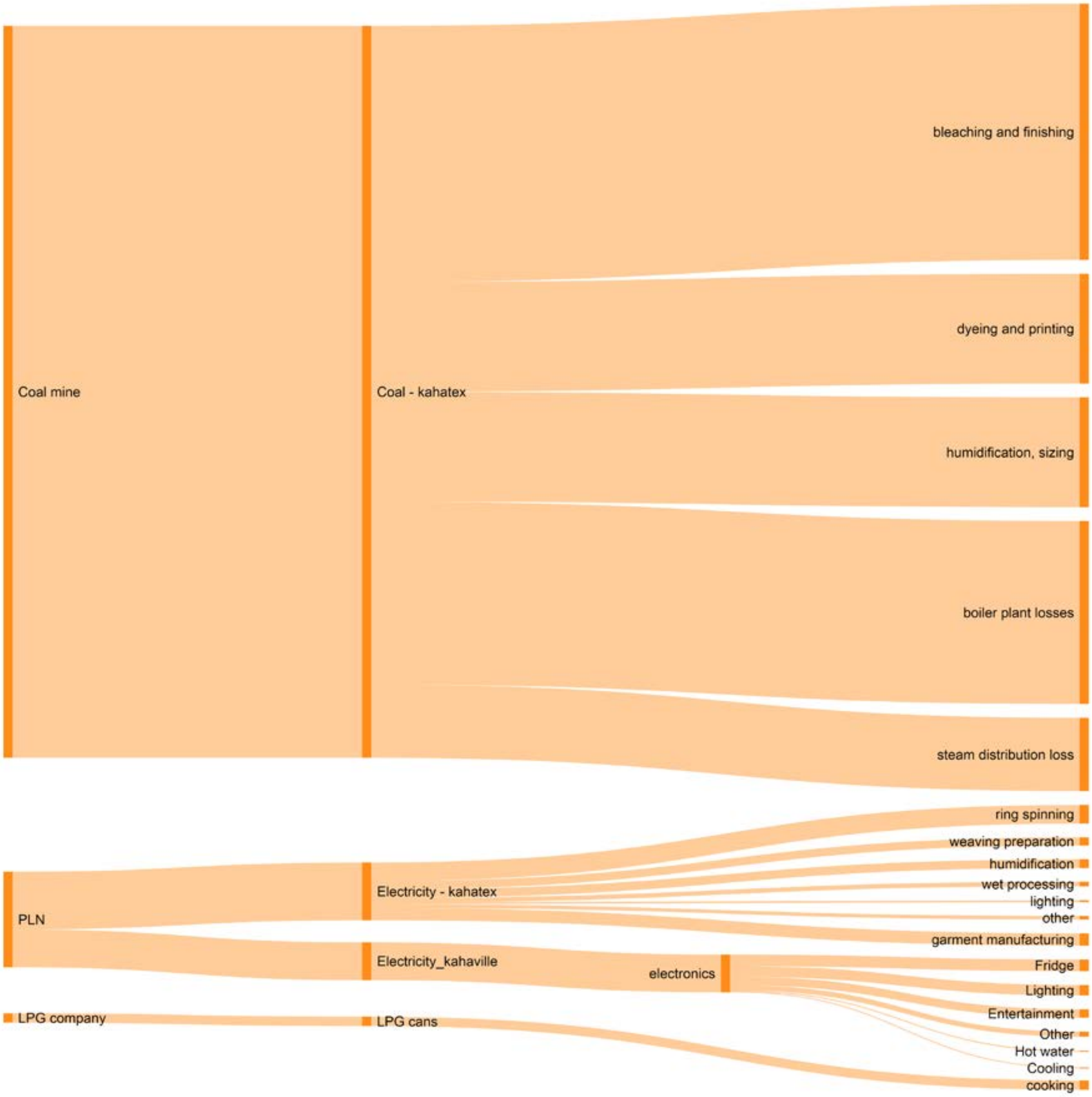

Figure 3. Sankey diagram of current energy usage of Kahatex and Kahaville (own illustration)

2.1. Existing flows of water

The sankey diagram above shows the usage of water for Kahatex and Kahaville. The total water usage of PT Kahatex is 439,200m^3/month. The water is extracted from the groundwater using on site deep water pumps that have been installed by the factory. The percentages of the water use for each manufacturing process is:
50% - dyeing and finishing
40% - steam boiler
10% - weaving.

The wastewater is then treated on site by the factory's own facilities until it reaches the standards of the Indonesian government. (see appendix) Then, the effluent is disposed into the river. (FactoryA, 2017)

The total water usage of Kahaville is 122,549m^3/month. The water usage can the separated into two parts: drinking water, and household water, which includes water used in the shower, faucet, laundry, and toilet.

The total drinking water usage for Kahaville is 708m^3/month.
80% - buy bottled water by the gallon from the water kiosk.
20% - use communal sibel well and boil the water to improve its quality.
(Magister Arsitektur ITB , 2015, p. 37)

The total household water usage of Kahaville is 121,841 m^3/month.
54% - communal sibel well
30% - private shallow well
6% - communal tap provided by Kahatex
5% - private deep well
5% - communal tap provided by public toilet
(Magister Arsitektur ITB , 2015, p. 48)

The wastewater treatment for households is either minimal or non-existent. The wastewater treatment methods are as follows:
60% septic tank
30% open and closed sewage, leading directly to the river with no further treatment
10% directly disposed into the river
(Magister Arsitektur ITB , 2015, p. 72)

2.2. Existing flows of electricity

Electricity is supplied to the area by the national electricity grid, Perusahaan Listrik Negara (PLN).
The total electricity usage of Kahatex is 3,374,123 kWh/month. (FactoryA, 2017)
The total electricity usage of Kahaville is 2,210,000 kWh/month. (Magister Arsitektur ITB , 2015, p. 176)

2.3. Existing flows of fuel

The total fuel usage of Kahatex is 42,823,921 kWh/month. The factory uses coal as a direct source of heat for its manufacturing processes, the percentage of heat usage of each process is as follows:
35% Bleaching and finishing
25% Boiler plant losses
15% Dyeing and printing
15% Humidification, sizing
10% Steam distribution losses

The total fuel usage of Kahaville is 92,274 kWh/month, and is entirely used for cooking. The fuel is supplied to the area in the form of LPG (liquid petroleum gas) cans, and sold to the residents via kiosks. (Magister Arsitektur ITB , 2015, p. 176)

III. POSSIBILITIES OF DECENTRALIZED SUPPLY OF WATER AND ENERGY

This section will explore different alternatives of providing water and energy to the area in a more decentralized and sustainable manner. For detailed calculations, see the appendix.

3.1. Potential sources of water

In an attempt to reduce the extraction of ground water by both the factory and the residences, this section will explore alternative sources of water for the area. Both fresh and re-useable water are considered as water sources in this section. For detailed descriptions of each water treatment process and technology, refer to the appendix. The potential sources of water are summarized in Table 1.

Rainwater

The only alternative fresh water source to ground water is rainwater, which can potentially be harvested from the roof of the factory. Rainwater is a relatively clean source of water that can be used for drinking if it is further filtered (Adipurnomo, 2017). Currently, there are kiosks in the neighborhood that filter mountain spring water with their own machinery. This water is then filled in plastic bottles (1 gallon each), and sold to the residents as drinking water. There is therefore a potential for the rainwater collected from the factory roof to be sold to the existing water kiosks at a lower price than mountain water because of the lower transportation costs. Rainwater collected from the roof is enough to supply two purposes: 100% of the drinking water needs of Kahaville, and 72% of water needed for a new public laundry and shower facility, or 99% of water needed for a public laundry facility.

There is a potential to sell the collected rainwater to the residents in the area. If all the rainwater collected was sold as drinking water, the total value of water collected every month has the value of approximately 1,000,000 euros, and can satisfy the drinking water needs of 9,201,400 people, 353 times the size of Kahaville's population. (for detailed calculations, refer to the appendix)

Other potential water sources comes from reusing the wastewater in the area. In order to collect wastewater in the area, it is necessary to introduce new water-related facilities that are able to collect and treat wastewater so that it can be reused. Although it is also possible to collect wastewater from the existing sewage system, this option was not considered because there is no way to separate grey water from black water to reuse. The new facilities that can be introduced are: a public laundry facility, a public toilet, and converting the existing rice field into a constructed wetland, where rice production can still be continued.

Public laundry and shower (reuse as flushing water)

The new public laundry and shower facility targets the entire Kahaville population for laundry, and 42% of the population for the shower. This is because doing the laundry is already an activity that is done outside the house, and 42% of the population do not have access to a shower inside their home. (Magister Arsitektur ITB , 2015) If connected to a septic tank and constructed wetland for filtration, the wastewater of this facility can be reused to flush the toilets of the new public toilet. The calculations for this facility was based on a wetland system constructed and tested in India, the GROW system. (Ramprasad, et al., 2017) However, there is not enough land in the area to accommodate for laundry and shower, so it is more practical to provide only a public laundry. (see section 3.3 for more details)

Public toilet (reuse as irrigation water)

The new public toilet targets 42% of the Kahaville population, who don't have access to private toilets in their own house. (Magister Arsitektur ITB , 2015) The flushing water of the toilets can be provided by the public laundry and shower facility, and the wastewater can be treated with a septic tank, an anaerobic digester, a settling pond, and a constructed wetland. See appendix for details. The treatment processes removes enough pathogens for the wastewater to be reused as nutrient-rich irrigation for the rice fields. The calculations for this facility are based on the Aravind Eye Hospital in India, which treated blackwater from the hospital and used the effluent for irrigation of the surrounding fields. (Wilders, 2015, p. 78)

Rice field converted into constructed wetland (reuse as laundry + shower water)

The final facility that can be provided is the existing rice field converted into a constructed wetland. Effluent from the public toilet, which has already been treated by a separate wetland, can flow into the rice field for further treatment. Because rice is a wetland plant, rice can still be grown in the constructed wetland. The difference is with the constructed wetland, water used to irrigate the rice fields will not seep into the ground, but instead can be collected again for reuse. Constructed wetlands planted with rice can reduce levels of BOD, COD, and Ammonia. (Meira, et al., 2013, p. 4) The effluent from the rice field can then be reused as water for the public laundry and shower facility.

Table 1. Potential water sources for Kahatex and Kahaville

water facility	**water quantity**	**Kahaville served**	**Kahatex served**	**public laundry & shower served**	**public toilet served**	**rice field served**
	m3/month	%	%	%	%	%
Rainwater collection from Kahatex roof (drinking water)	27535	100	6.3	72		589
New public laundry + shower (grey water)	37161		8.5		102	795
New public toilet (irrigation water)	14084					301
Constructed rice field (household water)	8637		2.0	23	24	

Rejected potential sources of water

Other sources of water were considered for this section, but were ultimately rejected after further research, because of concerns of health, safety, and practicality.

Treating and reusing industrial wastewater was considered, because the enormous volume of industrial wastewater is more than enough to cover the entire water supply of Kahaville. However, treating industrial wastewater is an expensive and high-tech process. Because the wastewater contains heavy metals and toxic chemicals, treatment is not physical and biological, but chemical. It was ultimately decided that the chemical treatment process of water is not an architectural problem and has no spatial concerns - it involves adding chemicals to the effluent and breaking down chemicals at a molecular level. The treatment of industrial wastewater is therefore situated in the field of chemical engineering, and not architecture.

Another rejected proposal was for the public laundry and shower facility to supply its treated effluent to PT Kahatex as industrial freshwater. This is technically possible, and a study was made to use wetlands to treat and reuse industrial waste water. (Riggio, et al., 2017) However, the public laundry and shower facility provided enough treated effluent for only 8.5% of PT Kahatex's water usage. Because of extra infrastructure needed to direct wastewater from the public shower and laundry to PT Kahatex, reusing the wastewater for flushing the public toilet was deemed a better way of reuse.

3.2. Potential sources of energy

This section will explore alternative sources of energy for the area, in terms of electricity and fuel. The potential sources of energy are summarized in Table 2.

Electricity

Solar PV

The roof of the factory can be fitted with solar panels, which provides enough electricity for the electricity usage of Kahatex. For detailed calculations, refer to the appendix.

Fuel

Biogas from human waste

It is possible to collect biogas from human waste to use as fuel, by using a biogas digester. If all the human waste could be collected from Kahaville, the biogas extracted is enough to generate 49% of the fuel needs of Kahaville. However, it is not possible to collect all the human waste produced from Kahaville. Firstly, private toilets already have their own septic tank, where biogas is already created and lost. In some toilets, wastewater is directly disposed in the existing sewage system. However, human waste collected from the sewage system would be diluted by grey water and rainwater, which is unsuitable for biogas digesters, as only black water should be processed. (Tilley, et al., 2014, p. 80)

It is therefore more realistic to assume that only human waste from the public toilet can be collected to produce biogas. This is enough to supply 19% of the fuel Kahaville needs for cooking.

Table 2. Potential energy sources for Kahatex and Kahaville

Energy source	**Energy supplied**	**% of Kahaville served**	**% of Kahatex served**
	kWh/month	%	%
Electricity			
Solar PV on factory roof	3273160	148	123
Fuel			
Biogas from human waste (of users of public toilet)	101960	19	0.2
Fuel (rejected sources)			
Biogas from human waste (of entire Kahaville population)	267038	49	0.6
Microalgae (on factory roof)	606048	111	1.4
Microalgae (on Kahaville green space)	87260	16	0.2
Microalgae (from facultative pond of public toilet)	17279	3	0.04

Agricultural waste	4153	0.8	0.01

Rejected sources of fuel

Microalgae

Although microalgae seems to be a promising source of energy, it requires a significant amount of land, which is a limited resource in the area. There are two methods to growing microalgae: raceway pond systems, and photo-bioreactors. A typical raceway pond is a closed loop channel, open to air, where algae grows in the water circulated by a paddle wheel. A photo-bioreactor is an array of transparent tubes where the micro-algal broth is circulated from a central reservoir. Although a photo-bioreactor requires significantly less space than a raceway pond, a study has found that only raceway ponds have a net energy ratio (NER) less than 1. NER is defined in the study as the sum of the energy used for cultivation, harvesting, and drying, divided by the energy content of the dry algae biomass. (Slade & Bauen, 2013, pp. 30-31) Therefore, only raceway pond systems are suitable because they produce more energy than they consume. The energy production of a raceway pond system is 3.4 kWh/month/m^2. (Slade & Bauen, 2013, p. 35)

Because the microalgae must be directly exposed to sunlight, in the open air for raceway systems, the options to grow microalgae in the area are: the roof of PT Kahatex, and the agricultural land of Kahaville. Although the roof can produce enough algae to supply 111% of Kahaville's fuel, and the agricultural land can supply 16%, growing algae on these spaces also means giving up on solar panels and rice production. With the low energy production per m^2 of the microalgae, having a raceway pond in the area is not realistic.

Biomass from agricultural waste

Rice husks and straw are waste products from growing rice. Rice husk is the outer layer of a rice seed, and rice straw is the long stalk of the rice plant. It is common practice in Asia to burn the straw and husk in an open field after harvesting season. (Lim, et al., 2012, p. 2) If all the agricultural waste was collected from the rice fields, it would be enough to supply 0.8% of the fuel of Kahaville. Because of the low energy yield, it is not worth investing in a facility that converts agricultural waste into energy.

Fuel for PT Kahatex

The fuel usage of PT Kahatex is too large compared to fuel generated by local resources in Kahaville. Out of the options, the largest production of fuel is growing microalgae on the factory roof, but even this option is only enough to power 1.4% of the fuel usage.

3.3. Proposed water and energy system

To summarize the previous findings, four facilities can be proposed in the area:

1. The current PT Kahatex factory roofs can be converted into an integrated system that combines solar panels and rainwater collection. The new roof can fulfill 100% of the electricity usage of factory, 100% of the drinking water usage of Kahaville, and 23% of water usage for the public laundry and shower.

2. The public laundry and shower will serve 100% of the residents' needs for laundry, and 42% of the residents' needs for showers. Water for the facility will be supplied by two sources: 23% rainwater, and 77% constructed rice field wetland. The wastewater of the facility will be will be filtered with a constructed wetland, and will be supplied to the public toilet to use for flushing. However, there is not enough land in the area to accommodate for laundry and shower, so it is more practical to provide only a public laundry. (see section 3.3 for more details)

3. The public toilet will use 100% water from the wastewater of the public laundry and shower. The blackwater of the toilets will be filtered by an anaerobic baffled reactor, an biogas digester, a settling pond, and a constructed wetland. 33% of the treated effluent will be used as irrigation for the rice fields, and 67% will be disposed in the river. The biogas collected can supply 19% of Kahaville's fuel needs.

4. The existing rice fields will be converted into constructed wetlands, and rice will continue to be planted there. Because they are constructed wetlands, it is possible to collect all the water (irrigation water and rainwater) from the rice field. The field will be irrigated by the effluent of the public toilet and rainwater. The effluent of the ricefield can then be reused by the public laundry and shower.

Despite the addition of the four new facilities, most of the existing system remains unchanged. 100% of fuel supply to PT Kahatex, 81% of fuel supply to Kahaville, 58% of water supply to Kahaville's showers and toilets, and 100% of water supply to PT Kahatex remains unchanged. There are simply not enough resources within the area to satisfy these needs. If these needs cannot be satisfied by decentralized, neighborhood scale infrastructure, they will need to be supplied by centralized infrastructures at a larger scale, such the scale of the city, or the country.

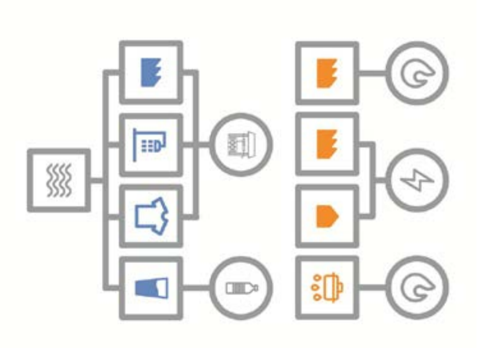

Figure 4. Diagram of current water and energy system in the area (own illustration)

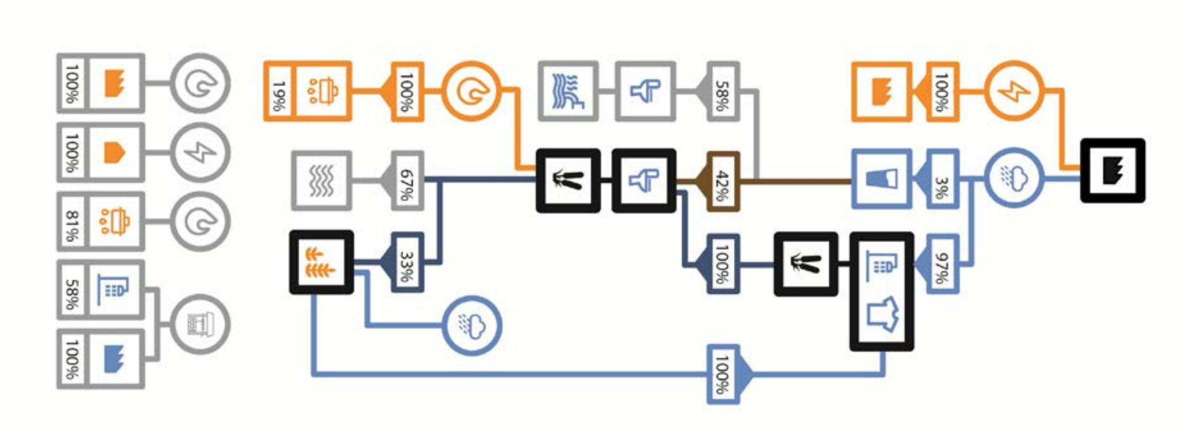

Figure 5. Diagram of proposed water and energy system in the area (own illustration). The parts of the system that remain unchanged is in grey.

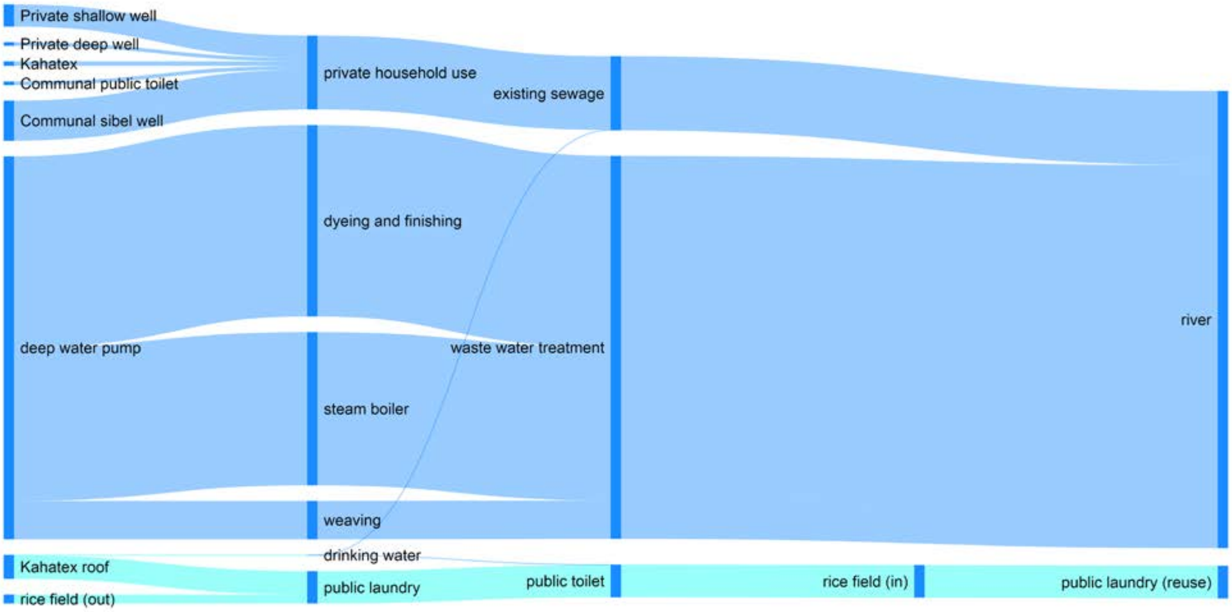

Figure 5. Sankey diagram of flow of water, after introduction of new facilities (own illustration). New changes in the system are highlighted in light blue.

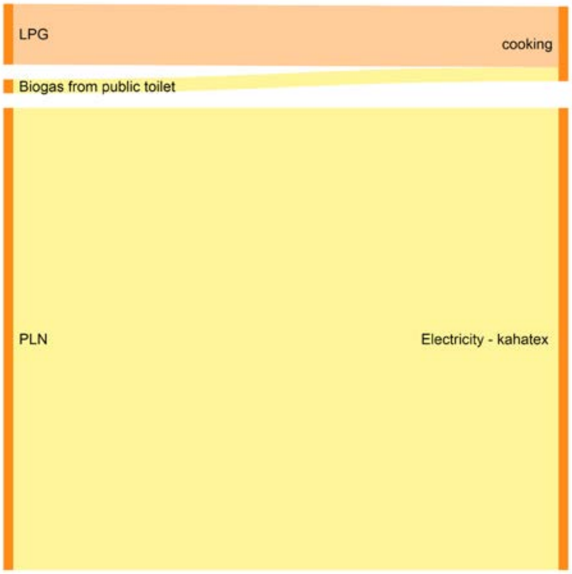

Figure 6. Sankey diagram of flow of energy, after introduction of new facilities (own illustration). New changes highlighted in yellow.

3.3. Area requirements for each facility

The area requirements of each facility are as follows: (for detailed calculations, refer to the appendix)

1. Solar and rainwater collection roof: 179,968 m^2
2. Public laundry and shower: 31,602 m^2
3. Public toilet: 9,095 m^2
4. Rice field: 17,993 m^2

Total land required: 238,658 m^2

The facilities and their service capacities were proposed based on the available water and energy resources within the area, and the needs of the residents. Now, the next step is to consider the amount of land available on site, and to adjust the facilities accordingly.

The total amount land available on site is: 208,222 m^2, less than the land required for all the facilities. The land available includes the roof of PT Kahatex and all the green spaces of the area. The public football field, public pond, and residential areas were not included as available land, because these spaces are an important part of the residents' lives, and should not be removed. Also, there is no way to 'stack up' the proposed facilities on top of each other into a multi-storey building, because all the facilities (wetlands, solar collection...) need to be in direct contact with the sun. Thus, there is not enough land available to accommodate all the facilities proposed.

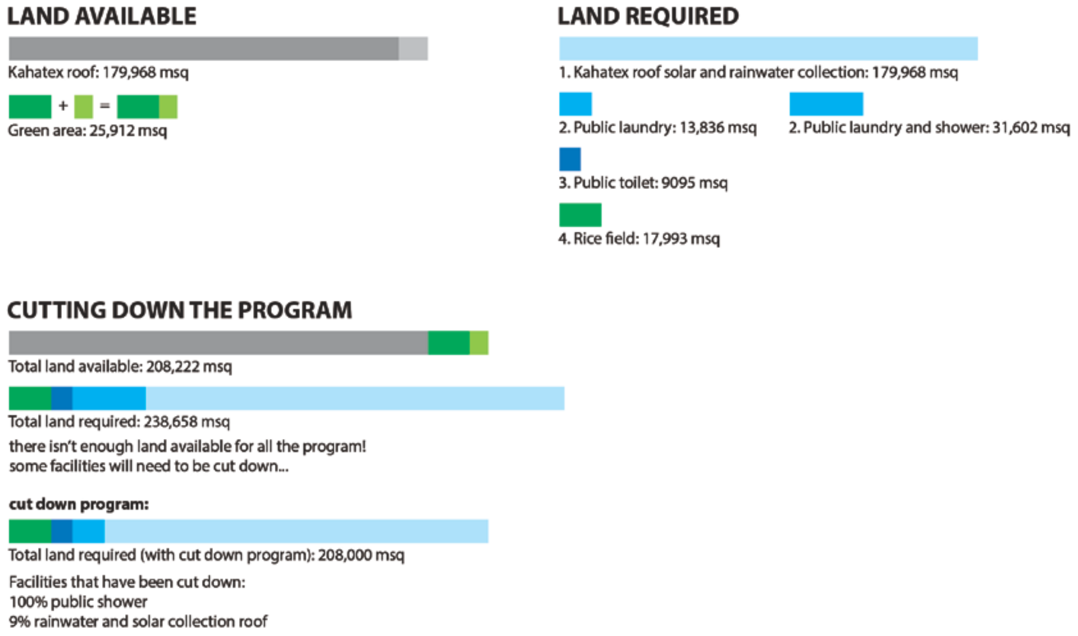

Figure 7. Program bars of land calculations (own illustration)

Because of the lack of land available, two facilities need to be cut down:

1. The rainwater and solar collection roof is cut down by 9%. The solar and rainwater collection capacity is also lowered accordingly:
Electricity generated from solar power: 112% of PT Kahatex electricity usage
Water collected from rainwater collection system: 100% of public laundry water usage (66% of public laundry **and shower** usage)

2. The public shower was cut down, so the 'public laundry and shower' is cut down to 'public laundry'. The public laundry will continue to serve the needs of all the residents of Kahaville. The public shower should be cut down instead of the laundry because there is a potential to invest in better laundry equipment such as washing machines, if laundry is being done communally. On the other hand, showers are a much more private activity that can be done at low cost within the private home.

Because the public shower was cut down, the greywater produced by the public laundry is not enough to flush the toilets of the public toilet. Thus, the water collected from the rice fields will be redirected and reused as flushing water. See Figure 8 below for a modified flow diagram of the water and energy system.

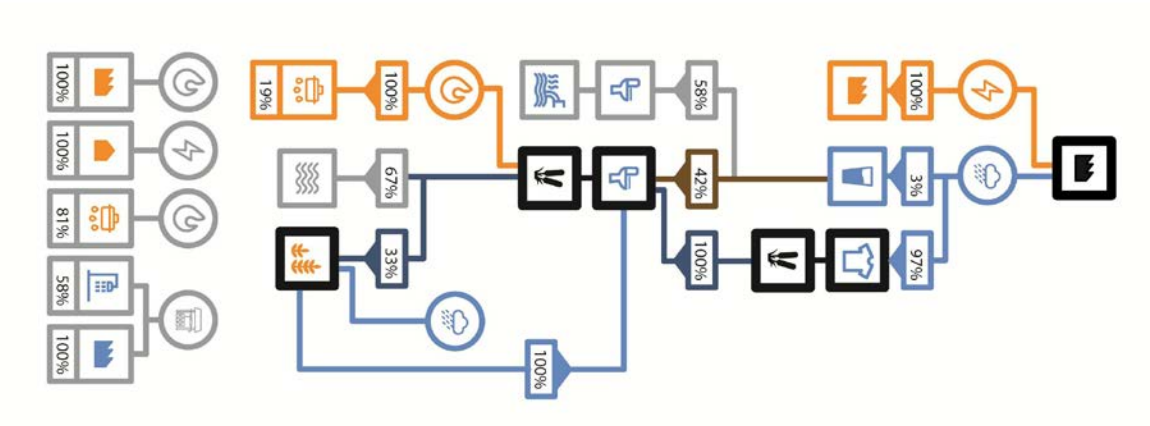

Figure 8. Diagram of proposed water and energy system in the area (own illustration).

One centralized public toilet and laundry for 26,000 people cannot be practical for the residents, therefore both facilities can be separated into 52 smaller units, with each unit serving 500 people. For each of the smaller units, the area requirements are:

Public laundry
washing area: 10m^2
underground septic tank: 9m^2
wetland: 256m^2

Public toilet
toilet area: 8m^2
underground septic tank and biogas reactor: 40m^2
wetland: 167m^2

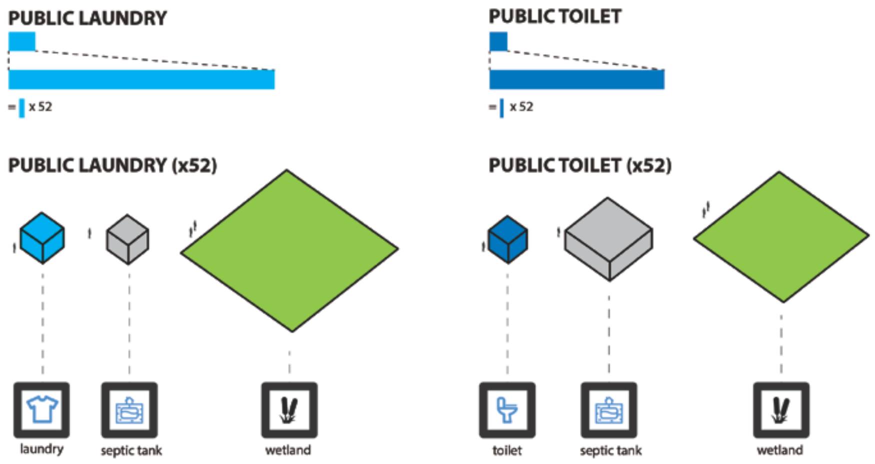

Figure 9. Area requirements for public laundry and toilet

The size of each public laundry and toilet unit will need to be further developed. The suitable service size of each facility will need to be determined. For example, what is a suitable sized public toilet? 50, 500, or 5,000 people? The current number, 500, is a rough guess based on the current population in the village (~4,000) and the number of public toilets (8) currently provided there. (Wilders, 2015, p. 19)

By comparing the land required and land available for the facilities (Figure 10.), it can be seen that the roof of PT Kahatex can be used for rainwater and solar collection, the roof of the smaller factory can be used for the public laundry and wetlands, and the green areas will be used for the public toilets. This is option 1 of placing the facilities. However, a problem posed by option 1 is that all the toilets are centralized into three areas (see areas shaded in dark blue in option 1). As a result, residents of Kahaville may need to walk for more than 5 minutes in order to reach a public toilet, which is not practical. Therefore, option 2 is proposed. This option suggests for the edge condition of PT Kahatex to be changed. The buildings of the factory can be modified to incorporate public toilets on the edge of the site. This allows a wider spread of toilets in the area. On the other hand, having a centralized public laundry is not unreasonable. Since residents do their laundry no more than once a week, walking for 10 minutes to the laundry facility is not an inconvenience.

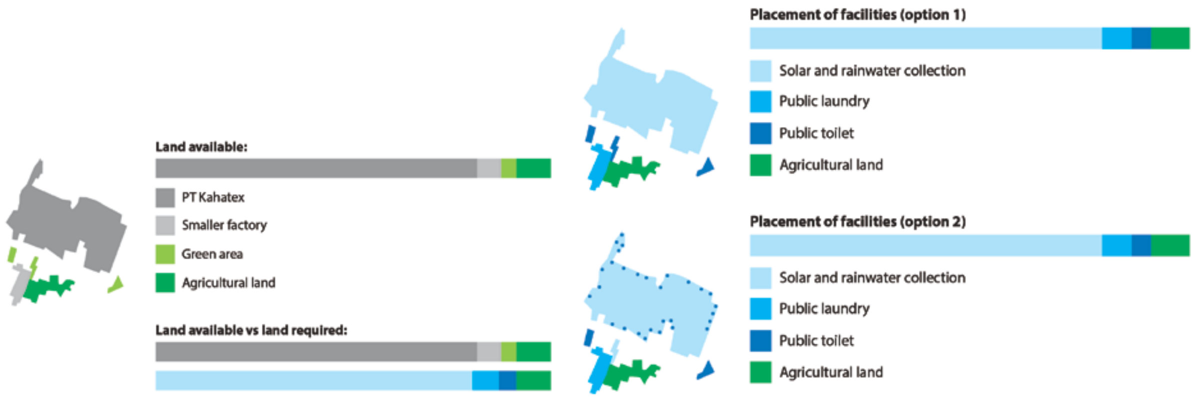

Figure 10. Potential placement of new facilities on available land on site

The process of determining the placement of facilities in the area will need to be continued, as there are many more options for arranging the facilities, which will lead to different architectural solutions.

IV. CONCLUSION

The purpose of this paper was to answer the research question: Can a decentralized, circular system be used to provide energy and water to PT Kahatex and its surrounding neighborhood of 26,000 people? The conclusion is: a decentralized system can be a potential solution for **a part** of the energy and water demand. Decentralized facilities, which take advantage of existing energy and water resources, can provide for the electricity usage of PT Kahatex, the water demand for drinking and laundry in Kahaville, and the water demands of 42% of the toilets. Providing decentralized services is technically feasible, but it is important to take note that it can only solve part of a larger problem.

Other water and energy demands of the neighborhood could not be met with a decentralized system. This is because there is a limited amount of land available in the area. Many of the facilities required for a decentralized system, such as solar collection, rainwater collection, and wetland filtration systems, requires land directly exposed to sun and open air. Thus it is impossible to 'stack up' these facilities into a multi-storey building.

An important piece of knowledge to be gained from this research is that each type of infrastructure has an appropriate scale. It is therefore unrealistic to assume that all the water and energy needs within a neighborhood can be satisfied at a neighborhood scale. It is important to note that decentralized infrastructure is merely providing an sustainable alternative to centralized infrastructure, and it is not the only solution that is sustainable. Sustainable energy and water provision can and should also be provided at a centralized, national scale, utilizing larger renewable energy and water resources.

Providing decentralized infrastructure to a neighborhood requires more than just architectural and engineering research and knowledge. One major issue that was not discussed in the paper is how it would be legally possible for the proposed facilities to be set up within the area. The provision of water services in urban areas is the responsibility of PDAMs (Perusahaan Daerah Air Minum), Local Government Owned Water Utilities, who legally have a monopoly on water supply. If the villagers or the factory decided to build these facilities, they will legally need to apply for a permit from PDAM. However, it is not in PDAM's interests to provide the permit if they see the area as a potential customer in the future. If the population of the area increases, it will become profitable for PDAM to supply water to the area because of the high density of users.

Another issue that has not been addressed is that the calculations of this paper is a snapshot of the current water and energy usage of the area, and does not address the changes of this usage in the future, when the population of the area will change. The neighborhood's population in the future will depend heavily on the textile industry. If it continues to grow, the population will follow. If the area densifies, then available land area will decrease, which makes the public toilet and laundry facility less viable because of high land usage of the wetlands. A potential solution is to develop wetland filtration on the roofs of existing buildings, as seen in by the GROW project in India. (Ramprasad, et al., 2017)

However, there is also a possibility that PT Kahatex could decide to move to another country in search of lower wages. If this happens, the population could drop significantly, leaving abandoned buildings and infrastructure.

This research paper will be followed by a architectural design proposal for the area. The next steps after the paper will therefore be to further explore the positioning and capacity of the facilities proposed as seen in Figure 10. For the design project, there is potential to develop a roof system for rainwater collection, solar collection, and wetland filtration. The system could either propose a major change to the entire layout of the textile factory, or it could be an additional element to the existing structure of the factory buildings.

After the process of writing this paper, it can concluded that the challenges of sustainability, even at a neighborhood scale, cannot be addressed by one discipline alone. This paper was a literature review of engineering solutions for providing decentralized services. However, I also spoke to chemical engineers, textile engineers, textile factory managers, and water policy researchers, whose advice and insights I could not add to this research paper because the issues addressed were not directly related to technical solutions. Even at a neighborhood scale, the complexity of providing a decentralized infrastructure is immense. There is much work to do.

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APPENDIX

I. EXISTING FLOWS OF WATER AND ENERGY

1.1. Calculations for existing water system

Kahaville
Drinking water
According to an interview with the community chief of RW 12, each person buys six gallons of drinking water per month. (Magister Arsitektur ITB , 2015, p. 37)
6 imperial gallons / person / month
= 0.027m^3 / person / month
= 708m^3 / month

Household water
Residents pay 3,000 Rp / 1m^3 of water.
On average, each household pays 55,000 Rp per month for water.
The average size of each household is 3.9 people.
55,000 Rp/household/month
= 18.3 m^3 of water/household/month
= 121,841m^3/month of water used by Kahaville (population 26,000)

Kahatex
water usage of Factory A is 61,000m^3/month.
output of Factory A is 1,050 tons of fabric/month. (FactoryA, 2017)
PT Kahatex processes 10,000 tons of raw material / month. (PT Kahatex, 2005)
Assuming 75% efficiency (Joshi & Singh, 2009), the output of PT Kahatex is 7,500 tons of fabric/month.
This means the output of PT Kahatex is 7.2 times larger than Factory A.
We can estimate that the water usage of PT Kahatex is approximately
439,200m^3/month.

Indonesian wastewater standards for the textile industry (ZDHC, 2015)

Water standard	unit	quantity
BOD	mg/L	60
COD	mg/L	150
TSS	mg/L	50
Ammonia as N	mg/L	8
Tchromium	mg/L	1
Phenol	mg/L	0.5
Sulphide	mg/L	0.3

1.2. Calculations for existing energy system

Electricity
PT Kahatex
As seen in the water calculations, the output of PT Kahatex is 7.2 times larger than Factory A.

The electricity usage of Factory A is 468,630 kWh/month. (FactoryA, 2017)
The electricity usage of PT Kahatex is 3,374,123 kWh/month.

Kahaville
In RW12 and RW02, each household pays on average 200,000Rp/month for electricity.
The cost of electricity for indonesia is Rp600/kWh. (Magister Arsitektur ITB , 2015, p. 176)
The power consumption per household is 333kWh/household/month.
Assuming the average size of Indonesian households to be 3.9 people, power consumption per person is 85kWh/person/month.
Kahaville has a population of 26,000 people.
The total electricity usage of Kahaville is
2,210,000 kWh/month

Fuel
PT Kahatex
As seen in the water calculations, the output of PT Kahatex is 7.2 times larger than Factory A.
The fuel usage of Factory A is 5,947,766 kWh/month. (FactoryA, 2017)
The fuel usage of PT Kahatex is 42,823,921 kWh/month.

Kahaville
100% of the residents use liquid petroleum gas for cooking, and each unit bought is 3kg.
On average, each household uses 2 units/month. (that's 6kg/month)
1kg of LPG = 13.6 kWh
household fuel usage is 81.6 kWh/household/month.
assuming average household size of 3.9 people,
per capita fuel usage is 21 kWh/person/month.
Kahaville has a population of 26,000 people.
total usage of fuel for Kahaville is
546,000 kWh/month

II. POSSIBILITIES OF DECENTRALIZED SUPPLY OF WATER AND ENERGY

2.1. Decentralized water treatment methods

Septic tank

'inputs: blackwater and greywater. outputs: effluent and sludge.

A septic tank is a watertight chamber through which blackwater and greywater flows for primary treatment. settling and anaerobic processes reduce solids and organics, but the treatment is only moderate.

Removal of 50% of solids, 30-40% of BOD, and a 1-log removal of E.coli can be expected in the well-designed and maintained septic tank. The retention time should be 48 hours.' (Tilley, et al., 2014, p. 74)

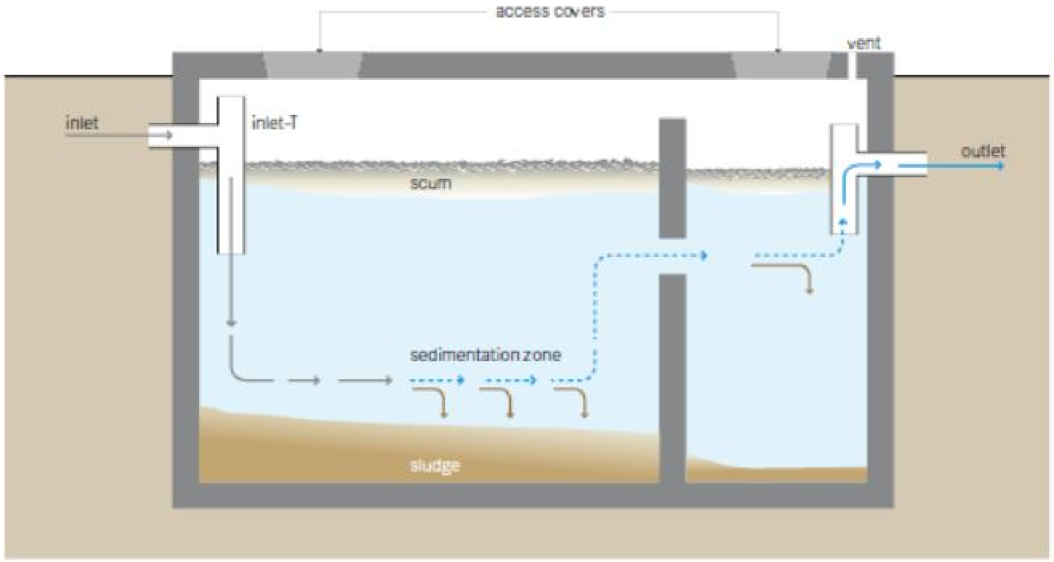


Diagram of septic tank (Tilley, et al., 2014, p. 74)

Aerobic baffled reactor

'Inputs: blackwater, greywater. Outputs: effluent, sludge.

An anaerobic baffled reactor is an improved septic tank with a series of baffles under which the wasterwater is forced to flow. the increased contact time with the active biomass (sludge) results in improved treatment.

BOD may be reduced by up to 90%. Typical inflows range from 2 to 200m^3 per day. Retention time should be 48-72 hours. Usually, the biogas produced in an ABR through anaerobic digestion is not collected because of its insufficient amount.' (Tilley, et al., 2014, p. 76)

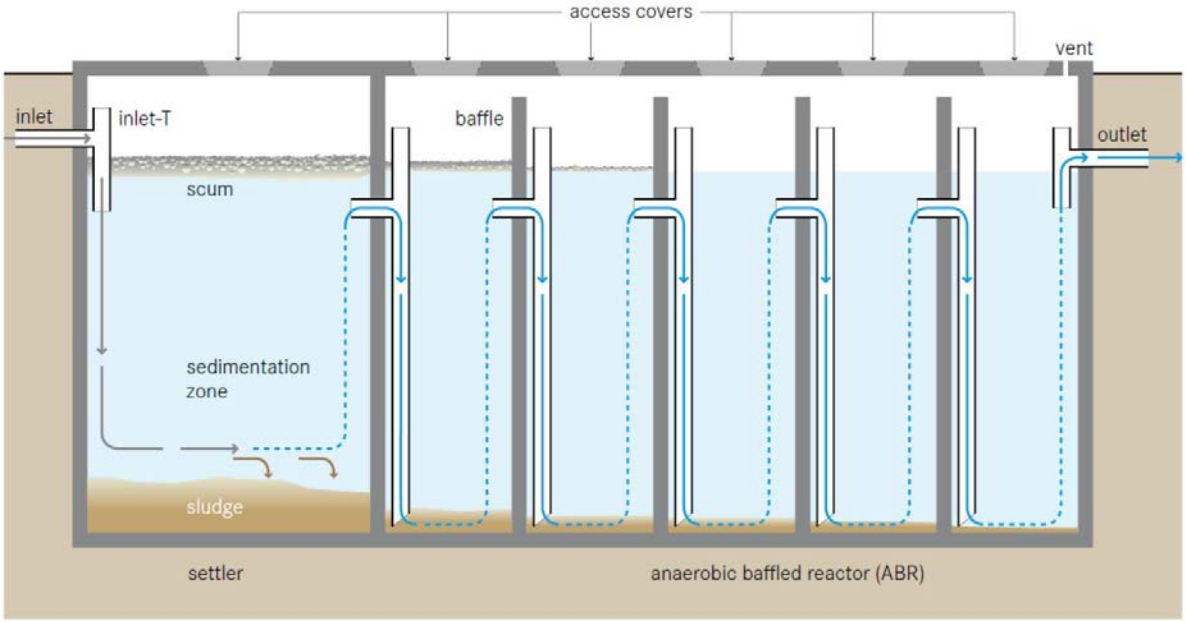


Diagram of anaerobic baffled reactor (Tilley, et al., 2014, p. 76)

Anaerobic filter

' Inputs: blackwater, greywater. Outputs: effluent, sludge.

An anaerobic filter is a fixed-bed biological reactor with one or more filtration chambers in series. As wastewater flows through the filter, particles are trapped and organic matter id degraded by the active biomass that is attached to the surface of the filter material.

Suspended solids and BOD removal can be as high as 90%, but typically between 50-80%. Nitrogen removal is limited and normally does not exceed 15% in terms of total nitrogen (TN).

Retention time should be 12-36 hours.' (Tilley, et al., 2014, p. 78)

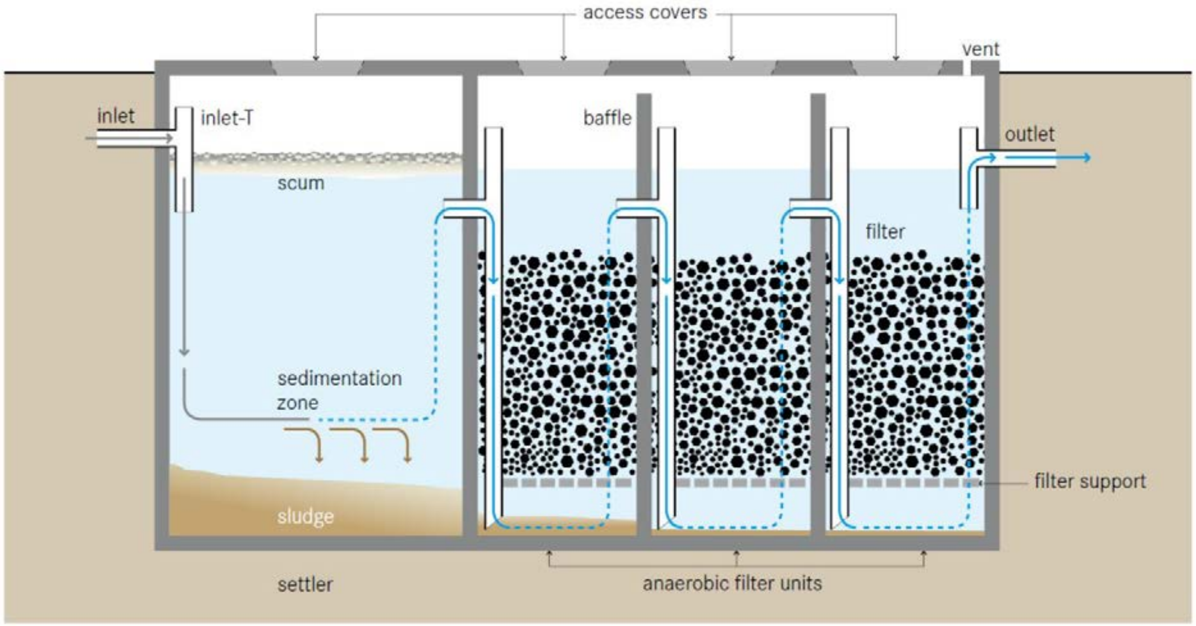


Diagram of anaerobic filter (Tilley, et al., 2014, p. 78)

Biogas reactor

'Inputs: sludge, blackwater, organics. outputs: sludge, biogas

A biogas reactor or anaerobic digester is an anaerobic treatment technology that produces (a) a digested slurry (digestate) that can be used as a fertilizer and (b) biogas that can be used for energy. Biogas is a mix of methane, carbon dioxide and other trace gases which can be converted to heat, electricity or light. Often, biogas reactors are directly connected to private or public toilets with an additional access point for organic materials.

Sizes can vary from 1,000L for a single family up to 100,000L for institutional or public toilet applications. The retention time in the reactor should be at least 15 days in hot climates. A biogas reactor can be used as an alternative to a septic tank, since it offers a similar level of treatment, but with the added benefit of biogas.

The highest levels of biogas production are obtained with concentrated substrates, which are rich in organic material, such as animal manure and organic market or household waste. Greywater should not be added as it substantially reduces the HRT.' (Tilley, et al., 2014, pp. 80-81)

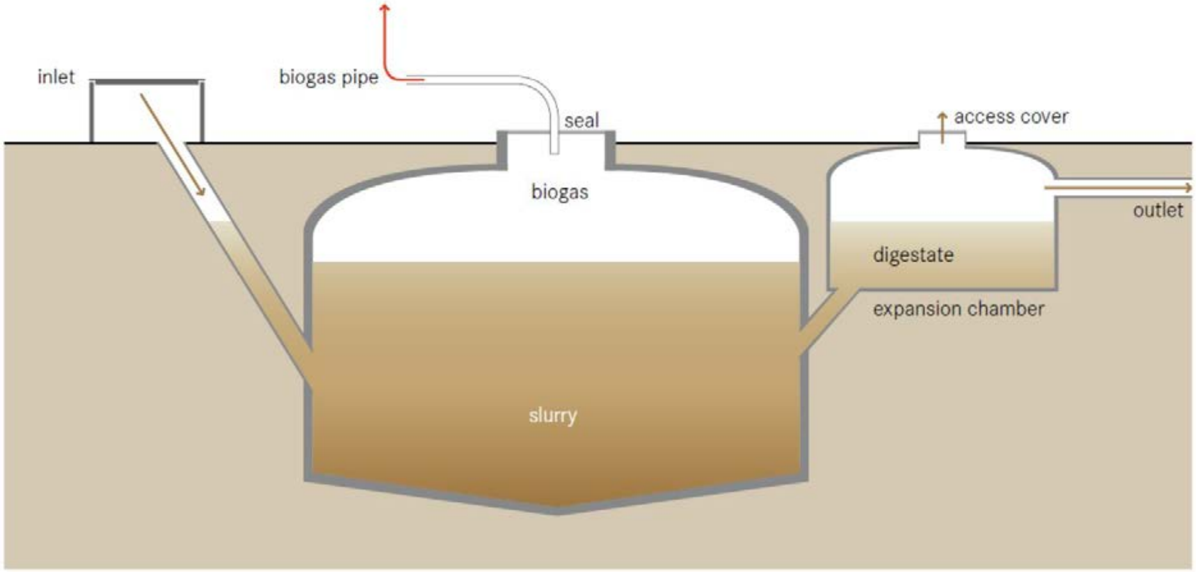


Diagram of anaerobic filter (Tilley, et al., 2014, p. 80)

Constructed wetland

There are three types of wetland: free-water surface constructed wetland, horizontal subsurface flow constructed wetland, and vertical flow constructed wetland.

'A free-water surface constructed wetland aims to replicate the naturally occurring processes of a natural wetland, marsh or swamp. As water slowly flows through the wetland, particles settle, pathogens are destroyed, and organisms and plants utilize the nutrients. This type of constructed wetland is commonly used as an advanced treatment after secondary or tertiary treatment processes.' (Tilley, et al., 2014, p. 114)

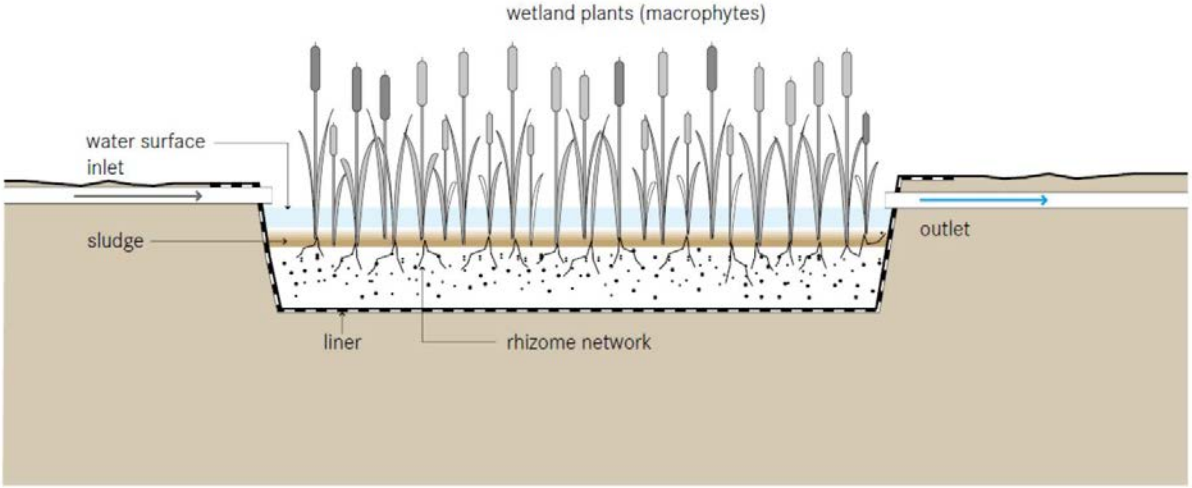


Diagram of free-water surface constructed wetland (Tilley, et al., 2014, p. 114)

'A horizontal subsurface flow constructed wetland is a large gravel and sand-filled basin that is planted with wetland vegetation. As wastewater flows horizontally through the basin, the filter material filters out particles and microorganisms degrade the organics.' (Tilley, et al., 2014, p. 116)

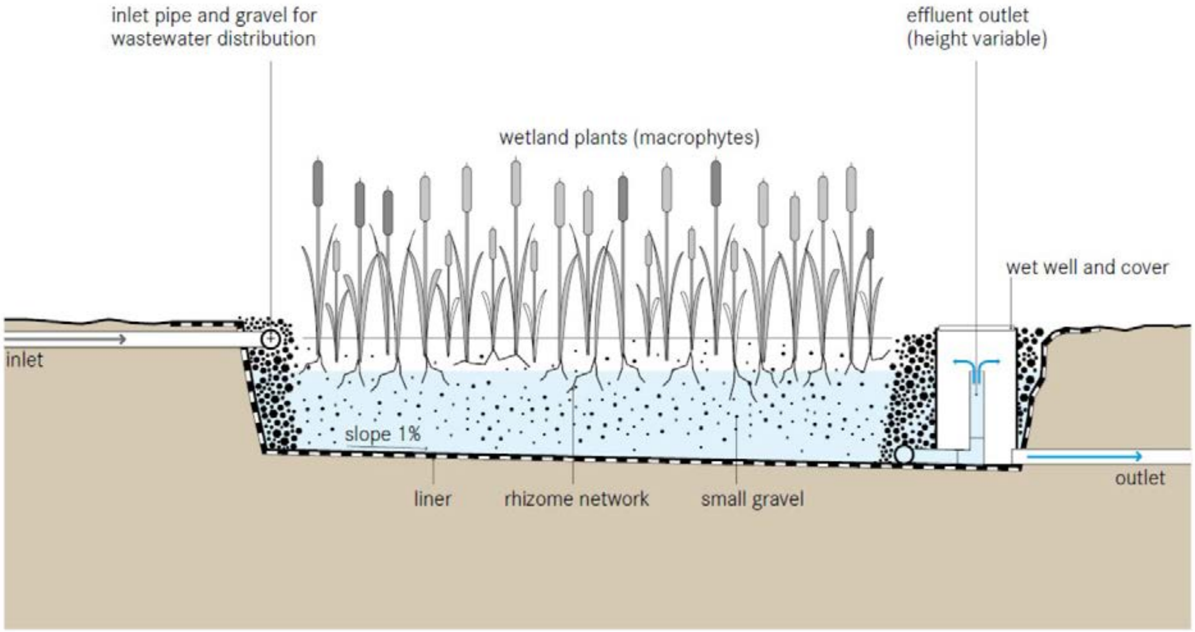


Diagram of a horizontal subsurface flow constructed wetland (Tilley, et al., 2014, p. 116)

'A vertical flow constructed wetland is a planted filter bed that is drained at the bottom. Wastewater is poured or dosed onto the surface from above using a mechanical dosing system. The water flows vertically down through the filter matrix to the bottom of the basin where it is collected in a drainage pipe. The important difference between a vertical and horizontal wetland is not simply the direction of the flow path, but rather the aerobic conditions.' (Tilley, et al., 2014, p. 118)

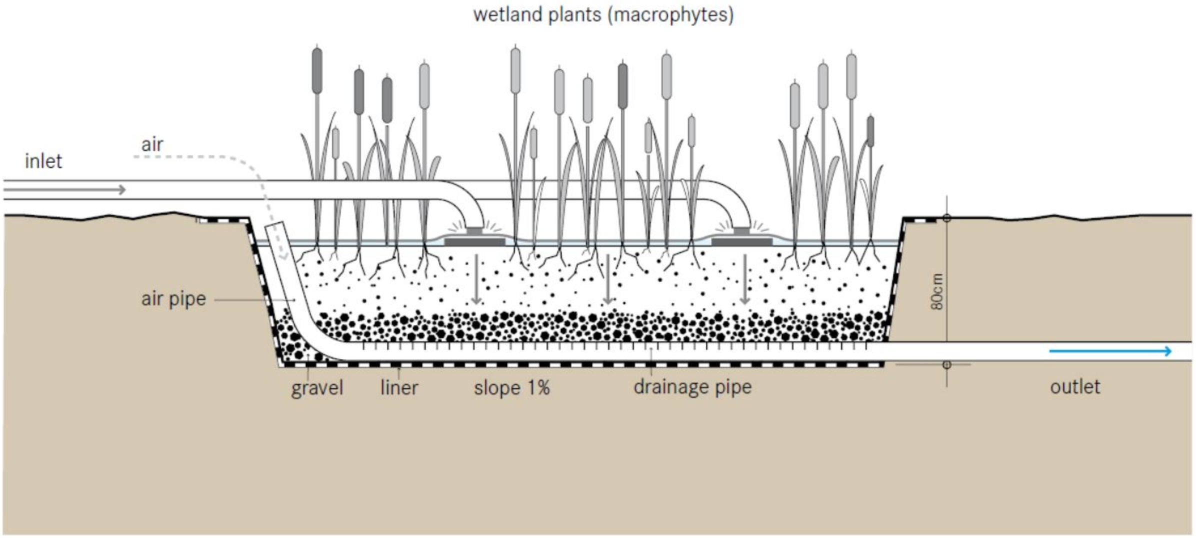


Diagram of a horizontal subsurface flow constructed wetland (Tilley, et al., 2014, p. 118)

Waste stabilization ponds

'Inputs: blackwater, greywater. Outputs: effluent, sludge.

Waste Stabilization Ponds (WSPs) are large, manmade water bodies. The ponds can be used individually, or linked in a series for improved treatment. There are three types of ponds, (1) anaerobic, (2) facultative and (3) aerobic (maturation), each with different treatment and design characteristics.

The anaerobic pond is the primary treatment stage and reduces the organic load in the wastewater. The entire depth of this fairly deep pond is anaerobic. Up to 60% of BOD is removed.

The effluent from the anaerobic pond is transferred to the facultative pond, where further BOD is removed. The top layer of the pond receives oxygen from natural diffusion, wind mixing and algae-driven photosynthesis. The lower layer is deprived of oxygen and becomes anoxic or anaerobic. The aerobic and anaerobic organisms work together to achieve BOD reductions of up to 75%.

Anaerobic and facultative ponds are designed for BOD removal, while aerobic ponds are designed for pathogen removal. An aerobic pond is commonly referred to as a maturation, polishing, or finishing pond because it is usually the last step in a series of ponds and provides the final level of treatment. It is the shallowest of the ponds, ensuring that sunlight penetrates the full depth for photosynthesis to occur. Photosynthetic algae release oxygen into the water and at the same time consume carbon dioxide produced by the respiration of bacteria.

Anaerobic ponds are built to a depth of 2 to 5 m and have a relatively short detention time of 1 to 7 days. Facultative ponds should be constructed to a depth of 1 to 2.5 m and have a detention time between 5 to 30 days. Aerobic ponds are usually between 0.5 to 1.5 m deep.' (Tilley, et al., 2014, p. 110)

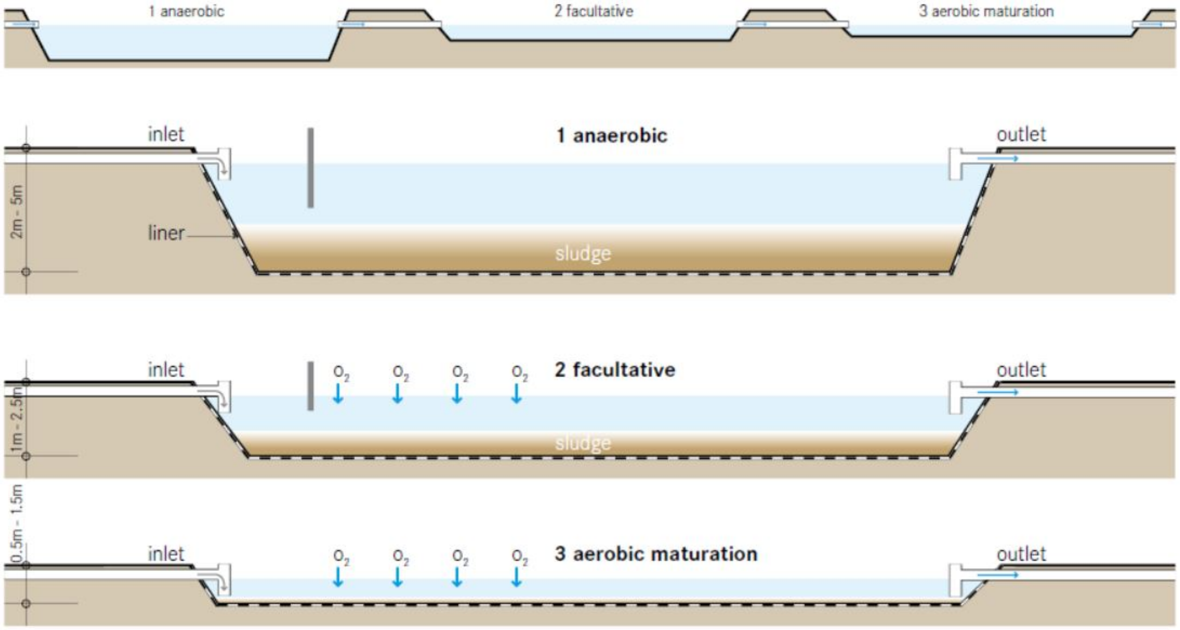


Diagram of a horizontal subsurface flow constructed wetland (Tilley, et al., 2014, p. 110)

2.2. Kahatex and Kahaville statistics

Kahaville statistics		
residential area	m2	432543
factory area	m2	179968
green area	m2	25912
public football field (owned by Kahatex)	m2	2342
fishpond area	m2	135
Population (Kampung * 5.9)	# people	26000
Fuel usage	kWh/month	546000

Electricity usage	kWh/month	2210000
Rice field water usage	mm/6 months	1082
	m/month	0.18
	m3/month	4673
Drinking Water usage	m3/month	708
Household Water usage	m3/month	121841
Shower	m3/month	30460
Faucet	m3/month	30460
Laundry	m3/month	24368
Toilet	m3/month	36552
Blackwater production	m3/month	37260
greywater production	m3/month	85289
total wastewater production	m3/month	122549

Kahatex statistics

area	m2	179968
Population	# people	26000
Fuel usage	kWh/month	42823921
Electricity usage	kWh/month	3374123
Water usage	m3/month	439200
Rainwater harvest production	m3/month	26329

2.3. Calculations for proposed water facilities

Rainwater collection: rain >> drinking water

Supplier		
Factory roofs		
roof area (reduced to 91%)	m2	163770.88
water produced (average precipitation)	m3/month	25057
		1654836902
water profit	rph/month	7
	euro/month	1042547
Consumers		
Kahaville (average precipitation)		
total consumption	m3/month	708
% supplied by Kahatex roof	%	3539
		1818502090
water profit	rph/month	9
	euro/month	1145656
Kahaville (lowest precipitation, september)		

water produced	m3/month	8998
% supplied by Kahatex roof	%	1271
water profit	rph/month	5942817291
	euro/month	374397
Kahaville (highest precipitation, feb)		
water produced	m3/month	45892
% supplied by Kahatex roof	%	6482
water profit	rph/month	30308368182
	euro/month	1909427
Public laundry + shower		
total consumption	m3/month	37161
rainwater collected - drinking water	m3/month	24349
% supplied by Kahatex roof	%	66
Public laundry		
total consumption	m3/month	24368
rainwater collected - drinking water	m3/month	24349
% supplied by Kahatex roof	%	99.9

Public laundry (for 26,000 people)

case study - GROW rooftop wetland system, India		
greywater treated	L/day	480
	m3/month	14.64
area required (wetland)	m2	8
treatment efficiency	m2/m3/month	0.55
Requirements		
water required		
water required by Kahaville for washing	m3/month	24368
water required by public laundry facility	m3/month	24368
land required - laundry facility		
users	# people	26000
# people / washing machine	# people	50
# washing machines required	# washing machines	520
area / washing machine	m2	1
land required	m2	520
land required - wetland		
treatment efficiency	m2/m3/month	0.55
greywater produced by laundry	m3/month	24368
area required for wetland	m2	13316
above ground land required - total		
area	m2	13836
land required - septic tank		

retention time	days	1.5
# users	# people	26000
wastewater generated (grey water)	m3/month	24368
	m3/day	798.96
septic tank volume required	m3	1198.4
septic tank area	m2	479.37
Product		
greywater		
greywater produced by laundry	m3/month	24368
Consumers		
public toilet		
flushing water required/toilet	m3/month/toilet	15352
% served by laundry	%	159

Public toilet: blackwater >> irrigation water + effluent

users	# people	10920
above ground areas		
toilets + wetland	m2	3982
underground areas		
septic tank	m2	4822
anaerobic filter	m2	205
Product (irrigation water)		
Blackwater produced by public toilet	m3/month	15649
Irrigation water produced by public toilet	m3/month	14084
land area		
toilets + wetland	m2	3982.101883
% green area	%	15
% public space	%	170
% factory space	%	2
Consumer		
rice fields		
total irrigation water consumption	m3/month	4673
% rice field served	%	301
Kahaville public laundry + shower		
water available after rice fields	m3/month	10977
water needed	m3/month	37161
% provided by treated black water	%	30
Supplier (biogas from human waste)		
Biogas reactor		
energy produced by public toilet	kWh/month	101960

Consumer **Kahaville**		
kahaville fuel usage	kWh/month	546000
% provided by biogas	%	19
Kahatex		
Kahatex fuel usage	kWh/month	42823921.18
% provided by biogas	%	0.2

Supplier (algae) **Facultative pond**		
area	m2	5131
% factory	%	3
% public space	%	219
energy produced by algae	kWh/month	17279

Consumer **Kahaville**		
kahaville fuel usage	kWh/month	546000
% fuel provided by algae	%	3
Kahatex		
Kahatex fuel usage	kWh/month	42823921.18
% fuel provided by algae	%	0.04

2.4. Calculations for proposed energy facilities

Solar PV calculations		
Input		
irradiation	MJ/m2/day	14.3
irradiation	kWh/m2/month	121.2497
Output		
energy productivity	kWh/m2/month	18.187455
factory roof area	m2	179968
Kahatex roof energy	kWh/month	3273159.901
Kahaville		
Total electricity usage of Kahaville	kWh/month	2210000
What % solar roof needed	%	67.51885232
Kahaville population	# people	26000
Total electricity usage per person	kWh/month/person	85
People served by Kahatex roof	# people	38507.76355
% population served by Kahatex roof	%	148.1067829
Kahatex		

Electricity usage of Kahatex	kWh/month	2652640
What % solar roof needed	%	81.04217575
# Kahatexs served by roof	# Kahatexes	1.233925411

Micro algae

biomass productivity	g/m2/day	20
biomass productivity	kg/m2/month	0.61
dried biomass energy content	kcal/kg	3250
dried biomass energy content	kWh/kg	3.777215
recovered oil energy content	kcal/kg	4750
recovered oil energy content	kWh/kg	5.520545
energy productivity	kWh/m2/month	3.36753245

Inputs required for algae production

land area	m2/kg/month	1.639344262
CO2 needed	kg/m2/month	3.189428571
Nitrogen	kg/m2/month	0.0427
Phosphorus	kg/m2/month	0.0061

Fuel suppliers

from kahatex roof algae farm

roof area	m2	179968
energy produced from biomass	kWh/month	606048.08

from kahaville algae farm

area	m2	25912
energy produced from biomass	kWh/month	87259.50

Fuel consumeres

Kahatex

Kahatex fuel usage	kWh/month	42823921.18
% supplied by kahatex roof	%	1.415209218
% supplied by kahaville green area	%	0.203763454

Kahaville

Kahatex fuel usage	kWh/month	546000
% supplied by kahatex roof	%	110.9978168
% supplied by kahaville green area	%	15.98159356

Biogas from human waste

volitile waste	lbs/person/day	0.25
	kg/person/day	0.11
methane from waste	kg/person/day	0.03968254
efficiency		0.55

specific heat of methane	kJ/kg	55500
energy produced	kJ/person/day	1211
	kJ/person/month	36944.94048
	kWh/person/month	10
energy produced by Kahaville	kWh/month	267038
% of Kahaville fuel usage	%	49

Agricultural waste (rice)

rice yield (weight no including straw and husk)	tons/hectare/year	3
	kg/hectare/year	3000
	kg/m2/year	0.3
	kg/m2/month	0.025
rice husk yield	kg/m2/month	0.006625
rice husk energy value	MJ/kg	15.84
	kWh/kg	4.40352
	kWh/m2/month	0.02917332
rice straw yield	kg/m2/month	0.03125
rice straw energy value	MJ/kg	15.09
	kWh/kg	4.19502
	kWh/m2	0.131094375
husk+straw energy value	kWh/m2/month	0.160267695

Fuel suppliers		
Kahaville		
area	m2	25912
energy produced	kWh/month	4152.856513

Fuel consumers		
Kahatex		
Kahatex fuel usage	kWh/month	42823921.18
% supplied by kahaville	%	0.009697516
Kahaville		
Kahaville fuel usage	kWh/month	546000
% supplied by kahaville	%	0.760596431

III. PROPOSED WATER AND ENERGY SYSTEM

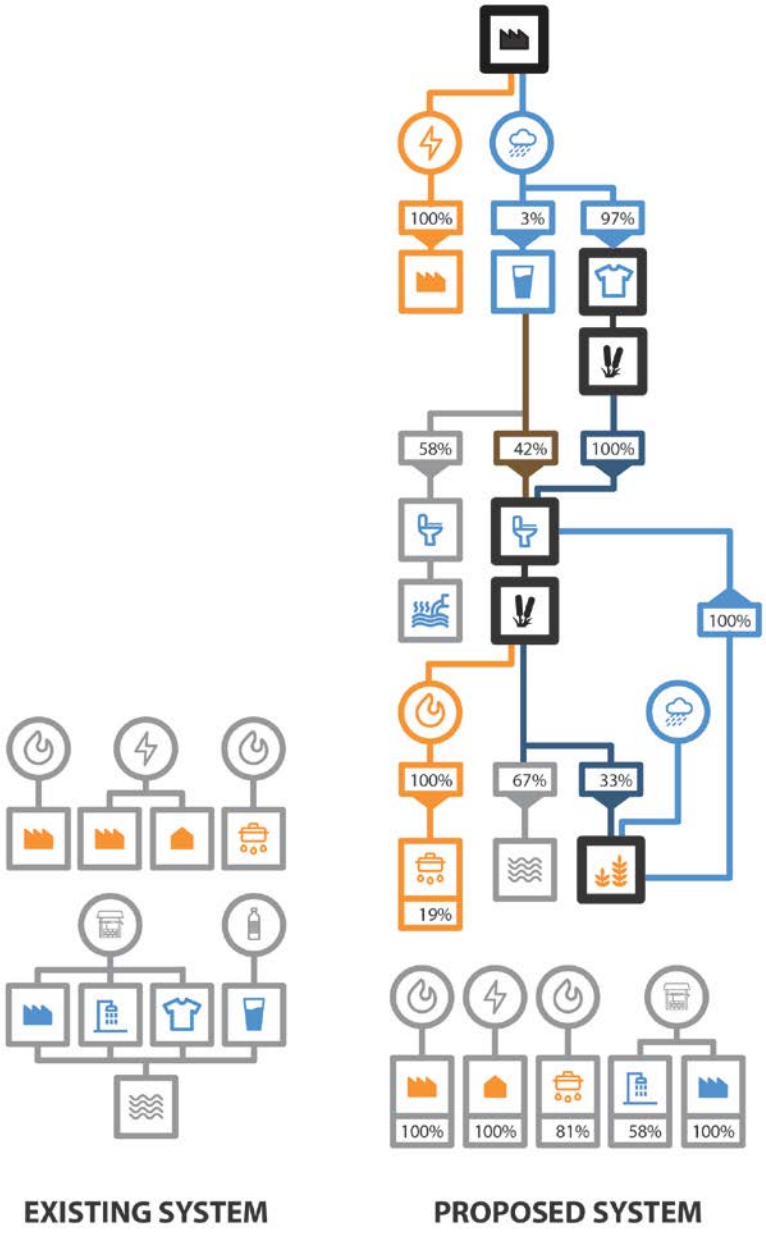
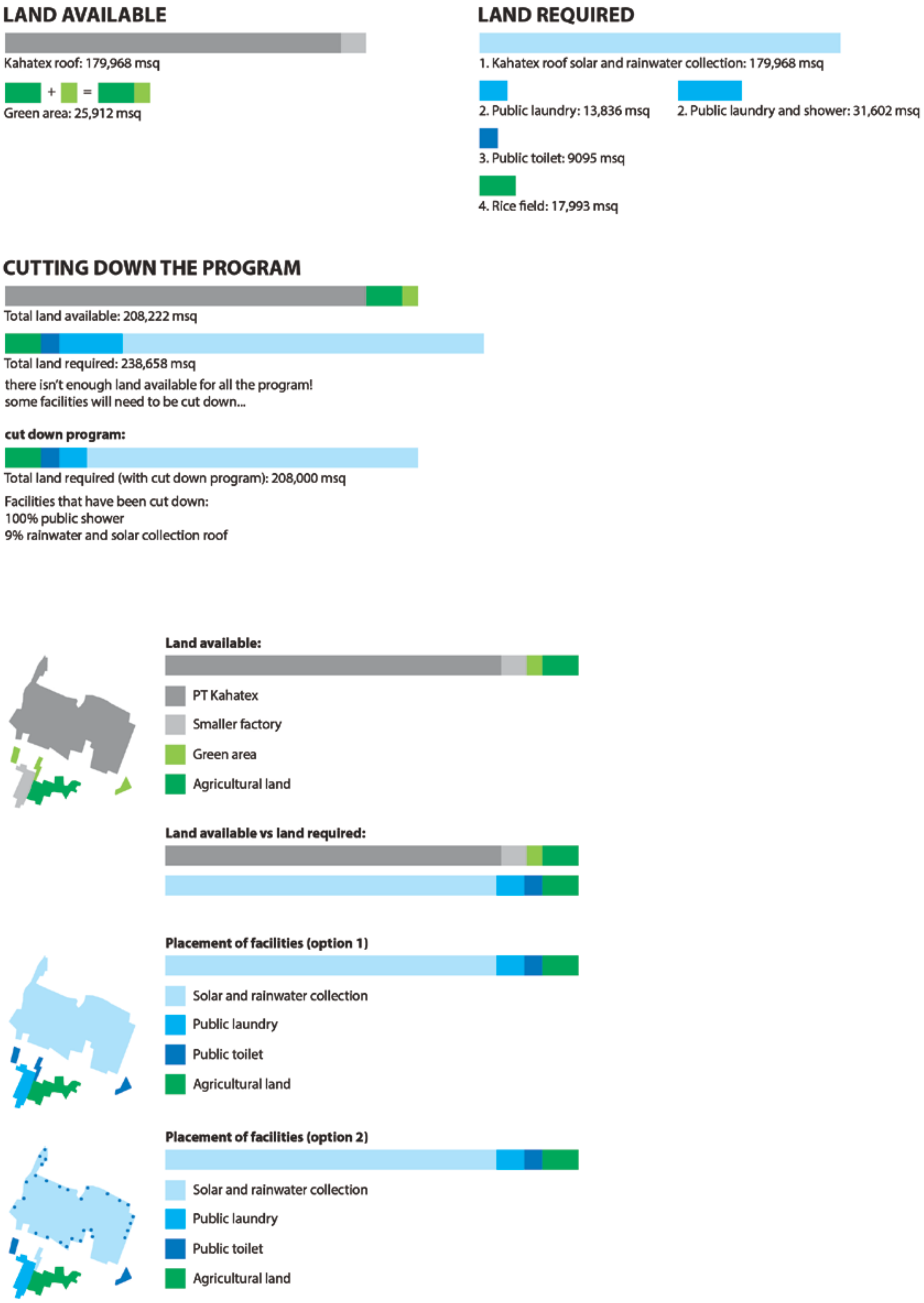


Diagram of existing vs proposed system



there isn't enough land available for all the program!
some facilities will need to be cut down...

Facilities that have been cut down:
100% public shower
9% rainwater and solar collection roof

Diagram of land requirements