# SUPPORTING INFORMATION

# Minimization of the resource consumption and carbon footprint of a circular organic waste valorization system

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## Appendix A. Waste composition

Tables S1 and S2 show the energy content and the composition of the OW coming from the different waste collection systems. The energy content, Total Wet Weight (TWW), Total Solids (TS), Volatile solids (VS), ash and water contents of each waste fraction, as well as the fossil C (FossilC), the biogenic C (BioC) and the anaerobically degradable biogenic carbon ($BioC_{AD}$) present in the OW are shown. It is assumed that the composition of the SS-OW is 98% organic matter and 2% impurities. Even higher contents of organic matter have been achieved in real source separation experiences.[1] The composition of the OW collected in the mixed waste collection system and after the trommel separation (mix-OW) is taken from the Cantabrian waste management plant,[2] which also provides the amount of OW generated yearly in Cantabria (83544 ton).

**Table S1.** Composition of SS-OW (kg/ton OW)

| Fraction name | Energy (MJ/ton) | TS | Water | VS | Ash | BioC | $BioC_{AD}$ | FossilC | N |
|---|---|---|---|---|---|---|---|---|---|
| **Vegetable food waste** | 1363.51 | 94.75 | 317.04 | 89.83 | 4.93 | 45.01 | 40.08 | 0.23 | 1.80 |
| **Animal food waste** | 1070.87 | 55.49 | 73.97 | 50.66 | 4.83 | 30.74 | 19.97 | 0.63 | 3.88 |
| **Yard waste, flowers** | 2091.70 | 197.89 | 184.21 | 150.40 | 47.49 | 103.71 | 17.99 | 2.12 | 2.97 |
| **Wood** | 668.40 | 47.74 | 9.00 | 42.97 | 4.77 | 24.49 | 2.82 | 0.37 | 0.38 |
| **Non-recyclable glass** | 0.00 | 10.18 | 1.17 | 0.00 | 10.18 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Food cans (tinplate/steel)** | 0.00 | 0.65 | 0.10 | 0.00 | 0.65 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Beverage cans (Al)** | 0.00 | 0.17 | 0.02 | 0.00 | 0.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Other metals** | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Paper and carton containers** | 30.54 | 2.59 | 0.74 | 2.25 | 0.35 | 1.16 | 0.43 | 0.01 | 0.01 |
| **Plastic bottles** | 3.70 | 0.13 | 0.02 | 0.12 | 0.01 | 0.00 | 0.00 | 0.10 | 0.00 |
| **Soft plastic** | 24.02 | 0.76 | 0.13 | 0.73 | 0.03 | 0.00 | 0.00 | 0.62 | 0.00 |
| **Hard plastic** | 2.67 | 0.09 | 0.00 | 0.09 | 0.00 | 0.00 | 0.00 | 0.07 | 0.01 |
| **Non-recyclable plastic** | 11.52 | 0.46 | 0.04 | 0.43 | 0.03 | 0.00 | 0.00 | 0.32 | 0.00 |
| **Juice cartons** | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Textiles** | 1.96 | 0.13 | 0.01 | 0.12 | 0.00 | 0.05 | 0.00 | 0.02 | 0.00 |
| **Other non-combustibles** | 0.00 | 2.45 | 0.16 | 0.00 | 2.45 | 0.02 | 0.00 | 0.02 | 0.00 |

**Table S2.** Composition of mix-OW (kg/ton OW)

| Fraction name | Energy (MJ/ton) | TS | Water | VS | Ash | BioC | $BioC_{AD}$ | FossilC | N |
|---|---|---|---|---|---|---|---|---|---|
| **Vegetable food waste** | 1341.46 | 93.22 | 311.91 | 88.37 | 4.85 | 44.28 | 39.43 | 0.22 | 1.77 |
| **Animal food waste** | 1053.33 | 54.58 | 72.76 | 49.83 | 4.75 | 30.24 | 19.65 | 0.62 | 3.82 |
| **Yard waste, flowers** | 2057.96 | 194.70 | 181.24 | 147.97 | 46.73 | 102.04 | 17.70 | 2.08 | 2.92 |
| **Wood** | 18.97 | 1.35 | 0.26 | 1.22 | 0.14 | 0.69 | 0.08 | 0.01 | 0.01 |
| **Non-recyclable glass** | 0.00 | 45.77 | 5.26 | 0.00 | 45.77 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Food cans (tinplate/steel)** | 0.00 | 2.95 | 0.45 | 0.00 | 2.95 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Beverage cans (Al)** | 0.00 | 0.75 | 0.07 | 0.00 | 0.75 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Other metals** | 0.00 | 0.07 | 0.01 | 0.00 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Paper and carton containers** | 137.41 | 11.67 | 3.34 | 10.11 | 1.56 | 5.24 | 1.93 | 0.03 | 0.02 |
| **Plastic bottles** | 16.77 | 0.58 | 0.07 | 0.55 | 0.04 | 0.00 | 0.00 | 0.45 | 0.00 |
| **Soft plastic** | 107.97 | 3.43 | 0.56 | 3.28 | 0.15 | 0.01 | 0.00 | 2.80 | 0.01 |
| **Hard plastic** | 12.04 | 0.41 | 0.01 | 0.40 | 0.01 | 0.00 | 0.00 | 0.33 | 0.02 |
| **Non-recyclable plastic** | 51.79 | 2.06 | 0.16 | 1.95 | 0.11 | 0.01 | 0.00 | 1.46 | 0.01 |
| **Juice cartons** | 0.31 | 0.02 | 0.00 | 0.02 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| **Textiles** | 8.83 | 0.57 | 0.04 | 0.55 | 0.02 | 0.22 | 0.00 | 0.07 | 0.02 |
| **Other non-combustibles** | 0.00 | 11.03 | 0.71 | 0.00 | 11.03 | 0.07 | 0.00 | 0.07 | 0.00 |

**APPENDIX B. Unit processes modeling**

**Technologies for the recovery of nutrients from the liquid digestate**

Table S3 and S4 compile the life cycle inventories (LCI) of the technologies modeled to treat the liquid digestate. The content of $NH_4$ and P in the liquid digestate is 781.97e$^{-6}$ and 60.74e$^{-6}$ kg/kg respectively.

**Table S3.** LCI of the ammonia stripping and absorption process

| | |
|---|---|
| **INPUTS** | |
| 3.02 | kg $H_2SO_4$ (96% wt)/kg $NH_4$ in the digestate |
| 0.87 | kg NaOH/kg $NH_4$ in the digestate |
| 5.48 | kg $H_2O$/kg $NH_4$ in the digestate |
| 20.96 | kWh heat/ton digestate |
| 0.81 | kWh electricity/ton digestate |
| **OUTPUTS** | |
| 1.11e-2 | kg $SO_3$/kg $NH_4$ in the digestate |
| 4.8e-3 | kg $NH_3$/kg $NH_4$ in the digestate |
| 5.81e-3 | kg $(NH_4)_2SO_4$/kg liquid digestate |

**Table S4.** LCI of the struvite precipitation process

| | |
|---|---|
| **INPUTS** | |
| 1.561 | kg MgO/kg $(PO_4)^{3-}$–P in the liquid digestate |
| 0.064 | kWh/m$^3$ digestate |
| **OUTPUT** | |
| 4.45 | kg $MgNH_4PO_4{\cdot}6H_2O$/ kg $(PO_4)^{3-}$–P in the liquid digestate |

**Trommel separation**

The trommel energy consumption was assumed to be 0.55 kWh/ton for the SS-OW and 1.35 kWh/ton for the mixed waste. The data was extrapolated from commercial trommels,[3] considering that the densities of the materials that compose waste are those provided by EPA Victoria.[4]

Table S5 compiles the trommel separation efficiencies for each material; that is to say, how much of each material ends up in the OW stream after the sorting process. The efficiencies were calculated from the data provided by the Cantabrian waste management plant.[2]

**Table S5**. Trommel separation efficiencies

| Fraction name | Sorting efficiencies (%) |
|---|---|
| **Vegetable food waste** | 90.23 |
| **Animal food waste** | 90.23 |
| **Yard waste, flowers** | 90.23 |
| **Wood** | 3.20 |
| **Non-recyclable glass** | 51.10 |
| **Food cans (tinplate/steel)** | 20.00 |
| **Beverage cans (aluminium)** | 20.00 |
| **Other metals** | 20.00 |
| **Paper and carton containers** | 3.50 |
| **Plastic bottles** | 51.10 |
| **Soft plastic** | 51.10 |
| **Hard plastic** | 51.10 |
| **Non-recyclable plastic** | 51.10 |
| **Juice cartons** | 0.10 |
| **Textiles** | 0.50 |
| **Other non-combustibles** | 8.40 |

The efficiency of the magnetic and Eddy current separators is 73.42%.[2]

**Landfill**

Figure S1 shows the life cycle stages associated with the landfill unit process.

The generation of landfill gas is modeled according to equation 1, which indicates that the initial amount of anaerobically degradable biogenic carbon in fraction *i* of waste ($BioC_{AD_i}0$) experiences a first order decay.

$$BioC_{AD_i} = BioC_{AD_i}0 \cdot e^{-k \cdot t} \quad (1)$$

The decay rates (k) of each waste fraction are shown in Table S6. The assumed time horizon is 100 years.

**Table S6**. 1st order decay rate for the anaerobically degradable biogenic C in landfill

| **Fraction name** | **k (1/year)** |
|---|---|
| Vegetable food waste | 0.137 |
| Animal food waste | 0.137 |
| Yard waste, flowers | 0.162 |
| Wood | 0.014 |
| Non-recyclable glass | 0.000 |
| Food cans (tinplate/steel) | 0.000 |
| Beverage cans (aluminium) | 0.000 |
| Other metals | 0.000 |
| Paper and carton containers | 0.019 |
| Plastic bottles | 0.000 |
| Soft plastic | 0.000 |
| Hard plastic | 0.000 |
| Non-recyclable plastic | 0.000 |
| Juice cartons | 0.019 |
| Textiles | 0.021 |
| Other non-combustibles | 0.000 |

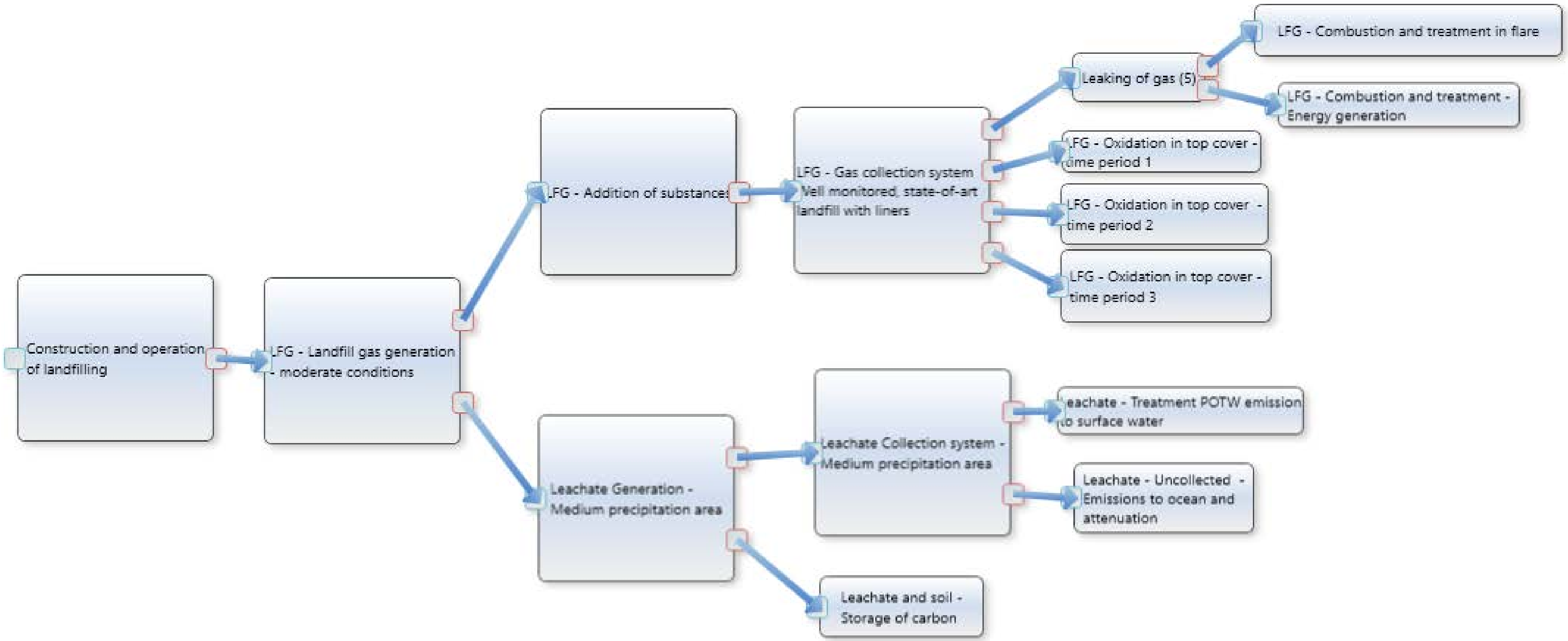


**Figure S1**. Life cycle stages considered in the landfill unit process

63% of the generated biogas is $CH_4$. The concentration of other substances (except for $CO_2$) in the biogas is compiled in Table S7.

**Table S7.** Additional substances in biogas

| Substance | Amount ($g/m^3$) |
|---|---|
| **Phenol** | 0.001 |
| **CO** | 0.028 |
| **Dichlorobenzene** | 0.006 |
| **Ethylchloride** | 0.010 |
| **Chloromethane** | 0.0003 |
| **Naphtalene** | 0.0006 |
| **Hg** | 1E-06 |
| **$H_2S$** | 0.04 |
| **NMVOC** | 0.03 |
| **VC** | 0.004 |
| **TCE** | 0.004 |
| **PCE** | 0.01 |
| **Benzene** | 0.008 |
| **Chlorobenzene** | 0.002 |
| **Ethylbenzene** | 0.02 |
| **Propylbenzene** | 0.002 |
| **Dichloromethane** | 0.02 |
| **Chloroform** | 0.0003 |
| **Carbon tetrachloride** | 5e-05 |
| **Xylenes** | 0.04 |
| **Toluene** | 0.11 |
| **CFC11** | 0.001 |
| **CFC12** | 0.005 |
| **CFC113** | 0.0005 |
| **HCFC21** | 0.01 |
| **HCFC22** | 0.003 |

Table S8 shows the efficiency of the gas collection system and the fraction of the not collected $CH_4$ that is oxidized.

**Table S8**. Efficiency of the gas collection system and the fraction of the not collected $CH_4$ that is oxidized

| Time period (years) | Collected gas (%) | Not collected $CH_4$ oxidized to $CO_2$ (%) |
|---|---|---|
| **0-5** | 45 | 10 |
| **5-15** | 80 | 20 |
| **15-55** | 95 | 36 |
| **55-100** | 0 | 36 |

Table S9 compiles the fraction of each substance that is oxidized in the combustion process of the collected gas (the combustion in flare of the gas that leaks, which is 7.21% of the collected gas, and the gas that is combusted for energy generation). All the substances are oxidized to $CO_2$, except for $H_2S$, which is transformed into $SO_2$.

**Table S9**. Fraction of each substance that is oxidized in the combustion process (%)

| Substance | In flare | For energy generation |
|---|---|---|
| **$CH_4$** | 99.0 | 99.0 |
| **NMVOC** | 97.7 | 97.2 |
| **$H_2S$** | 97.7 | 97.2 |
| **Vynil chloride** | 98.0 | 93.0 |
| **Trichloroethylene** | 98.0 | 93.0 |
| **Perchloroethene** | 98.0 | 93.0 |
| **Benzene** | 99.7 | 86.1 |
| **Chlorobenzene** | 99.7 | 86.1 |
| **Dichlorobenzene** | 99.7 | 86.1 |
| **Ethylbenzene** | 99.7 | 86.1 |
| **Propylbenzene** | 99.7 | 86.1 |
| **Ethylchloride** | 98.0 | 93.0 |
| **Chloromethane** | 98.0 | 93.0 |
| **Dichloromethane** | 98.0 | 93.0 |
| **Chloroform** | 98.0 | 93.0 |
| **Carbon tetrachloride** | 98.0 | 93.0 |
| **Xylenes** | 99.7 | 86.1 |
| **Toluene** | 99.7 | 86.1 |
| **CFC11** | 98.0 | 93.0 |
| **CFC12** | 98.0 | 93.0 |
| **CFC113** | 98.0 | 93.0 |
| **HCFC21** | 98.0 | 93.0 |
| **Phenol** | 99.7 | 86.1 |
| **Naphtalene** | 2.3 | 86.1 |

Table S10 shows the additional substances (besides $CO_2$) that are generated in the combustion process.

**Table S10.** Additional substances generated in the combustion and treatment of landfill gas (kg/m$^3$ $CH_4$)

| | In flare | For energy generation |
|---|---|---|
| **CO** | 7.40E-04 | 8.46E-03 |
| **Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin** | 6.70E-13 | 3.60E-12 |
| **$NO_x$** | 9.10E-04 | 8.20E-03 |
| **PAH, polycyclic aromatic hydrocarbons** | 1.00E-06 | 1.00E-06 |
| **Particulates (2.5-10µm)** | 7.00E-05 | 1.80E-04 |
| **Polychlorinated biphenyls** | 1.00E-06 | 1.00E-06 |
| **$SO_2$** | 1.70E-04 | 1.70E-04 |
| **HCl** | 1.70E-04 | 4.00E-05 |
| **HF** | 4.00E-05 | 4.00E-05 |

The leachate generation was calculated assuming a net infiltration rate of 300 mm/year. Table S11 compiles the concentration of different substances in the leachate. It was assumed that 99.9% of leachate was collected in the first 80 years of operation, whereas in the remaining 20 years of the time horizon, 87% of the leachate is collected.

**Table S11.** Concentration of different substances in the leachate (mg/L)

| Substance | Period 1 (1 year) | Period 2 (2 years) | Period 3 (7 years) | Period 4 (90 years) |
|---|---|---|---|---|
| **DEHP** | 1.00E-02 | 1.00E-02 | 1.00E-02 | 1.00E-02 |
| **Ethylchloride** | 1.00E-01 | 1.00E-01 | 1.00E-01 | 1.00E-01 |
| **Propylbenzene** | 2.00E-03 | 2.00E-03 | 2.00E-03 | 2.00E-03 |
| **Fe** | 7.80E+02 | 6.60E+02 | 3.20E+02 | 1.50E+01 |
| **$SO_4$** | 5.00E+02 | 4.40E+02 | 2.50E+02 | 8.00E+01 |
| **Se** | 1.00E-02 | 9.00E-03 | 6.00E-03 | 3.00E-03 |
| **Ca** | 1.20E+03 | 1.00E+03 | 5.00E+02 | 6.00E+01 |
| **Cl** | 2.12E+03 | 1.90E+03 | 1.10E+03 | 3.60E+02 |
| **Na** | 7.00E+02 | 6.00E+02 | 3.50E+02 | 1.00E+02 |
| **Ag** | 1.20E-01 | 1.00E-01 | 5.00E-02 | 1.00E-02 |
| **As** | 3.00E-02 | 3.00E-02 | 3.00E-02 | 3.00E-02 |
| **Ba** | 5.00E-01 | 4.50E-01 | 3.00E-01 | 1.60E-01 |
| **Cd** | 1.30E-02 | 1.20E-02 | 9.00E-03 | 6.00E-03 |
| **Cr** | 7.00E-02 | 6.50E-02 | 5.20E-02 | 4.00E-02 |
| **Cu** | 7.00E-02 | 7.00E-02 | 7.00E-02 | 7.00E-02 |
| **Hg** | 4.00E-04 | 3.00E-04 | 2.00E-04 | 1.00E-04 |
| **Mg** | 4.70E+02 | 4.10E+02 | 2.30E+02 | 6.00E+01 |
| **Ni** | 7.00E-02 | 7.00E-02 | 7.00E-02 | 7.00E-02 |
| **Pb** | 5.00E-02 | 4.50E-02 | 3.20E-02 | 2.00E-02 |
| **Zn** | 4.00E+00 | 3.50E+00 | 2.00E+00 | 7.00E-01 |
| **$NH_3$** | 3.50E+03 | 2.90E+03 | 1.60E+03 | 1.10E+02 |
| **$PO_4$** | 1.00E+00 | 1.00E+00 | 1.00E+00 | 1.00E+00 |
| **COD** | 2.00E+04 | 1.50E+04 | 5.00E+03 | 4.00E+02 |
| **BOD** | 1.60E+04 | 1.00E+04 | 1.00E+03 | 4.00E+01 |
| **TSS** | 6.00E+01 | 6.00E+01 | 6.00E+01 | 6.00E+01 |
| **VC** | 5.00E-03 | 4.80E-03 | 4.40E-03 | 4.00E-03 |
| **TCE** | 5.00E-03 | 5.00E-03 | 6.00E-03 | 6.00E-03 |
| **PCE** | 1.00E-02 | 9.00E-03 | 6.00E-03 | 3.00E-03 |
| **Benzene** | 6.00E-03 | 5.60E-03 | 4.80E-03 | 4.00E-03 |
| **Chlorobenzene** | 3.00E-03 | 3.00E-03 | 3.00E-03 | 3.00E-03 |
| **Dichlorobenzene** | 6.00E-03 | 6.00E-03 | 6.00E-03 | 6.00E-03 |
| **Ethylbenzene** | 3.00E-02 | 2.80E-03 | 2.40E-02 | 2.00E-02 |
| **Dichloromethane** | 3.00E-02 | 2.50E-02 | 1.30E-02 | 3.00E-03 |
| **Chloroform** | 3.00E-04 | 3.00E-04 | 3.00E-04 | 3.00E-04 |
| **Carbon tetrachloride** | 2.00E-04 | 2.00E-04 | 2.00E-04 | 2.00E-04 |
| **Xylenes** | 8.00E-02 | 7.50E-02 | 6.20E-02 | 5.00E-01 |
| **Toluene** | 9.00E-02 | 8.00E-02 | 5.00E-02 | 2.00E-02 |
| **Phenol** | 8.00E-04 | 3.00E-03 | 5.00E-03 | 3.00E-03 |
| **Naphtalene** | 3.00E-02 | 2.80E-02 | 2.40E-02 | 2.00E-02 |

Table S12 shows the LCI of the landfill unit process. The electricity generated in the gas combustion process is 2.64 kWh/m3 $CH_4$.

**Table S12.** LCI of landfill operation

| **INPUTS** | | |
|---|---|---|
| **Gravel** | 0.18 | kg/kg TWW |
| **Clay** | 8.2e-02 | kg/kg TWW |
| **Copper** | 9.87e-09 | kg/kg TWW |
| **Steel sheets** | 1.40e-04 | kg/kg TWW |
| **Aluminum** | 5.80e-08 | kg/kg TWW |
| **Polyvinylchloride resin** | 1.00e-05 | kg/kg TWW |
| **Polyethylene high density granulate** | 2.30e-04 | kg/kg TWW |
| **Polypropylene fibers** | 4.00e-08 | kg/kg TWW |
| **Diesel oil** | 2.02e-04 | kg/kg TWW |
| **Electricity consumption (construction and operation of landfill)** | 8.00e-03 | kWh/kg TWW |
| **Electricity consumption (leachate treatment)** | 4.43e-02 | kWh/kg leachate |

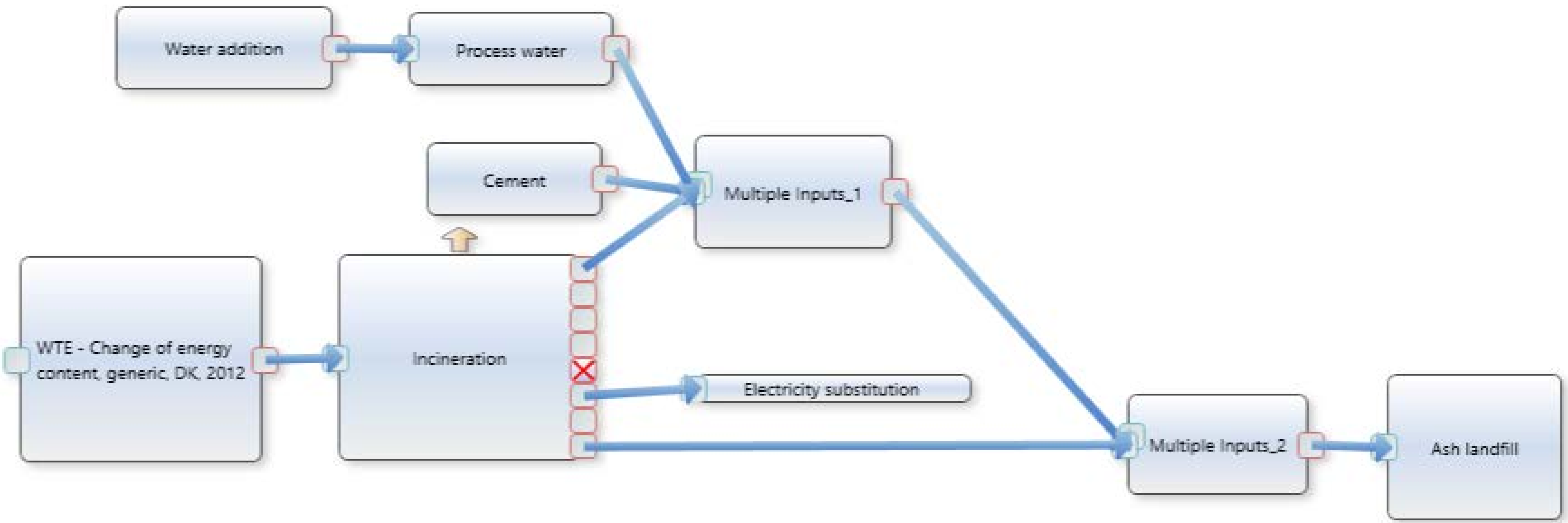


**Figure S2**. Life cycle stages considered in the incineration unit process

## Incineration

Figure S2 shows the life cycle stages of the incineration unit process. Table S13 compiles the percentages associated with the material transfer of the different substances present in waste after the incineration process. The energy efficiency of the incineration process is 23.8%.

**Table S13.** Substance transfer in the incineration unit process (%)

| | Air | Fly Ash | Fe scrap | Al srap | Wastewater | Degradation | Bottom ash |
|---|---|---|---|---|---|---|---|
| **Water** | | | | | | 100.00 | |
| **VS** | | | | | | 100.00 | |
| **C** | 99.9000 | | | | | | 0.10 |
| **Ca** | 0.0000 | 20.59 | | | | | 79.41 |
| **Cl** | 0.1073 | 32.13 | | | 62.4600 | | 5.3 |
| **F** | | | | | | 0.23 | 99.77 |
| **H** | | | | | | 100 | |
| **K** | | 20.59 | | | | | 79.41 |
| **N** | | | | | | 4.24 | 95.76 |
| **Na** | | 20.59 | | | | | 79.41 |
| **O** | | 18.36 | | | | 10.07 | 71.57 |
| **S** | 0.0990 | 60.91 | | | 15.0000 | | 23.991 |
| **Al** | | 8.60 | | 58.23 | | | 33.17 |
| **As** | 0.0121 | 58.92 | | | 0.4554 | | 40.61 |
| **Cd** | 0.0064 | 88.13 | | | 0.0311 | | 11.83 |
| **Cr** | 0.0394 | 16.77 | | | 0.0455 | | 83.15 |
| **Cu** | 0.0026 | 7.35 | | | 0.0157 | | 92.63 |
| **Fe** | | 3.19 | 84.50 | | | | 12.31 |
| **Hg** | 0.7476 | 96.25 | | | 0.0936 | | 2.909 |
| **Mg** | | 20.59 | | | | | 79.41 |
| **Mn** | | 20.59 | | | | | 79.41 |
| **Mo** | | 2.54 | | | 0.8517 | | 96.61 |
| **Ni** | 0.0329 | 12.56 | | | 0.0873 | | 87.32 |
| **Pb** | 0.0008 | 51.29 | | | 0.2384 | | 48.47 |
| **Sb** | 0.1190 | 59.84 | | | 1.2340 | | 38.81 |
| **Zn** | | 48.18 | | | 0.0643 | | 51.76 |

Table S14 compiles the substances generated in the incineration process and present in the gas stream (besides $CO_2$).

**Table S14.** Substances generated in the incineration unit process

| | | |
|---|---|---|
| **CO** | 3.30E-05 | kg/kg TWW |
| **Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin** | 1.80E-14 | kg/kg TWW |
| **HCl** | 5.3 E-06 | kg/kg TWW |
| **HF** | 3.90E-07 | kg/kg TWW |
| **NOx** | 8.49E-04 | kg/kg TWW |
| **$SO_2$** | 2.91E-06 | kg/kg TWW |
| **Particulates > 10 µm** | 3.00E-05 | kg/kg TWW |

Table S15 shows the LCI of the incineration process. The inputs associated with the operation of the ash landfill are excluded from the inventory.

**Table S15.** LCI of the incineration unit process

| **INPUTS** | | |
|---|---|---|
| **Activated carbon** | 9.29E-04 | kg/kg TWW |
| **Process water** | 5.05E-01 | kg/kg TWW |
| **Hydrated Lime** | 8.57E-03 | kg/kg TWW |
| **Natural Gas** | 1.45E-02 | MJ/kg TWW |
| **Cement (fly ash stabilization)** | 5E-01 | kg/kg fly ash |
| **Process water (fly ash stabilization)** | 5E-01 | kg/kg fly ash |

**Anaerobic digestion**

Figure S3 shows the different stages of the anaerobic digestion process.

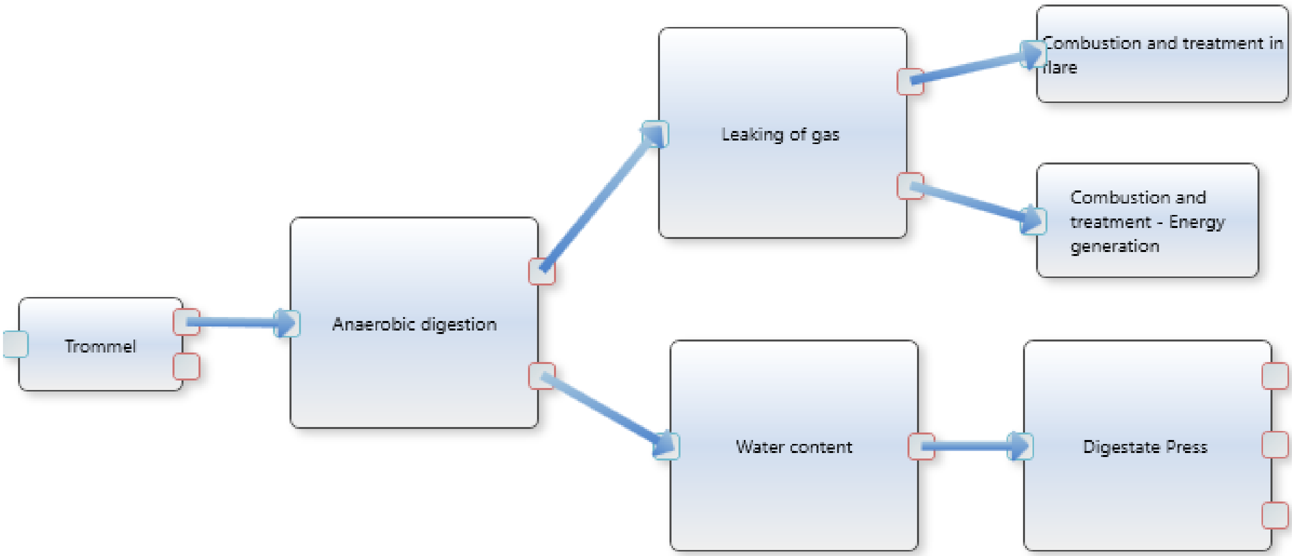


**Figure S3**. Life cycle stages considered in the anaerobic digestion unit process

Table S16 compiles the gas yields of the different materials present in the OW in the anaerobic digestion process. The yield is defined as the fraction of $BioC_{AD}$ of each material that is transferred to the gas phase. 63 % of the biogas is $CH_4$, the remaining fraction is $CO_2$. 2% of the generated biogas leaks and is combusted in a gas flare, whereas the rest of the biogas is combusted for energy generation. The electricity generated in the biogas combustion process is 2.64 kWh/m3 $CH_4$.

**Table S16.** Gas yield in the anaerobic digestion process

| Fraction name | Yield $BioC_{AD}$ (%) |
|---|---|
| **Vegetable food waste** | 70 |
| **Animal food waste** | 70 |
| **Yard waste, flowers** | 70 |
| **Wood** | 45 |
| **Paper and carton containers** | 45 |
| **Juice cartons** | 45 |

The fractions of each substance that are oxidized in the biogas combustion processes are those shown in Table S8, whereas the additional substances that are generated in the combustion process are compiled in Table S10.

The water content in the digestate is 96% (in weight). Table S17 compiles the distribution of different components of the liquid digestate between the liquid and the solid digestate after the screw press separation.[5] The rest of the components of the digestate are assumed to be transferred to the solid digestate. Regarding the energy consumption of the screw press, it is assumed to be 10 MJ per ton of digestate.[6]

**Table S17.** Distribution of the digestate components between the liquid and the solid digestate (%)

| Substance | Liquid digestate | Solid digestate |
|---|---|---|
| **Water** | 91.43 | 8.57 |
| **N** | 54.11 | 45.89 |
| **C** | 38.24 | 61.76 |
| **Mg** | 20.5 | 79.5 |
| **Ca** | 3.18 | 96.82 |
| **P** | 27.32 | 72.68 |
| **K** | 92.37 | 7.63 |
| **VS** | 30.56 | 69.44 |
| **Ash** | 6.95 | 93.05 |

Table S18 shows the LCI of the anaerobic digestion process. The results are expressed per kg of TWW that enters the pretreatment process. However, the table does not include the inputs associated with the trommel and the screw press. The heat required to achieve a temperature of 55 $^0$C in the reactor was calculated assuming that the specific heat of the solids is 3 kJ/kg.

**Table S18.** LCI of the anaerobic digestion unit process

| **INPUTS** | | |
|---|---|---|
| **Electricity consumption** | 4.12E-02 | kWh/kg TWW |
| **Diesel** | 7.57E-04 | l/kg TWW |
| **Process water** | 5.113 | kg/kg TWW |
| **Heat from natural gas** | 0.14 | kJ/kg TWW |

**Composting**

Figures S4 and S5 shows the life cycle stages of windrows and tunnel composting processes.

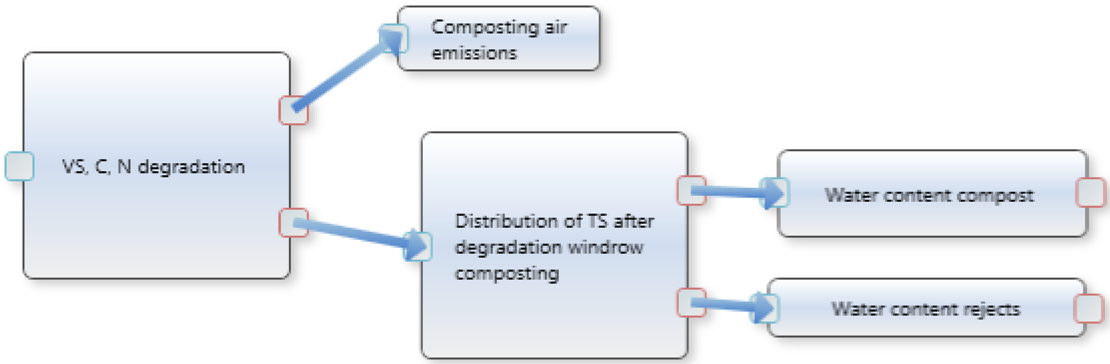


**Figure S4.** Life cycle stages considered in the windrows composting unit process

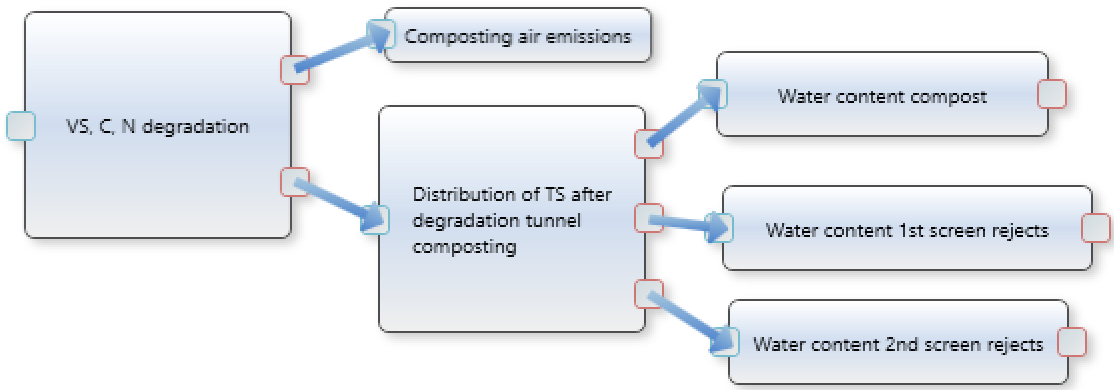


**Figure S5.** Life cycle stages considered in the tunnel composting unit process

Table S19 compiles the percentages of carbon in each fraction of the OW that is degraded in the composting processes. On the other hand, 71% of the N present in OW is degraded in the windrows and in the tunnel composting processes.

**Table S19**. Percentage of C in each fraction of the OW that is degraded in the composting processes

| Fraction name | Windrows | Tunnel |
|---|---|---|
| **Vegetable food waste** | 74.56 | 73.54 |
| **Animal food waste** | 74.56 | 73.54 |
| **Yard waste, flowers** | 74.56 | 63.79 |
| **Wood** | 11.28 | 20 |
| **Paper and carton containers** | 10 | 10 |
| **Juice cartons** | 5 | 5 |
| **Textiles** | 5 | 5 |
| **Others** | 0 | 0 |

Table S20 shows the percentages of each degraded element that are converted into new compounds in the composting process.

**Table S20.** Transformation of degraded elements into new compounds

| Element | Conversion (%) | Compound |
|---|---|---|
| **C** | 99.990 | $CO_2$ |
| **C** | 0.010 | $CH_4$ |
| **N** | 0.100 | $N_2$ |
| **N** | 0.985 | $NH_3$ |
| **N** | 1.400 | $N_2O$ |
| **N** | 97.515 | $NO_X$ |

Table S21 shows the gas emissions that are generated in the composting process.

**Table S21.** Substances generated in the composting process

| Substance | Amount (kg/kg TWW) |
|---|---|
| **Terpenes** | 1.22E-06 |
| **$H_2S$** | 1.93E-07 |

Table S22 shows the distribution of the materials that compose OW between the generated compost or bio-stabilized material (comp or BS) and reject for different composting technologies.

**Table S22.** Distribution of the materials between compost and reject

| | Tunnel composting | | | Windrows composting | |
|---|---|---|---|---|---|
| **Fraction name** | comp/BS | $1^{st}$ screen reject | $2^{nd}$ screen reject | comp/BS | Rejects |
| **Vegetable food waste** | 95 | 0 | 5 | 95 | 5 |
| **Animal food waste** | 95 | 2 | 3 | 95 | 5 |
| **Yard waste, flowers** | 95 | 0 | 5 | 95 | 5 |
| **Wood** | 80 | 20 | 0 | 50 | 50 |
| **Non-recyclable glass** | 5 | 30 | 65 | 50 | 50 |
| **Food cans (tinplate/steel)** | 0 | 30 | 70 | 0 | 100 |
| **Beverage cans (aluminium)** | 5 | 30 | 65 | 5 | 95 |
| **Other metals** | 5 | 30 | 65 | 5 | 95 |
| **Paper and carton containers** | 10 | 45 | 45 | 50 | 50 |
| **Plastic bottles** | 5 | 30 | 65 | 20 | 80 |
| **Soft plastic** | 5 | 30 | 65 | 20 | 80 |
| **Hard plastic** | 5 | 30 | 65 | 20 | 80 |
| **Non-recyclable plastic** | 5 | 30 | 65 | 20 | 80 |
| **Juice cartons** | 10 | 45 | 45 | 5 | 95 |
| **Textiles** | 5 | 30 | 65 | 50 | 50 |
| **Other non-combustibles** | 5 | 30 | 65 | 5 | 95 |

After the curing phase, the water content in the compost/bio-stabilized material is reduced to 30%.

The LCI of the composting processes is compiled in Table S23.

**Table S23.** LCI of the composting unit processes

| **INPUTS** | | |
|---|---|---|
| **Electricity consumption** | 0.053 | kWh/kg TWW |
| **Diesel** | 0.001 | l/kg TWW |

**Land application of products**

Table S24 compiles the LCI of the application of products to land.

**Table S24.** LCI of the application of products to land

| Inputs | | |
|---|---|---|
| **Diesel** | 0.01 | l/kg applied N |
| **Diesel** | 0.01 | l/kg applied P |
| **$NH_4NO_3$ (as N)** | 1.00 | kg/kg N from mineral fertilizer |
| **$(NH_4)_2HPO_4$** | 0.2347 | kg/kg P from mineral fertilizer |

**Transport**

The waste collected in Cantabria is taken to either one of the seven transfer stations of the region or to the mechanical-biological treatment plant located in the municipality of Meruelo. Table S26 compiles the distance of each regional municipality to the closest transfer station, as well as the distance from the transfer stations to Meruelo. The table also shows the population of each municipality.[7] The average distance that waste must be transported is calculated assuming that all the citizens generate the same amount of waste, regardless of where they live. It was calculated that the average distance that waste must go through from the municipalities to the transfer station is 24.7 km, and from the transfer station to Meruelo 21.6 km. Table S25 shows the LCI of the transport process.

**Table S25.** LCI of waste transport

| Transport | Vehicle type | LCI | |
|---|---|---|---|
| **Curbside collection** | Collection Vehicle, 10t Euro3, urban traffic | 0.00157 | l diesel/kg TWW |
| **From municipality to transfer station** | Truck, 7.5t-12t, Euro5, urban traffic | 24.7·2 | km/kg TWW |
| **From transfer station to Meruelo** | Truck, 20t-26t, Euro5, highway | 21.6·2 | km/kg TWW |

It was assumed that the products recovered from OW need to travel from the Meruelo facility to the different municipalities of Cantabria. On the other hand, it was assumed that all the mineral fertilizers that are applied in the region are produced at the PROFERSA plant in Bilbao. Table S27 compiles the cultivated areas of each Cantabrian municipality[7] and the distances from each municipality to Meruelo and Bilbao. Under the hypothesis that the amount of fertilizers and products recovered from OW that are sent to each municipality is directly proportional to the cultivated area, the average distance between Meruelo and the land where the recovered products are applied is 66.54 km, and the distance between Bilbao and the fertilized land, 105.05 km.

**Table S26.** Population and distance of each Cantabrian municipality to the closest transfer station

| Municipality | Population (inhabitants) | Transfer stations (km) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cabezón de la sal | Castañeda | Cabezón de Liebana | Campoo de Suso | Selaya | Ramales de la Victoria | Castro-urdiales | Meruelo |
| **Alfoz de Lloredo** | 2,466 | 13 | | | | | | | |
| **Ampuero** | 4,181 | | | | | | 12 | | |
| **Anievas** | 314 | | 39 | | | | | | |
| **Arenas de Iguña** | 1,711 | | 40 | | | | | | |
| **Argoños** | 1,720 | | | | | | | | 12 |
| **Arnuero** | 2,091 | | | | | | | | 40 |
| **Arredondo** | 480 | | | | | | 13 | | |
| **Astillero, El** | 18,134 | | | | | | | | 31 |
| **Bárcena de Cicero** | 4,124 | | | | | | | | 14 |
| **Bárcena de Pie de Concha** | 710 | | 45 | | | | | | |
| **Bareyo** | 1,999 | | | | | | | | 8 |
| **Cabezón de la Sal** | 8,345 | 0 | | | | | | | 69 |
| **Cabezón de Liébana** | 601 | | | 0 | | | | | 133 |
| **Cabuérniga** | 1,012 | 13 | | | | | | | |
| **Camaleño** | 977 | | | 12 | | | | | |
| **Camargo** | 30,611 | | | | | | | | 32 |
| **Campoó de Yuso** | 696 | | | | 25 | | | | |
| **Cartes** | 5,733 | | 17 | | | | | | |
| **Castañeda** | 2,687 | | 0 | | | | | | 39 |
| **Castro-Urdiales** | 31,901 | | | | | | | 0 | 48 |
| **Cieza** | 556 | | 35 | | | | | | |
| **Cillorigo de Liébana** | 1,310 | | | 13 | | | | | |
| **Colindres** | 8,331 | | | | | | | | 22 |
| **Comillas** | 2,228 | 10 | | | | | | | |
| **Corrales de Buelna, Los** | 11,003 | | 25 | | | | | | |
| **Corvera de Toranzo** | 2,074 | | 20 | | | | | | |
| **Enmedio, Campoó de** | 3,778 | | | | 16 | | | | |
| **Entrambasaguas** | 4,943 | | | | | | | | 13 |
| **Escalante** | 747 | | | | | | | | 11 |
| **Guriezo** | 2,359 | | | | | | | | 41 |
| **Hazas de Cesto** | 1,522 | | | | | | | | 9 |
| **Hermandad de Campoó de Suso** | 1,643 | | | | 0 | | | | 105 |
| **Herrerías** | 641 | 33 | | | | | | | |
| **Lamasón** | 298 | | | 37 | | | | | |
| **Laredo** | 11,446 | | | | | | | | 25 |
| **Liendo** | 1,227 | | | | | | | | 30 |
| **Liérganes** | 2,372 | | | | | | | | 25 |
| **Limpias** | 1,813 | | | | | | | | 25 |
| **Luena** | 615 | | 34 | | | | | | |
| **Marina de Cudeyo** | 5,174 | | | | | | | | 21 |
| **Mazcuerras** | 2,119 | 6 | | | | | | | |

| Municipality | Population (inhabitants) | Transfer stations (km) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cabezón de la sal | Castañeda | Cabezón de Liebana | Campoo de Suso | Selaya | Ramales de la Victoria | Castro-urdiales | Meruelo |
| **Medio Cudeyo** | 7,482 | | | | | | | | 23 |
| **Meruelo** | 1,965 | | | | | | | | 0 |
| **Miengo** | 4,741 | | 24 | | | | | | |
| **Miera** | 395 | | | | | | | | 38 |
| **Molledo** | 1,589 | | 37 | | | | | | |
| **Noja** | 2,562 | | | | | | | | 11 |
| **Penagos** | 2,060 | | | | | | | | 26 |
| **Peñarrubia** | 349 | | | 25 | | | | | |
| **Pesaguero** | 311 | | | 8 | | | | | |
| **Pesquera** | 71 | | | | 24 | | | | |
| **Piélagos** | 24,574 | | 16 | | | | | | |
| **Polaciones** | 237 | | | 33 | | | | | |
| **Polanco** | 5,794 | | 19 | | | | | | |
| **Potes** | 1,360 | 6 | | | | | | | |
| **Puente Viesgo** | 2,877 | | 7 | | | | | | |
| **Ramales de la Victoria** | 2,827 | | | | | | 0 | | 40 |
| **Rasines** | 959 | | | | | | 11 | | |
| **Reinosa** | 9,496 | | | | 11 | | | | |
| **Reocín** | 8,318 | | 21 | | | | | | |
| **Ribamontán al Mar** | 4,422 | | | | | | | | 13 |
| **Ribamontán al Monte** | 2,231 | | | | | | | | 8 |
| **Rionansa** | 1,058 | 31 | | | | | | | |
| **Riotuerto** | 1,610 | | | | | | | | 19 |
| **Rozas de Valdearroyo, Las** | 275 | | | | 27 | | | | |
| **Ruente** | 1,044 | 7 | | | | | | | |
| **Ruesga** | 870 | | | | | | 10 | | |
| **Ruiloba** | 765 | 12 | | | | | | | |
| **San Felices de Buelna** | 2,381 | | 18 | | | | | | |
| **San Miguel de Aguayo** | 160 | | | | 30 | | | | |
| **San Pedro del Romeral** | 453 | | | | | 31 | | | |
| **San Roque del Río Miera** | 386 | | | | | 23 | | | |
| **Santa Cruz de Bezana** | 12,679 | | | | | | | | 38 |
| **Santa María de Cayón** | 9,078 | | | | | | | | 32 |
| **Santander** | 172,656 | | | | | | | | 39 |
| **Santillana del Mar** | 4,184 | | 23 | | | | | | |
| **Santiurde de Reinosa** | 265 | | | | 21 | | | | |
| **Santiurde de Toranzo** | 1,602 | | | | | 25 | | | |
| **Santoña** | 11,085 | | | | | | | | 16 |
| **San Vicente de la Barquera** | 4,196 | 18 | | | | | | | |
| **Saro** | 512 | | | | | 15 | | | |
| **Selaya** | 1,931 | | | | | 0 | | | 52 |
| **Soba** | 1,249 | | | | | | | | 58 |
| **Solórzano** | 1,012 | | | | | | | | 11 |
| **Suances** | 8,579 | | 28 | | | | | | |

| Municipality | Population (inhabitants) | Transfer stations (km) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cabezón de la sal | Castañeda | Cabezón de Liebana | Campoo de Suso | Selaya | Ramales de la Victoria | Castro-urdiales | Meruelo |
| **Tojos, Los** | 399 | 26 | | | | | | | |
| **Torrelavega** | 52,819 | | 13 | | | | | | |
| **Tresviso** | 71 | | | 51 | | | | | |
| **Tudanca** | 147 | 41 | | | | | | | |
| **Udías** | 903 | 5 | | | | | | | |
| **Valdáliga** | 2,272 | 14 | | | | | | | |
| **Valdeolea** | 987 | | | | 26 | | | | |
| **Valdeprado del Río** | 331 | | | | 34 | | | | |
| **Valderredible** | 1,001 | | | | 45 | | | | |
| **Val de San Vicente** | 2,763 | 26 | | | | | | | |
| **Vega de Liébana** | 788 | | | 19 | | | | | |
| **Vega de Pas** | 795 | | | | | 19 | | | |
| **Villacarriedo** | 1,636 | | | | | 8 | | | |
| **Villaescusa** | 3,883 | | | | | | | | 34 |
| **Villafufre** | 1,017 | | | | | 17 | | | |
| **Valle de Villaverde** | 327 | | | | | | | 29 | |
| **Voto** | 2,725 | | | | | | | | 30 |

**Table S27.** Cultivated area of each municipality and distances to Meruelo and Bilbao

| Municipalities | Cultivated area (ha) | Distance to Meruelo (km) | Distance to Bilbao (km) |
|---|---|---|---|
| **Alfoz de Lloredo** | 104.26 | 65 | 133 |
| **Ampuero** | 22.68 | 29 | 68 |
| **Anievas** | 7.28 | 77 | 145 |
| **Arenas de Iguña** | 51.99 | 77 | 145 |
| **Argoños** | 0.64 | 12 | 72 |
| **Arnuero** | 190.55 | 40 | 82 |
| **Arredondo** | 0.61 | 52 | 91 |
| **Astillero (El)** | 15.68 | 31 | 94 |
| **Bárcena de Cicero** | 163.01 | 14 | 68 |
| **Bárcena de Pie de Concha** | 5.33 | 77 | 146 |
| **Bareyo** | 158.32 | 8 | 82 |
| **Cabezón de la Sal** | 64.61 | 69 | 137 |
| **Cabezón de Liébana** | 13.18 | 133 | 202 |
| **Cabuérniga** | 23.32 | 82 | 150 |
| **Camaleño** | 22.97 | 137 | 205 |
| **Camargo** | 56.42 | 32 | 101 |
| **Campoo de Yuso** | 11.54 | 68 | 148 |
| **Cartes** | 1.59 | 53 | 122 |
| **Castañeda** | 87.66 | 39 | 107 |
| **Castro-Urdiales** | 145.15 | 48 | 35 |
| **Cieza** | 59.35 | 71 | 139 |
| **Cillorigo de Liébana** | 12.86 | 134 | 202 |
| **Colindres** | 0.12 | 22 | 61 |
| **Comillas** | 24.09 | 76 | 144 |
| **Corrales de Buelna (Los)** | 49.35 | 60 | 129 |
| **Corvera de Toranzo** | 40.04 | 55 | 124 |
| **Campoo de Enmedio** | 33.54 | 95 | 164 |
| **Entrambasaguas** | 75.87 | 13 | 83 |
| **Escalante** | 6.73 | 11 | 70 |
| **Guriezo** | 24.71 | 41 | 53 |
| **Hazas de Cesto** | 36.12 | 9 | 75 |
| **Hermandad de Campoo de Suso** | 4.55 | 105 | 185 |
| **Herrerías** | 71.06 | 101 | 170 |
| **Lamasón** | 8.56 | 115 | 184 |
| **Laredo** | 8.73 | 25 | 60 |
| **Liendo** | 6.84 | 30 | 53 |
| **Liérganes** | 20.22 | 25 | 94 |
| **Limpias** | 3.16 | 25 | 64 |
| **Luena** | 12.55 | 70 | 138 |
| **Marina de Cudeyo** | 134.58 | 21 | 90 |
| **Mazcuerras** | 60.13 | 66 | 135 |
| **Medio Cudeyo** | 48.07 | 23 | 92 |
| **Meruelo** | 80.01 | 0 | 81 |
| **Miengo** | 46.93 | 47 | 116 |
| **Miera** | 4.49 | 38 | 106 |
| **Molledo** | 30.98 | 74 | 142 |
| **Noja** | 1.15 | 11 | 82 |
| **Penagos** | 40.86 | 26 | 94 |
| **Peñarrubia** | 26.00 | 120 | 188 |
| **Pesaguero** | 7.17 | 141 | 210 |
| **Pesquera** | 35.96 | 86 | 167 |
| **Piélagos** | 302.42 | 41 | 109 |
| **Polaciones** | 0.46 | 133 | 201 |
| **Polanco** | 39.47 | 49 | 118 |
| **Potes** | 0.08 | 130 | 199 |
| **Puente Viesgo** | 89.10 | 43 | 111 |
| **Ramales de la Victoria** | 9.06 | 40 | 79 |
| **Rasines** | 7.70 | 35 | 74 |

| Municipalities | Cultivated area (ha) | Distance to Meruelo (km) | Distance to Bilbao (km) |
|---|---|---|---|
| Reinosa | 8.61 | 106 | 162 |
| Reocín | 49.93 | 57 | 125 |
| Ribamontán al Mar | 610.78 | 13 | 93 |
| Ribamontán al Monte | 78.94 | 8 | 80 |
| Rionansa | 13.76 | 113 | 181 |
| Riotuerto | 3.73 | 19 | 89 |
| Rozas de Valdearroyo (Las) | 2.03 | 108 | 127 |
| Ruente | 4.11 | 76 | 145 |
| Ruesga | 13.58 | 49 | 88 |
| Ruiloba | 93.64 | 77 | 146 |
| San Felices de Buelna | 33.21 | 54 | 122 |
| San Miguel de Aguayo | 0.06 | 92 | 161 |
| San Pedro del Romeral | 10.09 | 76 | 144 |
| San Roque de Riomiera | 8.07 | 42 | 110 |
| Santa Cruz de Bezana | 85.34 | 38 | 107 |
| Santa María de Cayón | 181.02 | 32 | 100 |
| Santander | 16.93 | 39 | 102 |
| Santillana del Mar | 200.13 | 58 | 127 |
| Santiurde de Reinosa | 28.87 | 85 | 154 |
| 39078 - Santiurde de Toranzo | 11.96 | 52 | 120 |
| Santoña | 1.10 | 16 | 71 |
| San Vicente de la Barquera | 36.19 | 83 | 152 |
| Saro | 6.89 | 40 | 108 |
| Selaya | 9.16 | 52 | 121 |
| Soba | 62.72 | 58 | 97 |
| Solórzano | 102.26 | 11 | 76 |
| Suances | 203.11 | 63 | 131 |
| Tojos (Los) | 0.20 | 95 | 163 |
| Torrelavega | 128.98 | 50 | 28 |
| Tresviso | 4.00 | 153 | 221 |
| Tudanca | 0.22 | 123 | 191 |
| Udías | 5.61 | 70 | 139 |
| Valdáliga | 104.51 | 84 | 152 |
| Valdeolea | 683.14 | 110 | 179 |
| Valdeprado del Río | 81.70 | 113 | 181 |
| Valderredible | 1,352.17 | 124 | 193 |
| Val de San Vicente | 175.27 | 92 | 160 |
| Vega de Liébana | 21.29 | 143 | 211 |
| Vega de Pas | 2.71 | 71 | 104 |
| Villacarriedo | 87.47 | 45 | 113 |
| Villaescusa | 11.87 | 34 | 102 |
| Villafufre | 13.00 | 43 | 111 |
| Valle de Villaverde | 12.12 | 58 | 40 |
| Voto | 120.47 | 30 | 75 |

## Additional data

The ancillary data compiled in Table S28 has been taken from Ecoinvent 3.3.

**Table S28.** CF and consumption of NR-RM of different commodities

| | Functional unit | CF (kg $CO_2$-eq) | NR-RM (kg) |
|---|---|---|---|
| **Spanish electricity** | 1 kWh | 0.3054 | 0.4677 |
| **Heat from natural gas** | 1 MJ | 0.1410 | 0.0020 |
| **Cement** | 1 kg | 0.8840 | 1.6147 |
| **Steel sheet** | 1 kg | 0.3310 | 0.1875 |
| **Aluminum** | 1 kg | 4.9000 | 3.0196 |
| **Urea** | 2.14 kg | 3.1800 | 0.3571 |
| **$H_2SO_4$** | 1 kg | 0.2567 | 0.2632 |
| **MgO** | 1 kg | 1.0400 | 2.2793 |
| **NaOH** | 1 kg | 1.4143 | 0.9999 |
| **HCl** | 1 kg | 1.1400 | 0.9783 |
| **Water** | 1 kg | 0.0065 | 0.0195 |
| **$(NH_4)_2HPO_4$** | 1 kg | 1.4300 | 0.9591 |
| **$NH_4NO_3$** | 1 kg N | 8.7200 | 0.6574 |

APPENDIX C. LCA results of the unit processes

The annual CF of the food production and consumption subsystem in Cantabria is 1.56 million tons of $CO_2$-eq, whereas the annual consumption of NR-RM required for the production of food in the region is 0.69 million tons.[8] These figures exclude the CF and the consumption of NR-RM associated with the production of corn.

The contributions to the CF of the unit processes that manage the solid OW are shown in Figure S6. The results are referred to 1 ton of mix-OW or 1 ton of SS-OW after collection. The results do not include the management of the recovered products.

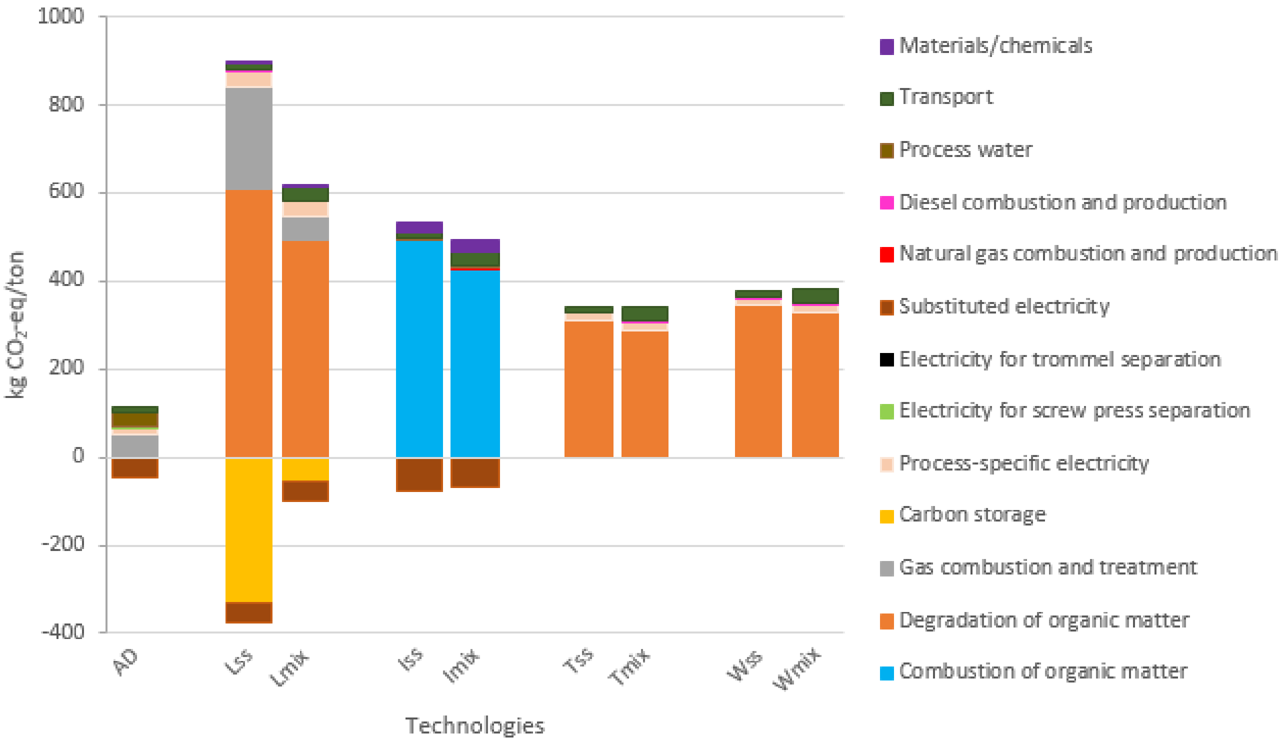


**Figure S6.** Contribution to the CF of the solid waste technologies

Table S29 compiles the consumption of NR-RM, the production of rejects (or ashes) and the LFA of the studied technologies for the management of OW. The LFA is estimated assuming that i) the rejects of the solid waste treatment technologies are sent to landfill, ii) the depth of each waste layer in the landfill is 4 m, and iii) the density of the compacted waste is 0.75 ton/$m^3$. The fly ash generated in the incineration process must be stabilized with cement and water prior to their disposal in landfill.

**Table S29.** Consumption of NR-RM, generation of rejects and LFA related to the solid waste technologies

| | ADss | Lss | Iss | Tss | Wss | Lmix | Imix | Tmix | Wmix |
|---|---|---|---|---|---|---|---|---|---|
| **NR-RM (kg/ton)** | 40.96 | 247.87 | -30.83 | 0.17 | 0.17 | 253.27 | 6.64 | 0.17 | 0.17 |
| **Reject (kg/ton)** | 158.80 | 0.00 | 75.31 | 32.27 | 61.5 | 0.00 | 116.21 | 87.86 | 83.25 |
| **LFA (m2/ton)** | 0.0529 | 0.3333 | 0.0303 | 0.0124 | 0.0205 | 0.3333 | 0.0467 | 0.0293 | 0.0278 |

Regarding the unit processes that treat the liquid digestate generated in the anaerobic digestion process: ammonia stripping and absorption (ASA), struvite precipitation (SP) and management in a wastewater treatment plant (WW), their CFs and consumption of NR-RM are compiled in Table S30.

**Table S30.** CF and consumption of NR-RM of the technologies to treat the liquid digestate

| | ASA | SP | WW |
|---|---|---|---|
| **CF (kg $CO_2$-eq/kg)** | 2.66E-03 | 1.18E-04 | 4.97E-04 |
| **NR-RM (kg/kg)** | 2.90E-03 | 2.27E-04 | 1.83E-3 |

The available N sources within the system are i) fertilizers (Fert), which are $NH_4NO_3$ (205 kg N/ha) and $(NH_4)_2HPO_4$ (7.9 kg P/ha), ii) compost (comp), iii) bio-stabilized material (BS), iv) solid digestate (SD), v) ammonium sulphate ($(NH_4)_2SO_4$) and vi) struvite ($MgNH_4PO_4 \cdot 6H_2O$). Each product (except for the fertilizers) can be obtained from some of the following unit processes: tunnel composting (T), windrows composting (W), anaerobic digestion (AD), ammonia stripping and absorption (ASA) and struvite precipitation (SP). Table S31 shows the CF and the consumption of NR-RM associated to the transport and land application of the products recovered from the OW.

**Table S31.** CF and consumption of NR-RM of the transport and land application of the recovered products

| **Product**<br>**Unit process** | **Comp**<br>**T** | **BS**<br>**T** | **Comp**<br>**W** | **BS**<br>**W** | **SD**<br>**AD** | **$(NH_4)_2SO_4$**<br>**ASA** | **Struvite**<br>**SP** |
|---|---|---|---|---|---|---|---|
| **CF (kg $CO_2$eq/kg)** | -0.3182 | -0.3050 | -0.2867 | -0.2500 | -0.1904 | -0.6832 | -0.1845 |
| **NR-RM (kg/kg)** | 7.434E-04 | 7.434E-04 | 7.434E-04 | 7.434E-04 | 7.783E-04 | 3.463E-02 | 9.788E-04 |

The CF of transporting and applying to land 1 kg of mineral fertilizer is 2.75 kg $CO_2$-eq/kg, whereas its consumption of NR-RM is 0.27 kg.

**APPENDIX D. C and N distribution**

The soil properties that the DNDC software demands as input data are the following:

- Texture: loam.[9]
- pH: 4.55.[9]
- Organic C content (0-10cm): 0.0412 kg C/kg soil.[10]
- Bulk density (0-10cm): 1.03 g/cm$^3$.[10]

Table S32 and S33 compile some of the input parameters regarding the quality of the recovered products that the DNDC software needs.

**Table S32.** Distribution of N in the compost and solid digestate (%)

| | Comp[11] | SD[12] |
|---|---|---|
| **Organic-N** | 93 | 62.96 |
| **$NH_4^+$-N** | 1 | 37.04 |
| **$NO_3^-$-N-** | 6 | 0 |

**Table S33.** Ratio C/N in the recovered products

| Product<br>Unit process | Comp<br>T | BS<br>T | Comp<br>W | BS<br>W | SD<br>AD |
|---|---|---|---|---|---|
| **C/N** | 29.0 | 23.8 | 22.9 | 20.0 | 19.99 |

Table S34 compiles the amounts of N from different sources that is applied to land. It is assumed that the amount of N applied to soil is the amount of N functionally equivalent to the minimum amount of N from fertilizers that results in a net storage of inorganic N in soil; that is to say, the amount of N from fertilizers that prevents the inorganic N in soil from being depleted. The application of the N rates shown in table S34 leads to a N uptake of 143 kg/ha, which results in a net production of 2.89 ton C/ha (7.13 tons of corn per ha). Another source of N is that present in root litter (19 kg/ha). Table S35 shows what the C deposits in soil are.

**Table S34.** Amount of N from different sources that needs to be applied to soil

| Product<br>Unit process | Fert<br>- | C<br>T | BS<br>T | C<br>W | BS<br>W | SD<br>AD | $(NH_4)_2SO_4$<br>ASA | $MgNH_4PO_4{\cdot}6H_2O$<br>SP |
|---|---|---|---|---|---|---|---|---|
| **kg N/ha/year** | 205 | 352 | 362 | 364 | 371 | 233 | 205 | 205 |

**Table S35.** C deposits in soil

| Carbon sources | kg C/ha/year |
|---|---|
| **Shoot litter** | 6.23 |
| **Root litter** | 1528.43 |
| **Root exudation** | 283.49 |

Tables S36 and S37 compile the results obtained from the DNDC software about the distribution of C and N after the application of these products to soil (the C and N present in the products and the C and N that are already in the soil). The results are obtained for the simulation of one year, which covers the crop rotation period.

**Table S36.** C distribution (%)

| **Product**<br>**Unit process** | **Fert**<br>**-** | **C**<br>**T** | **BS**<br>**T** | **C**<br>**W** | **BS**<br>**W** | **SD**<br>**AD** | **$(NH_4)_2SO_4$**<br>**ASA** | **$MgNH_4PO_4{\cdot}6H_2O$**<br>**SP** |
|---|---|---|---|---|---|---|---|---|
| **$CO_2$ emissions** | 87.31 | 62.35 | 60.90 | 60.58 | 59.45 | 65.55 | 87.32 | 87.32 |
| **Storage** | 12.69 | 37.65 | 39.10 | 39.42 | 40.55 | 34.45 | 12.68 | 12.68 |

**Table S37.** N distribution (%)

| **Product**<br>**Unit process** | **Fert**<br>**-** | **C**<br>**T** | **BS**<br>**T** | **C**<br>**W** | **BS**<br>**W** | **SD**<br>**AD** | **$(NH_4)_2SO_4$**<br>**ASA** | **$MgNH_4PO_4{\cdot}6H_2O$**<br>**SP** |
|---|---|---|---|---|---|---|---|---|
| **Soil leaching** | 34.66 | 5.26 | 5.38 | 5.39 | 5.46 | 13.16 | 34.88 | 34.88 |
| **Crop N uptake** | 64.56 | 38.37 | 37.40 | 37.22 | 36.58 | 56.40 | 64.31 | 64.31 |
| **$N_2O$** | 0.66 | 0.03 | 0.03 | 0.03 | 0.03 | 0.06 | 0.11 | 0.11 |
| **Storage** | 0.13 | 56.33 | 57.19 | 57.36 | 57.93 | 30.38 | 0.69 | 0.69 |

## APPENDIX E. MILP problem

The single-period MILP is formulated as follows:

$$\min\ U(x,y) = \{f_1(x,y),\ \ f_2(x,y), f_3(x,y)\}\ \ s.t.\ \left\{\begin{array}{c} h(x,y) = 0 \\ g(x,y) \leq 0 \\ x \in \Re^n \\ y \in \{0,1\}^m \end{array}\right. \qquad (2)$$

being $\{f_1(x,y), f_2(x,y), f_3(x,y)\}$ the objective functions to be minimized (the CF, the LFA and the consumption of NR-RM of the system). The equations that describe the behavior of the system $h(x,y) = 0$ are based on the mass balances of the unit processes. The restrictions of the model $g(x,y) \leq 0$ are described in the paper. In total, the model comprises 581 single equations and 18 inequations. The binary variables $(y)$ indicate whether a given unit processes is included or not in the system. Finally, the continuous variables represent the mass flows within the system. The model has 28 binary variables and 520 continuous variables. The numerical results were generated on an Intel(R) Core(TM) i3-2100 CPU with 3.10 GHz and 4 GB of RAM. It takes 0.203 seconds to solve each single-objective optimization with the CPLEX solver.

The main input parameters to the models are the SSR, the total area available for corn production (4810 ha) and the amount of OW generated yearly in Cantabria (83544 ton).

The Ɛ-constraint method was applied for the multi-objective optimization of the problem; first, a single-objective optimization was performed for each objective function and keeping the CF as the objective function, the domain of the others (LFA, NR-RM) was divided into 9 equal intervals. Then, 67 single-objective optimizations were subsequently solved setting the limits of those intervals as restrictions, and the Pareto points were generated.

## APPENDIX F. Optimization results

**Table S38.** Pre-Directive scenario, SSR=20%

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | ($m^2$) | (kg) | (kg $CO_2$-eq) | ($m^2$) | (kg) | (ton) | | | | | | | | (ton) | |
| 1 | None, min(CF) | | 3.9E+07 | 2.4E+03 | 4.7E+06 | | | 17050 | | | | | 63200 | | 80578 |
| 2 | None, min(LFA) | | 4.2E+07 | 1.1E+03 | 4.0E+06 | | | | | 17050 | | 63200 | | | |
| 3 | None, min(NR-RM) | | 4.2E+07 | 2.6E+03 | 1.8E+06 | 17050 | | | | | 23075 | | 40125 | | |
| 4 | 1.2E+03 | 2.1E+06 | | | | | | | Infeasible | | | | | | |
| 5 | 1.2E+03 | 2.4E+06 | | | | | | | Infeasible | | | | | | |
| 6 | 1.2E+03 | 2.7E+06 | | | | | | | Infeasible | | | | | | |
| 7 | 1.2E+03 | 3.1E+06 | | | | | | | Infeasible | | | | | | |
| 8 | 1.2E+03 | 3.4E+06 | | | | | | | Infeasible | | | | | | |
| 9 | 1.2E+03 | 3.7E+06 | 4.2E+07 | 1.2E+03 | 3.7E+06 | 5786 | 11264 | | | | 607 | 62593 | | 53235 | |
| 10 | 1.2E+03 | 4.0E+06 | 4.1E+07 | 1.2E+03 | 4.0E+06 | | 17050 | | | | 4859 | 58341 | | 38592 | 41986 |
| 11 | 1.2E+03 | 4.3E+06 | 4.0E+07 | 1.2E+03 | 4.3E+06 | | 15068 | 1982 | | | 1979 | 61221 | | | 80578 |
| 12 | 1.4E+03 | 2.1E+06 | | | | | | | Infeasible | | | | | | |
| 13 | 1.4E+03 | 2.4E+06 | | | | | | | Infeasible | | | | | | |
| 14 | 1.4E+03 | 2.7E+06 | | | | | | | Infeasible | | | | | | |
| 15 | 1.4E+03 | 3.1E+06 | | | | | | | Infeasible | | | | | | |
| 16 | 1.4E+03 | 3.4E+06 | 4.2E+07 | 1.4E+03 | 3.4E+06 | 9168 | 7882 | | | | 3528 | 59672 | | 37252 | |
| 17 | 1.4E+03 | 3.7E+06 | 4.1E+07 | 1.4E+03 | 3.7E+06 | 341 | 16709 | | | | 10014 | 53186 | | 78966 | |
| 18 | 1.4E+03 | 4.0E+06 | 4.1E+07 | 1.4E+03 | 4.0E+06 | | 16179 | 871 | | | 8999 | 54201 | | | 80578 |
| 19 | 1.4E+03 | 4.3E+06 | 4.0E+07 | 1.4E+03 | 4.3E+06 | | 13279 | 3771 | | | 4784 | 58416 | | | 80578 |
| 20 | 1.6E+03 | 2.1E+06 | | | | | | | Infeasible | | | | | | |
| 21 | 1.6E+03 | 2.4E+06 | | | | | | | Infeasible | | | | | | |
| 22 | 1.6E+03 | 2.7E+06 | | | | | | | Infeasible | | | | | | |
| 23 | 1.6E+03 | 3.1E+06 | 4.2E+07 | 1.6E+03 | 3.1E+06 | 12870 | 4180 | | | | 5895 | 57305 | | 19755 | |
| 24 | 1.6E+03 | 3.4E+06 | 4.1E+07 | 1.6E+03 | 3.4E+06 | 4043 | 13007 | | | | 12381 | 50819 | | 61469 | |
| 25 | 1.6E+03 | 3.7E+06 | 4.1E+07 | 1.6E+03 | 3.7E+06 | | 17050 | | | | 15352 | 47848 | | 14534 | 66044 |
| 26 | 1.6E+03 | 4.0E+06 | 4.0E+07 | 1.6E+03 | 4.0E+06 | | 14495 | 2555 | | | 11639 | 51561 | | | 80578 |
| 27 | 1.6E+03 | 4.3E+06 | 4.0E+07 | 1.6E+03 | 4.3E+06 | | 11595 | 5455 | | | 7425 | 55775 | | | 80578 |
| 28 | 1.7E+03 | 2.1E+06 | | | | | | | Infeasible | | | | | | |
| 29 | 1.7E+03 | 2.4E+06 | | | | | | | Infeasible | | | | | | |
| 30 | 1.7E+03 | 2.7E+06 | 4.3E+07 | 1.7E+03 | 2.7E+06 | 16572 | 478 | | | | 8262 | 54938 | | 2259 | |
| 31 | 1.7E+03 | 3.1E+06 | 4.2E+07 | 1.7E+03 | 3.1E+06 | 4975 | 1107 | | 10968 | | | | 63200 | 5234 | |
| 32 | 1.7E+03 | 3.4E+06 | 4.0E+07 | 1.7E+03 | 3.4E+06 | 4008 | 13042 | | | | 71 | | 63129 | | 61638 |
| 33 | 1.7E+03 | 3.7E+06 | 4.0E+07 | 1.7E+03 | 3.7E+06 | | 15911 | 1139 | | | 1853 | | 61347 | | 80578 |
| 34 | 1.7E+03 | 4.0E+06 | 4.0E+07 | 1.7E+03 | 3.8E+06 | | 15003 | 2047 | | | | | 63200 | | 80559 |
| 35 | 1.7E+03 | 4.3E+06 | 4.0E+07 | 1.7E+03 | 3.8E+06 | | 15003 | 2047 | | | | | 63200 | | 80559 |
| 36 | 1.9E+03 | 2.1E+06 | | | | | | | Infeasible | | | | | | |
| 37 | 1.9E+03 | 2.4E+06 | | | | | | | Infeasible | | | | | | |
| 38 | 1.9E+03 | 2.7E+06 | 4.2E+07 | 1.9E+03 | 2.7E+06 | 11486 | 4591 | | 973 | | | | 63199 | 21696 | |
| 39 | 1.9E+03 | 3.1E+06 | 4.1E+07 | 1.9E+03 | 3.1E+06 | 6491 | 10559 | | | | 5017 | | 58183 | | 49903 |
| 40 | 1.9E+03 | 3.4E+06 | 4.0E+07 | 1.9E+03 | 3.4E+06 | | 16991 | 59 | | | 11487 | | 51713 | | 80578 |
| 41 | 1.9E+03 | 3.7E+06 | 4.0E+07 | 1.9E+03 | 3.7E+06 | | 14110 | 2940 | | | 5703 | | 57497 | | 80578 |
| 42 | 1.9E+03 | 4.0E+06 | 4.0E+07 | 1.9E+03 | 4.0E+06 | | 11291 | 5769 | | | | | 63200 | | 80559 |
| 43 | 1.9E+03 | 4.3E+06 | 4.0E+07 | 1.9E+03 | 4.0E+06 | | 11291 | 5769 | | | | | 63200 | | 80559 |
| 44 | 2.1E+03 | 2.1E+06 | | | | | | | Infeasible | | | | | | |
| 45 | 2.1E+03 | 2.4E+06 | 4.2E+07 | 2.1E+03 | 2.4E+06 | 15843 | 1207 | | | | 2552 | | 60648 | | 5705 |
| 46 | 2.1E+03 | 2.7E+06 | 4.1E+07 | 2.1E+03 | 2.7E+06 | 9217 | 7833 | | | | 9276 | | 53924 | | 37017 |
| 47 | 2.1E+03 | 3.1E+06 | 4.0E+07 | 2.1E+03 | 3.1E+06 | 2592 | 14458 | | | | 16000 | | 47200 | | 68328 |
| 48 | 2.1E+03 | 3.4E+06 | 4.0E+07 | 2.1E+03 | 3.4E+06 | | 15296 | 1754 | | | 15110 | | 48090 | | 80578 |
| 49 | 2.1E+03 | 3.7E+06 | 4.0E+07 | 2.1E+03 | 3.7E+06 | | 12414 | 4636 | | | 9326 | | 53874 | | 80578 |
| 50 | 2.1E+03 | 4.0E+06 | 4.0E+07 | 2.1E+03 | 4.0E+06 | | 9532 | 7518 | | | 3543 | | 59657 | | |
| 51 | 2.1E+03 | 4.3E+06 | 3.9E+07 | 2.1E+03 | 4.2E+06 | | 7780 | 9270 | | | | | 63200 | | 80559 |
| 52 | 2.2E+03 | 2.1E+06 | | | | | | | Infeasible | | | | | | |

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | ($m^2$) | (kg) | (kg $CO_2$-eq) | ($m^2$) | (kg) | (ton) | | | | | | | | (ton) | |
| 53 | 2.2E+03 | 2.4E+06 | 4.2E+07 | 2.2E+03 | 2.4E+06 | 11700 | 5349 | | | | 14222 | | 48978 | | 25282 |
| 54 | 2.2E+03 | 2.7E+06 | 4.1E+07 | 2.2E+03 | 2.7E+06 | 5075 | 11975 | | | | 20946 | | 42254 | | 56593 |
| 55 | 2.2E+03 | 3.1E+06 | 4.0E+07 | 2.2E+03 | 3.1E+06 | | 16376 | 674 | | | 24744 | | 38456 | | 80578 |
| 56 | 2.2E+03 | 3.4E+06 | 4.0E+07 | 2.2E+03 | 3.4E+06 | | 13494 | 3556 | | | 18960 | | 44240 | | 80578 |
| 57 | 2.2E+03 | 3.7E+06 | 4.0E+07 | 2.2E+03 | 3.7E+06 | | 10612 | 6438 | | | 13176 | | 50024 | | 80578 |
| 58 | 2.2E+03 | 4.0E+06 | 4.0E+07 | 2.2E+03 | 4.0E+06 | | 7730 | 9320 | | | 7393 | | 55807 | | 80578 |
| 59 | 2.2E+03 | 4.3E+06 | 3.9E+07 | 2.2E+03 | 4.3E+06 | | 4849 | 12201 | | | 1609 | | 61591 | | 80578 |
| 60 | 2.4E+03 | 2.1E+06 | 4.2E+07 | 2.4E+03 | 2.1E+06 | 14427 | 2623 | | | | 18481 | | 44719 | | 12395 |
| 61 | 2.4E+03 | 2.4E+06 | 4.1E+07 | 2.4E+03 | 2.4E+06 | 7802 | 9248 | | | | 25206 | | 37994 | | 43706 |
| 62 | 2.4E+03 | 2.7E+06 | 4.1E+07 | 2.4E+03 | 2.7E+06 | 1177 | 15873 | | | | 31930 | | 31270 | | 75017 |
| 63 | 2.4E+03 | 3.1E+06 | 4.0E+07 | 2.4E+03 | 3.1E+06 | | 14680 | 2370 | | | 28367 | | 34833 | | 80578 |
| 64 | 2.4E+03 | 3.4E+06 | 4.0E+07 | 2.4E+03 | 3.4E+06 | | 11798 | 5252 | | | 22584 | | 40616 | | 80578 |
| 65 | 2.4E+03 | 3.7E+06 | 4.0E+07 | 2.4E+03 | 3.7E+06 | | 8916 | 8134 | | | 16800 | | 46400 | | 80578 |
| 66 | 2.4E+03 | 4.0E+06 | 4.0E+07 | 2.4E+03 | 4.0E+06 | | 6035 | 11015 | | | 11016 | | 52184 | | 80578 |
| 67 | 2.4E+03 | 4.3E+06 | 3.9E+07 | 2.4E+03 | 4.3E+06 | | 3153 | 13897 | | | 5232 | | 57968 | | 80578 |

## **Table S39.** Pre-Directive scenario, SSR=50%

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | ($m^2$) | (kg) | (kg $CO_2$-eq) | ($m^2$) | (kg) | (ton) | | | | | | | | (ton) | |
| 1 | None, min(CF) | | 3.6E+07 | 3.2E+03 | 6.5E+06 | | | 42625 | | | | | 39500 | | 201444 |
| 2 | None, min(LFA) | | 4.4E+07 | 8.9E+02 | 3.7E+06 | | | | | 42625 | | 39500 | | | |
| 3 | None, min(NR-RM) | | 4.4E+07 | 2.2E+03 | 9.0E+05 | 41062 | | | 1562 | | | | 39500 | | |
| 4 | 1.1E+03 | 1.5E+06 | Infeasible | | | | | | | | | | | | |
| 5 | 1.1E+03 | 2.1E+06 | Infeasible | | | | | | | | | | | | |
| 6 | 1.1E+03 | 2.8E+06 | Infeasible | | | | | | | | | | | | |
| 7 | 1.1E+03 | 3.4E+06 | 4.1E+07 | 1.1E+03 | 3.4E+06 | 6671 | 35954 | | | | 2422 | 37078 | | 169917 | |
| 8 | 1.1E+03 | 4.0E+06 | 4.0E+07 | 1.1E+03 | 4.0E+06 | | 42625 | | | | 7324 | 32176 | | 57430 | 144014 |
| 9 | 1.1E+03 | 4.6E+06 | 3.9E+07 | 1.1E+03 | 4.6E+06 | | 38372 | 4253 | | | 1144 | 38356 | | | 201444 |
| 10 | 1.1E+03 | 5.2E+06 | 3.9E+07 | 1.1E+03 | 4.7E+06 | | 37585 | 5040 | | | 39500 | | | | 201444 |
| 11 | 1.1E+03 | 5.9E+06 | 3.9E+07 | 1.1E+03 | 4.7E+06 | | 37585 | 5040 | | | 39500 | | | | 201444 |
| 12 | 1.4E+03 | 1.5E+06 | Infeasible | | | | | | | | | | | | |
| 13 | 1.4E+03 | 2.1E+06 | Infeasible | | | | | | | | | | | | |
| 14 | 1.4E+03 | 2.8E+06 | 4.3E+07 | 1.4E+03 | 2.8E+06 | 8378 | 10300 | | 23947 | | | | 39500 | 48680 | |
| 15 | 1.4E+03 | 3.4E+06 | 4.0E+07 | 1.4E+03 | 3.4E+06 | 6381 | 36243 | | | | | | 39500 | 65708 | 105579 |
| 16 | 1.4E+03 | 4.0E+06 | 3.9E+07 | 1.4E+03 | 4.0E+06 | | 41371 | 1254 | | | 3960 | | 35540 | | 201444 |
| 17 | 1.4E+03 | 4.6E+06 | 3.9E+07 | 1.4E+03 | 4.2E+06 | | 39411 | 3214 | | | | | 39500 | | 201426 |
| 18 | 1.4E+03 | 5.2E+06 | 3.9E+07 | 1.4E+03 | 5.0E+06 | | 31895 | 10729 | | | | 39500 | | | 201444 |
| 19 | 1.4E+03 | 5.9E+06 | 3.9E+07 | 1.4E+03 | 5.0E+06 | | 31895 | 10729 | | | | 39500 | | | 201444 |
| 20 | 1.7E+03 | 1.5E+06 | Infeasible | | | | | | | | | | | | |
| 21 | 1.7E+03 | 2.1E+06 | 4.3E+07 | 1.7E+03 | 2.1E+06 | 19100 | 5804 | | 17720 | | | | 39500 | 27427 | |
| 22 | 1.7E+03 | 2.8E+06 | 4.1E+07 | 1.7E+03 | 2.8E+06 | 16455 | 26170 | | | | 1195 | | 38305 | | 123679 |
| 23 | 1.7E+03 | 3.4E+06 | 3.9E+07 | 1.7E+03 | 3.4E+06 | 3618 | 39006 | | | | 14223 | | 25277 | | 184344 |
| 24 | 1.7E+03 | 4.0E+06 | 3.9E+07 | 1.7E+03 | 4.0E+06 | | 38615 | 4010 | | | 9848 | | 29652 | | 201444 |
| 25 | 1.7E+03 | 4.6E+06 | 3.8E+07 | 1.7E+03 | 4.5E+06 | | 33722 | 8903 | | | | | 39500 | | 201426 |
| 26 | 1.7E+03 | 5.2E+06 | 3.8E+07 | 1.7E+03 | 4.5E+06 | | 33722 | 8903 | | | | | 39500 | | 201426 |
| 27 | 1.7E+03 | 5.9E+06 | 3.8E+07 | 1.7E+03 | 5.4E+06 | | 26206 | 16419 | | | | 39500 | | | 201444 |
| 28 | 1.9E+03 | 1.5E+06 | 4.4E+07 | 1.9E+03 | 1.5E+06 | 33314 | 9310 | | | | 7327 | 32173 | | 44001 | |
| 29 | 1.9E+03 | 2.1E+06 | 4.2E+07 | 1.9E+03 | 2.1E+06 | 23200 | 19425 | | | | 5328 | | 34172 | | 91802 |
| 30 | 1.9E+03 | 2.8E+06 | 4.0E+07 | 1.9E+03 | 2.8E+06 | 10363 | 32261 | | | | 18356 | | 21144 | | 152468 |
| 31 | 1.9E+03 | 3.4E+06 | 3.9E+07 | 1.9E+03 | 3.4E+06 | | 41549 | 1076 | | | 26715 | | 12785 | | 201444 |
| 32 | 1.9E+03 | 4.0E+06 | 3.9E+07 | 1.9E+03 | 4.0E+06 | | 35966 | 6659 | | | 15509 | | 23991 | | 201444 |
| 33 | 1.9E+03 | 4.6E+06 | 3.8E+07 | 1.9E+03 | 4.6E+06 | | 30382 | 12243 | | | 4303 | | 35197 | | 201444 |
| 34 | 1.9E+03 | 5.2E+06 | 3.8E+07 | 1.9E+03 | 4.9E+06 | | 28251 | 14373 | | | | | 39500 | | 201426 |
| 35 | 1.9E+03 | 5.9E+06 | 3.8E+07 | 1.9E+03 | 5.7E+06 | | 20736 | 21889 | | | | 39500 | | | 201444 |
| 36 | 2.2E+03 | 1.5E+06 | 4.3E+07 | 2.2E+03 | 1.5E+06 | 29701 | 12924 | | | | 10148 | | 29352 | | 61077 |
| 37 | 2.2E+03 | 2.1E+06 | 4.1E+07 | 2.2E+03 | 2.1E+06 | 16865 | 25760 | | | | 23177 | | 16323 | | 121742 |
| 38 | 2.2E+03 | 2.8E+06 | 4.0E+07 | 2.2E+03 | 2.8E+06 | 4028 | 38597 | | | | 36205 | | 3295 | | 182408 |
| 39 | 2.2E+03 | 3.4E+06 | 3.9E+07 | 2.2E+03 | 3.0E+06 | | 38793 | 3831 | | | 32603 | | 6897 | | 201444 |
| 40 | 2.2E+03 | 4.0E+06 | 3.9E+07 | 2.2E+03 | 3.0E+06 | | 38793 | 3831 | | | 32603 | | 6897 | | 201444 |
| 41 | 2.2E+03 | 4.6E+06 | 3.9E+07 | 2.2E+03 | 3.0E+06 | | 38793 | 3831 | | | 32603 | | 6897 | | 201444 |
| 42 | 2.2E+03 | 5.2E+06 | 3.9E+07 | 2.2E+03 | 3.0E+06 | | 38793 | 3831 | | | 32603 | | 6897 | | 201444 |
| 43 | 2.2E+03 | 5.9E+06 | 3.9E+07 | 2.2E+03 | 3.0E+06 | | 38793 | 3831 | | | 32603 | | 6897 | | 201444 |
| 44 | 2.4E+03 | 1.5E+06 | 4.2E+07 | 2.2E+03 | 1.5E+06 | 29034 | 13591 | | | | 12029 | | 27471 | | 64231 |
| 45 | 2.4E+03 | 2.1E+06 | 4.1E+07 | 2.2E+03 | 2.1E+06 | 16303 | 26322 | | | | 24760 | | 14740 | | 124398 |
| 46 | 2.4E+03 | 2.8E+06 | 4.0E+07 | 2.2E+03 | 2.8E+06 | 3572 | 39053 | | | | 37491 | | 2009 | | 184565 |
| 47 | 2.4E+03 | 3.4E+06 | 3.9E+07 | 2.4E+03 | 3.3E+06 | | 36038 | 6587 | | | 38491 | | 1009 | | 201444 |
| 48 | 2.4E+03 | 4.0E+06 | 3.9E+07 | 2.4E+03 | 3.3E+06 | | 36038 | 6587 | | | 38491 | | 1009 | | 201444 |
| 49 | 2.4E+03 | 4.6E+06 | 3.9E+07 | 2.4E+03 | 3.3E+06 | | 36038 | 6587 | | | 38491 | | 1009 | | 201444 |
| 50 | 2.4E+03 | 5.2E+06 | 3.9E+07 | 2.4E+03 | 3.3E+06 | | 36038 | 6587 | | | 38491 | | 1009 | | 201444 |
| 51 | 2.4E+03 | 5.9E+06 | 3.9E+07 | 2.4E+03 | 3.3E+06 | | 36038 | 6587 | | | 38491 | | 1009 | | 201444 |
| 52 | 2.7E+03 | 1.5E+06 | 4.2E+07 | 2.2E+03 | 1.5E+06 | 29034 | 13591 | | | | 12029 | | 27471 | | 64231 |
| 53 | 2.7E+03 | 2.1E+06 | 4.1E+07 | 2.2E+03 | 2.1E+06 | 16303 | 26322 | | | | 24760 | | 14740 | | 124398 |
| 54 | 2.7E+03 | 2.8E+06 | 4.0E+07 | 2.2E+03 | 2.8E+06 | 3572 | 39053 | | | | 37491 | | 2009 | | 184565 |
| 55 | 2.7E+03 | 3.4E+06 | 3.9E+07 | 2.7E+03 | 3.6E+06 | | 30865 | 11760 | | | 39500 | | | | 201435 |

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | ($m^2$) | (kg) | (kg $CO_2$-eq) | ($m^2$) | (kg) | (ton) | | | | | | | | (ton) | |
| 56 | 2.7E+03 | 4.0E+06 | 3.9E+07 | 2.7E+03 | 3.6E+06 | | 30865 | 11760 | | | 39500 | | | | 201435 |
| 57 | 2.7E+03 | 4.6E+06 | 3.9E+07 | 2.7E+03 | 3.6E+06 | | 30865 | 11760 | | | 39500 | | | | 201435 |
| 58 | 2.7E+03 | 5.2E+06 | 3.9E+07 | 2.7E+03 | 3.6E+06 | | 30865 | 11760 | | | 39500 | | | | 201435 |
| 59 | 2.7E+03 | 5.9E+06 | 3.9E+07 | 2.7E+03 | 3.6E+06 | | 30865 | 11760 | | | 39500 | | | | 201435 |
| 60 | 2.9E+03 | 1.5E+06 | 4.2E+07 | 2.2E+03 | 1.5E+06 | 29034 | 13591 | | | | 12029 | | 27471 | | 64231 |
| 61 | 2.9E+03 | 2.1E+06 | 4.1E+07 | 2.2E+03 | 2.1E+06 | 16303 | 26322 | | | | 24760 | | 14740 | | 124398 |
| 62 | 2.9E+03 | 2.8E+06 | 4.0E+07 | 2.2E+03 | 2.8E+06 | 3572 | 39053 | | | | 37491 | | 2009 | | 184565 |
| 63 | 2.9E+03 | 3.4E+06 | 3.9E+07 | 2.5E+03 | 3.4E+06 | | 35566 | 7059 | | | 39500 | | | | 201444 |
| 64 | 2.9E+03 | 4.0E+06 | 3.8E+07 | 2.9E+03 | 4.0E+06 | | 25049 | 17575 | | | 38835 | | 665 | | 201444 |
| 65 | 2.9E+03 | 4.6E+06 | 3.8E+07 | 2.9E+03 | 4.6E+06 | | 19466 | 23159 | | | 27629 | | 11871 | | 201444 |
| 66 | 2.9E+03 | 5.2E+06 | 3.7E+07 | 2.9E+03 | 5.2E+06 | | 13882 | 28742 | | | 16423 | | 23077 | | 201444 |
| 67 | 2.9E+03 | 5.9E+06 | 3.7E+07 | 2.9E+03 | 5.9E+06 | | 8299 | 34326 | | | 5217 | | 34283 | | 201444 |

## **Table S40.** Pre-Directive scenario, SSR=80%

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | (m²) | (kg) | (kg $CO_2$-eq) | (m²) | (kg) | (ton) | | | | | | | | (ton) | |
| 1 | None, min(CF) | | 3.4E+07 | 4.0E+03 | 8.3E+06 | | | 68200 | | | | | 15800 | | 322311 |
| 2 | None, min(LFA) | | 4.5E+07 | 7.0E+02 | 3.4E+06 | | | | | 68200 | | 15800 | | | |
| 3 | None, min(NR-RM) | | 4.6E+07 | 1.8E+03 | 6.5E+05 | 42000 | | | 26200 | | | | 15800 | | |
| 4 | 1.1E+03 | 1.5E+06 | Infeasible | | | | | | | | | | | | |
| 5 | 1.1E+03 | 2.3E+06 | 4.5E+07 | 1.1E+03 | 2.4E+06 | 12153 | 9597 | | 46449 | | | | 15800 | 45355 | |
| 6 | 1.1E+03 | 3.2E+06 | 4.0E+07 | 1.1E+03 | 3.2E+06 | 8252 | 59947 | | | | | | 15800 | 213697 | 69614 |
| 7 | 1.1E+03 | 4.0E+06 | 3.8E+07 | 1.1E+03 | 4.1E+06 | 2271 | 65928 | | | | 6070 | | 9730 | | 311577 |
| 8 | 1.1E+03 | 4.9E+06 | 3.7E+07 | 1.1E+03 | 4.6E+06 | | 64040 | 4160 | | | | | 15800 | | |
| 9 | 1.1E+03 | 5.7E+06 | 3.7E+07 | 1.1E+03 | 4.9E+06 | | 61025 | 7174 | | | | 15800 | | | 322311 |
| 10 | 1.1E+03 | 6.6E+06 | 3.7E+07 | 1.1E+03 | 4.9E+06 | | 61025 | 7174 | | | | 15800 | | | 322311 |
| 11 | 1.1E+03 | 7.4E+06 | 3.7E+07 | 1.1E+03 | 4.9E+06 | | 61025 | 7174 | | | | 15800 | | | 322311 |
| 12 | 1.4E+03 | 1.5E+06 | 4.5E+07 | 1.4E+03 | 1.5E+06 | 27224 | 5627 | | 35349 | | | | 15800 | 26597 | |
| 13 | 1.4E+03 | 2.3E+06 | 4.1E+07 | 1.4E+03 | 2.4E+06 | 24263 | 43937 | | | | | | 15800 | 77075 | 130571 |
| 14 | 1.4E+03 | 3.2E+06 | 3.9E+07 | 1.4E+03 | 3.2E+06 | 10854 | 57345 | | | | 13609 | | 2191 | | 271013 |
| 15 | 1.4E+03 | 4.0E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 66641 | 1559 | | | 15800 | | | | 322311 |
| 16 | 1.4E+03 | 4.9E+06 | 3.7E+07 | 1.4E+03 | 4.9E+06 | | 57701 | 10498 | | | 3555 | | 12245 | | 322311 |
| 17 | 1.4E+03 | 5.7E+06 | 3.7E+07 | 1.4E+03 | 5.4E+06 | | | | | | | | | | |
| 18 | 1.4E+03 | 6.6E+06 | 3.7E+07 | 1.4E+03 | 5.4E+06 | | | | | | | | | | |
| 19 | 1.4E+03 | 7.4E+06 | 3.7E+07 | 1.4E+03 | 5.4E+06 | | 52929 | 15270 | | | | 15800 | | | 322311 |
| 20 | 1.8E+03 | 1.5E+06 | 4.2E+07 | 1.8E+03 | 1.5E+06 | 37279 | 30920 | | | | 2599 | | 13201 | | 146128 |
| 21 | 1.8E+03 | 2.3E+06 | 4.0E+07 | 1.7E+03 | 2.4E+06 | 21335 | 46864 | | | | 15800 | | | | 221481 |
| 22 | 1.8E+03 | 3.2E+06 | 3.9E+07 | 1.5E+03 | 3.2E+06 | 10077 | 58123 | | | | 15800 | | | | 274690 |
| 23 | 1.8E+03 | 4.0E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 66641 | 1559 | | | 15800 | | | | 322311 |
| 24 | 1.8E+03 | 4.9E+06 | 3.7E+07 | 1.8E+03 | 4.9E+06 | | 53886 | 14313 | | | 11708 | | 4092 | | 322311 |
| 25 | 1.8E+03 | 5.7E+06 | 3.6E+07 | 1.8E+03 | 5.9E+06 | | 45052 | 23148 | | | | 15800 | | | 322311 |
| 26 | 1.8E+03 | 6.6E+06 | 3.6E+07 | 1.8E+03 | 5.9E+06 | | 45052 | 23148 | | | | 15800 | | | 322311 |
| 27 | 1.8E+03 | 7.4E+06 | 3.6E+07 | 1.8E+03 | 5.9E+06 | | 45052 | 23148 | | | | 15800 | | | 322311 |
| 28 | 2.2E+03 | 1.5E+06 | 4.2E+07 | 1.8E+03 | 1.5E+06 | 36112 | 32087 | | | | 5887 | | 9913 | | 151644 |
| 29 | 2.2E+03 | 2.3E+06 | 4.0E+07 | 1.7E+03 | 2.4E+06 | 21335 | 46864 | | | | 15800 | | | | 221481 |
| 30 | 2.2E+03 | 3.2E+06 | 3.9E+07 | 1.5E+03 | 3.2E+06 | 10077 | 58123 | | | | 15800 | | | | 274690 |
| 31 | 2.2E+03 | 4.0E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 66641 | 1559 | | | 15800 | | | | 322311 |
| 32 | 2.2E+03 | 4.9E+06 | 3.7E+07 | 2.0E+03 | 4.9E+06 | | 51971 | 16229 | | | 15800 | | | | 322311 |
| 33 | 2.2E+03 | 5.7E+06 | 3.6E+07 | 2.2E+03 | 5.7E+06 | | 42310 | 25890 | | | 4724 | | 11076 | | 322311 |
| 34 | 2.2E+03 | 6.6E+06 | 3.6E+07 | 2.2E+03 | 6.3E+06 | | 36955 | 31244 | | | | 15800 | | | 322311 |
| 35 | 2.2E+03 | 7.4E+06 | 3.6E+07 | 2.2E+03 | 6.3E+06 | | 36955 | 31244 | | | | 15800 | | | 322311 |
| 36 | 2.5E+03 | 1.5E+06 | 4.2E+07 | 1.8E+03 | 1.5E+06 | 36112 | 32087 | | | | 5887 | | 9913 | | 151644 |
| 37 | 2.5E+03 | 2.3E+06 | 4.0E+07 | 1.7E+03 | 2.4E+06 | 21335 | 46864 | | | | 15800 | | | | 221481 |
| 38 | 2.5E+03 | 3.2E+06 | 3.9E+07 | 1.5E+03 | 3.2E+06 | 10077 | 58123 | | | | 15800 | | | | 274690 |
| 39 | 2.5E+03 | 4.0E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 66641 | 1559 | | | 15800 | | | | 322311 |
| 40 | 2.5E+03 | 4.9E+06 | 3.7E+07 | 2.0E+03 | 4.9E+06 | | 51971 | 16229 | | | 15800 | | | | 322311 |
| 41 | 2.5E+03 | 5.7E+06 | 3.6E+07 | 2.5E+03 | 5.7E+06 | | 38495 | 29705 | | | 12876 | | 2924 | | 322311 |
| 42 | 2.5E+03 | 6.6E+06 | 3.6E+07 | 2.5E+03 | 6.5E+06 | | 32079 | 36121 | | | | | 15800 | | 322311 |
| 43 | 2.5E+03 | 7.4E+06 | 3.6E+07 | 2.5E+03 | 6.8E+06 | | 29078 | 39122 | | | | 15800 | | | 322311 |
| 44 | 2.9E+03 | 1.5E+06 | 4.2E+07 | 1.8E+03 | 1.5E+06 | 36112 | 32087 | | | | 5887 | | 9913 | | 151644 |
| 45 | 2.9E+03 | 2.3E+06 | 4.0E+07 | 1.7E+03 | 2.4E+06 | 21335 | 46864 | | | | 15800 | | | | 221481 |
| 46 | 2.9E+03 | 3.2E+06 | 3.9E+07 | 1.5E+03 | 3.2E+06 | 10077 | 58123 | | | | 15800 | | | | 274690 |
| 47 | 2.9E+03 | 4.0E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 66641 | 1559 | | | 15800 | | | | 322311 |
| 48 | 2.9E+03 | 4.9E+06 | 3.7E+07 | 2.0E+03 | 4.9E+06 | | 51971 | 16229 | | | 15800 | | | | 322311 |
| 49 | 2.9E+03 | 5.7E+06 | 3.6E+07 | 2.6E+03 | 5.7E+06 | | 37126 | 31073 | | | 15800 | | | | 322311 |
| 50 | 2.9E+03 | 6.6E+06 | 3.5E+07 | 2.9E+03 | 6.6E+06 | | 26919 | 41281 | | | 5892 | | 9908 | | 322311 |
| 51 | 2.9E+03 | 7.4E+06 | 3.5E+07 | 2.9E+03 | 7.2E+06 | | 20982 | 47218 | | | | 15800 | | | 322311 |
| 52 | 3.3E+03 | 1.5E+06 | 4.2E+07 | 1.8E+03 | 1.5E+06 | 36112 | 32087 | | | | 5887 | | 9913 | | 151644 |
| 53 | 3.3E+03 | 2.3E+06 | 4.0E+07 | 1.7E+03 | 2.4E+06 | 21335 | 46864 | | | | 15800 | | | | 221481 |
| 54 | 3.3E+03 | 3.2E+06 | 3.9E+07 | 1.5E+03 | 3.2E+06 | 10077 | 58123 | | | | 15800 | | | | 274690 |
| 55 | 3.3E+03 | 4.0E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 66641 | 1559 | | | 15800 | | | | 322311 |
| 56 | 3.3E+03 | 4.9E+06 | 3.7E+07 | 2.0E+03 | 4.9E+06 | | 51971 | 16229 | | | 15800 | | | | 322311 |

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | ($m^2$) | (kg) | (kg $CO_2$-eq) | ($m^2$) | (kg) | (ton) | | | | | | | | (ton) | |
| 57 | 3.3E+03 | 5.7E+06 | 3.6E+07 | 2.6E+03 | 5.7E+06 | | 37126 | 31073 | | | 15800 | | | | 322311 |
| 58 | 3.3E+03 | 6.6E+06 | 3.5E+07 | 3.3E+03 | 6.6E+06 | | 23103 | 45096 | | | 14045 | | 1755 | | 322311 |
| 59 | 3.3E+03 | 7.4E+06 | 3.5E+07 | 3.3E+03 | 7.4E+06 | | 16105 | 52094 | | | | | 15800 | | 322311 |
| 60 | 3.6E+03 | 1.5E+06 | 4.2E+07 | 1.8E+03 | 1.5E+06 | 36112 | 32087 | | | | 5887 | | 9913 | | 151644 |
| 61 | 3.6E+03 | 2.3E+06 | 4.0E+07 | 1.7E+03 | 2.4E+06 | 21335 | 46864 | | | | 15800 | | | | 221481 |
| 62 | 3.6E+03 | 3.2E+06 | 3.9E+07 | 1.5E+03 | 3.2E+06 | 10077 | 58123 | | | | 15800 | | | | 274690 |
| 63 | 3.6E+03 | 4.0E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 66641 | 1559 | | | 15800 | | | | 322311 |
| 64 | 3.6E+03 | 4.9E+06 | 3.7E+07 | 2.0E+03 | 4.9E+06 | | 51971 | 16229 | | | 15800 | | | | 322311 |
| 65 | 3.6E+03 | 5.7E+06 | 3.6E+07 | 2.6E+03 | 5.7E+06 | | 37126 | 31073 | | | 15800 | | | | 322311 |
| 66 | 3.6E+03 | 6.6E+06 | 3.5E+07 | 3.3E+03 | 6.6E+06 | | 22282 | 45918 | | | 15800 | | | | 322311 |
| 67 | 3.6E+03 | 7.4E+06 | 3.5E+07 | 3.6E+03 | 7.4E+06 | | 11527 | 56673 | | | 7061 | | 8739 | | 322311 |

## **Table S41.** Post-Directive scenario, SSR=20%

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | ($m^2$) | (kg) | (kg $CO_2$-eq) | ($m^2$) | (kg) | (ton) | | | | | | | | (ton) | |
| 1 | None, min(CF) | | 4.0E+07 | 3.9E+03 | 3.0E+06 | | | 17050 | | | 63200 | | | | 80578 |
| 2 | None, min(LFA) | | 4.3E+07 | 3.0E+03 | 1.6E+06 | | | | 17050 | | 63200 | | | | |
| 3 | None, min(NR-RM) | | 4.3E+07 | 3.1E+03 | 1.6E+06 | 1000 | | | 16050 | | 63200 | | | | |
| 4 | 3.1E+03 | 1.7E+06 | 4.1E+07 | 3.1E+03 | 1.7E+06 | 1000 | 16050 | | | | 63200 | | | 70599 | 5253 |
| 5 | 3.1E+03 | 1.9E+06 | 4.1E+07 | 3.1E+03 | 1.9E+06 | 1000 | 16050 | | | | 63200 | | | 13473 | 62379 |
| 6 | 3.1E+03 | 2.0E+06 | 4.1E+07 | 3.1E+03 | 2.0E+06 | | 16192 | 858 | | | 63200 | | | | 80578 |
| 7 | 3.1E+03 | 2.2E+06 | 4.1E+07 | 3.1E+03 | 2.1E+06 | | 15843 | 1207 | | | 63200 | | | | 80578 |
| 8 | 3.1E+03 | 2.3E+06 | 4.1E+07 | 3.1E+03 | 2.1E+06 | | 15843 | 1207 | | | 63200 | | | | 80578 |
| 9 | 3.1E+03 | 2.5E+06 | 4.1E+07 | 3.1E+03 | 2.1E+06 | | 15843 | 1207 | | | 63200 | | | | 80578 |
| 10 | 3.1E+03 | 2.7E+06 | 4.1E+07 | 3.1E+03 | 2.1E+06 | | 15843 | 1207 | | | 63200 | | | | 80578 |
| 11 | 3.1E+03 | 2.8E+06 | 4.1E+07 | 3.1E+03 | 2.1E+06 | | 15843 | 1207 | | | 63200 | | | | 80578 |
| 12 | 3.2E+03 | 1.7E+06 | 4.1E+07 | 3.1E+03 | 1.7E+06 | 1000 | 16050 | | | | 63200 | | | 70599 | 5253 |
| 13 | 3.2E+03 | 1.9E+06 | 4.1E+07 | 3.1E+03 | 1.9E+06 | 1000 | 16050 | | | | 63200 | | | | 62379 |
| 14 | 3.2E+03 | 2.0E+06 | 4.1E+07 | 3.1E+03 | 2.0E+06 | 16192 | 858 | | | | 63200 | | | | 80578 |
| 15 | 3.2E+03 | 2.2E+06 | 4.1E+07 | 3.2E+03 | 2.2E+06 | 13873 | 3177 | | | | 63200 | | | | 80578 |
| 16 | 3.2E+03 | 2.3E+06 | 4.1E+07 | 3.2E+03 | 2.2E+06 | 13873 | 3177 | | | | 63200 | | | | 80578 |
| 17 | 3.2E+03 | 2.5E+06 | 4.1E+07 | 3.2E+03 | 2.2E+06 | 13873 | 3177 | | | | 63200 | | | | 80578 |
| 18 | 3.2E+03 | 2.7E+06 | 4.1E+07 | 3.2E+03 | 2.2E+06 | 13873 | 3177 | | | | 63200 | | | | 80578 |
| 19 | 3.2E+03 | 2.8E+06 | 4.1E+07 | 3.2E+03 | 2.2E+06 | 13873 | 3177 | | | | 63200 | | | | 80578 |
| 20 | 3.3E+03 | 1.7E+06 | 4.1E+07 | 3.1E+03 | 1.7E+06 | 1000 | 16050 | | | | 63200 | | | 70599 | 5253 |
| 21 | 3.3E+03 | 1.9E+06 | 4.1E+07 | 3.1E+03 | 1.9E+06 | 1000 | 16050 | | | | 63200 | | | 13473 | 62379 |
| 22 | 3.3E+03 | 2.0E+06 | 4.1E+07 | 3.1E+03 | 2.0E+06 | | 16192 | 858 | | | 63200 | | | | 80578 |
| 23 | 3.3E+03 | 2.2E+06 | 4.1E+07 | 3.2E+03 | 2.2E+06 | | 13572 | 3478 | | | 63200 | | | | 80578 |
| 24 | 3.3E+03 | 2.3E+06 | 4.0E+07 | 3.3E+03 | 2.3E+06 | | 11904 | 5146 | | | 63200 | | | | 80578 |
| 25 | 3.3E+03 | 2.5E+06 | 4.0E+07 | 3.3E+03 | 2.3E+06 | | 11904 | 5145.9 | | | 63200 | | | | 80578 |
| 26 | 3.3E+03 | 2.7E+06 | 4.0E+07 | 3.3E+03 | 2.3E+06 | | 11904 | 5145.9 | | | 63200 | | | | 80578 |
| 27 | 3.3E+03 | 2.8E+06 | 4.0E+07 | 3.3E+03 | 2.3E+06 | | 11904 | 5145.9 | | | 63200 | | | | 80578 |
| 28 | 3.4E+03 | 1.7E+06 | 4.1E+07 | 3.1E+03 | 1.7E+06 | | 1000 | 16050 | | | 63200 | | | 70599 | 5253 |
| 29 | 3.4E+03 | 1.9E+06 | 4.1E+07 | 3.1E+03 | 1.9E+06 | | 1000 | 16050 | | | 63200 | | | 13473 | 62379 |
| 30 | 3.4E+03 | 2.0E+06 | 4.1E+07 | 3.1E+03 | 2.0E+06 | | 16192 | 858 | | | 63200 | | | | 80578 |
| 31 | 3.4E+03 | 2.2E+06 | 4.1E+07 | 3.2E+03 | 2.2E+06 | | 13572 | 3478 | | | 63200 | | | | 80578 |
| 32 | 3.4E+03 | 2.3E+06 | 4.0E+07 | 3.4E+03 | 2.4E+06 | | 10778 | 6272 | | | 63200 | | | | 80578 |
| 33 | 3.4E+03 | 2.5E+06 | 4.0E+07 | 3.4E+03 | 2.4E+06 | | 9935 | 7115 | | | 63200 | | | | 80578 |
| 34 | 3.4E+03 | 2.7E+06 | 4.0E+07 | 3.4E+03 | 2.4E+06 | | 9935 | 7115 | | | 63200 | | | | 80578 |
| 35 | 3.4E+03 | 2.8E+06 | 4.0E+07 | 3.4E+03 | 2.4E+06 | | 9935 | 7115 | | | 63200 | | | | 80578 |
| 36 | 3.5E+03 | 1.7E+06 | 4.1E+07 | 3.1E+03 | 1.7E+06 | 1000 | 16050 | | | | 63200 | | | 70599 | |
| 37 | 3.5E+03 | 1.9E+06 | 4.1E+07 | 3.1E+03 | 1.9E+06 | 1000 | 16050 | | | | 63200 | | | 13473 | 62379 |
| 38 | 3.5E+03 | 2.0E+06 | 4.1E+07 | 3.1E+03 | 2.0E+06 | | 16192 | 858 | | | 63200 | | | | 80578 |
| 39 | 3.5E+03 | 2.2E+06 | 4.1E+07 | 3.2E+03 | 2.2E+06 | | 13572 | 3478 | | | 63200 | | | | 80578 |
| 40 | 3.5E+03 | 2.3E+06 | 4.0E+07 | 3.4E+03 | 2.4E+06 | | 10778 | 6272 | | | 63200 | | | | 80578 |
| 41 | 3.5E+03 | 2.5E+06 | 4.0E+07 | 3.5E+03 | 2.5E+06 | | 8158 | 8892 | | | 63200 | | | | 80578 |
| 42 | 3.5E+03 | 2.7E+06 | 4.0E+07 | 3.5E+03 | 2.5E+06 | | 7965 | 9085 | | | 63200 | | | | 80578 |
| 43 | 3.5E+03 | 2.8E+06 | 4.0E+07 | 3.5E+03 | 2.5E+06 | | 7965 | 9085 | | | 63200 | | | | 80578 |
| 44 | 3.6E+03 | 1.7E+06 | 4.1E+07 | 3.1E+03 | 1.7E+06 | 1000 | 16050 | | | | 63200 | | | 70599 | 5253 |
| 45 | 3.6E+03 | 1.9E+06 | 4.1E+07 | 3.1E+03 | 1.9E+06 | 1000 | 16050 | | | | 63200 | | | | 62379 |
| 46 | 3.6E+03 | 2.0E+06 | 4.1E+07 | 3.1E+03 | 2.0E+06 | | 16192 | 858 | | | 63200 | | | | 80578 |
| 47 | 3.6E+03 | 2.2E+06 | 4.1E+07 | 3.2E+03 | 2.2E+06 | | 13572 | 3478 | | | 63200 | | | | 80578 |
| 48 | 3.6E+03 | 2.3E+06 | 4.0E+07 | 3.4E+03 | 2.4E+06 | | 10778 | 6272 | | | 63200 | | | | 80578 |
| 49 | 3.6E+03 | 2.5E+06 | 4.0E+07 | 3.5E+03 | 2.5E+06 | | 8158 | 8892 | | | 63200 | | | | 80578 |
| 50 | 3.6E+03 | 2.7E+06 | 4.0E+07 | 3.5E+03 | 2.5E+06 | | 7965 | 9085 | | | 63200 | | | | 80578 |
| 51 | 3.6E+03 | 2.8E+06 | 4.0E+07 | 3.5E+03 | 2.5E+06 | | 7965 | 9085 | | | 63200 | | | | 80578 |
| 52 | 3.7E+03 | 1.7E+06 | 4.1E+07 | 3.1E+03 | 1.7E+06 | 1000 | 16050 | | | | 63200 | | | 70599 | 5253 |
| 53 | 3.7E+03 | 1.9E+06 | 4.1E+07 | 3.1E+03 | 1.9E+06 | | 1000 | 16050 | | | 63200 | | | 13473 | 62379 |
| 54 | 3.7E+03 | 2.0E+06 | 4.1E+07 | 3.1E+03 | 2.0E+06 | | 16192 | 858 | | | 63200 | | | | 80578 |
| 55 | 3.7E+03 | 2.2E+06 | 4.1E+07 | 3.2E+03 | 2.2E+06 | | 13572 | 3478 | | | 63200 | | | | 80578 |
| 56 | 3.7E+03 | 2.3E+06 | 4.0E+07 | 3.4E+03 | 2.4E+06 | | 10778 | 6272 | | | 63200 | | | | 80578 |

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | ($m^2$) | (kg) | (kg $CO_2$-eq) | ($m^2$) | (kg) | (ton) | | | | | | | | (ton) | |
| 57 | 3.7E+03 | 2.5E+06 | 4.0E+07 | 3.5E+03 | 2.5E+06 | | 8158 | 8892 | | | 63200 | | | | 80578 |
| 58 | 3.7E+03 | 2.7E+06 | 4.0E+07 | 3.6E+03 | 2.7E+06 | | 5364 | 11686 | | | 63200 | | | | 80578 |
| 59 | 3.7E+03 | 2.8E+06 | 4.0E+07 | 3.7E+03 | 2.7E+06 | | 4026 | 13023 | | | 63200 | | | | 80578 |
| 60 | 3.8E+03 | 1.7E+06 | 4.1E+07 | 3.1E+03 | 1.7E+06 | 1000 | 16050 | | | | 63200 | | | 70599 | 5253 |
| 61 | 3.8E+03 | 1.9E+06 | 4.1E+07 | 3.1E+03 | 1.9E+06 | | 1000 | 16050 | | | 63200 | | | 13473 | 62379 |
| 62 | 3.8E+03 | 2.0E+06 | 4.1E+07 | 3.1E+03 | 2.0E+06 | | 16192 | 858 | | | 63200 | | | | 80578 |
| 63 | 3.8E+03 | 2.2E+06 | 4.1E+07 | 3.2E+03 | 2.2E+06 | | 13572 | 3478 | | | 63200 | | | | 80578 |
| 64 | 3.8E+03 | 2.3E+06 | 4.0E+07 | 3.4E+03 | 2.4E+06 | | 10778 | 6272 | | | 63200 | | | | 80578 |
| 65 | 3.8E+03 | 2.5E+06 | 4.0E+07 | 3.5E+03 | 2.5E+06 | | 8158 | 8892 | | | 63200 | | | | 80578 |
| 66 | 3.8E+03 | 2.7E+06 | 4.0E+07 | 3.6E+03 | 2.7E+06 | | 5364 | 11686 | | | 63200 | | | | 80578 |
| 67 | 3.8E+03 | 2.8E+06 | 4.0E+07 | 3.7E+03 | 2.8E+06 | | 2744 | 14305 | | | 63200 | | | | 80578 |

## **Table S42.** Post-Directive scenario, SSR=50%

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | ($m^2$) | (kg) | (kg $CO_2$-eq) | ($m^2$) | (kg) | | | | (ton) | | | | | (ton) | |
| 1 | None, min(CF) | | 3.7E+07 | 4.1E+03 | 5.4E+06 | | | 42625 | | | 39500 | | | | 201444 |
| 2 | None, min(LFA) | | 4.4E+07 | 2.1E+03 | 2.1E+06 | | | | 42625 | | 39500 | | | | |
| 3 | None, min(NR-RM) | | 4.4E+07 | 2.1E+03 | 2.0E+06 | 1562 | | | 41062 | | 39500 | | | | |
| 4 | 2.3E+03 | 2.4E+06 | 4.1E+07 | 2.2E+03 | 2.4E+06 | 1562 | 41062 | | | | 39500 | | | 189603 | 4458 |
| 5 | 2.3E+03 | 2.7E+06 | 4.0E+07 | 2.2E+03 | 2.7E+06 | 1562 | 41062 | | | | 39500 | | | 44884 | 149177 |
| 6 | 2.3E+03 | 3.1E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 40107 | 2518 | | | 39500 | | | | 201444 |
| 7 | 2.3E+03 | 3.5E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 39604 | 3021 | | | 39500 | | | | 201444 |
| 8 | 2.3E+03 | 3.9E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 39604 | 3021 | | | 39500 | | | | 201444 |
| 9 | 2.3E+03 | 4.3E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 39604 | 3021 | | | 39500 | | | | 201444 |
| 10 | 2.3E+03 | 4.7E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 39604 | 3021 | | | 39500 | | | | 201444 |
| 11 | 2.3E+03 | 5.0E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 39604 | 3021 | | | 39500 | | | | 201444 |
| 12 | 2.5E+03 | 2.4E+06 | 4.1E+07 | 2.2E+03 | 2.4E+06 | 1562 | 41062 | | | | 39500 | | | 189603 | 4458 |
| 13 | 2.5E+03 | 2.7E+06 | 4.0E+07 | 2.2E+03 | 2.7E+06 | 1562 | 41062 | | | | 39500 | | | 44884 | 149177 |
| 14 | 2.5E+03 | 3.1E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 40107 | 2518 | | | 39500 | | | | 201444 |
| 15 | 2.5E+03 | 3.5E+06 | 3.9E+07 | 2.5E+03 | 3.4E+06 | | 34571 | 8054 | | | 39500 | | | | 201444 |
| 16 | 2.5E+03 | 3.9E+06 | 3.9E+07 | 2.5E+03 | 3.4E+06 | | 34571 | 8054 | | | 39500 | | | | 201444 |
| 17 | 2.5E+03 | 4.3E+06 | 3.9E+07 | 2.5E+03 | 3.4E+06 | | 34571 | 8054 | | | 39500 | | | | 201444 |
| 18 | 2.5E+03 | 4.7E+06 | 3.9E+07 | 2.5E+03 | 3.4E+06 | | 34571 | 8054 | | | 39500 | | | | 201444 |
| 19 | 2.5E+03 | 5.0E+06 | 3.9E+07 | 2.5E+03 | 3.4E+06 | | 34571 | 8054 | | | 39500 | | | | 201444 |
| 20 | 2.7E+03 | 2.4E+06 | 4.1E+07 | 2.2E+03 | 2.4E+06 | 1562 | 41062 | | | | 39500 | | | 189603 | 4458 |
| 21 | 2.7E+03 | 2.7E+06 | 4.0E+07 | 2.2E+03 | 2.7E+06 | 1562 | 41062 | | | | 39500 | | | 44884 | 149177 |
| 22 | 2.7E+03 | 3.1E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 40107 | 2518 | | | 39500 | | | | 201444 |
| 23 | 2.7E+03 | 3.5E+06 | 3.9E+07 | 2.6E+03 | 3.5E+06 | | 33470 | 9155 | | | 39500 | | | | 201444 |
| 24 | 2.7E+03 | 3.9E+06 | 3.9E+07 | 2.8E+03 | 3.7E+06 | | 29538 | 13087 | | | 39500 | | | | 201444 |
| 25 | 2.7E+03 | 4.3E+06 | 3.9E+07 | 2.8E+03 | 3.7E+06 | | 29538 | 13087 | | | 39500 | | | | 201444 |
| 26 | 2.7E+03 | 4.7E+06 | 3.9E+07 | 2.8E+03 | 3.7E+06 | | 29538 | 13087 | | | 39500 | | | | 201444 |
| 27 | 2.7E+03 | 5.0E+06 | 3.9E+07 | 2.8E+03 | 3.7E+06 | | 29538 | 13087 | | | 39500 | | | | 201444 |
| 28 | 3.0E+03 | 2.4E+06 | 4.1E+07 | 2.2E+03 | 2.4E+06 | 1562 | 41062 | | | | 39500 | | | 189603 | 4458 |
| 29 | 3.0E+03 | 2.7E+06 | 4.0E+07 | 2.2E+03 | 2.7E+06 | 1562 | 41062 | | | | 39500 | | | 44884 | 149177 |
| 30 | 3.0E+03 | 3.1E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 40107 | 2518 | | | 39500 | | | | 201444 |
| 31 | 3.0E+03 | 3.5E+06 | 3.9E+07 | 2.6E+03 | 3.5E+06 | | 33470 | 9155 | | | 39500 | | | | 201444 |
| 32 | 3.0E+03 | 3.9E+06 | 3.8E+07 | 2.9E+03 | 3.9E+06 | | 26659 | 15966 | | | 39500 | | | | 201444 |
| 33 | 3.0E+03 | 4.3E+06 | 3.8E+07 | 3.0E+03 | 4.0E+06 | | 24724 | 17901 | | | 39500 | | | | 201444 |
| 34 | 3.0E+03 | 4.7E+06 | 3.8E+07 | 3.0E+03 | 4.0E+06 | | 24724 | 17901 | | | 39500 | | | | 201444 |
| 35 | 3.0E+03 | 5.0E+06 | 3.8E+07 | 3.0E+03 | 4.0E+06 | | 24724 | 17901 | | | 39500 | | | | 201444 |
| 36 | 3.2E+03 | 2.4E+06 | 4.1E+07 | 2.2E+03 | 2.4E+06 | 1562 | 41062 | | | | 39500 | | | 189603 | 4458 |
| 37 | 3.2E+03 | 2.7E+06 | 4.0E+07 | 2.2E+03 | 2.7E+06 | 1562 | 41062 | | | | 39500 | | | 44884 | 149177 |
| 38 | 3.2E+03 | 3.1E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 40107 | 2518 | | | 39500 | | | | 201444 |
| 39 | 3.2E+03 | 3.5E+06 | 3.9E+07 | 2.6E+03 | 3.5E+06 | | 33470 | 9155 | | | 39500 | | | | 201444 |
| 40 | 3.2E+03 | 3.9E+06 | 3.8E+07 | 2.9E+03 | 3.9E+06 | | 26659 | 15966 | | | 39500 | | | | 201444 |
| 41 | 3.2E+03 | 4.3E+06 | 3.8E+07 | 3.2E+03 | 4.3E+06 | | 20023 | 22602 | | | 39500 | | | | 201444 |
| 42 | 3.2E+03 | 4.7E+06 | 3.8E+07 | 3.2E+03 | 4.3E+06 | | 19691 | 22933 | | | 39500 | | | | 201444 |
| 43 | 3.2E+03 | 5.0E+06 | 3.8E+07 | 3.2E+03 | 4.3E+06 | | 19691 | 22933 | | | 39500 | | | | 201444 |
| 44 | 3.4E+03 | 2.4E+06 | 4.1E+07 | 2.2E+03 | 2.4E+06 | 1562 | 41062 | | | | 39500 | | | 189603 | 4458 |
| 45 | 3.4E+03 | 2.7E+06 | 4.0E+07 | 2.2E+03 | 2.7E+06 | 1562 | 41062 | | | | 39500 | | | 44884 | 149177 |
| 46 | 3.4E+03 | 3.1E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 40107 | 2518 | | | 39500 | | | | 201444 |
| 47 | 3.4E+03 | 3.5E+06 | 3.9E+07 | 2.6E+03 | 3.5E+06 | | 33470 | 9155 | | | 39500 | | | | 201444 |
| 48 | 3.4E+03 | 3.9E+06 | 3.8E+07 | 2.9E+03 | 3.9E+06 | | 26659 | 15966 | | | 39500 | | | | 201444 |
| 49 | 3.4E+03 | 4.3E+06 | 3.8E+07 | 3.2E+03 | 4.3E+06 | | 20023 | 22602 | | | 39500 | | | | 201444 |
| 50 | 3.4E+03 | 4.7E+06 | 3.8E+07 | 3.4E+03 | 4.6E+06 | | 14877 | 27747 | | | 39500 | | | | 201444 |
| 51 | 3.4E+03 | 5.0E+06 | 3.8E+07 | 3.4E+03 | 4.6E+06 | | 14877 | 27747 | | | 39500 | | | | 201444 |
| 52 | 3.6E+03 | 2.4E+06 | 4.1E+07 | 2.2E+03 | 2.4E+06 | 1562 | 41062 | | | | 39500 | | | 189603 | 4458 |
| 53 | 3.6E+03 | 2.7E+06 | 4.0E+07 | 2.2E+03 | 2.7E+06 | 1562 | 41062 | | | | 39500 | | | 44884 | 149177 |
| 54 | 3.6E+03 | 3.1E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 40107 | 2518 | | | 39500 | | | | 201444 |
| 55 | 3.6E+03 | 3.5E+06 | 3.9E+07 | 2.6E+03 | 3.5E+06 | | 33470 | 9155 | | | 39500 | | | | 201444 |
| 56 | 3.6E+03 | 3.9E+06 | 3.8E+07 | 2.9E+03 | 3.9E+06 | | 26659 | 15966 | | | 39500 | | | | 201444 |

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | ($m^2$) | (kg) | (kg $CO_2$-eq) | ($m^2$) | (kg) | (ton) | | | | | | | | (ton) | |
| 57 | 3.6E+03 | 4.3E+06 | 3.8E+07 | 3.2E+03 | 4.3E+06 | | 20023 | 22602 | | | 39500 | | | | 201444 |
| 58 | 3.6E+03 | 4.7E+06 | 3.8E+07 | 3.5E+03 | 4.7E+06 | | 13386 | 29238 | | | 39500 | | | | 201444 |
| 59 | 3.6E+03 | 5.0E+06 | 3.7E+07 | 3.7E+03 | 4.9E+06 | | 9844 | 32780 | | | 39500 | | | | 201444 |
| 60 | 3.9E+03 | 2.4E+06 | 4.1E+07 | 2.2E+03 | 2.4E+06 | 1562 | 41062 | | | | 39500 | | | 189603 | 4458 |
| 61 | 3.9E+03 | 2.7E+06 | 4.0E+07 | 2.2E+03 | 2.7E+06 | | 1562 | 41062 | | | 39500 | | | 44884 | 149177 |
| 62 | 3.9E+03 | 3.1E+06 | 3.9E+07 | 2.3E+03 | 3.1E+06 | | 40107 | 2518 | | | 39500 | | | | 201444 |
| 63 | 3.9E+03 | 3.5E+06 | 3.9E+07 | 2.6E+03 | 3.5E+06 | | 33470 | 9155 | | | 39500 | | | | 201444 |
| 64 | 3.9E+03 | 3.9E+06 | 3.8E+07 | 2.9E+03 | 3.9E+06 | | 26659 | 15966 | | | 39500 | | | | 201444 |
| 65 | 3.9E+03 | 4.3E+06 | 3.8E+07 | 3.2E+03 | 4.3E+06 | | 20023 | 22602 | | | 39500 | | | | 201444 |
| 66 | 3.9E+03 | 4.7E+06 | 3.8E+07 | 3.5E+03 | 4.7E+06 | | 13386 | 29238 | | | 39500 | | | | 201444 |
| 67 | 3.9E+03 | 5.0E+06 | 3.7E+07 | 3.8E+03 | 5.0E+06 | | 6750 | 35875 | | | 39500 | | | | 201444 |

## **Table S43.** Post-Directive scenario, SSR=80%

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | ($m^2$) | (kg) | (kg $CO_2$-eq) | ($m^2$) | (kg) | (ton) | | | | | | | | (ton) | |
| 1 | None, min(CF) | | 3.4E+07 | 4.3E+03 | 7.9E+06 | | | 68200 | | | 15800 | | | | 322311 |
| 2 | None, min(LFA) | | 4.6E+07 | 1.1E+03 | 2.5E+06 | | | | 68200 | | 15800 | | | | |
| 3 | None, min(NR-RM) | | 4.6E+07 | 1.8E+03 | 1.1E+06 | 26200 | | | 42000 | | 15800 | | | | |
| 4 | 1.5E+03 | 1.8E+06 | 4.5E+07 | 1.5E+03 | 1.8E+06 | 13832 | 9007 | | 45360 | | 15800 | | | 42569 | |
| 5 | 1.5E+03 | 2.6E+06 | 4.0E+07 | 1.5E+03 | 2.6E+06 | 9993 | 58206 | | | | 15800 | | | 234705 | 40378 |
| 6 | 1.5E+03 | 3.3E+06 | 3.9E+07 | 1.4E+03 | 3.3E+06 | 8222 | 59977 | | | | 15800 | | | | 283453 |
| 7 | 1.5E+03 | 4.1E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 65768 | 2432 | | | 15800 | | | | 322311 |
| 8 | 1.5E+03 | 4.9E+06 | 3.8E+07 | 1.5E+03 | 4.3E+06 | | 63146 | 5054 | | | 15800 | | | | 322311 |
| 9 | 1.5E+03 | 5.6E+06 | 3.8E+07 | 1.5E+03 | 4.3E+06 | | 63146 | 5054 | | | 15800 | | | | 322311 |
| 10 | 1.5E+03 | 6.4E+06 | 3.8E+07 | 1.5E+03 | 4.3E+06 | | 63146 | 5054 | | | 15800 | | | | 322311 |
| 11 | 1.5E+03 | 7.1E+06 | 3.8E+07 | 1.5E+03 | 4.3E+06 | | 63146 | 5054 | | | 15800 | | | | 322311 |
| 12 | 1.8E+03 | 1.8E+06 | 4.1E+07 | 1.8E+03 | 1.8E+06 | 25571 | 42629 | | | | 15800 | | | 76248 | 125214 |
| 13 | 1.8E+03 | 2.6E+06 | 4.0E+07 | 1.6E+03 | 2.6E+06 | 18156 | 50043 | | | | 15800 | | | | 236505 |
| 14 | 1.8E+03 | 3.3E+06 | 3.9E+07 | 1.4E+03 | 3.3E+06 | 8222 | 59977 | | | | 15800 | | | | 283453 |
| 15 | 1.8E+03 | 4.1E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 65768 | 2432 | | | 15800 | | | | 322311 |
| 16 | 1.8E+03 | 4.9E+06 | 3.7E+07 | 1.8E+03 | 4.7E+06 | | 55269 | 12931 | | | 15800 | | | | 322311 |
| 17 | 1.8E+03 | 5.6E+06 | 3.7E+07 | 1.8E+03 | 4.7E+06 | | 55269 | 12931 | | | 15800 | | | | 322311 |
| 18 | 1.8E+03 | 6.4E+06 | 3.7E+07 | 1.8E+03 | 4.7E+06 | | 55269 | 12931 | | | 15800 | | | | 322311 |
| 19 | 1.8E+03 | 7.1E+06 | 3.7E+07 | 1.8E+03 | 4.7E+06 | | 55269 | 12931 | | | 15800 | | | | 322311 |
| 20 | 2.2E+03 | 1.8E+06 | 4.1E+07 | 1.8E+03 | 1.8E+06 | 26200 | 42000 | | | | 15800 | | | 58169 | 140322 |
| 21 | 2.2E+03 | 2.6E+06 | 4.0E+07 | 1.6E+03 | 2.6E+06 | 18156 | 50043 | | | | 15800 | | | | 236505 |
| 22 | 2.2E+03 | 3.3E+06 | 3.9E+07 | 1.4E+03 | 3.3E+06 | | 8222 | 59977 | | | 15800 | | | | 283453 |
| 23 | 2.2E+03 | 4.1E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 65768 | 2432 | | | 15800 | | | | 322311 |
| 24 | 2.2E+03 | 4.9E+06 | 3.7E+07 | 1.9E+03 | 4.9E+06 | | 52669 | 15530 | | | 15800 | | | | 322311 |
| 25 | 2.2E+03 | 5.6E+06 | 3.7E+07 | 2.2E+03 | 5.2E+06 | | 47391 | 20808 | | | 15800 | | | | 322311 |
| 26 | 2.2E+03 | 6.4E+06 | 3.7E+07 | 2.2E+03 | 5.2E+06 | | 47391 | 20808 | | | 15800 | | | | 322311 |
| 27 | 2.2E+03 | 7.1E+06 | 3.7E+07 | 2.2E+03 | 5.2E+06 | | 47391 | 20808 | | | 15800 | | | | 322311 |
| 28 | 2.5E+03 | 1.8E+06 | 4.1E+07 | 1.8E+03 | 1.8E+06 | 26200 | 42000 | | | | 15800 | | | 58169 | 140322 |
| 29 | 2.5E+03 | 2.6E+06 | 4.0E+07 | 1.6E+03 | 2.6E+06 | 18156 | 50043 | | | | 15800 | | | | 236505 |
| 30 | 2.5E+03 | 3.3E+06 | 3.9E+07 | 1.4E+03 | 3.3E+06 | 8222 | 59977 | | | | 15800 | | | | 283453 |
| 31 | 2.5E+03 | 4.1E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 65768 | 2432 | | | 15800 | | | | 322311 |
| 32 | 2.5E+03 | 4.9E+06 | 3.7E+07 | 1.9E+03 | 4.9E+06 | | 52669 | 15530 | | | 15800 | | | | 322311 |
| 33 | 2.5E+03 | 5.6E+06 | 3.6E+07 | 2.5E+03 | 5.6E+06 | | 39514 | 28686 | | | 15800 | | | | 322311 |
| 34 | 2.5E+03 | 6.4E+06 | 3.6E+07 | 2.5E+03 | 5.6E+06 | | 39514 | 28686 | | | 15800 | | | | 322311 |
| 35 | 2.5E+03 | 7.1E+06 | 3.6E+07 | 2.5E+03 | 5.6E+06 | | 39514 | 28686 | | | 15800 | | | | 322311 |
| 36 | 2.9E+03 | 1.8E+06 | 4.1E+07 | 1.8E+03 | 1.8E+06 | 26200 | 42000 | | | | 15800 | | | 58169 | 140322 |
| 37 | 2.9E+03 | 2.6E+06 | 4.0E+07 | 1.6E+03 | 2.6E+06 | 18156 | 50043 | | | | 15800 | | | | 236505 |
| 38 | 2.9E+03 | 3.3E+06 | 3.9E+07 | 1.4E+03 | 3.3E+06 | 8222 | 59977 | | | | 15800 | | | | 283453 |
| 39 | 2.9E+03 | 4.1E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 65768 | 2432 | | | 15800 | | | | 322311 |
| 40 | 2.9E+03 | 4.9E+06 | 3.7E+07 | 1.9E+03 | 4.9E+06 | | 52669 | 15530 | | | 15800 | | | | 322311 |
| 41 | 2.9E+03 | 5.6E+06 | 3.6E+07 | 2.5E+03 | 5.6E+06 | | 39571 | 28628 | | | 15800 | | | | 322311 |
| 42 | 2.9E+03 | 6.4E+06 | 3.6E+07 | 2.9E+03 | 6.1E+06 | | 31636 | 36563 | | | 15800 | | | | 322311 |
| 43 | 2.9E+03 | 7.1E+06 | 3.6E+07 | 2.9E+03 | 6.1E+06 | | 31636 | 36563 | | | 15800 | | | | 322311 |
| 44 | 3.3E+03 | 1.8E+06 | 4.1E+07 | 1.8E+03 | 1.8E+06 | 26200 | 42000 | | | | 15800 | | | 58169 | 140322 |
| 45 | 3.3E+03 | 2.6E+06 | 4.0E+07 | 1.6E+03 | 2.6E+06 | 18156 | 50043 | | | | 15800 | | | | 236505 |
| 46 | 3.3E+03 | 3.3E+06 | 3.9E+07 | 1.4E+03 | 3.3E+06 | 8222 | 59977 | | | | 15800 | | | | 283453 |
| 47 | 3.3E+03 | 4.1E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 65768 | 2432 | | | 15800 | | | | 322311 |
| 48 | 3.3E+03 | 4.9E+06 | 3.7E+07 | 1.9E+03 | 4.9E+06 | | 52669 | 15530 | | | 15800 | | | | 322311 |
| 49 | 3.3E+03 | 5.6E+06 | 3.6E+07 | 2.5E+03 | 5.6E+06 | | 39571 | 28628 | | | 15800 | | | | 322311 |
| 50 | 3.3E+03 | 6.4E+06 | 3.6E+07 | 3.1E+03 | 6.4E+06 | | 26299 | 41901 | | | 15800 | | | | 322311 |
| 51 | 3.3E+03 | 7.1E+06 | 3.5E+07 | 3.3E+03 | 6.5E+06 | | 23759 | 44441 | | | 15800 | | | | 322311 |
| 52 | 3.6E+03 | 1.8E+06 | 4.1E+07 | 1.8E+03 | 1.8E+06 | 26200 | 42000 | | | | 15800 | | | 58169 | 140322 |
| 53 | 3.6E+03 | 2.6E+06 | 4.0E+07 | 1.6E+03 | 2.6E+06 | 18156 | 50043 | | | | 15800 | | | | 236505 |
| 54 | 3.6E+03 | 3.3E+06 | 3.9E+07 | 1.4E+03 | 3.3E+06 | 8222 | 59977 | | | | 15800 | | | | 283453 |
| 55 | 3.6E+03 | 4.1E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | | 65768 | 2432 | | | 15800 | | | | 322311 |
| 56 | 3.6E+03 | 4.9E+06 | 3.7E+07 | 1.9E+03 | 4.9E+06 | | 52669 | 15530 | | | 15800 | | | | 322311 |

| | RESTRICTIONS | | OPTIMIZED VALUES | | | OW | | | | | | | | LIQ. DIGEST. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LFA | NR-RM | CF | LFA | NR-RM | Iss | AD+Iss | AD+Lss | W+Iss | T+Iss | Imix | W+Imix | T+Imix | WW | ASA |
| | ($m^2$) | (kg) | (kg $CO_2$-eq) | ($m^2$) | (kg) | (ton) | | | | | | | | (ton) | |
| 57 | 3.6E+03 | 5.6E+06 | 3.6E+07 | 2.5E+03 | 5.6E+06 | | 39571 | 28628 | | | 15800 | | | | 322311 |
| 58 | 3.6E+03 | 6.4E+06 | 3.6E+07 | 3.1E+03 | 6.4E+06 | | 26299 | 41901 | | | 15800 | | | | 322311 |
| 59 | 3.6E+03 | 7.1E+06 | 3.5E+07 | 3.6E+03 | 7.0E+06 | | 15881 | 52318 | | | 15800 | | | | 322311 |
| 60 | 4.0E+03 | 1.8E+06 | 4.1E+07 | 1.8E+03 | 1.8E+06 | 26200 | 42000 | | | | 15800 | | | 58169 | 140322 |
| 61 | 4.0E+03 | 2.6E+06 | 4.0E+07 | 1.6E+03 | 2.6E+06 | 18156 | 50043 | | | | 15800 | | | | 236505 |
| 62 | 4.0E+03 | 3.3E+06 | 3.9E+07 | 1.4E+03 | 3.3E+06 | 8222 | 59977 | | | | 15800 | | | | 283453 |
| 63 | 4.0E+03 | 4.1E+06 | 3.8E+07 | 1.3E+03 | 4.1E+06 | 65768 | 2432 | | | | 15800 | | | | 322311 |
| 64 | 4.0E+03 | 4.9E+06 | 3.7E+07 | 1.9E+03 | 4.9E+06 | 52669 | 15530 | | | | 15800 | | | | 322311 |
| 65 | 4.0E+03 | 5.6E+06 | 3.6E+07 | 2.5E+03 | 5.6E+06 | | 39571 | 28628 | | | 15800 | | | | 322311 |
| 66 | 4.0E+03 | 6.4E+06 | 3.6E+07 | 3.1E+03 | 6.4E+06 | | 26299 | 41901 | | | 15800 | | | | 322311 |
| 67 | 4.0E+03 | 7.1E+06 | 3.5E+07 | 3.7E+03 | 7.1E+06 | | 13200 | 54999 | | | 15800 | | | | 322311 |

**NOMENCLATURE**

| | |
|---|---|
| AD | Anaerobic digestion |
| BioC | Biogenic C |
| $BioC_{AD}$ | Anaerobically degradable biogenic carbon |
| $BioC_{ADi}0$ | Initial amount of anaerobically degradable biogenic carbon in fraction *i* of waste |
| BS | Bio-stabilized material |
| C | Carbon |
| CF | Carbon footprint |
| Comp | Compost |
| Fert | Fertilizers |
| FossilC | Fossil C |
| LCA | Life Cycle Assessment |
| LCI | Life cycle inventory |
| LFA | Landfill area |
| mix-OW | OW recovered from the mixed waste stream after the trommel separation |
| N | Nitrogen |
| NR-RM | Non-renewable raw materials |
| OW | Organic waste |
| P | Phosphorus |
| SD | Solid digestate |
| SS-OW | Source-separated organic waste |
| SSR | Source separation rate |
| T | Tunnel composting |
| TS | Total Solids |
| TWW | Total Wet Weight |
| VS | Volatile solids |
| W | Windrows composting |

**Unit processes**

| | |
|---|---|
| ADss | Anaerobic digestion (SS-OW) |
| AD+Iss | Anaerobic digestion + Incineration of rejects (SS-OW) |
| AD+Lss | Anaerobic digestion + Landfill of rejects (SS-OW) |
| ASA | Ammonia stripping and absorption |
| Imix | Incineration (mix-OW) |
| Iss | Incineration (SS-OW) |
| Lmix | Landfill (mix-OW) |
| Lss | Landfill (SS-OW) |
| SP | Struvite precipitation |
| Tmix | Tunnel composting (mix-OW) |
| Tss | Tunnel composting (SS-OW) |
| T+Imix | Tunnel composting + Incineration of rejects (mix-OW) |
| T+Iss | Tunnel composting + Incineration of rejects (SS-OW) |
| Wmix | Windrows composting (mix-OW) |
| Wss | Windrows composting (SS-OW) |
| W+Imix | Windrows composting + Incineration of rejects (mix-OW) |
| W+Iss | Windrows composting + Incineration of rejects (SS-OW) |
| WW | Wastewater treatment |

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