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ten Caat, P.N.; Tillie, Nico; Tenpierik, M.J.

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Chapter 12
Pig Farming vs. Solar Farming: Exploring Novel Opportunities for the Energy Transition

Nick ten Caat, Nico Tillie, and Martin Tenpierik

Abstract Amsterdam aims to bring down its carbon footprint by 55% in 2030 and by 95% in 2050. For the built environment, plotted pathways towards carbon neutrality primarily revolve around the reduction of fossil based energy demand and the transition towards renewable energy production strategies. The consumption of food resources, and its significant corresponding carbon footprints, remain up to this day outside the scope of the city's carbon accounting. At the interface of the building sector and the agricultural sector, under-explored possibilities for synergistic and sustainable resource management come to light. For a more holistic and veracious evaluation, this research expands the carbon inventory of the urban dweller with the food category and then explores, by means of a case study, a novel strategy for the decarbonisation of the built environment: urban pig farming in Amsterdam. A theoretical farming system is added to an urban context and coupled with the existing local resource flows, allowing for new output-input links. The capacity of the farm, i.e. the maximum number of animals at any time, is determined by the daily food waste output of the neighbourhood. A comparison is drawn with a conventional method for the energy transition: photovoltaic energy, for which two common array configurations are assessed. The three scenarios are evaluated on three aspects relevant to the energy transition of the built environment: avoided carbon emissions, produced thermal energy and produced electrical energy, normalised per square meter surface area. Carbon accounting shows that an integrated pig production facility of 495 m^2, holding 79 animals, can potentially reduce the carbon emissions of Kattenburg by 218 tons (−5.6%) a year, i.e. 441 kg CO_2/m^2. The solar farm has a net impact of 42 kg/m^2/yr if the panel array configuration is based on optimal panel angle and 77 kg/m^2/yr if the configuration is based on optimal ground surface area cover. This study intends to spark further discussion on

N. ten Caat (✉) · N. Tillie · M. Tenpierik
Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, Netherlands
e-mail: p.n.tencaat@tudelft.nl

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urban farming by showing that an integrated pig farm can potentially avoid between 6–10 times more carbon emissions compared to a solar farm.

Keywords Urban farming · Energy transition · Renewable energy · Carbon footprint · Amsterdam

12.1 Introduction

Gradual depletion of fossil fuel supplies and anthropogenic climate change necessitate a transition towards renewable energy solutions in cities (IPCC 2018; UN Habitat 2014). In the city of Amsterdam, the designated city for this study, around 30% (~1.325 kton) of the carbon emissions can be attributed to the city's residential and commercial natural gas demand alone (Gemeente Amsterdam 2016). Both national and local governments committed themselves to the Europa 2020 agreements and to the global UNFCCC Paris 2015 climate agreement. For the Amsterdam metropolitan area, this leads to stringent CO_2 emission targets: a reduction of 55% by 2030 and 95% by 2050 (relative to 1990 levels) (Gemeente Amsterdam 2019).

In order to become free of fossil energy, cities are compelled to undergo an *energy transition* towards renewable energy sources as well as to better manage demand and supply (Solomon and Krishna 2011). This implies a progressive disconnection from fossil based energy resources and an increasing reliance on a combination of renewable electrical and thermal sources, such as photovotaics, wind power or biogas. Amsterdam has conceived a roadmap towards (near) fossil energy freedom (Gemeente Amsterdam 2019). At the moment, conventional strategies mainly include expanding the photovoltaic surface area, increasing the wind turbine capacity at the perimeter of the city, expanding the existing high temperature district heating grid and setting high standards for the energy performance of future and retrofitted buildings (Gemeente Amsterdam 2015). One of the milestones the municipality has set for itself is to fully abandon natural gas use in the built environment by 2040 (Gemeente Amsterdam 2019).

The carbon footprint of Amsterdam's dwellings can initially be allocated to the use of electricity and the burning of natural gas for domestic heating. However, the carbon footprint of the urban dweller goes beyond energy consumption of merely its housing and is topped up by, but not limited to, emissions related to:

1. the production, distribution and treatment of water;
2. personal and public mobility;
3. the processing of domestic waste;
4. the production and transportation of food.

This study describes the hypothetical introduction of an organic pig farm into the residential neighbourhood of Kattenburg (Amsterdam). Such a farming system is not an autarkic entity and will put additional demands on the existing energy, water and waste infrastructure, subsequently implicating changes to the overall carbon footprint of the neigbourhood. Simultaneously, the global warming potential (GWP) of pork produced in the urban setting cannot be estimated with life cycle analysis (LCA) data of conventional farming practices since alternative and unconventional farming methods are used at the feed and on-farm stage of the pork production chain.

Urban farming is co-incentivized by the idea that food chain carbon emissions (and other environmental burdens) are mitigated or even avoided due to more sustainable farming practices at a closer proximity to the consumers. However, to which extent this intended positive impact on the carbon balance outweighs the negative impact due to the increased demand for water and energy should be studied and calculated per case. Therefore, this study expands the scope of urban carbon accounting by adding pork consumption to the inventory. This integrated carbon profile – energy, mobility, water, waste and food – acts as the initial condition for the appraisal of urban food strategies and allows for a holistic assessment of the contribution of urban agriculture (UA) to the decarbonisation of the city. The aim of this research is to spark reconsiderations on urban livestock farming by demonstrating the decarbonisation potential of deploying a pig farm as an energy transition strategy.

12.2 Materials and Method

12.2.1 Sharing Waste Flows

For many centuries, the scale of a city was determined by the amount of food its arable belt could produce and how quickly this food could be transported to the markets (Steel 2008). Innovations in ocean bulk transportation and the expansion of railway networks in the nineteenth century allowed cities to expand this belt and the agriculture to areas where space was abundant. Innovations in preservation and refrigerated transport lead to the global food system we rely on today (Hackauf 2015). Livestock farming has changed over the last decades into a bio-industry, it has become more specialised, intensive, effective, large-scale, mechanised and less labour is involved in agricultural practices. Urban agriculture is ‘the production, processing and marketing of food and related products and services in urban areas, making use of urban resources and waste’ (Veen et al. 2012, p.4). A farming system could act as a nexus within the network of urban waste, nutrient, water and energy flows. The farm receives urban output, converts it into crops or animal protein, creating new value out of waste, and circulates it back to the city. This limits the use of virgin or imported materials and offers ecological and environmental benefits at various stages of the food production chain. A second ecological key benefit of UA is the reduction of carbon equivalent emissions due to a reduction of food miles, as food products or animal feed are no longer imported/exported to overseas countries but directly brought onto the local market (van Timmeren and Hackauf 2014).

This study theorises that Kattenburg's organic waste output becomes valuable farm input and the farm's output becomes valuable city input in the form of pork products and biogas. As such, the capacity of the farm is determined by the availability of organic waste generated within the neighbourhood. In other words: pig feed is not imported from external sources but produced onsite.

12.2.2 Urban Livestock Farming

Urban livestock farming, the raising of domesticated animals for the production of human food within or at the perimeters of cities and villages, used to be an ordinary practice in the beginning of the twentieth century. After the second world war, however, the growing global population led to an increasing demand for pork meat that could only be met though modernisation and upscaling. Therefore, in major pork exporting counties like the Netherlands and Denmark, the total number of pig farms decreased while the average number of pigs per farm increased (Wageningen UR 2019a; Willems et al. 2016).

Not including neighbourhood petting zoos, there are no initiatives in the Netherlands where pigs are kept within the urban context, let alone for the purpose of meat production. Online research reveals that (design) studies on the idea of commercial urban pig raising are limited. In 2001, MVRDV proposed *Pig City*, a radical re-imagination of organic and humane pig farming in The Netherlands. The design concept highly valued pig wellbeing and comfort while at the same time maintaining an animal concentration high enough to remain economically feasible (MVRDV 2011). In the design- studio 'City Pig', Fig. 12.1, the benefits and challenges of urban pig production are explored by proposing a series of urban integrated reimaginations of pig farms (Hackauf 2015).

Though various studies have researched the environmental impact of livestock production in general, there is little quantitative information available about livestock farming in (peri)urban environments (Wei et al. 2016). The debate against the return of pigs to cities revolves around the impacts of manure (mis)management, inadequate farming facilities that attract rodents and insects, risks around zoonosis, pollution of local water bodies due to polluted rainwater runoff and nuisance due to odour, noise, dust or fine particulate matter (Mfewou and Lendzele 2018; Ström et al. 2017). Also, an inner-city farm would, even though expected to be smaller in production capacity, increase incoming and outgoing truck and tractor transport movements in the locality. Yet, it should be adressed that these disadvantages are more common in small-scale unregulated farming methods. Technologically advanced closed production systems, meeting stringent health, environmental and safety regulations with well-organised manure management are less likely to impose the mentioned burdens on their direct environments.

Fig. 12.1 One of the out-of-the-box farming concepts. (Copyright: The Why Factory (Delft University of Technology))

12.2.3 Import, Export and Carbon Footprint of Pork

Over the past decades, the distance between the consumer and the farm has increased, as did the distance between the animal and the farm that produces its feedstock. Nowadays, subsistent farming has made place for virtually landless pig farms. Grain, currently the main component of a pig's diet (56%) is for 90% imported from countries like France and Germany (Willems et al. 2016). Waste products of the food industry, like wheat bran, supply only part of the pig feed (13%). Recycling valuable manure nutrients in an environmentally friendly way depends essentially on the total manure produced by all the livestock in an area and the amount of available arable land in the proximity of the farm (Wei et al. 2016). The EU Nitrates directive installed limitations (170 kg/hectare) on land spreading of manure to avoid (ground) water eutrophication by nitrogen and phosphorus wash off (EU Commission 1991). The total manure production tends to exceed this limitation, forcing Dutch farmers to export about 90% of their (pasteurised) excess manure to other farmers or even across borders (Willems et al. 2016).

Life Cycle Assessment methods are used to determine the global warming potential (GWP), i.e. carbon equivalent impact, of the pork meat production chain. In the Netherlands, three pork production methods can be distinguished: a *global* system - pig feed imported from abroad, meat exported abroad, *semi-local* - feed imported, meat sold locally and *local* -local feed, local market (Rougoor et al. 2015). The assessment was performed for the five main stages in the pork production chain (Fig. 12.2). Even though there are national concerns about sustainability and animal welfare, the majority of pork meat is still produced on large scale intensive farms

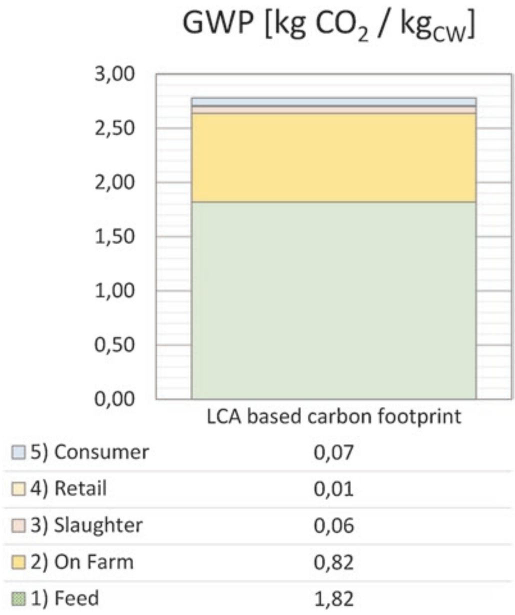

Fig. 12.2 Carbon equivalent footprint of Dutch pork meat: 2,78 kg/kg pork, based on Rougoor et al. (2015)

tied to a global pig feed supply network. The Netherlands is market leader on the international pork meat market: with a self-sufficiency rate of 330% in 2019 (Wageningen UR 2019b), the majority of pork produced is exported to neighbouring European countries. However, this study assumes the *semi-local* scenario for the pork meat consumed in Kattenburg: pig feed is supplied with a global system, animals are slaughtered and processed centrally in the region and meat is sold within the Netherlands. This corresponds with a GWP of 2,78 kg CO_2/kg carcass weight (CW) (Rougoor et al. 2015). The GWP at the slaughter, retail and consumer stage (in total 0,14 kg CO_2/kg_{CW}) is also applied in the Kattenburg pig farm, without alterations.

12.2.4 Kattenburg, Amsterdam

Kattenburg is a high-density residential neighbourhood and former harbour zone located in the city centre of Amsterdam (Fig. 12.3). As of 2019, Kattenburg has 1801 residents divided over 1061 households (OIS Amsterdam 2019).

Fig. 12.3 Kattenburg, East-Amsterdam. (Source: ©Google Earth)

12.2.5 Scenarios

Two sustainable scenarios are evaluated based on their avoided carbon emissions and generated thermal or electrical energy, normalised per square meter.

- *Status quo*. The existing condition assumes no existing urban interventions that support the energy transition with a major impact and represents a conventional system regarding the production and management of FEW resources.
- In s*cenario 1* an organic pig farm is introduced and positioned in the neighbourhood resource network. The farm, further elaborated in Sect. 12.2.8, is imagined as an archetypical pig farm and fitted with a *feed station*, where domestic organic waste is sorted and converted into pig feed. This station includes the bio waste collection service by an electric vehicle. Additionally, the pig farm is equipped with a *waste station* with an anaerobic digester (AD) and cogeneration plant (CHP) for manure management and energy generation to use onsite. In this station the digestate processing and bio gas upgrading also takes place. Excess biogas is shared with the adjacent residential buildings in the Kattenburg neighbourhood.
- In s*cenario 2* photovoltaic solar collectors (PV) are installed in the neighbourhood. PV panels are a widely accepted system of solar electricity generation and have made their way to the Dutch consumer market for many years now. Two *sub-scenarios* are taken into consideration: (2a) PV array configuration based on maximal solar gain and (2b) PV array configuration based on optimal ground/rooftop surface coverage.

12.2.6 Scope

Carbon accounting is applied to assess the impact of the farming system on the status-quo. The consumption of food, energy and water and the production of household waste within the Kattenburg boundaries result in upstream, territorial and downstream emissions of greenhouse gasses (World Resources Institute 2014). In this study, only carbon emission drivers that can be allocated to Kattenburg's activities and that are directly affected by the proposed interventions are considered for evaluation. To give an example: the pig farm has an impact on Kattenburg's energy provision since excess green gas is directly shared with the adjacent dwellings, leading to a decrease in the demand for natural gas. The remaining digestate, even though rich in nutrients and a potential substitution for mineral based fertiliser, does not have a direct link with any of Kattenburg's activities and potential avoided carbon emissions are therefore not subtracted from the total carbon footprint. On the contrary, the on-site produced pork meat can virtually substitute imported pork meat on a one to one basis, subsequently lowering the carbon emissions of the food category. The integrated footprint of Kattenburg is trimmed down to include consumed resources that are relevant to this study only, an overview is provided in Table 12.1.

Table 12.1 shows the per capita consumption (PCC) of the five assessed components of an average Kattenburg resident. Annual pork meat consumption is assumed to be similar to the Dutch national average consumption of 2017, which includes all types of (treated) meat products (i.e. fresh meat, frozen meat, meat products) but not meat added to secondary products (e.g. canned soups) (Dagevos et al. 2018). Energy consumption is divided in electrical energy and fuel consumption to meet the thermal energy demand. For reasons of simplicity, incidental electrical energy generation on household level (e.g. private PV systems) are not included and it is assumed all households are connected to the national gas grid. Energy consumption data is provided at the household level (Liander 2019). Domestic water consumption is retrieved from the district supplier (Waternet 2016). Annual domestic waste

Table 12.1 Per capita resource consumption/production of Kattenburg. Selection of relevant Business as Usual consumed resources

Sector + component	Product/activity	PCC/PCP[a]	*Unit*	(Source)/note
Food, meat	Pork meat	36,5	*kg/yr*	(Dagevos et al. 2018) Dutch national average
Energy, electrical	National grid mix	1614	*kWh/yr*	(Liander 2019) Neighbourhood specific data
Energy, thermal	Natural gas	549	*m^3/yr*	(Liander 2019) Neighbourhood specific data
Water, consumption	Centralised production	107	*L/day*	(Waternet 2016) Regional average consumption of household water
	Centralised treatment	107	*L/day*	Assume water demand = water processed.
Waste, processing	Domestic waste production	492	*kg/yr*	(Rijkswaterstaat 2017) Dutch national average value
	Organic fraction, 32%	157	*kg/yr*	(Rijkswaterstaat 2017) Dutch national average fraction
	Organic fraction waste-to-incineration	100	*%*	Subject to change in the future

[a]PCC: Per Capita Consumption, PCP: Per Capita Production

produced per capita and its organic waste fraction (GFT) are retrieved from an online database (Rijkswaterstaat 2017). Since the municipality of Amsterdam does not administer the organic waste fraction, national values are applied. Apart from a handful of small bottom-up initiatives and local pilots, there has not yet been a municipality-wide centralised bio-waste collection and processing service in Amsterdam (Van Zoelen 2016). There is a lack of unambiguous data available that describes the processing method of separated organic fraction in the future. For these reasons it is assumed all the domestic bio waste is treated as domestic residual waste and is incinerated by the AEB waste incineration plant.

12.2.7 Functional Units

The pig farm and the two PV configuration options are assessed on three performance indicators:

1. Avoided carbon dioxide emissions	[kg $CO_2e/m^2/yr$]	(all scenarios)
2. Net electrical energy generated	[$MJ_e/m^2/yr$]	(scenario 2a and 2b)
3. Net thermal energy generated	[$MJ_t/m^2/yr$]	(scenario 1)

Urban interventions proposed within the framework of the energy transition tend to aim for carbon-neutrality as the critical objective (Van den Dobbelsteen et al. 2018; Pulselli et al. 2019). The environmental impact of the built environment is assessed as the footprint of carbon dioxide equivalents (CO_2e), corresponding to the three main greenhouse gasses released into the atmosphere, multiplied by their 100 year GWP, i.e. carbon dioxide (CO_2, GWP = 1), methane (CH_4, GWP = 28) and nitrous oxide (N_2O, GWP = 265). The GWP measures the potential greenhouse effect of an emitted gas relative to an equivalent mass of carbon dioxide, measured over a period of 100 years after its release into the atmosphere (World Resources Institute 2014). Table 12.2 gives an overview of the applied environmental footprints (EF).

Avoided CO_2e is normalised for the surface area the urban intervention occupies hence $CO_2e/m^2/yr$ is used to describe the impact of the intervention. Additionally, net produced electrical energy [kWh/m^2/yr] or net produced thermal energy [MJ/m^2/yr] are calculated, where *net* implies that the energy demand resulting from the farm system is subtracted from the gross energy yield.

12.2.8 Kattenburg Farming System

The pig farm is divided into three stations: feed station, farming station and waste station. See Fig. 12.4 below.

Table 12.2 Inventory of greenhouse gas emissions (GHG) of relevant components of the three scenarios

Sector	Component	Product/activity	EF	Unit	Note
Food	Meat	Pork meat production	2,7800	kg CO_2e/kg	(Rougoor et al. 2015), LCA Dutch Pork meat
Energy	Electrical	Grid mix	0,5260	kg CO_2e/kWh	(Otten and Afman 2015), Country Specific value
	Electrical	Solar: PV system	0,0000	kg CO_2e/kWh	No direct emissions occur[b]
	Thermal	Natural gas	1,8900	kg CO_2e/m^3	(Zijlema 2018), Country Specific value
	Thermal	Biogas	0,0000	kg CO_2e/m^3	See below[a,b]
Water	Consumption	Centralised production	0,3600	kg CO_2e/m^3	(Frijns et al. 2008), GWP – country specific value
	Consumption	Centralised treatment	1,0700	kg CO_2e/m^3	(Frijns et al. 2008), GWP – country Specific value
Waste	Processing	Waste-to-energy	0,6520	kg CO_2e/kg	(Pulselli et al. 2019) European average values

[a]The combustion of biogas or green gas (predominantly methane) releases CO_2 into the atmosphere. However, since the biogas originates from agricultural biomass that has sequestered this carbon earlier in the season (i.e. short carbon cycle), the net emission is zero. Carbon emission reductions are possible if the biogas substitutes natural gas

[b]Energy is invested for the production of the PV modules and the anaerobic digester systems, generally coined embodied energy. These invested energies are left out of the calculations in this study

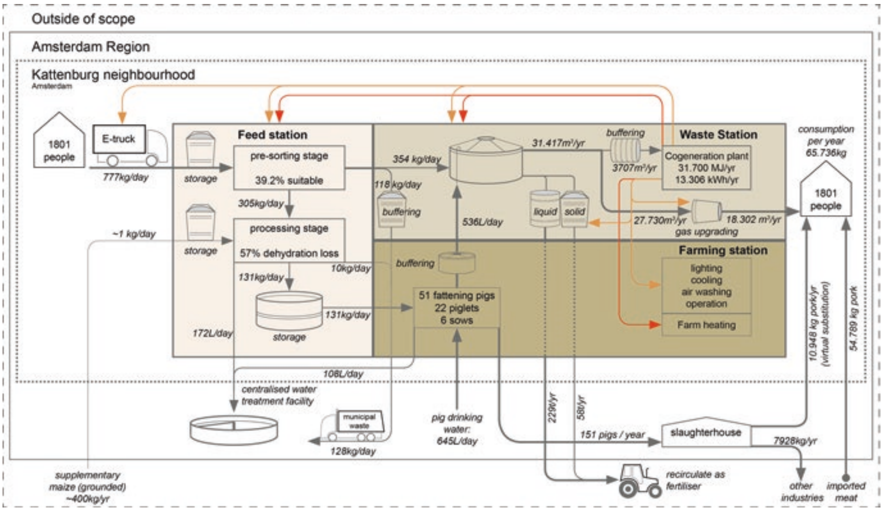

Fig. 12.4 The Kattenburg integrated pig farm with three stations. Some flows are given in daily quantities due to daily cycles (e.g. pig food consumption) and others per annum. Some small rounding errors may occur

12.2.8.1 Feed Station

Food waste is archetypical pig feed and has historically been applied as such in Europe until 2002, when a farmer in the U.K. illegally fed uncooked food waste to pigs, igniting the foot-and-mouth disease epidemic (Salemdeeb et al. 2016). This caused the EU to ban the use of food waste for animal feed. This legislation steers away from a large saving potential on the environmental impact of pig raising. A potential land saving opportunity of around 1.8 M hectares of agricultural land in Europe can be estimated if the European Union would change its legislation on the use of food waste for pork swill (Zu Ermgassen et al. 2016). Salemdeeb et al. (2016) compare the application of food waste for pig feed with conventional anaerobic digestion and composting food waste management methods on 14 environmental and health impact points. Food waste processing into wet pig feed scored best on 13 out of 14 these indicators. In countries such as Japan and South-Korea food waste is still converted into pig feed (called *Ecofeed* in Japan), under the condition that manufacturers are subject to stringent regulations and obligations by the food safety law (Sugiura et al. 2009).

According to the Ministry of Infrastructure and Water Management, an average Dutch person produces 492 kg of domestic waste per year. Around 32% of this total amount is biodegradable waste equivalent to 157 kg/cap/yr (Rijkswaterstaat 2017). For the sake of this study it is assumed all of Kattenburg's residents are consciously participating in the necessary semi-centralised waste separation program and that the new local waste collection and management system is operating without significant losses, hence a biowaste flow of 777 kg/day is theoretically possible.

Not all biodegradable waste is suitable to serve as pig feed and pre-processing filtration separates the unsuitable biomass from the suitable matter. This study applies the suitability coefficient of 39.2% (Zu Ermgassen et al. 2016) which leaves 305 kg/day available for processing. The rejected biowaste can be fermented in an anaerobic digester to serve as biofuel. Suitable biowaste is fed into a shredder and filtered for solid contaminants. The hygienisation process includes partial dehydration before the wet residue is heat-treated on a temperature of 100 °C for sterilisation. Before storage, grounded maize is added. One ton of suitable domestic organic waste results in 430 kg of pig feed (Kim and Kim 2010; Salemdeeb et al. 2016). This wet pig feed can substitute conventional pig feed on a one to one basis (Salemdeeb et al. 2016). The amount of pig feed that can theoretically be generated from Kattenburg's biowaste flow is calculated with equation (12.1):

$$F = \frac{W_{bio} * r_1 * r_2 * N_{KB}}{365} \quad (12.1)$$

where:

F	[kg/day]	is the daily wet pig feed produced from bio waste.
W_{bio}	[kg/cap/yr]	represents the annually produced bio-degradable waste per capita.

r_2 [−] notes the assumed part of bio waste suitable for further conversion (0.392)
r_2 [−] notes the waste-to-food conversion rate of 0,430 (0,405 + 0,025 maize)
N_{KB} [−] represents the total population of Kattenburg

12.2.8.2 Farming Station

The productivity of the pig farm is based on the food conversion ratio and the number of pigs sent to slaughter each year. For this study it is assumed no bulk feed is imported from outside the system. Sows are artificially inseminated, which excludes boars from the farm. Based on the average life stage duration of the pigs and assuming a continuous and steady breeding cycle, we calculate that for every one piglet (42 days life stage, see Table 12.3) there are 3,28 fattening pigs (138 days) present at any time. Incorperating this ratio, the average daily feed intake of one animal

Table 12.3 Technical data pork production chain and spatial specifications pig farm

Pork production specifics	*Unit*	Piglet (PL)	Fattening pig (FP)	Sow	Note/source
Life stage length	*Days*	42[a]	138[b]	730 (2 yr)[c]	Total life cycle animal [LC_{pig}] = 180 days
Feed intake	*kg/day*	0,71[d]	1,92[e]	1,92	(Rougoor et al. 2015) assume sow = FP
Water cons./slurry produced	*ton/pig/yr*	2,98/2,48	2,98/2,48	2,98/2,48	Indicative values for calculations[f]
Water exhaled/lost otherwise	*ton/pig/yr*	0,50	0,50	0,50	Own calculation. Assume sink = WWTF
Carcass weight/life weight	kg_{CW}/kg_{LW}	n.a./n.a.	102/125	102/125	(Rougoor et al. 2015) assume sow = FP
Min space: pig pen/free roaming	*m^2/animal*	0,6/1,0	1,3/1,0	2,5/1,9	(SBLk 2018)
No of animals	*[−]*	22	51	6	Own calculations. Equations 12.4–12.6
Total space required	*m^2*	35,2	117,3	26,4	Own calculations.

[a](SBLk 2018). Piglets should stay a minimum of 42 days with the sow according to 3-star organic farming standards
[b](Rougoor et al. 2015, Table 12.4) final weight slaughter pig [kg_{LW}]/average growth rate [kg/day] = 125/0,9 = 138 days
[c]Life span sows vary per farming method. We assume 2 years/720 days
[d](Rougoor et al. 2015) total feed intake [kg]/life span [days] = 30/42 = 0,71 kg/day
[e](Rougoor et al. 2015) total feed intake fattening pig [kg]/life span [days] = 265/138 = 1,92 kg/day
[f](Schiavon et al. 2016). Exact values depend on many parameters (i.e. farm typology, climate, pig life phase). Mentioned values are for fattening pigs with a life weight of 120 kg that are on a wet feed diet (water-food intake ratio = 4:1). Assume floor is partially slatted. For simplicity we assume the fattening pig, piglet and sow are equal

Table 12.4 Substrate properties (SGC 2012) and biogas yield AD

AD input	Quantity [ton/yr]	Mix ratio [kg/ 1000 kg]	Solids [%]	Solids in mix [kg/ 1000 kg]	Biogas content [m³/1000kg]	Biogas yield [m³/1000kg]	CH_4 [%]	Gas yield V_{prod} [m³/yr]
Pig slurry	195,9	603	8	48,2	26	15,7	63	–
Bio waste	129,0	397	33	131,0	204	81,0	63	–
Total	325,1	1000		179,2	–	96,7		31.437

(C_{pig}) on this farm is 1,62 kg/day and is represented with equation (12.2). The calculation is based on the average daily feed intake of a piglet (0,9 kg) and of a fattening pig (1,92 kg) combined with the before mentioned animal life stage ratio. The maximum number of animals on the farm is determined by the available biowaste based pig fodder and can be calculated with equation (12.3).

$$C_{pig} = \frac{(1*0,9)+(3.28*1,9)}{4.28} \tag{12.2}$$

$$\sum N_{pig} = \frac{F}{c_{pig}} \tag{12.3}$$

The minimum number of sows required to sustain the farm's pig population can be using equation (12.4). The farm keeps its own sows to produce piglets so that no weaning pigs are imported from external breeding farms. It is assumed that one sow can produce 28 piglets per year (Zu Ermgassen et al. 2016). The number of piglets (PL) and fattening pigs (FP) can be calculated with equations (12.5) and (12.6).

$$N_{sow} = \frac{\sum N_{pig} * (365 / LC_{pig})}{28} \tag{12.4}$$

$$N_{fp} = \left(1 - \frac{LS_{pl}}{LS_{fp}}\right) * \left(\sum N_{pigs} - N_{sow}\right) \tag{12.5}$$

$$N_{pl} = \sum N_{pigs} - N_{fp} - N_{sow} \tag{12.6}$$

The maximum number of animals at any time on this farm is represented by $\sum N_{pig}$. The number of piglets (PL), fattening pigs (FP) and sows are represented by N_{PL}, N_{FP} and N_{sow}. The duration of *piglet* life stage (LS_{PL}) and *fattening pig* life stage (LS_{FP}) can be found in Table 12.3.

The annual pork yield of this farm is described by M_{farm} [kg/yr] and depends on the number of animals the farm delivers, the life weight (kg_{LW} [kg/pig]) of a slaughter pig (Table 12.3) and the amount of consumable meat that can be retrieved from the carcass, indicated by m_{pig} [%] (Vion 2017, p.19). Also sows are brought to slaughter at the end of their intended life cycle (LC_{sow}).

$$M_{farm} = \frac{N_{sow}}{LC_{sow}/365} + \frac{N_{fp} + N_{pl}}{(LS_{PL} + LS_{FP})/365} * kg_{LW} * m_{pig} \tag{12.7}$$

The equations above point out that, based on the food waste revenue, the maximum number of animals that can be kept at any time in the farm is 79 (6 sows, 22 piglets and 51 fattening pigs), which means that the farm could theoretically deliver 151 slaughter pigs per year. This study assumes the animals are slaughtered at conventional large scale facilities, where 58% of the full body weight can be retrieved for human consumption (Vion 2017). Assuming a life weight of 125 kg_{LW} per animal and an edible meat fraction of 58%, this farm can generate 10.948 kg of pork meat per year. The remaining pig products are used in other industries but are not carbon accounted for in this study.

12.2.8.3 Waste Station

The pig farm is heated and cooled to maintain a comfortable environment for the animals and electricity is required for farm lighting, ventilation, air cleaning and other on-farm processes (see Table 12.5). The farm generates its own thermal and electrical energy by means of anaerobic digestion (AD) and combined heat and power generation (CHP). The annual biogas yield is sufficient to meet the energy demand of the electric waste collection vehicle, the feed station, the pig farm, the AD and the biogas upgrading station. Excess biogas is cleaned and upgraded in a water scrubber, after which it is suitable to be mixed with the natural gas grid.

Pigs produce manure or slurry, which can be valuable for crops as it contains large amounts of Nitrogen (N), Phosphorus (P) and Potassium (K), but can pose an environmental threat if managed poorly (Loyon et al. 2016). Slurry produced by the pigs is collected through the partially slotted floor and buffered in a storage tank. Together with the rejected biowaste, the manure serves as input for the AD. Depending on the fermentation speed in the AD, the manure is mixed with shredded biowaste and the resulting substrate pumped into the AD tank, ensuring a continuous production of biogas. In the AD tank, the co-digestion process of pig manure and food waste occurs under zero-oxygen conditions, resulting in the production of methane, carbon dioxide and small amounts of incondensable gasses like N_2, O_2 and H_2 (Chen et al. 2015). The temperature of the AD substrate is kept within the mesophilic range (35–45 °C), speeding up the digestion process. The biogas output of the AD co-depends on the substrate typology and on the solid fraction of that substrate (Table 12.4) (SGC 2012). The biogas yield of this farming system is calculated to be 96,7 m^3 per ton input, resulting in 31.437 m^3 of biogas per annum. After the anaerobic digestion process a mineral rich and odourless digestate remains in the reactor vessel, which is centrifuged to separate the liquid and solid fraction and then

Table 12.5 Life cycle inventory of various system components and other parameters

n.	Comp.	Description	Value	Unit	Note
1	Feed station	Electricity demand feed processing	13,9	MJ_e/1000 kg	(Kim and Kim 2010)
2		Thermal energy demand feed processing[a]	105,7	MJ_t/1000 kg	(Kim and Kim 2010) See footnote a
3		Waste water production during feed processing (r_2)	564	L/1000 kg	(Kim and Kim 2010)
4		Supplementary grounded maize added	25	kg/1000 kg	(Kim and Kim 2010)
5		Screenings produced during feed processing	30	kg/1000 kg	(Kim and Kim 2010)
6		Accepted bio waste in pre-processing (r_1)	392	kg/1000 kg	(Zu Ermgassen et al. 2016). i.e. 39.2% is suitable
7		Electricity demand food waste collection vehicle	460	kWh/yr	Estimation, see[b]
8	Farming station	Electricity demand pig farm	87,8	MJ_e/animal delivered	Based on 19,5 kWh/100 kg_{LW} (Dalgaard et al. 2007)
9		Energy demand pig farm	29,9	MJ_T/animal delivered	Based on 23,9 MJ/100kg_{LW} (Dalgaard et al. 2007)
10		Water demand pig/manure production pig	–	–	See Table 12.3
11	Waste station	Electricity demand A.D. process	7,20	MJ_e/1000 kg input	(Nguyen et al. 2010)
12		Energy demand A.D. process	46,8	MJ_t/1000 kg input	(Nguyen et al. 2010)
13		Fraction of rejected bio waste suitable for AD	75	%	Assumption
14		Digestate production A.D. process	886	kg/1000 kg input	Own calculation[c]
15		Liquid fraction in residual digestate	79,8	%	Own calculation[d]
16		Solid fraction in residual digestate	20,2	%	Own calculation[d]
17		Volumetric loss during conversion biogas > green gas, conversion value	0,746	–	Own calculation[e]
18		CHP: efficiency (η_{CHP})	90	%	Standard efficiency, 10% is lost to the system
19		CHP: Thermal energy produced	11,5	MJ_t/m^3	50% of fuel input, standardized calculation value
20		CHP: Electricity energy produced	9,2	MJ_e/m^3	(Wylock and Budzianowski 2017) 40% of fuel input

(continued)

Table 12.5 (continued)

n.	Comp.	Description	Value	Unit	Note
21		Electricity demand solid-liquid separation digestate (centrifugal method)	9,00	MJ_e/1000 kg digestate	(Timonen et al. 2019)
22	Misc.	Electricity required for biogas upgrading (e_{up})	0,90	MJ_e/Nm^3	(Baena-Moreno et al. 2019) conservative value
23		Energy content biogas (q_{bgas})	23,00	MJ/m^3	(SGC 2012) Lower caloric value, 67% CH_4
24		Energy content natural gas/green gas	31,65	MJ_t/Nm^3	(Zijlema 2018)

[a]Source mentions diesel. So 2,91 L^{-1} Diesel/1000 kg food waste = 105 MJ/t (assuming Diesel = 36 MJ/L^{-1}). Converted to biogas this gives (23 MJ/m^3): 4,55 m^3/1000kg food waste

[b]Assumed vehicle type: Goupil G4 electric freight cart. Lithium battery with 7,2 kWh capacity offers 85 km driving range (vehicle brochure). Assume 15 km/day = ~5500 km/year. This comes down to roughly 65 full charges/year, or 460 kWh/yr

[c]CH_4 concentration biogas = 63% (SGC 2012). Density CH_4/CO_2 = resp. 0,72/1,96 kg/m^3 (Timonen et al. 2019). This gives a biogas density of 1179 kg/m^3. The biogas yield of this substrate composition is 96,7m^3/1000 kg substrate (Table 12.4), i.e. 114 kg of biogas is removed from the reactor vessel, leaving 886 kg of digestate. Bio gas trace elements like H_2O, H_2, N, H_2S and O_2 are ignored for this calculation for simplicity due to their small concentrations

[d]Total solids in substrate is 179,2 kg/1000 kg (Table 12.4). We assume this amount remains the same for the digestate, but the biogas yield should be subtracted. This makes 179,2 kg/886 kg digestate, or ~20% of the digestate

[e]Methane concentration should be increased from 63% to 97% (+34%) to make *green gas*, i.e. 0,34 × 1,96 = 0,67 kg/m^3 CO_2 is removed from the biogas. This conversion leads to a volume reduction for the green gas (at equal pressure) of 1/1,34 = 0,756. The *green gas* density after upgrading is 0,756 kg/m^3 (3% CO_2, 97% CH_4)

stored. Mass balance calculations are used to determine the amount of liquid and solid digestate produced, based on the feedstock characteristics (Table 12.4), biogas composition (63% methane, 37% carbon dioxide) and component densities (Table 12.5, c and f). The digestate could potentially substitute mineral fertiliser on the crop field, but this is left out of this study.

The produced biogas fuels an on-site combined heat and power plant (CHP) to generate the electricity required by the feed station, the pig farm, the AD and the electric collection vehicle (Table 12.5). Excess biogas is cleaned and upgraded, which means that the carbon dioxide concentration is reduced and unwanted trace elements are removed before mixing with the gas grid (Chen et al. 2015). There are several methods for biogas upgrading that all come with various advantages and disadvantages. High Pressure Water Scrubbing (HPWS) seems to be most suitable for small scale applications, is cheap and can handle fluctuating capacities (Baena-Moreno et al. 2019; Wylock and Budzianowski 2017). Upgraded biogas is called *green gas* and can be shared with the adjacent residential buildings, where it can substitute conventional natural gas on a one to one basis.

Removed carbon dioxide cannot be collected and repurposed with this technique and is left out of the carbon emission evaluation. For simplicity, it is assumed no methane is lost during the scrubbing process.

12.2.9 Solar Farm

12.2.9.1 PV Panel Configuration: Two Options

The carbon performance of the farm, i.e. the avoided CO_2e emissions per square meter of farm, is compared with the carbon performance of photovoltaic (PV) panels. PV systems, convert solar radiation into useful electrical energy. Since PV panels or arrays can be clustered, oriented and distributed throughout the urban context in essentially unlimited manners, two key setups are further elaborated:

- Setup A is installed according to the optimal angle relative to the solar trajectory in the Netherlands (Fig. 12.5, left, top): respectively 36° and 180° South for most optimal angle for the altitude and azimuth. A consequence of this method is the required free space between two panels in a PV field to avoid inter-panel shading, leading to a larger ground surface area per panel and a less efficient use of the available space. The minimal distance between two panels within a solar array is calculated with a rule of thumb, suitable for a context in the Netherlands: 2,7× panel height.
- Setup B is based on an optimised use of the available land and proposes an east-west panel orientation under a lower inclination: respectively 10° and 90° East/270° West. Now the panels no longer shade each other but the yield per panel is reduced. A maintenance corridor of 50 cm is applied (Fig. 12.5, left, bottom)

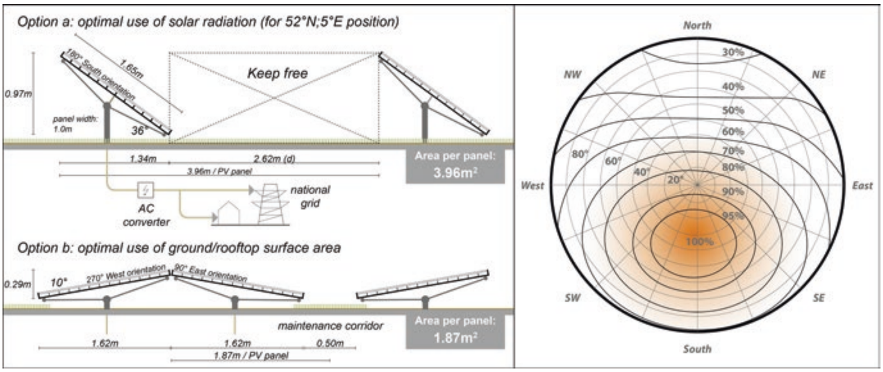

Fig. 12.5 *Left, top*: Panel setup A, oriented to the South. *Left, bottom:* Panel setup B, oriented to the East and West. *Right:* Diagram displaying the optimal panel inclination and azimuth for a panel in the Netherlands: respectively 36° and +/−180°

12.2.9.2 Electrical Output

The annual electricity yield of one PV panel can be calculated with equations (12.8)–(12.11):

$$PV\ yield\left(E_{sys}\right) = A_{sys} * \eta_{PV} * \eta_{other} * \int_{0}^{t} G_M\left(t\right) * dt \qquad (12.8)$$

A_{sys} [m²] Surface area of the panel. This study applies the standard dimensions of 1,00 × 1,65 m.

η_{PV} [−] is the efficiency of the PV module and is given by the manufacturer. Set to 18%.

η_{other} [−] represents the combined efficiency of all the other factors (e.g. thermal losses and inverter losses) and is set to 0,9, a suitable value for the city of Amsterdam (RVO 2014).

$\int_{0}^{t} G_M\left(t\right) * dt$ [Wh/m²] is the total irradiation incident on the surface of the PV module and depends on the solar irradiance (DNI, DHI, GHI) and the sun's position at a specific moment (*t*). Hourly time steps are calculated for one full year. Equation 12.10 calculates the relative orientation between the panel surface and the sun at moment *t* (*AOI*(*t*)) and assumes that no obstructions are shading the PV modules.

$$G_M\left(t\right) = DNI\left(t\right) * \cos\left(AOI\left(t\right)\right) + DHI\left(t\right) * SVF + GHI\left(t\right) * \left(1 - SVF\right) * \alpha \qquad (12.9)$$

where

$$\cos\left(AOI\left(t\right)\right) = \sin\theta_M * \cos\left(a_s\left(t\right)\right) * \cos\left(A_M - A_S\left(t\right)\right) + \cos\theta_M * \sin\left(a_S\left(t\right)\right) \quad (12.10)$$

$$SVF = \frac{1 + \cos\theta_M}{2} \qquad (12.11)$$

DNI [−] Direct normal irradiance. Retrieved from Meteonorm (2019) for position 52°N,5°E.

GHI [−] Global horizontal irradiance (Meteonorm 2019).

DHI [−] Direct Horizontal irradiance (Meteonorm 2019).

A_S/a_S [°] Respectively solar azimuth and solar elevation at (*t*) (Meteonorm 2019)

θ_M/A_M [°] Respectively panel tilt and panel azimuth. Set on 36°/180° for scenario A (ISSO 2017) and 10°/90°, 270° (East/West) for scenario B.

SVF [−] Sky View Factor. Calculated with equation 12.11.

α [−] Albedo factor. Depends primarily on the (ground) surfaces in the direct vicinity and is set to 0,2 for this inner city location.

At 52°N,5°E there is a small (less than 1%) dissimilarity between the electricity yield of the East-facing panel and the West-facing panel, which is neglected in this study.

12.3 Results

12.3.1 Green Gas Production

Produced excess biogas can be upgraded, pressurised and pumped into the gas network, offering a renewable alternative for natural gas for domestic heating or cooking purposes. Equations 12.12–12.14 are applied to calculate the net production of biogas in this farming system. All the energy flows considered in this study are represented in Fig. 12.6. Approximately 8% of the produced biogas is required to run all the processes within the farming system, leaving 28.656 m^3 of biogas available for upgrading. This purification process from biogas into green gas claims another 26.300 MJ$_e$ and leads to a volume reduction of 34%, as almost all of the carbon dioxide is scrubbed from the gas mix (See Table 12.5). On an annual basis the pig farming system could export 18.301 m^3 of green gas to the adjacent dwellings, which is about 2% of Kattenburg's present natural gas demand, or roughly the average annual use of 33 Kattenburg residents.

$$V_{\text{exp}} = \left(V_{\text{prod}} - V_{\text{syst}} - V_{\text{up}}\right) * \left(1 - 0.34\right) \tag{12.12}$$

where:

$$V_{\text{syst}} = \frac{\sum\left(E_{PF} + E_{FS} + E_{WS}\right) * \frac{1}{n}}{q_{\text{b.gas}}} \tag{12.13}$$

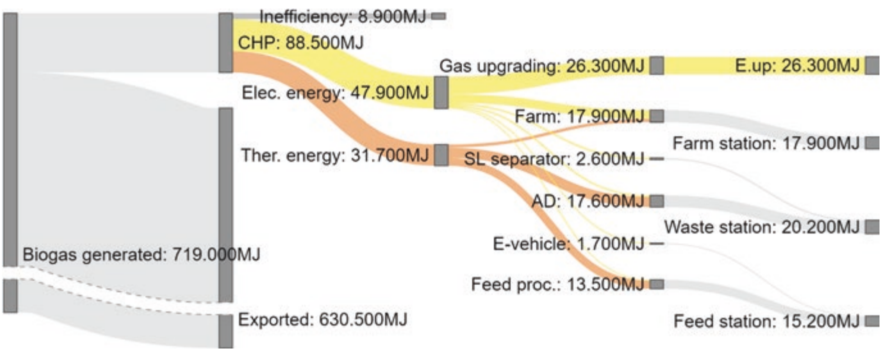

Fig. 12.6 Energy flows within the pig farm

$$V_{\text{up}} = \frac{\left(V_{\text{prod}} - V_{\text{syst}}\right) * e_{\text{up}}}{q_{\text{biogas}}} \tag{12.14}$$

V_{exp}	[m^3/yr]	The net produced green gas pumped into the local gas grid.
V_{prod}	[m^3/yr]	Notes the biogas produced in the anaerobic digester (see Table 12.4).
V_{sys}	[m^3/yr]	Represents the biogas needed to energise the feed-, pig- and waste station.
V_{up}	[m^3/yr]	Describes the biogas demand to energise the gas upgrading process.
η_{CHP}	[−]	Represents the efficiency of the CHP plant is and is set to 0,9 in this study
q_{bgas}	[MJ/m^3]	Notes the caloric value of biogas: 23 MJ/m^3
e_{up}	[MJ/m^3]	Fenotes the electricity demand of the biogas upgrading process
$E_{FS,\ PS,\ WS}$	[MJ_{E+T}/yr]	Energy demands of feed station, pig station and waste station and are calculated with the conversion data mentioned in Table 12.5.

12.3.2 Energy Yield per Square Meter

One PV panel oriented according to optimal solar irradiation (setup A) can produce 314 kWh_e/yr. A panel oriented according to optimal use of available surface area can generate 272 kWh_e/yr. The electricity yields of the two panel setups are normalised per square meter of ground area occupied. Basic goniometric formulas are used to determine the total space demand for one panel and point out that setup A requires at least 3,96 m^2 (including free zone) and setup B at least 1,87 m^2 (including maintenance corridor) land area per panel, drawn in Fig. 12.5.

Setup A yields 314 kWh_e annually per panel, or 79 kWh (286 MJ_e) per square meter of land area (Fig. 12.7).

Setup B yields 272 kWh_e per year per panel, or 147 kWh_e (529 MJ_e) per square meter of land area.

Pig farm: The farm can pump 18.301m^3 greengas into the national gas grid. Table 12.6 shows a breakdown of the considered functions of the farming system and the (estimated) minimal space required. Per square meter of farm, 37 m^3 of green gas is produced, or 1170 MJ_T.

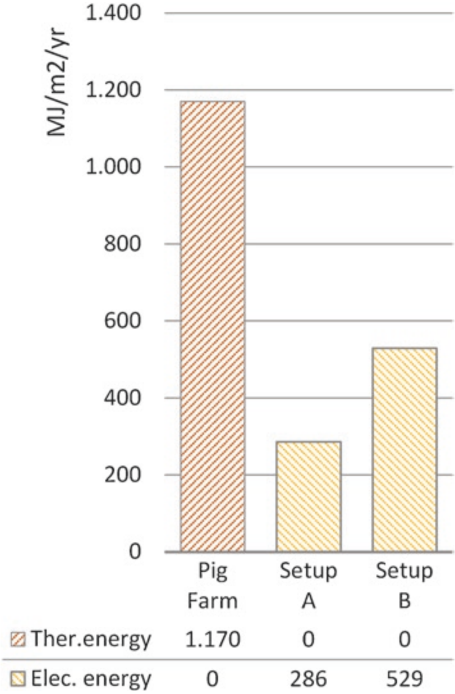

Fig. 12.7 Energy yield and corresponding avoided carbon emissions per m²

12.3.3 Avoided Carbon Emissions

Figure 12.8 shows the carbon profile of both Kattenburg's status quo and the scenario with the pig farm integrated. The CO_2e footprint of Kattenburg could theoretically drop with 218 ton, or 5.6% per year. The two most significant contributors to this decarbonisation effort are the avoided emissions related to the substitution of imported pork and the avoided emissions corresponding to incineration of biodegradable waste. The farm puts additional pressures on the existing water system: around 235.000 liter of drinking water is needed to hydrate the animals and for farm processes, of which 131.000 liter is pumped to the central waste water treatment facility after use. This increase does not lead to a significant rise in carbon emissions in the *water* sector: around 200 kg of additional CO_2e emissions are added to the carbon profile. There are no changes in the electricity related carbon emissions as excess energy is not exported as electricity but as green gas. About 18.301 m^3 of natural gas can be substituted with green gas, resulting in a decarbonisation impact of almost 35 ton/yr. Of the total waste flow, 48 ton is converted into pig feed, 103 ton is directed to the AD and due to dehydration 63 ton is removed from the system as waste water. From the initial 284 ton of organic waste, 46 ton (16%) still has to be incinerated, leading to a carbon emission decrease of 155 ton/yr. Finally, about 11.000 kg of pork (from 151 animals delivered) is produced on this urban farm, which can virtually replace about 17% of the current imported meat consumed,

Table 12.6 Spatial breakdown of farm. Most values represent educated estimations

Station	Space	[m²]	Note
Pig station (PS)	Pig production space (3 star animal well-being)	178,9	See Table 12.3
	Maternity pens	15	2 × 7,5 m²/sow
	Other (e.g. sick pen, installations, office, storage)	100	
	Traffic zone	90	Assume 0,5× PS
Feed station (FS)	Waste processing (e.g. expedition, parking, sorting, processing)	30	
	Waste storage/pig feed storage/maize storage	10	
	Traffic zone	20	Assume 0,5× FS
Waste station (WS)	Rejected food waste storage + mixing vessel	10	
	Anaerobic digester + auxiliary systems	10	
	Biogas storage	4	
	SL separator	4	
	Solid digestate storage	6	
	Liquid digestate tank	6	
Gas upgrading	High pressure water scrubber	12	
Total		495	

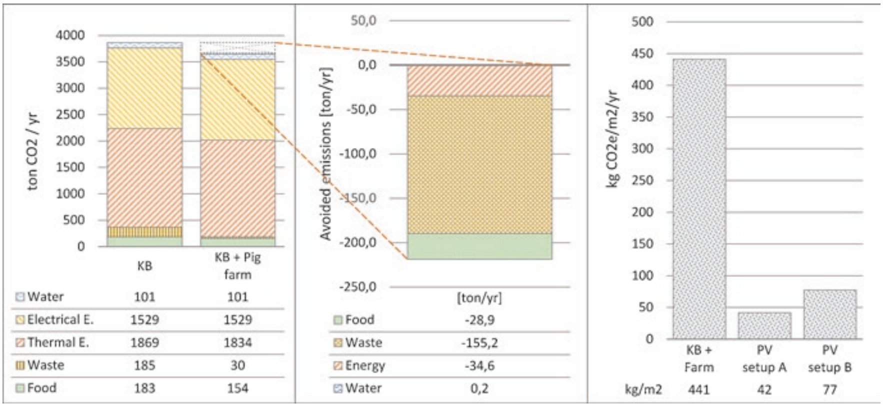

Fig. 12.8 *Left:* carbon footprint of KB status quo (left column) and after the addition of the pig farm (right column). *Middle*: break up of the avoided carbon footprint. *Right:* avoided carbon emissions per square meter Keep in mind that this footprint does not represent the full integrative CO_2 footprint of Kattenburg since only a selection of relevant resources are assessed for this study

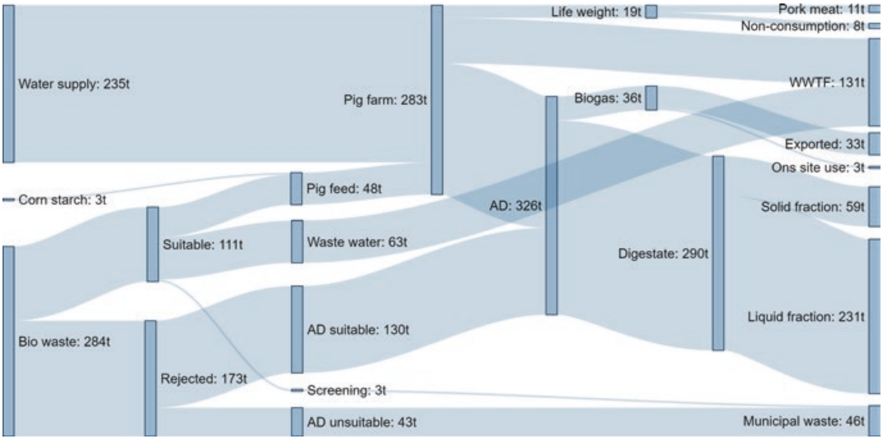

Fig. 12.9 Mass flow diagram of the pig farm system

leading to a reduction of 29 ton CO_2e per year. All mass flows entering and leaving the farming system are represented in Fig. 12.9.

The graph on the right side in Fig. 12.8 shows the avoided carbon emissions for the pig farm (KB + Farm) and the two PV setups. With regard to carbon emissions, the urban pig farm is roughly 6–10 times more effective, depending on the chosen PV setup.

12.4 Discussion

This study was performed to gain insight into the decarbonisation impact of urban pig farming. Carbon accounting of a theoretical urban pig farm in Kattenburg reveals that it is almost six times more effective compared to a space efficient PV array. However, there are limitations, assumptions and uncertainties surrounding this performance that are discussed here.

12.4.1 Limitations and Assumptions

There is no golden standard for the raising and fattening of pigs. The number of animals the farm can deliver depends on variables like the practised animal well-being standards, pig species, food diet and nutritional value, food accessibility, animal weight at slaughter and other variables a farmer could or could not influence. The production specifications used in this study are based on a combination of Dutch pork production LCA values and organic farming conditions. These values are assumed to be representative for an exploratory carbon accounting study, yet it is important to mention that any alterations affecting the food conversion ratio, will have knock on effects on succeeding elements like AD biogas production, delivered animals and eventually the avoided CO_2e/m^2.

A simular uncertainty applies to the physical scale of the pig farm. Based on organic farming standards, it is possible to give a reliable indication on the required surface area of the pig station. However, the area of the feed and waste station in this study are based on conservative estimations and in practise spatial requirements may deviate. If the project would be realised according to the principles proposed in this study, the required space will be co-determined by the constraints of the physical context and architectural design of the facility, possibly increasing the surface area. However, due to stacking of functions, underground storage rooms and efficient combining of processes in the same room, also a lower surface area could be possible.

Taking into consideration the various parameters and assumptions, it must be noted that the calculated performance of 441 kg $CO_2/m^2/yr$ is not a concrete outcome but likely remains at the positive side of an unspecified range.

12.4.2 Outlook

The productivity of this farm is entirely coupled with the domestic biowaste flow of Kattenburg and supplementary imported pig feed is excluded, emanating in a farm that produces around 151 animals (11.000 kg) per year, or 17% of the total pork demand of this neighbourhood. The number of animals at the farm could be increased if additional (local) food sources are addressed, e.g. food waste from supermarkets, small retail or waste from canteens in the commercial sector or waste from adjacent neighbourhoods. General farming tendency goes in the direction of upscaling and intensifying and producing 151 animals annually, even with an organic label, is unlikely to be sufficient to run an economically feasible farm. However, this should be investigated with additional research.

Further research should uncover the possibilities for symbioses with crop production as a way of manure management, which in this study is still exported to outside the system boundaries and left out of the carbon accounting scope.

CO_2e emission is chosen as the KPI of this study. There are however other environmental impacts surrounding the production, distribution and processing of pork (Salemdeeb et al. 2016). Carrying out additional LCA studies on environmental and health impacts, such as embodied water, eutrophication potential, particle matter emission and land use, could produce outcomes that are in support of UA.

12.4.3 Alternative System Design

There are alternative system designs/configurations possible to the one proposed in this study, that conceivably lead to different carbon performances. To provide one example: instead of exporting green gas as a substitute for natural gas, it could also fuel a CHP plant tied to a local district heating grid. Generated thermal and electrical energy will be shared with Kattenburg, subsequently arriving at different amounts of avoided CO_2.

This is a comparative analysis between urban pig farming and PV panels with regard to the avoided carbon emissions per m^2. In practice, the successive design move would naturally be to place the panels on top of the farm building, achieving the best of both methods. Due to endless variations in farm design and by that PV configurations, this can't be added as third comparable scenario. However, for indicative purposes, we can estimate that a farm structure of 18 × 28 m (504 m^2), with a 10° pitched roof facing East and West similar to PV setup B in this study, could in theory hold 270 PV panels (2 arrays of 5 × 27 panels). This generates about 73.440 kWh_e of renewable solar energy a year, potentially avoiding another 38.6 tons of carbon emission, roughly 1% of the total emissions of Kattenburg.

12.5 Conclusion

This study explored the potential of organic urban pig farming as a novel strategy for the energy transition, for which carbon neutrality is often the critical objective. It was paramount to expand the carbon inventory of the dweller with the food sector to perform a holistic evaluation on the impact of farming in the urban context. Integrating a pig farm into the Kattenburg residential neighbourhood in Amsterdam could potentially lead to a carbon emission decrease of 218 ton per year (5.6%). Calculations pointed out that at any time, about 79 animals can be sustained with the biowaste produced by Kattenburg's inhabitants (N = 1801), yielding almost 11.000 kg of pork meat each year. It is estimated that the farm would require a ground surface area of 495 m^2, which translates to a carbon avoiding potential of 441 kg $CO_2e/m^2/yr$. Compared to the carbon avoidance potential of PV panels, this pig farm is about ten times more effective than a panel array based on highest solar gain and about six times more effective than an array based on optimal surface coverage. Most of the avoided carbon emissions can be allocated to the reduction in incinerated biomass (−155 ton CO_2e/yr), followed by substituting natural gas with green gas (−35 ton) and virtually replacing imported pork meat with local produced meat (−29 ton).

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