abitare
Energy Consulting & Innovation

Zero^3

Life Cycle Inventory & Project Insights

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1. Executive Summary

The following report is a high-level analysis of the Lifecycle impacts that the $Zero^3$ project, a proposed circular bioeconomy development based in the Sydhavnen area of Copenhagen, will exert in environmental and socioeconomic terms. It builds on previous Lifecycle analyses conducted by The University of Edinburgh and represents an overview of the various inputs and outputs in the $Zero^3$ supply chain and associated resources. It also includes general project guidance and recommendations building on this overview, pertaining to the integration of $Zero^3$ with the existing community and sociotechnical structure in Sydhavnen.

It was found that the $Zero^3$ system as a whole, operating in coordination with improved waste management practices and consumer awareness strategies, has the potential to mitigate **1.302tCO_2e** of emissions for every 2t of commercial waste sourced. A supplementary analysis finds that approximately 98kg useable waste (corresponding to **112kgCO_2e** mitigated) per person every year from domestic sources would be a productive input if the logistical and business case can be made for a more diffuse, less concentrated waste collection mechanism. A full **Life Cycle Analysis** was then conducted establishing Carbon emissions savings and environmental externalities at 0.0005% and 1% cut-off rates respectively. Conducted comprehensively via SimaPro, it was found that the $Zero^3$ project has the potential to directly displace **1.06E3 kg$C0_2$e** worth of grid emissions factors in LCI terms, with the following summarised benefits across all relevant environmental externalities considered within the scope of this project:

Abiotic depletion	*0.02*	*kg Sb ee*
Abiotic depletion (fossil fuels)	*41770.00*	*MJ*
Global warming (GWP100a)	*3980.85*	*kg CO2 eq*
Ozone layer depletion (ODP)	*0.00*	*kg CFC-11 eq*
Human toxicity	*2277.33*	*kg 1,4-DB eq*
Fresh water aquatic ecotox.	*1411.04*	*kg 1,4-DB eq*
Marine aquatic ecotoxicity	*3491510.93*	*kg 1,4-DB eq*
Terrestrial ecotoxicity	*9.90*	*kg 1,4-DB eq*
Photochemical oxidation	*1.94*	*kg C2H4 eq*
Acidification	*36.79*	*kg SO2 eq*
Eutrophication	*11.29*	*kg PO4--- eq*

It was found that a number of pre-existing socioeconomic and infrastructural challenges in the area present significant opportunity for synergies with the $Zero^3$ platform. Increasing populations will produce a greater volume of more useable waste to incorporate; changing demographics in the area will likely drive-up favourability and public buy-in into the scheme; and pre-existing issues like traffic, pollution and social problems can be directly alleviated by a project development plan targeted with the local community in mind. A number of clear recommendations involve engaging with local bioeconomy and food waste initiatives to tap-into the growing commercial and public awareness of the circular economy. Also recommended are moves to investigate the potential impact of decentralised, modular sewage treatment facilities on the waste input-stream into $Zero^3$, and how alternative economically productive chemicals can be built-into the development's business model.

2. Introduction to Sydhavnen

Known as the sociotechnical system, the relationship between technologies and the human beings that use them is complex and dynamic. In fact, we are both shaped-by and shape our energy and waste systems, to the extent that the sociotechnical context for sustainable development remains a critical influence on whether technologies survive and flourish - or are rejected, and eventually forgotten. In the broadest possible terms: Carbon emissions are not mitigated when a technology or policy is transplanted, reductively, from a laboratory or University to real-life without systemic integration into the people, places, cultures, and communities that are shaped-by and shape it.

Zero^3 has the potential to integrate in this fashion. It is inherently collaborative in operational form, facilitating cooperation and relying on communication throughout the community. By reaching material efficiencies through the utilisation of waste streams and mutualistic symbiosis of participating organisations, Zero^3 could bring genuine positive change to the Sydhavnen area in environmental and economic terms.

Whilst the majority of this report focusses on determining and quantifying these benefits, it will begin by providing the socioeconomic context for the Zero^3 development.

The South Harbour of Copenhagen (referred to here as Sydhavnen) is part of the Kongens Enghave area, known traditionally as one of the more socioeconomically deprived districts in Copenhagen with major infrastructural ad industrial footprints. It has been formally identified by the Copenhagen Municipality as a "disadvantaged neighbourhood" which has "developed negatively compared to basic social parameters in Copenhagen" (Jens, 2016). Covering an area of 4.46km^2, Sydhavnen has a population of 15,414 at a mean density of 3,455/km^2. It is a part of the larger Vesterbro/Kongens Enghave jurisdictional district (see *Figure.1*), and dominated in land-use by housing, services and leisure facilities (see *Figure.2*).

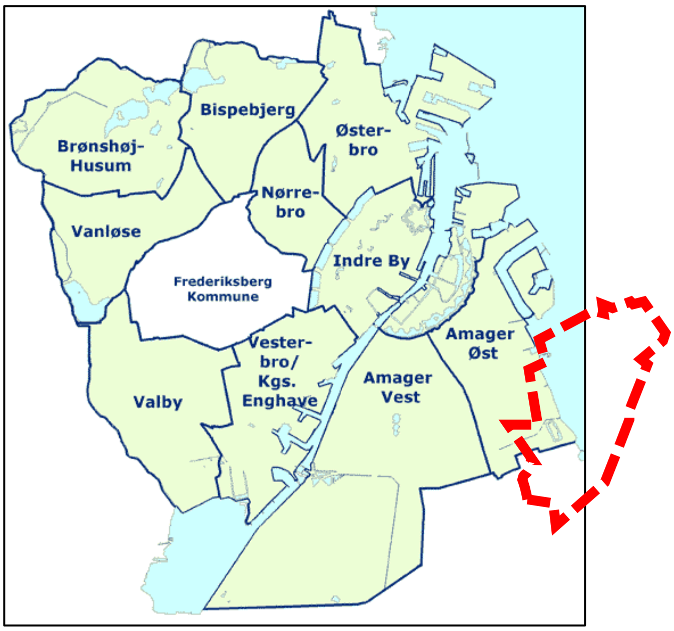


Figure.1: *Demarcation of Copenhagen districts showing Vesterbro/Kongens Enghave in red (amended from various sources by authors)*

Figure.2: *Overview of land-use in Sydhavnen aggregated by housing (red), services (blue), institutions (purple) and leisure facilities (green) (amended by authors from: Copenhagen Municipality, 2016)*

Figure.3: *Provision of green spaces in Sydhavnen (Copenhagen Municipality, 2016)*

From the turn of the 20th century, established commercial and industrial investment in the area (Ford manufacturing plant, Otto Monsted margarine factory, Burmeister & Wain foundry) began to recede leaving a legacy of exacerbated unemployment and social welfare claimants. In 2002, a redevelopment masterplan was launched by the Copenhagen municipality, By & Havn, and Sjoerd Soeters. This redevelopment, still ongoing, is significant in scale and has attracted an influx of new residents in broad socioeconomic categories. Students, young professionals, and a multi-ethnic mixed demographic population now merge to create a welcoming and diverse community in the area. This period of *well-thought-of* development coincides with drastically inflated property prices and a lack of property availability in Copenhagen generally, contributing to the rapid change in Syndhavnen within the last two decades.

Sydhavnen's Sluseholmen Canal District won the 'Danish Urban Planning Award' in 2009, and along with the Teglholment developmental area has (generally) attracted positive interest as a successful example of sustainable, inclusive urban planning. Nokia, Sonofon, Philips, TDC, Statoil, Daimler-Chrysler, BMW and MAN all currently have a significant manufacturing, employment or economic presence/investment in the area. Sydhavnen is well connected to surrounding districts in the Copenhagen municipality by train (two 'S-Train' stations), bus routes/services and cycle routes. A metro development (M4) is also scheduled to become operational in the district in 2023.

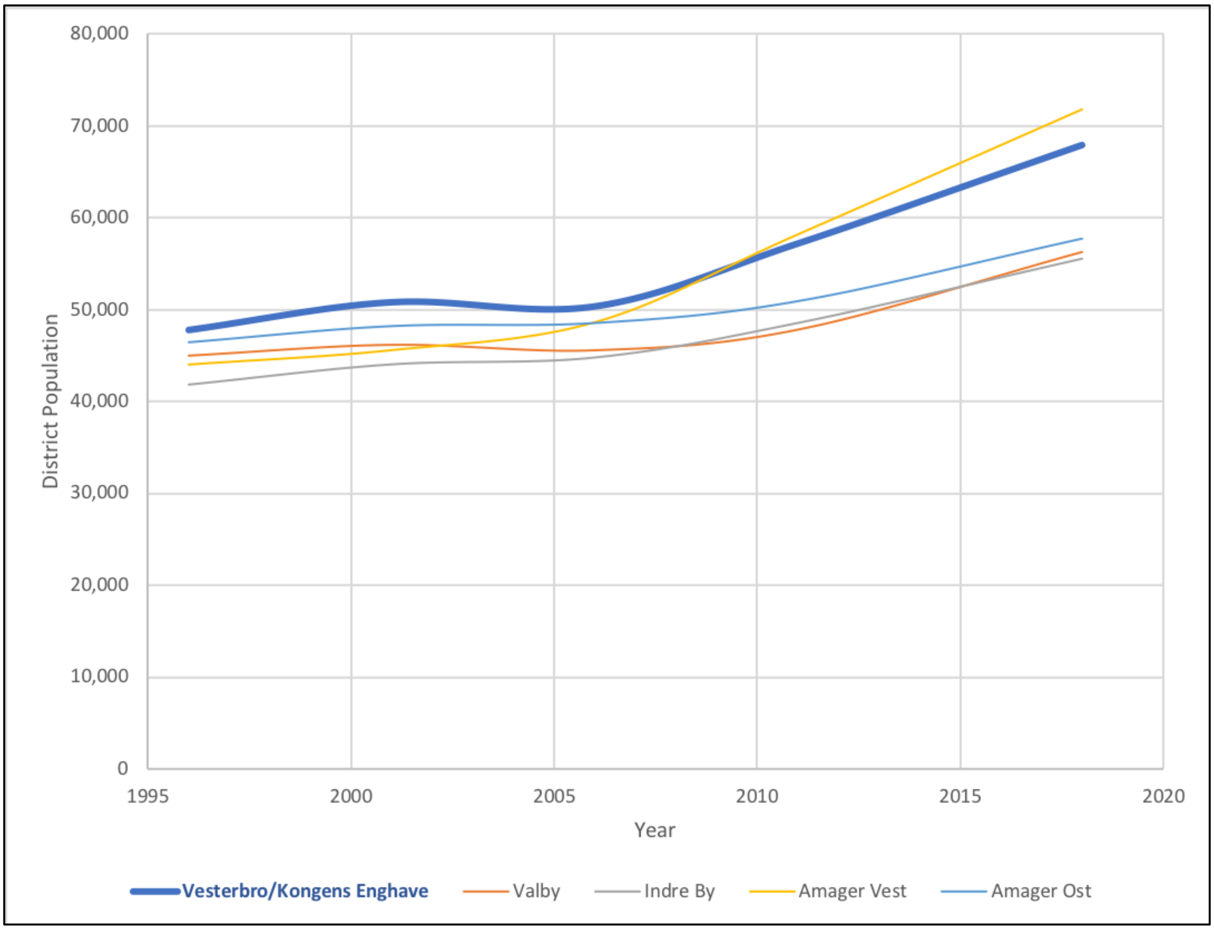


Figure.4: *Recent population trends of Vesterbro/Kongens Enghave (**blue**) and surrounding districts (amended by authors from: https://www.citypopulation.de/php/denmark-copenhagen.php)*

As *Figure.4* shows, there has been a marked population increase in Sydhavnen recently in-line with surrounding districts, and generally at a faster pace than much of inner and peri-urban Copenhagen. This rapid human influx and investment into the Sydhavnen area has, in a short period, changed the demographic and socioeconomic composition of the area.

Sections 5 and 6 (*Project Insights* and *Recommendations* respectively) will develop the integration of Zero^3 with these profound socioeconomic changes in detail. However, it is useful to understand the general (often self-identified) issues that the Sydhavnen community face in respect to these changes. Each will be related in sections 5 and 6 to a specific function or characteristic of Zero^3 suggesting great potential for synergy:

- Traffic and vehicular accidents have become increasingly common in the area. As *Figures.5* and *6* demonstrate, Sydhavnen has seen a statistically significant elevation in accidents in both car and bicycle forms within the last decade, and residents have an elevated probability of experiencing an accident compared to the rest of Copenhagen.

- Instances of crime, substance abuse and violence have risen in proportion with population. As *Figure.7* shows, reported instances of antisocial behaviour have risen (by varying metrics) between 25% and 100% in the last decade.

- Significant increases in noise and air pollution to the North-East of the area. As *Figure.8* demonstrates, major arterial roads bordering Sydhavnen are creating increasing problems with noise and particulate-matter pollution within residential and leisure areas.

These three outstanding themes are commonly identified in the community and have high levels of awareness; Zero^3 can directly tap-into and functionally ameliorate them all, by virtue of its circular and bioeconomy principles. These issues also relate to a broader portfolio of factors affecting Copenhagen more generally, such as education and reemployment facilities, and a relative lack of penetration in effective consumer awareness over waste management and uptake schemes (see Sections 5 and 6).

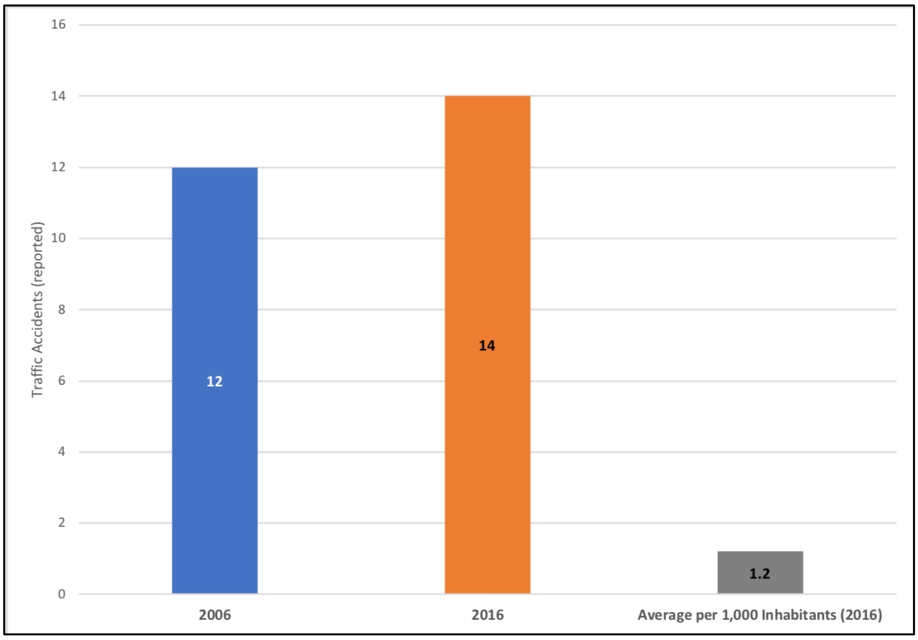


Figure.5: *Reported traffic accidents in Sydhavnen (amended by authors from: Police Register DS)*

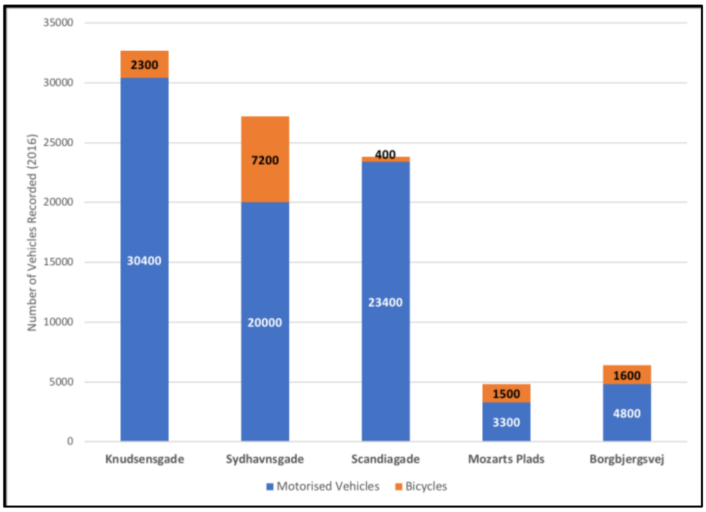


Figure.6: *Number of vehicles in Sydhavnen by major street artery (Copenhagen Municipality, 2016)*

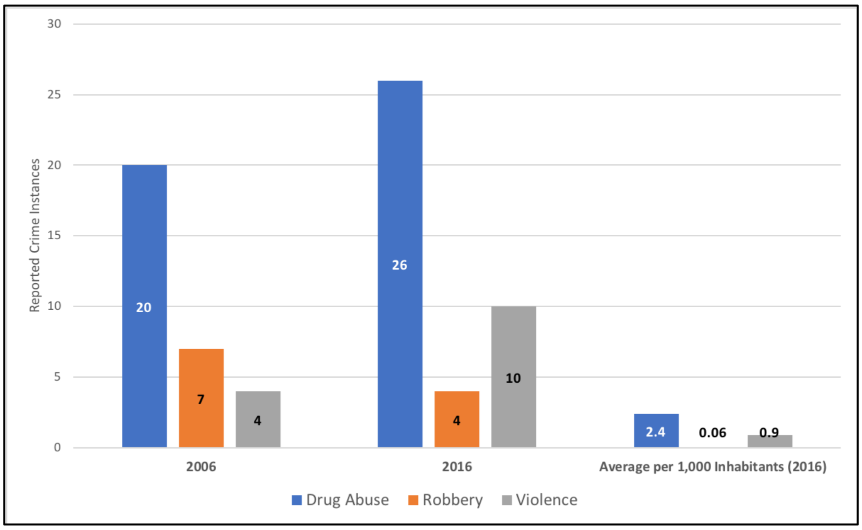


Figure.7: *Registered Crimes in Sydhavnen at Elevated Levels (source: Police Register DS)*

Figure.8: *Major arterial roads to NE of Sydhavnen and associated penetration of noise (yellow and gold) and air pollution (red & orange) (amended by authors from: Copenhagen Municipality, 2014)*

3. Zero^3 Carbon Footprinting

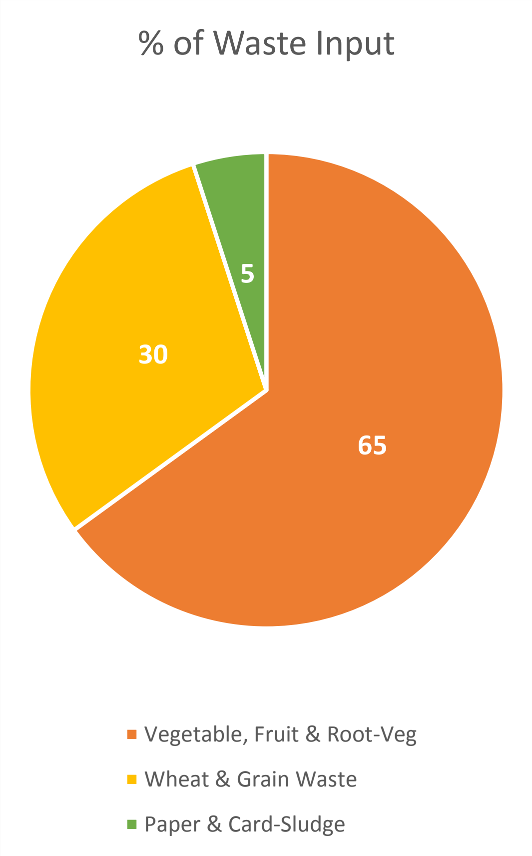
Whilst the Lifecycle Inventory section of this report will focus in on the categorisation of various environmental pollutants and negative externalities associated with Zero^3, it is worth computing a stylised Carbon Footprint of the operation to gain a sense, in a static and generalised way, of the **potential of the scheme to mitigate emissions in ordinary operation**. For the purposes of clarity and simplicity, this high-level analysis uses a comparison between major waste-resource flows as inputs and outputs into the Zero^3 system, and a 'Business as Usual' (BAU) alternative where energy is obtained by standard electricity & gas grid connections in Sydhavnen, and where waste is treated ordinarily by Waste-to-Energy centralised biogas production at Hashøj Biogas Plant near Slagelse.

The Zero^3 model is assumed here as operating from an input of **2t** of commercially-sourced biodegradable (AD-system appropriate) waste; *Table.1* below shows the energy productivity of various types of waste feedstock. Due to regulatory restrictions on food production, all animal derived waste sources are removed from the following calculations.

Feedstock Waste Type	**SynGas Productivity (m^3/t)**	**Energy Equivalent** (kWh/t)**
Wheat & Grain based waste	384-426	2,714
Turnip, Potato & Root-Veg based waste	276-400	2,265
Misc. Veg & Fruit based waste	240-434	2,499
Paper & Card Sludge based waste	160-242	1,347

Table.1: *Syngas and energy generation potential by waste type. Sources: Aggregated by authors from Priadi et al, 2014; NNFCC, 2016; CROPGEN, 2016. *Assumes median value from each productivity range applied. **Applies a conversion factor of 6.7kWh per m^3 of Syngas at 60% methane concentration (see CROPGEN, 2016).*

Assuming the 2t waste input has a bias towards vegetable & fruit waste sources, the following energy yields are possible (at theoretical 100% utilisation rate; see overleaf):

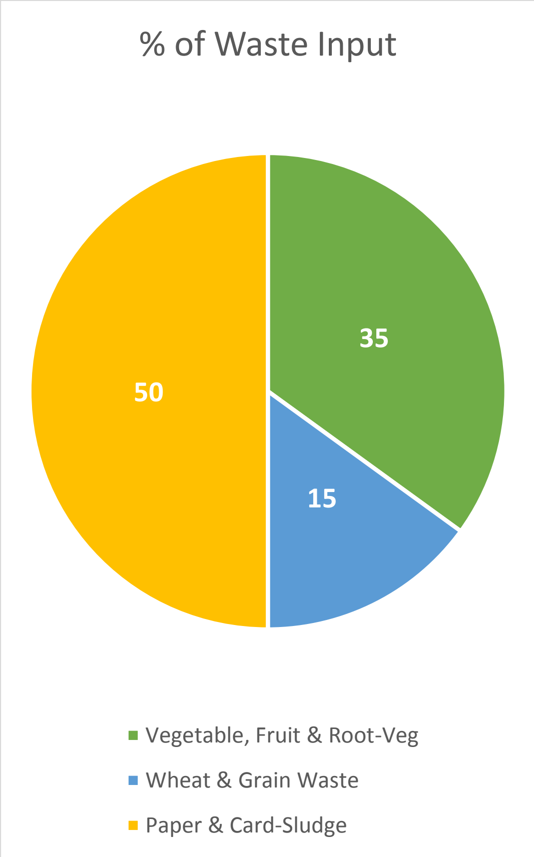


Feedstock Waste Type	Weight of Waste per 2t (kg)	SynGas Productivity** (m^3/2t)	Energy Equivalent (kWh/2t)
Compostable Vegetable, Fruit & Root-Veg Waste	1,300	422.5	3,249
Wheat & Grain based waste	600	234	1,628
Paper & Card Sludge based waste	100	19.5	135
TOTALS	**2000**	**676**	**5,012**

This vegetable/fruit waste biased feedstock source will have the capacity to generate the following Carbon savings (based on the standard generalised grid-emissions factor for Denmark):

Scenario	Emissions Factor ($kgCO_2e/kWh$)	CO_2e Emissions per 2t Waste Input ($kgCO_2e$)	TOTAL DIFFERENCE (tCO_2e)
Energy derived from Zero3	0.00023	1.153kg	
Energy Derived from Danish Grid	0.292	1,463.504kg	**1.462**

This analysis assumes 100% utilisation of the 2t waste stream and no fugitive emissions associated with the transport, handling and treatment of waste in the BAU alternative scenario. Adjusting the composition of this waste stream to a paper/card-biased commercial source, the following energy productivity and Carbon savings are possible (see overleaf):



Feedstock Waste Type	Weight of Waste per 2t (kg)	SynGas Productivity** (m^3/2t)	Energy Equivalent (kWh/2t)
Compostable Vegetable, Fruit & Root-Veg Waste	700	228	1,749
Wheat & Grain based waste	300	117	814
Paper & Card Sludge based waste	1,000	195	1,350
TOTALS	**2000**	**676**	**3,913**

This paper/card biased feedstock source will have the capacity to generate the following Carbon savings (based on the standard generalised grid-emissions factor for Denmark):

Scenario	Emissions Factor ($kgCO_2e$/kWh)	CO_2e Emissions per 2t Waste Input ($kgCO_2e$)	TOTAL DIFFERENCE (tCO_2e)
Energy derived from Zero3	0.00023	0.899kg	
Energy Derived from Danish Grid	0.292	1,142.596kg	**1.142**

Taking the median figure of these two Carbon savings as a fair representation of the variable waste composition of commercial feedstock sources, the Zero[3] scheme has the technical potential to mitigate **1.302tCO_2e** for every 2t of waste sourced as input.

4. Lifecycle Assessment & Inventory

A Life Cycle Assessment is a methodology through which any product of service undergoes an analysis to determine the environmental impacts during its full life cycle. A cradle-to-grave analysis is a common approach to this analysis; however, in this case, a conceptual or project approach is more suitable. An LCA can be tailored to satisfy the goals of the research, but in order to harvest valuable information from it, certain aspects of the LCA have to be generic. Some of the most relevant criteria and assumptions made for the analysis are listed below in *Table.8* (all other assumptions and input information are available on request from authors):

Modelling Software	***SimaPro (version 8.0)***
Method Selected	***CML-IA Baseline***
Functional Unit	***1kg Tomatoes Harvested***
Out-with Scope	***Shop, Leased Space, Green Classroom, Research Facility Area***
1st Degree Scope to Process Flow	

Table.8: *Relevant LCI Modelling Criteria*

With the aid of the SimaPro software the following model of the Zero 3 resources was developed (see pages 15 & 16):

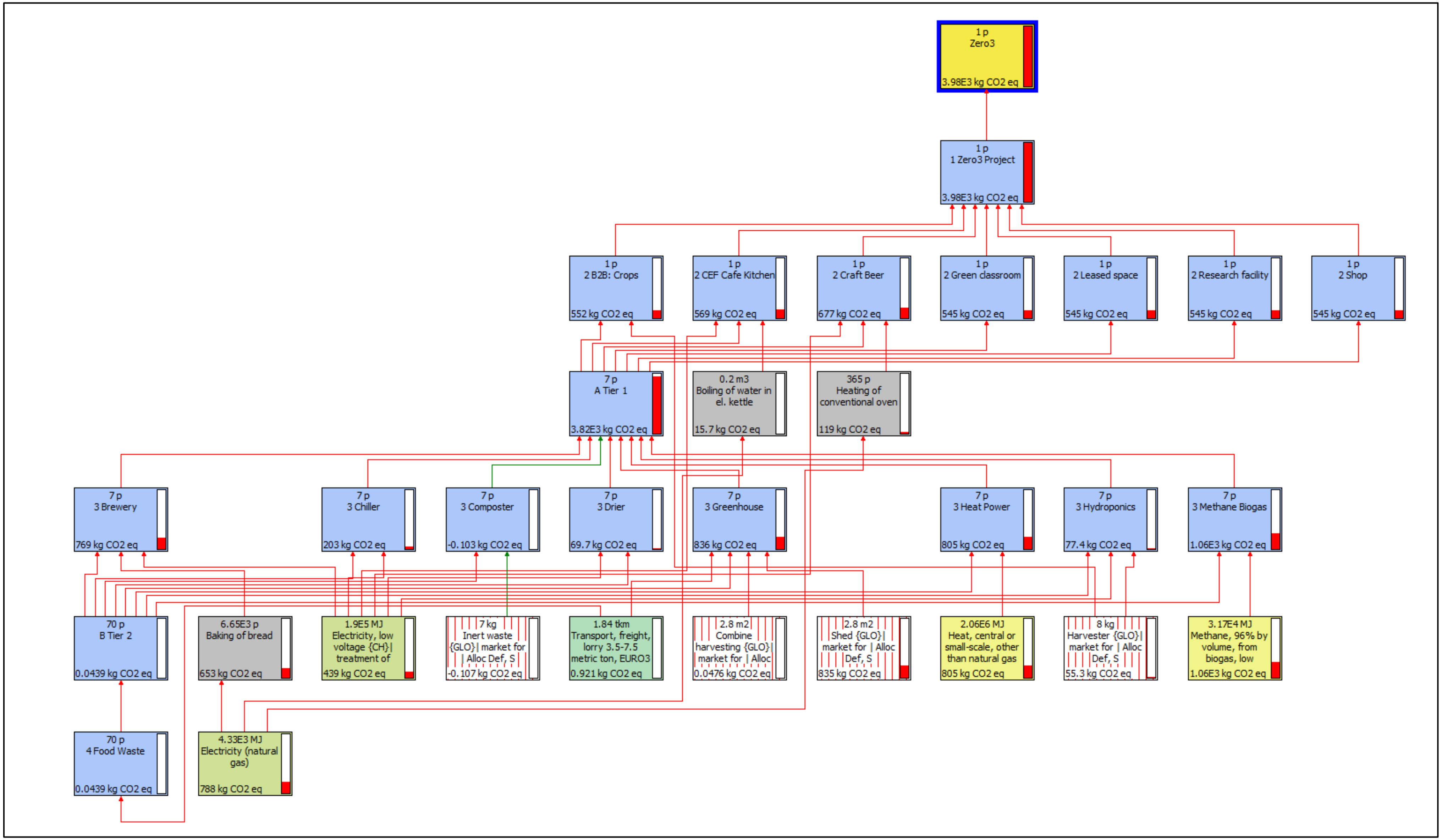


Figure.11: *Life Cycle model of the Zero³ project in terms of kgCO₂e at 0.0005% cut-off*

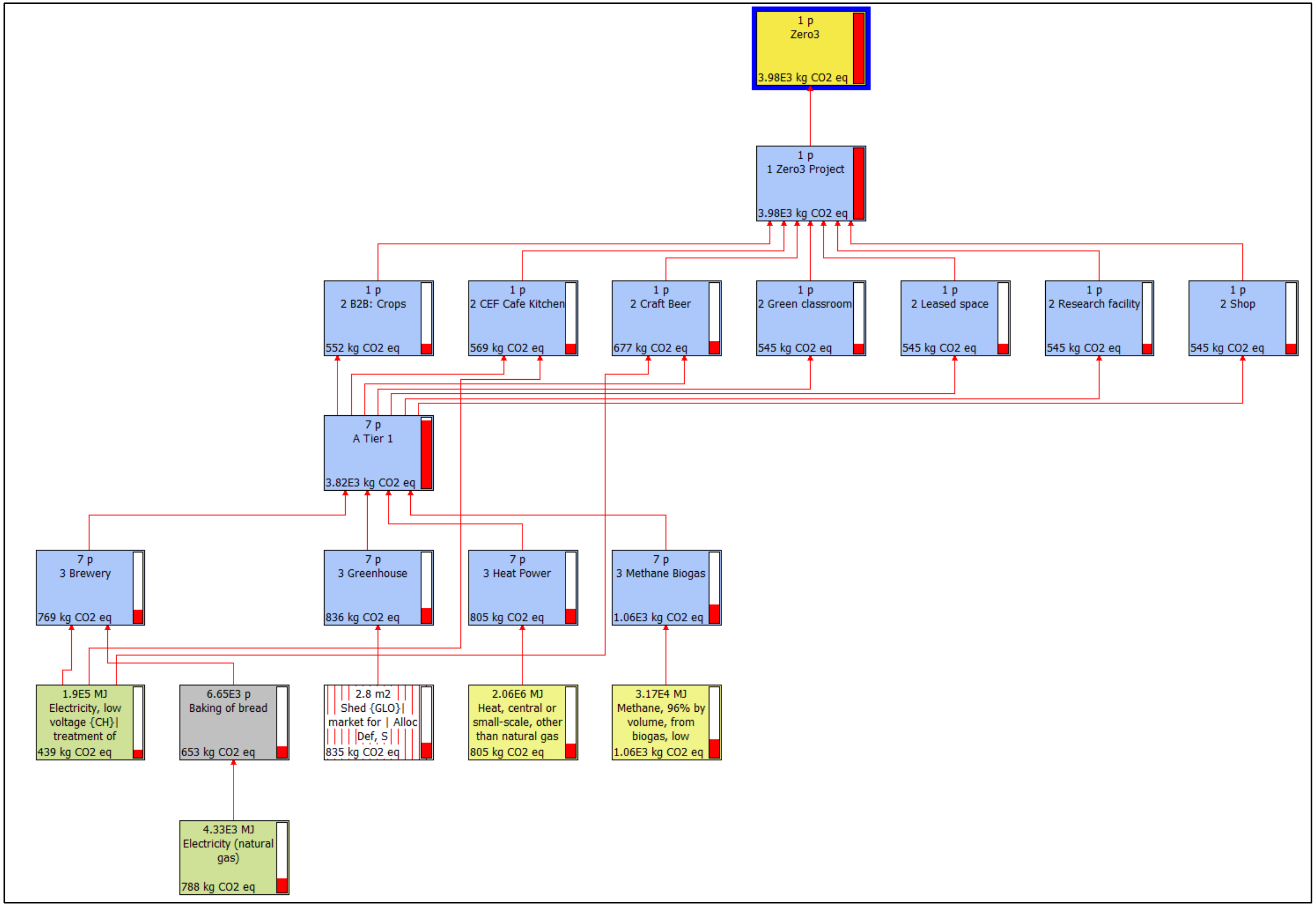


Figure.12: *Life Cycle model of the Zero*[3] *project in terms of kgCO₂e at 10% cut-off*

At a cut-off criteria level of 10% it becomes evident that the largest contributor to the benefits of displacing Carbon-embedded energy from the grid, and generating onsite, would come from Zero^3's AD process. The generation of energy using the biogas rather than the use of direct electricity from the grid displaces **1.06E3 kgC0$_2$e**.

The overall impacts of the Zero3 project are shown. It should be noted that that the previous model reports in terms of Global Warming Potential (kgCO$_2$e) but *Table.9* below shows a complete Life Cycle Inventory.

SimaPro 8.0.3.14		
Project:	*Zero^3*	
Calculation:	*Analyse*	
Results:	*Impact assessment*	
Product:	*1 p Zero3 (of project Zero)*	
Method:	*CML-IA baseline V3.01 / EU25*	
Indicator:	*Characterization*	
Skip categories:	*Never*	
Exclude infrastructure processes:	*No*	
Exclude long-term emissions:	*No*	
Sorted on item:	*Impact category*	
Sort order:	*Ascending*	
§Impact category	**Unit**	**Zero^3 Project**
Abiotic depletion	*kg Sb ee*	*0.02*
Abiotic depletion (fossil fuels)	*MJ*	*41770.00*
Global warming (GWP100a)	*kg CO2 eq*	*3980.85*
Ozone layer depletion (ODP)	*kg CFC-11 eq*	*0.00*
Human toxicity	*kg 1,4-DB eq*	*2277.33*
Fresh water aquatic ecotox.	*kg 1,4-DB eq*	*1411.04*
Marine aquatic ecotoxicity	*kg 1,4-DB eq*	*3491510.93*
Terrestrial ecotoxicity	*kg 1,4-DB eq*	*9.90*
Photochemical oxidation	*kg C2H4 eq*	*1.94*
Acidification	*kg SO2 eq*	*36.79*
Eutrophication	*kg PO4--- eq*	*11.29*

Table.9: *Life Cycle Analysis displaying all CML-IA environmental impacts from Zero3 project*

In terms of Global Warming potential, the total kgCO$_2$e is **3980.85** which is roughly equivalent to the mass of 1 elephant per functional unit.

Detailed Life Cycle Inventory for Zero3 per impact category:

The following tables will detail the components of each impact category to a value of 1% cut-off criteria:

Category:	**Abiotic Depletion (fossil fuels)**			
Cut-off:	1%			
No	**Substance**	**Compartment**	**Unit**	**Zero[3] Project**
	Total		MJ	41770.00
	Remaining substances		MJ	648.40
1	Coal, hard	Raw	MJ	7952.98
2	Gas, natural, 35 MJ per m3	Raw	MJ	10088.32
3	Gas, natural/m3	Raw	MJ	4299.91
4	Oil, crude	Raw	MJ	18780.39

Table.10: *Abiotic depletion (fossil fuels) LCI detailed contribution*

Category:	**Acidification**			
Cut-off:	1%			
No	**Substance**	**Compartment**	**Unit**	**Zero[3] Project**
	Total		kg SO2 eq	36.79
	Remaining substances		kg SO2 eq	0.23
1	Nitrogen oxides	Air	kg SO2 eq	25.92
2	Sulfur dioxide	Air	kg SO2 eq	9.76
3	Sulfuric acid	Air	kg SO2 eq	0.87

Table.11: *Acidification LCI detailed contribution*

Category:	**Eutrophication**			
Cut-off:	1%			
No	**Substance**	**Compartment**	**Unit**	**Zero[3] Project**
	Total		kg PO4--- eq	11.29
	Remaining substances		kg PO4--- eq	0.17
1	COD, Chemical Oxygen Demand	Water	kg PO4--- eq	0.13
2	Dinitrogen monoxide	Air	kg PO4--- eq	0.41
3	Nitrogen	Air	kg PO4--- eq	0.59
4	Nitrogen oxides	Air	kg PO4--- eq	6.74
5	Phosphate	Water	kg PO4--- eq	3.24

Table.12: *Eutrophication LCI detailed contribution*

Category:	Abiotic Depletion			
Cut-off:	1%			
No	**Substance**	**Compartment**	**Unit**	**Zero3 Project**
	Total		kg Sb eq	0.02054
	Remaining substances		kg Sb eq	0.00095
1	Cadmium	Raw	kg Sb eq	0.00158
2	Chromium	Raw	kg Sb eq	0.00143
3	Copper, 0.52% in sulfide, Cu 0.27% and Mo 8.2E-3% in crude ore	Raw	kg Sb eq	0.00158
4	Copper, 0.59% in sulfide, Cu 0.22% and Mo 8.2E-3% in crude ore	Raw	kg Sb eq	0.00093
5	Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore	Raw	kg Sb eq	0.00652
6	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore	Raw	kg Sb eq	0.00128
7	Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore	Raw	kg Sb eq	0.00021
8	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore	Raw	kg Sb eq	0.00063
9	Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore	Raw	kg Sb eq	-0.00023
10	Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore	Raw	kg Sb eq	0.00056
11	Lead	Raw	kg Sb eq	0.00107
12	Molybdenum	Raw	kg Sb eq	0.00021
13	Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore	Raw	kg Sb eq	0.00024
14	Molybdenum, 0.016% in sulfide, Mo 8.2E-3% and Cu 0.27% in crude ore	Raw	kg Sb eq	0.00049
15	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.22% in crude ore	Raw	kg Sb eq	0.00027
16	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore	Raw	kg Sb eq	0.00165
17	Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore	Raw	kg Sb eq	0.00033
18	Nickel, 1.98% in silicates, 1.04% in crude ore	Raw	kg Sb eq	0.00053
19	Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In	Raw	kg Sb eq	0.00029

Table.13: *Abiotic depletion LCI detailed contribution*

Category:	Fresh Water Aquatic Ecotoxicity.
Cut-off:	1%

No	**Substance**	**Compartment**	**Unit**	**Zero[3] Project**
	Total		kg 1,4-DB eq	1411.04
	Remaining substances		kg 1,4-DB eq	21.30
1	Beryllium	Water	kg 1,4-DB eq	235.72
2	Cadmium	Water	kg 1,4-DB eq	17.06
3	Cobalt	Water	kg 1,4-DB eq	160.08
4	Copper	Water	kg 1,4-DB eq	368.50
5	Nickel	Water	kg 1,4-DB eq	378.72
6	Selenium	Water	kg 1,4-DB eq	25.90
7	Vanadium	Water	kg 1,4-DB eq	146.24
8	Zinc	Water	kg 1,4-DB eq	57.51

Table.14: *Fresh water aquatic ecotoxicity LCI detailed contribution*

Category:	**Global Warming (GWP100a)**			
Cut-off:	1%			
No	**Substance**	**Compartment**	**Unit**	**Zero[3] Project**
	Total		kg CO2 eq	3980.85
	Remaining substances		kg CO2 eq	22.33
1	Carbon dioxide	Air	kg CO2 eq	774.39
2	Carbon dioxide, fossil	Air	kg CO2 eq	2470.98
3	Dinitrogen monoxide	Air	kg CO2 eq	448.63
4	Methane, biogenic	Air	kg CO2 eq	171.17
5	Methane, fossil	Air	kg CO2 eq	93.36

Table.15: *Global Warming LCI detailed contribution*

Category:	**Human Toxicity**
Cut-off:	1%

No	**Substance**	**Compartment**	**Unit**	**Zero^3 Project**
	Total		kg 1,4-DB eq	2277.33
	Remaining substances		kg 1,4-DB eq	88.42
1	Antimony	Water	kg 1,4-DB eq	39.58
2	Benzene	Air	kg 1,4-DB eq	115.30
3	Beryllium	Water	kg 1,4-DB eq	36.15
4	Chromium VI	Air	kg 1,4-DB eq	964.94
5	Hydrogen fluoride	Air	kg 1,4-DB eq	78.06
6	Molybdenum	Water	kg 1,4-DB eq	66.63
7	Nickel	Water	kg 1,4-DB eq	38.69
8	Nitrogen oxides	Air	kg 1,4-DB eq	62.21
9	Selenium	Water	kg 1,4-DB eq	496.95
10	Thallium	Water	kg 1,4-DB eq	238.86
11	Vanadium	Water	kg 1,4-DB eq	51.55

Table.16: *Human toxicity LCI detailed contribution*

Category:	**Marine Aquatic Ecotoxicity**			
Cut-off:	1%			
No	Substance	Compartment	Unit	**Zero^3 Project**
	Total		kg 1,4-DB eq	3491510.93
	Remaining substances		kg 1,4-DB eq	78101.68
1	Beryllium	Water	kg 1,4-DB eq	1391617.50
2	Cobalt	Water	kg 1,4-DB eq	205621.44
3	Copper	Water	kg 1,4-DB eq	73990.17
4	Hydrogen fluoride	Air	kg 1,4-DB eq	1114723.46
5	Nickel	Water	kg 1,4-DB eq	262969.52
6	Selenium	Water	kg 1,4-DB eq	224514.14
7	Vanadium	Water	kg 1,4-DB eq	139973.02

Table.17: *Marine aquatic ecotoxicity LCI detailed contribution*

Category:	**Ozone Layer Depletion (ODP)**
Cut-off:	1%

No	**Substance**	**Compartment**	**Unit**	**Zero[3] Project**
	Total		kg CFC-11 eq	0.000161
	Remaining substances		kg CFC-11 eq	0.000000
1	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	kg CFC-11 eq	0.000004
2	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	kg CFC-11 eq	0.000007
3	Methane, bromochlorodifluoro-, Halon 1211	Air	kg CFC-11 eq	-0.000004
4	Methane, bromotrifluoro-, Halon 1301	Air	kg CFC-11 eq	0.000130
5	Methane, chlorodifluoro-, HCFC-22	Air	kg CFC-11 eq	0.000008
6	Methane, dichlorodifluoro-, CFC-12	Air	kg CFC-11 eq	0.000013
7	Methane, tetrachloro-, CFC-10	Air	kg CFC-11 eq	0.000002

Table.18: *Ozone layer depletion LCI detailed contribution*

Category:	**Photochemical Oxidation**			
Cut-off:	1%			
No	**Substance**	**Compartment**	**Unit**	**Zero[3] Project**
	Total		kg C2H4 eq	1.94
	Remaining substances		kg C2H4 eq	0.10
1	Carbon monoxide, biogenic	Air	kg C2H4 eq	1.09
2	Carbon monoxide, fossil	Air	kg C2H4 eq	0.27
3	Methane, biogenic	Air	kg C2H4 eq	0.05
4	Methane, fossil	Air	kg C2H4 eq	0.02
5	Pentane	Air	kg C2H4 eq	0.02
6	Sulfur dioxide	Air	kg C2H4 eq	0.39

Table.19: *Photochemical oxidation LCI detailed contribution*

Category:	**Terrestrial Ecotoxicity**
Cut-off:	1%

No	**Substance**	**Compartment**	**Unit**	**Zero^3 Project**
	Total		kg 1,4-DB eq	9.90
	Remaining substances		kg 1,4-DB eq	0.19
1	Chromium VI	Air	kg 1,4-DB eq	0.85
2	Chromium VI	Soil	kg 1,4-DB eq	8.59
3	Cypermethrin	Soil	kg 1,4-DB eq	0.11
4	Mercury	Water	kg 1,4-DB eq	0.15

Table.20: *Terrestrial ecotoxicity LCI detailed contribution*

The previous individual impact contributions to the overall Zero3 LCI have been reported in characterized units for evaluation and comparison with alternative methods.

5. Project Insights

The following section represents a brief overview of the social and economic characteristics of the Sydhavnen area, and how these can be closely related to many of the inherent benefits of the Zero^3 system analysed in preceding sections. In recent times, the area has seen a greatly increased and diversified population meaning:

1.a. More waste by volume

2.a. Higher degrees of disposable income, entrepreneurship, and business activities

3.a. Potential issues around social cohesion and a lack of predeveloped social structures and networks

4.a. Radically changed forms of consumption and correspondingly varying waste generation profiles

5.a. The continuation and possible marginalisation of pre-existing social problems like substance abuse, violence and crime

6.a. Traffic and congestion issues, along with associated noise and air pollution

7.a. Stress on educational infrastructure and existing employment paradigms
*Informed by multiple sources: see references.

In fact, each of these seven developmental factors can be correlated with some aspect of the Zero3 design philosophy. For example:

1.b. Increased waste streams, if managed correctly and efficiently, are an opportunity for the Zero^3 model. It is unclear whether existing services can handle the increase in compostable waste production projected with Sydhavnen's recent and continuing population expansion; the initiative could place itself at the heart of this issue as a sustainable, integrated and efficient mechanism to alleviate pressure from existing waste management services in the area.

2.b. Changing demographics may also represent a clear opportunity for Zero^3. The younger demographics entering the area have been shown to possess more disposable income yet demonstrate a clear preference for sustainable, 'green' consumption choices. Whereas the traditional working-class demographics of historic Sydhavnen may have been recalcitrant to see such an innovative project integrating into the community, these new residents are statistically more likely to be accepting and favourable to Zero^3's design principles.

3.b. The circular bioeconomy approach taken here is integrative and cooperative, iterative and democratic; it is centrally integrated into the community, yet distributed from the Municipality's traditional operations. As such, Zero^3 has the chance to be more than a mere technology, but a vehicle for the restoration and maintenance of Sydhavnen's social infrastructure. Whilst this might seem an insubstantive idea, it is based on the Berkeley Group's framework 'Creating Strong Communities' (2012), according to which studies on Sydhavnen found that:

"*…the strong sense of belonging and neighborhood identity might take part in Sydhavnen's selforganizational, informal approach to absorb local challenges, and compensate for lacking public efforts in Sydhavnen*" (Jens, 2016)

"*…the social and cultural life in Sydhavnen is deeply rooted into the history of the neighborhood. Many people have lived there long enough to put down their roots, which created a unique neighborhood character with strong neighborhood-identity feelings among residents. The historic working class neighborhood is shaped by low-income and disadvantaged residents*" (Jens, 2016)

Reading these quotes, it is difficult to imagine a technology or systemised-principle that better fits the sense of identity and cohesion required for Sydhavnen than the Zero^3 concept. Currently the main social facilities in Sydhavnen are largely informalised around voluntary and community-run services, with a strong emphasis on 'bottom-up' services tailored to current local needs. This social infrastructural form is somewhat in keeping with cuts to municipal financial budgets in recent times; it has been found that the capacity of main social facilities are overwhelmed in the interior of Syndhavnen and relate in concentration to social housing and traffic issues. The area also suffers from a statistically significant elevation of social isolation and drug abuse compared to the rest of Copenhagen.

4.b. As consumption preferences change in the area, several elements of Zero3's waste input stream will change. For instance, the waste category with the highest negative impact in associated externalities has been shown to be animal products and meats. The newer demographics entering into Sydhavnen are going to be increasingly likely to reduce meat consumption, if not adopt vegetarian or vegan diets. This will alter the calorific and energy-capacity of the waste stream in a complex and uncertain manner that deserves further research in order for Zero^3's precise impacts and performance to be defined.

5,6&7.b. There is a significant scope for Zero^3 to integrate itself at the heart of a recently-developed (*still developing*) community by enabling further employment, training and educational capacities. As Figure.13 shows, the Sydhavnen area has a proportionately high number of kindergartens but only one re-employment centre; there are three leisure centres, and yet only one creche. As the population of the area continues to expand, Zero3 may be able to develop a programme of employment and training that is designed with the local community in mind.

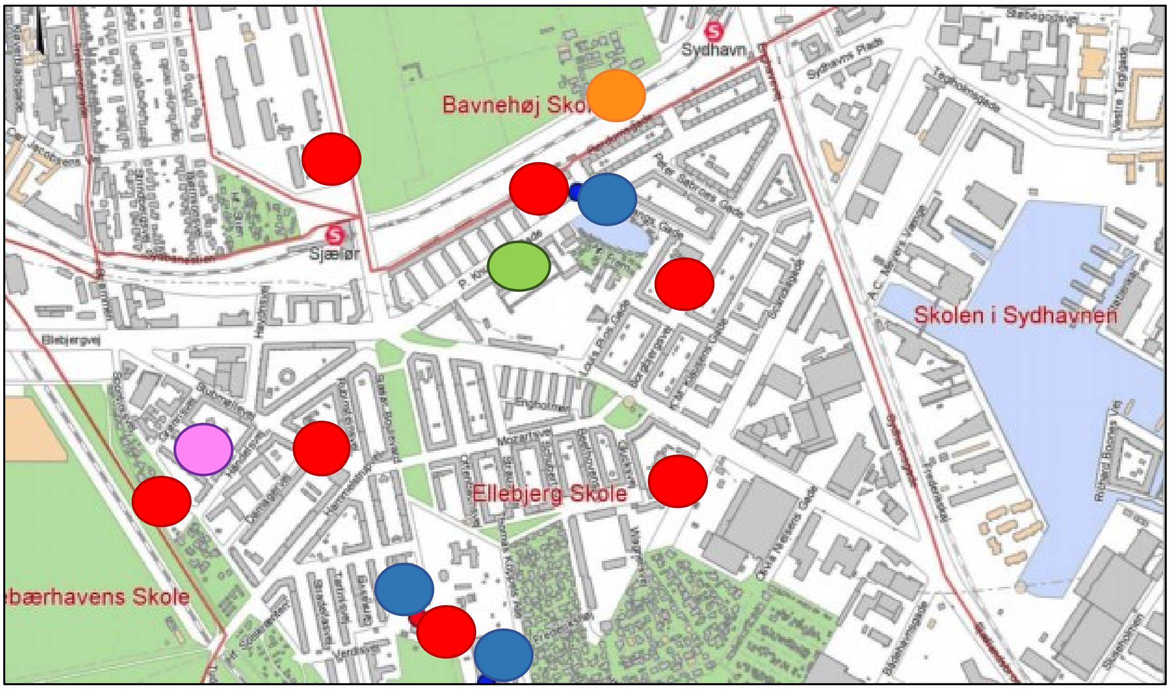


Figure.13: *Provision and displacement of educational facilities across Sydhavnen; kindergartens (**red**), re-employment centre (**orange**), school (**green**), leisure and recreational centres (**blue**) and creches (**pink**) (amended from multiple sources by authors*

6. Recommendations

6.1 Collaboration with local circular bioeconomy initiatives.

The Zero[3] project, if it has not already, could integrate and coordinate with the organisation Dansk Symbiosis; they operate a project called 'Residue to Resource' that offers free specialist instruction and a grant of up to DKK 60,000. This 3-phase plan is available to the district (although Sydhavnen is outwith the project's partner municipalities framework) and requires the screening of participatory companies and the development of a technical development plan as to how businesses can be interlinked with quantifiable benefits.
See: (https://symbiosecenter.dk/en/project/residue-to-resource/).

Additionally, the Dansk Symbiosis group offer another powerful tool that can potentially enhance and facilitate Denmark's circular bio-economy called 'Low Carbon Industrial Manufacturing Parks' (LOCIMAP); this models and evaluates the degree of sustainability and opportunities for symbiosis (circular, mutually-beneficial resource flows between participating businesses/actors) in terms of water, energy and materials.
See: (https://symbiosecenter.dk/en/project/locimap/).

6.2 Engage with the wider 'Food Waste' movement and funding streams.

The EU's 'European Year Against Food Waste' in 2014 extended into a number of EU-calls for innovation funding in "bio-based industries". All of the following initiatives, following this analysis, could legitimately be considered for the Zero[3] project, quoted directly from EU literature; although a number are now outdated or closed, they offer a useful example of the international support and frameworks for food waste initiatives and funding:

- BBI.2017.R4: Proteins and other bioactive ingredients from side streams and residues [budget: 81,000,000€, submission deadline: 4 September 2017 (single stage)]
- BIOTEC-06-2017: Optimisation of biocatalysis and downstream processing for the sustainable production of high value-added platform chemicals [budget: 48,000,000€, submission deadline: 11 May 2016 (first stage), 27 October 2016 (second stage)]
- SMEInst-07-2016-2017: Stimulating the innovation potential of SMEs for sustainable and competitive agriculture, forestry, agri-food and bio-based sectors [budget: 28,973,605€, deadline: 24 February, 03 May, 07 September, 09 November and 15 February 2017 (multi cut-off)]
- SMEInst-11-2016-2017: Boosting the potential of small businesses in the areas of climate action, environment, resource efficiency and raw materials [budget: 22,500,000€, deadline: 24 February, 03 May, 07 September, 09 November 2016 and 15 February 2017(multi cut-off)]
- CIRC-01-2016-2017: Systemic, eco-innovative approaches for the circular economy: large-scale demonstration projects [budget: 60,000,000€, deadline: 08 March and 06 September 2016 (two-stage)].
- SPIRE-07-2017: Integrated approach to process optimisation for raw material resources efficiency, excluding recovery technologies of waste streams [total budget: 80,000,000€ for 6 SPIRE actions, deadline: 19 January 2017 (single stage)]

6.3 Produce micro-algae from waste biorefineries.

Microalgae can be grown with liquid (COD, N and P) and gaseous (CO_2) effluents of anaerobic digestion. The organic acids present in this effluent mix are utilised most efficiently in a mixotrophic mode of cultivation, with the simultaneous production of biogas with over 90% methane content. The lipid content in microalgae grown via AD effluents can be improved for biofuel applications, and the integration of raw sewage sludge and corresponding microalgal cultivation is an interesting waste biorefinery option (Chen *et al*, 2017); it may particularly productive if applied in the Zero^3 context.

6.4 Consider Human Waste Streams.

There are a number of modular, decentralised waste treatment technologies in operation across Europe. Needless to say, if the waste stream of Zero^3 can involve this otherwise wasted resource there would be great leaps in efficiency. For example, the annual per capita human waste production is:

Human Waste Type	**Mass**
Faeces	45kg
Urine*	500l
(corresponds to usable equivalent dry-mass of)	
Phosphorus	300g
Potassium	300g
Sulphur	900g
Nitrogen	4.5kg
TOTAL (approximate*)	**545kg**

Table.21: *Human waste chemical potential in AD-systems. Sources: Aggregated by authors from Rose et al, 2016; Jonsson et al, 2005. *Assumes density equal to water equivalent to 1kg/1l*

The following European companies have successfully tested and deployed options for containing human waste into a resource input, including wastewater treatment and solar drying of material. They can be efficiently incorporated into the existing Zero^3 AD system. See:

- Modular Decentralised Wastewater Treatment System:
- Huber RoWin Heat Exchanger:
- Huber Solar Dryer SRT:

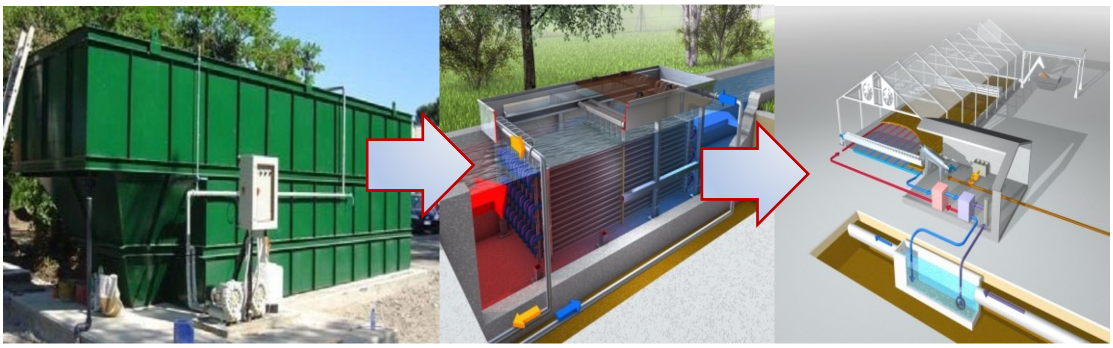


Figure.14: *Modular decentralised wastewater and solid waste treatment equipment*

6.5 Investigate Synergies with economically productive alternative chemicals.

Anaerobic digestion (AD) of organic fraction of municipal solid waste (OFMSW; in this circumstance from urban food residues and green waste), has the potential to provide consistent and clean energy to urban communities. OFMSW is inherently biodegradable, and has been proven under stylised conditions to achieve 400kWh per ton of waste; at a corresponding utilisation rate in Denmark it can be assumed that this would correspond to an approximate reduction of CO_2e by nearly 300kgCO_2e per ton of bio-waste under 'Business as Usual' waste management and fossil-fuel derived energy sourcing practices (Bolzonella *et al*, 2006).

This calculation builds-in the potential scalable synergies with AD and OFMSW and the production of 'Syngas' used for power, which can often be produced at higher cost- and technical-efficiency with urban compositions of food waste than purely agricultural waste streams. This process is often called co-digestion and has a number of commercial scale applications across the EU including Finland (at 1,400m^3 syngas production capacity), Slovenia, and 22 full-scale applications within Denmark itself. The current principle barriers to the integration of co-digestion with wastewater facilities, though, have been found to be:

- lack of design and professional experience on 'downstream' processing of biosolids an biogas
- lack of adequate investment into associated waste collection and handling mechanisms
- lack of Syngas utilisation and market options, including limited incentivisation for use and production
- complex interrelationships between authorities responsible for wastewater and solid wastewater management (Nghiem et al. 2017)

OFMSW has the potentiality as a vehicle for economically-efficient production of a number of value-added products arising entirely from a 'waste stream' (Tyagi *et al*, 2017). Although the precise cost-efficiency and scalability of relevant production processes is an area of uncertainty requiring further research, the following products have all been shown to be possible to generate:

- biofuels (methane, hydrogen, ethanol),
- bio-plastics
- bio-pesticides
- organic acids
- chemicals (acetone and butanol, glycerol)
- enzymes (lipase, amylase, and pectinases)

Source: Anaerobic co-digestion of organic fraction of municipal solid waste (OFMSW): Progress and challenges.

6.6 Engaging with the thorny issue of behavioural change over food waste.

Despite a progressive and sustainable image and outlook internationally, Denmark still has a lamentable record on the uptake and rates of preventable food waste and material going to inert landfill. For example, the picture overleaf shows the exact composition of a Danish person's waste output in percentages:

Fractions (Level I)	Fractions (Level II&III)	SF[4] (%w/w[1])	MF[3] (%w/w[1])
Food waste			
	Vegetable food waste	36.6	31.3
	Animal-derived food waste	8.1	9.5
Gardening waste			
	Dead animal and animal excrements[7]	0.5	0.3
	Garden waste etc.		
Paper			
	Other paper[5]	2.5	4.9
	Miscellaneous paper		
	Tissue paper	4.1	3.8
	Envelopes[1]	0.1	0.2
	Kraft paper	0.1	0.0
	Wrapping paper	0.1	0.0
	Other paper	0.2	0.1
Board			
	Other board[6]	6.5	6.0
	Corrugated boxes[1]		
	Egg boxes&alike[1]	0.1	0.1
	Cards&labels[1]	0.1	0.1
	Board tubes[1]	0.3	0.3
	Other board	0.2	0.1
Plastic			
	Non-packaging containers	0.5	0.9
	Packaging plastic[1]		
	1-PET	1.1	0.6
	2-HDPE	0.9	1.1
	3-PVC	0.0	0.5
	4-LDPE	0.0	0.0
	5-PP	1.4	0.4
	6 PS	0.4	1.2
	7-19	0.0	0.0
	Unspecified	1.4	0.8
	Plastic film	9.8	6.7
Metal			
	Metal packaging containers[1]		
	Ferrous	0.8	1.1
	Non-ferrous	0.5	0.8
	Aluminium wrapping foil	0.0	0.0
	Non-packaging metals		
	Ferrous	0.3	0.4
	Non-ferrous	0.3	0.3
Glass			
	Packaging container glass[1]	1.8	2.2
	Table and kitchen ware glass[1]	0.2	0.0
	Other/special glass[1]	0.1	0.1
Miscellaneous combustible	Human hygiene waste	14.1	19.5
	Wood untreated		
	Textiles, leather and rubber		
	Vacuum cleaner bags		
	Other combustible waste		
Inert		1.3	3.2
Special waste[1]		0.7	0.5
Total		100	100

[1]Mis-sorted recyclable material fractions; [2]Mis-sorted other material fractions; [3]Composition of single-family houses areas as % wet weight; [4]Composition of multi-family areas as (% mass per wet basis);[5]Advertising flyers, books & booklets, magazines & journals, newspapers, office paper, phonebook; [6]Corrugated boxes, folding boxes, beverage cartons; [7]Exclude cat litter.

Figure.15: *Exact composition of Danish waste stream output (Edjabou, 2016)*

However, Edjabou further explores the avoidable elements of Danish food waste in the following analysis:

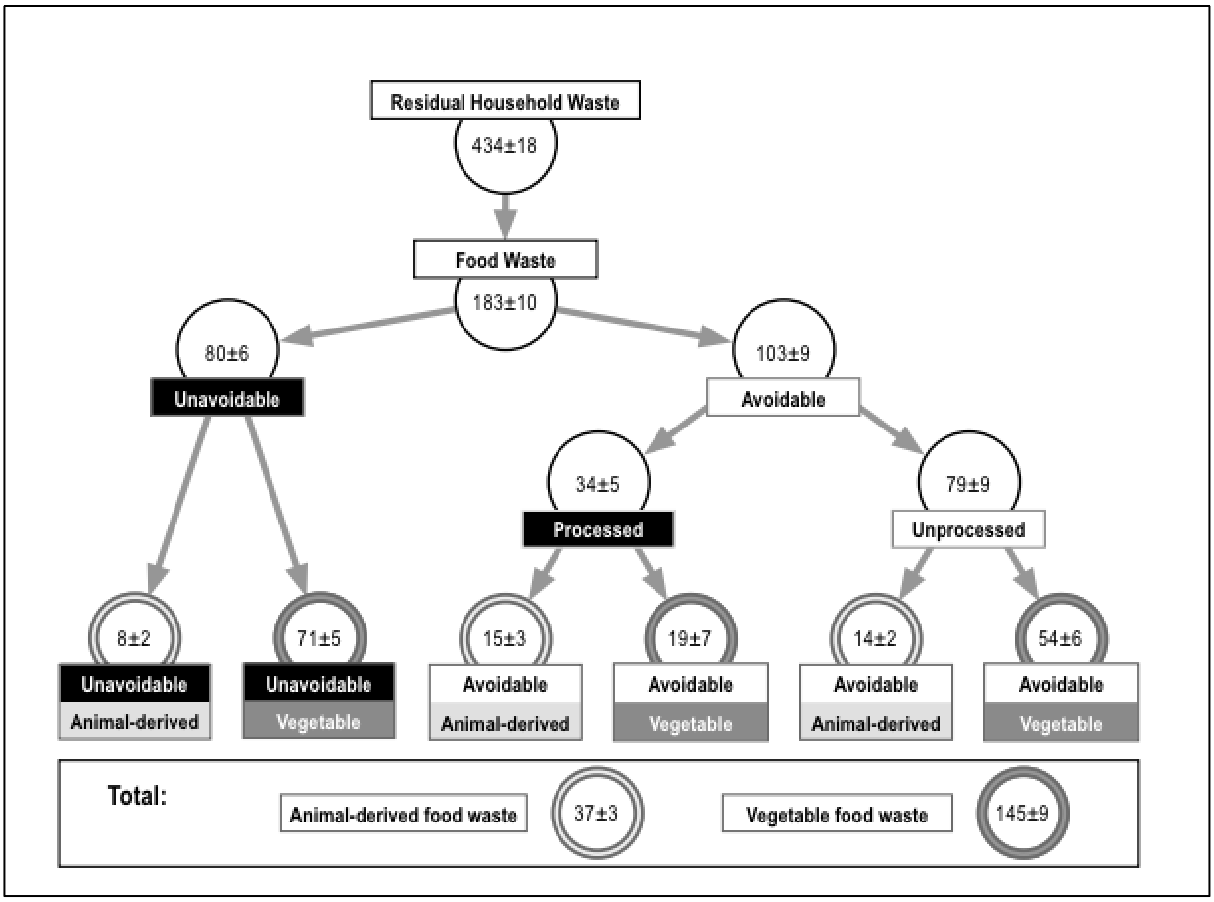


Figure.16: *Edjabou's avoidable and unavoidable food waste tree*

Food waste should be considered as fuel to the Zero³ project developers; as such, Danes are wasting great amounts of a free and extremely calorific resource, with great negative environmental impacts to boot. Engaging with the work of the 'Stop Wasting Food Initiative' (http://stopwastingfoodmovement.org/) and the 'National Knowledge Centre on Foodwaste' (http://madspild.dk/) would be a doubly beneficial tool for spreading positive change amongst communities, and also networking and publishing Zero³'s agenda in the area. The Danish Environmental Protection Agency estimates the annual food waste in Denmark amounts to more than 700,000 tonnes, with households accounting for 36%, 23% from the retail sector, 19% from the food industry, 14% from primary production methods, and the remaining 8% share form mixed sources.

6.7 Incorporating Domestic Waste Sources

Zero^3's environmental benefits could be further improved by incorporating domestic waste sources into Section.3's calculations, subsequently defining the magnitude of energy (output) that this system ameliorates by adding a per capita per year generation of useable energy from domestic food waste. The estimation of Zero3's Carbon Footprint can thus begin by considering the annual composition of a Copenhagen resident's waste output. This is waste that is considered available for use in standard AD systems:

Waste Type	Weight (kg)	% of Total Waste (Wet-Weight)
Vegetable Food Waste	*70.416*	*36.6*
*Animal Derived Food Waste**	*15.584*	*8.1*
*Dead Animal/Excrement & Garden Waste**	*0.962*	*0.5*
*Compostable Human Hygiene Waste**	*27.128*	*14.1*
Compostable Paper	*4.810*	*2.5*
Compostable tissue & 'other' paper	*8.850*	*4.6*
Compostable card textiles	*13.660*	*7.1*
TOTAL	***97.736***	

Table.1: *Composition of Sydhavnen's mean per capita annual waste composition. Sources: Aggregated by authors from Edjabou, 2016; Kjaer, 2013; Madsplild, 2018; Rabobank, 2014; Danish Environmental Protection Agency, 2014. *Not considered as waste feedstock due to regulatory restrictions on food production*

For an analysis of the incorporation of **sewage treatment** into AD systems, see Section.6.4 (*above*). From compostable standard waste alone, a typical AD-system is claimed to generate 300kWh of useable energy from 1 tonne of waste. This figure, however, ignores the specific composition of waste and energy-productivity in the form of Biogas recovery (see overleaf):

Feedstock Waste Type	SynGas Productivity (m^3/t)	Energy Equivalent** (kWh/t)
Wheat & Grain based waste	384-426	2,714
Turnip, Potato & Root-Veg based waste	276-400	2,265
Misc. Veg & Fruit based waste	240-434	2,499
Animal Fats & Misc. based waste	560-610	3,919
Paper & Card Sludge based waste	160-242	1,347

Table.3: *Syngas and energy generation potential by waste type. Sources: Aggregated by authors from Priadi et al, 2014; NNFCC, 2016; CROPGEN, 2016. *Assumes median value from each productivity range applied. **Applies a conversion factor of 6.7kWh per m^3 of Syngas at 60% methane concentration (see CROPGEN, 2016).*

Based on these figures, the stylised annual *per capita* energy generation potential of Sydhavnen residents was formed as follows: The total theoretical potential energy production from each resident of Sydhavnen per year is **222.008kWh**, and the (theoretical) market value of this energy is 68.82 Euros based on an electricity wholesale price of 31-euro cents per kWh, the current mean rate in Copenhagen. If this scheme were scaled up to the entire population on Sydhavnen with 25% uptake (3,853 of the 15,414 population) and 100% system utilisation, it would correspond to a theoretical maximum capacity of **855,396.824kWh** and a possible saving in market electricity value of up to 265,173.02 Euros.

Feedstock Type	SynGas Productivity (m^3/t)	Energy Equivalent** (kWh/t)
Vegetable & Organic Matter	22.885	185.326
Paper & Card Sources	5.464	36.682
TOTALS	**28.349**	**222.008**

As the variation in waste composition of residents across property type, demographic, socioeconomic status, etc. has been found to be statistically negligible within the parameters considered here (Edjabou, 2016; Tyagi et al, 2017; Kjaer, 2013).

This system comes with clear generalised Carbon benefits. If the *per capita* annual values determined above are corelated with Denmark's grid emissions factor for wholesale electricity, each participant on the scheme can potentially save **64.775kgCO_2e** per year in carbon outputs assuming all AD-produced energy replaces energy sources with equivalent emissions-intensity to the grid emissions factor.

Scenario	**Emissions Factor ($kgCO_2e/kWh$)**	**CO_2e Emissions per Capita per year**	**TOTAL DIFFERENCE ($kgCO_2e$)**
Energy derived from Zero3	0.00023	0.051kg	
Energy Derived from Danish Grid	0.292	64.826kg	**64.775**

Table.5: *Carbon benefit possible from sourcing energy from Zero[3]*

Furthermore, if the scheme were rolled-out into a jurisdiction or international context where landfill treatment of waste is prevalent, the environmental benefits of Zero3 would be further heightened. Although this is not the case in Sydhavnen (or the vast majority of Denmark) this concept can be useful to understand the true potential of Zero3 when applied in less progressive, 'clean' contexts.

Table.6: *Composition of Syngas and Landfill Gas. Sources: Aggregated from Al Seadi, 2008; IRENA, 2013; Persson et al, 2006. *Derived from median values for Landfill fractional composition by gas type*

Gas Type	**Compositional Fraction of Syngas**	**Compositional Fraction of Landfill Emissions**	**Landfill Volume of Gas* (m^3)**
Methane	*50-70%*	*35-65%*	*14.175*
Carbon Dioxide	*25-45%*	*15-40%*	*11.554*
Water Vapour	*1-5%*	*-*	*-*
Oxygen	*<2%*	*5%*	*1.444*
Nitrogen	*<2%*	*5-30%*	*1.444*
Hydrogen Sulphide	*0-4000ppm*	*0-100ppm*	*-*
Ammonia	*100ppm*	*5ppm*	*-*
Hydrogen	*<1%*	*<1%*	*-*
Other Hydrocarbons	*0%*	*0*	*-*

For the purposes of methodological consistency, a generalised Carbon footprint of waste in landfill attributable to gas exhausts of 262.359kgCO_2e per person can be derived from an emissions mass of 20.517kg. This calculation assumes uniform landfill gas density of 0.717kg/m^3 and an emissions factor of 588.8kgCO_2e per tonne for landfill waste and 21.8kgCO_2e per ton for associated emissions in AD (DEFRA, 2017).

Gas Type	Compositional Fraction of Landfill Emissions	Landfill Volume of Gas* (m^3)	Mass* (kg)	Equivalent $kgCO_2$ ratio
Methane	*35-65%*	*14.175*	*10.163*	*25*
Carbon Dioxide	*15-40%*	*11.554*	*8.284*	*1*
Oxygen	*5%*	*1.444*	*1.035*	*-*
Nitrogen	*5-30%*	*1.444*	*1.035*	*-*
TOTAL	***100%***	***28.349***	***20.517***	***-***

Table.7: *Compositional analysis of landfill gas types. *Assumes a uniform density of 0.717kg/m^3 applicable to all constituent gases.*

Importantly, as these per capita results are scaled-up the scheme could realise significant Carbon savings. *Figure.10* shows how electricity, landfill and total emissions savings grow as the scheme achieves greater penetration through a population where landfill is used a means of waste treatment – meant only as a useful contextualisation of the objective environmental benefits of the scheme:

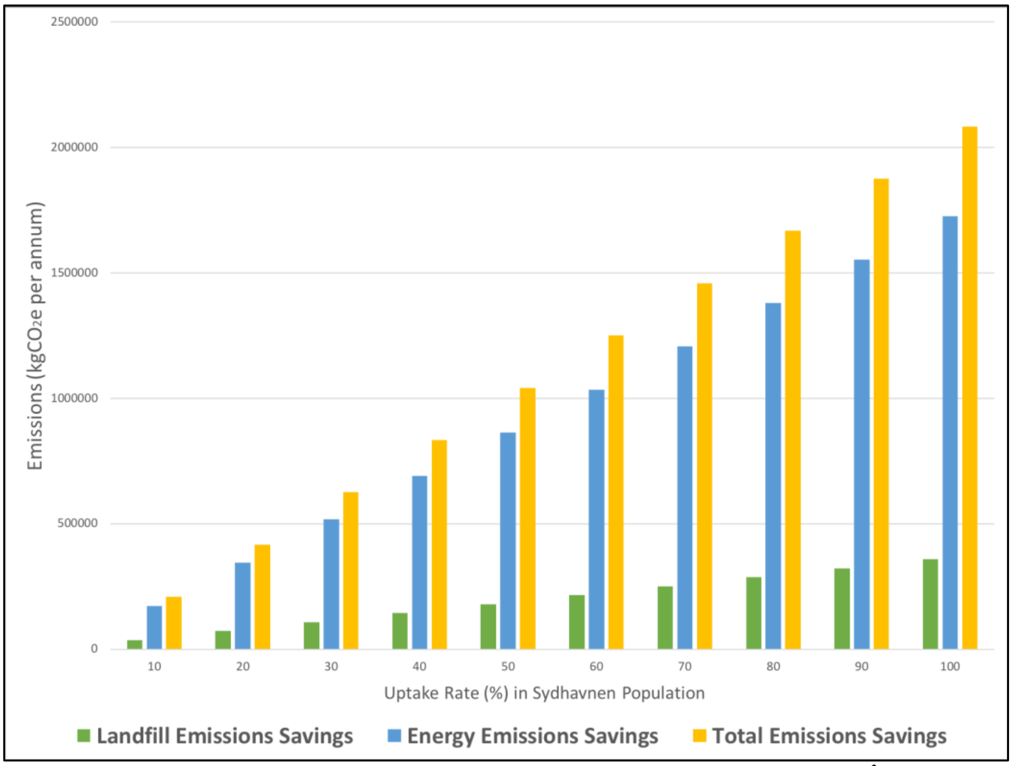


Figure.10: *Landfill, energy and total emissions savings brought about by the Zero^3 scheme with increasing uptake in Sydhavnen*

7. Appendices

References:

Al Seadi et al (2008) 'Biogas Handbook'. University of Southern Denmark Esbjerg, pp126

Bacon, N., Cochrane, D., Woodcraft , S., & Brown, J. (2012). Creating Strong Communities - How to measure the social sustainability of new housing developments. The Berkeley Group.
Bolzonella D, Pavan P, Mace S, Cecchi F. Dry anaerobic digestion of differently sorted organic municipal solid waste: a full-scale experience. Water Sci Technol 2006; 53: 23-32.

Chen et al (2017) 'Waste biorefineries – integrating anaerobic digestion and microalgae cultivation for bioenergy production', Current Opinion in Biotechnology 50(2018) pp101-110.

CROPGEN (2016) 'Renewable energy from crops and agrowaste'. Databse & associated articles available at: http://www.cropgen.soton.ac.uk/deliverables.htm. Accessed: 29/07/2017

Copenhagen Municipality (2014) 'Værdifulde Kulturmiljøer i København - Københavnernes Velfærd'. Copenhagen: Sammen om Byen.

Copenhagen Municipality (2016) 'Copenhagen Municipality'. Accessed: 27/07/2018. Available at: =themecontainer%20klima&mapext=718806%206169864.0912267%20731951.6%206179054.4912267&layers=themestartkort%20theme-disclaimer%20themehmax156_ext%20themehmax200_ext%20theme-hmax263_ext&mapheight=723&mapwidth.

DEFRA (2017) Grid and Waste Emissions Factor Database; calculations derived from figures contained therein.

Edjabou (2016) 'Composition of municipal solid waste in Denmark', Technical University of Denmark. Available from: http://orbit.dtu.dk/files/124242212/Maklawe_Essonanawe_Edjabou_PhD_thesis_WWW_Version.pdf. Accessed: 27/07/2018

EPA (2018) 'Anaerobic Digestion Facilities Processing Food Waste in the United States in 2015'. Report available from: http://biocycle.net/pdf/2018/AD_Data_Report.pdf. Accessed: 27/07/2018

IRENA (2013) 'Biomass for Power Generation. Renewable Energy Technologies: Cost Analysis' 1(5)

Jens (2016) 'Creating liveable neighbourhoods: A case study on social sustainability in Sydhavnen', Aalborg University Copenhagen. Available from: https://projekter.aau.dk/projekter/files/239577949/2016_SusCi4_Krister_Jens.pdf. Accessed: 28/07/2018

Jonsson.H et al (2005) 'Composition of Urine, Faeces, Greywater & Biowaste', Chalmers University of Technology. Available from: http://www.iea.lth.se/publications/Reports/LTH-IEA-7222.pdf. Accessed: 12/02/2018

Kjaer (2013) 'Municipal waste management in Denmark', European Environment Agency. Availabel from: Municipal waste management in Denmark - European Environment .... Accessed: 27/08/2018

Nghiem LD, Koch K, Bolzonella D, Drewes JE. Full-scale co-digestion of wastewater sludge and food waste: Bottlenecks and possibilities. Renew Sustain Energy Rev 2017; 72: 354–62.

NNFCC (2016) Anderson Centre: Feedstock Cost and Productivity Calculator. Available from: https://www.nnfcc.co.uk/publications/tool-ad-cost-calculator. Accessed: 29/07/2018

Persson et al (2006) 'Biogas Upgrading to Vehicle Fuel Standards and Grid Injection'. Energy Agency - Bioenergy, Task 37, Energy from Biogas and Landfill Gas, 19p

Priadi et al (2014) 'Biogas Production in the Anaerobic Digestion of Paper Sludge', APCBEE Procedia 9(2014) pp65-69

Rose.C et al (2015) 'The Characterization of Feces and Urine: A Review of the Literature to Inform Advanced Treatment Technology', Critical Review in Environmental Science & Technology 45(17) pp1827-1879

Tyagi et al (2017) 'Anaerobic co-digestion of organic fraction of municipal solid waste (OFMSW): Progress and challenges', Renewable and Sustainable Energy Reviews 93(2018) pp380-399