# Supporting Information

## Part A: Modelling assumptions and data source

**Table A1**. Social-demographic model input data and assumptions

|  |  |
| --- | --- |
| **Base year of modelling** | 2016 |
| **End year of modelling** | 2036 |
| **Interval** | 5 years |
| **Population disaggregation** | Sex, Age, Employment status, Income status |
| **Annual population growth rate** | Same level as 2016 |

**Table A2**. Agent-based model input data and assumptions\*

|  |  |
| --- | --- |
| **Demand baseline** | 2016 data |
| **Demand growth rate** | Based on population growth |
| **Real-time simulation interval** | 5 min |

\*Central Coast is included in the model with the assumption that water and wastewater demand per capita are same as Hunter Region due to lack of detailed data

**Table A3**. Resource Technology Network input data and assumptions\*

|  |  |
| --- | --- |
| **Water leakage** | 10% |
| **Electricity transmission loss** | 4% |
| **Gas transmission loss** | 1% |
| **Waste transportation loss** | 0% |
| **Upper bound on water flow** | ~ 1800 m3/h |
| **Upper bound on energy transport** | ~ 2140 MW |
| **Optimization Weightage** | CAPEX: OPEX: GHG = $1: $15: 0.5kg |
| **Demand to be satisfied** | Water (residential and industrial), electricity, natural gas |
| **Waste to be treated** | Biosolid, municipal solid waste, agricultural and other organic waste |
| **Importable resource** | Raw water, electricity, gas, labour hours |
| **Resources can be removed from the system** | Liquid effluent, biosolid, municipal solid waste, agricultural and other organic waste |
| **Optimization tolerant**  | 0.001 |

\*Central Coast is assumed to be only externally connected to Lake Macquarie.

The model currently does not consider any additional land-use constraints, for example related to built-up areas and protected land. Further refined studies are necessary to explore such possibilities in more detail.

**Table A4.** List of data sources used in the modelling

|  |  |
| --- | --- |
| **Data type** | **Data source** |
| **Sociodemographic data per region** | Australian Bureau for Statistics [1] |
| **Water supply and demand** | Hunter Water water consumption data [2] |
| **Recycle water supply** | Hunter Water effluent reuse data  |
| **Wastewater generation and treatment** | Hunter Water forward capital program data |
| **Biosolids data** | GHD’s biosolid guideline update impacts on HWC WWTWs [3] |
| **Electricity supply and demand** | Ausgrid [4] |
| **Gas supply and demand** | Jemena [5] |
| **Municipal solid waste generation** | WARR Survey from Hunter Water |
| **Agricultural waste generation** | MRA’s report [6] |
| **Other organic waste data** | MRA’s report [6] |
| **Waste technology data** | Hunter Water-planning technical advice, Jain et al. [7], Lofrano & Giusy [8] and Sun et al. [9] |
| **Water and wastewater technology data** | Hunter Water data [10, 11] |
| **Electricity generation technology data** | Australian Energy Market Operator [12] |
| **Existing water / wastewater network** | Hunter Water network figure [13] |
| **Existing electricity network** | Australian Energy Market Operator [12] |
| **Central Coast data** | Central Coast Council website [14] |

The agricultural and other organic waste data in the study area is from MRA’s report to Hunter Water. The report identifies a total of 3.3 million tpa of organic feedstock in Lower Hunter and Central Coast. It is understood that the spatial distribution and amounts of accessible organic waste is unclear at this time. However, since the model investigates the development of Hunter region until 2036, all feedstocks are assumed to be accessible and their spatial distribution is assumed to follow the sociodemographic growth trends in different regions.

## Part B: Modelling basis of water and wastewater technologies

**Table B1**. Detailed modelling basis of water and wastewater technologies [15]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment technology** | **Referenced capacity****(m3 per year)** | **Life span (year)** | **Referenced capital investment (AUD)** | **Capital cost function exponent** | **O&M costs (% of capital costs)** | **GHG emissions (kg per m3)** |  |
|
| **source water treatment plant** | 8212500 | 20 | 67796921 | 0.70 | 3.6 | 0.017 |  |
| **wastewater treatment plant with recycle water** | 3000000 | 20 | 162478334 | 0.74 | 4.0 | 0.05 |  |
| **wastewater treatment plant** | 3000000 | 20 | 50226372 | 0.74 | 4.0 | 0.04 |  |
| **NEWater** | 3042000 | 20 | 156128000 | 0.75 | 4.5 | 0.54 |  |
| **waste stabilisation pond** | 1374225 | 20 | 14145810 | 0.64 | 3.5 | 0.38 |  |
| **aerated lagoon** | 4288750 | 20 | 768544 | 0.64 | 3.5 | 1.01 |  |
| **decentralized activated sludge system** | 239062 | 20 | 1516850 | 0.64 | 3.5 | 0 |  |
| **faecal sludge polymer separation drying plant** | 153000 | 20 | 4816845 | 0.64 | 3.5 | 0 |  |
| **Desalination** | 10950000 | 20 | 130000000 | 0.72 | 4.5 | 1.78 |  |

**Table B2**. Resource mass and energy balance of water and wastewater technologies

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Technology/ Resources** | **Raw source water (m3)** | **Electricity (MJ)** | **Labour hours (hrs)** | **Potable water (m3)** | **Influent waste-water (m3)** | **Non-drinking potable water (m3)** | **Liquid effluent (m3)** |
| **source water treatment plant** | -1 | -0.75 | -0.002 | 0.573 | 0 | 0.427 | 0 |
| **wastewater treatment plant with recycle water** | 0 | -2.57 | -0.02 | 0 | -1 | 0.1 | 0.9 |
| **wastewater treatment plant** | 0 | -1.07 | -0.02 | 0 | -1 | 0 | 1 |
| **NEWater** | 0.8 | -15 | -0.02 | 0 | 0 | 0.2 | -1 |
| **waste stabilisation pond** | 0 | -0.05 | -0.0025 | 0 | -1 | 0 | 1 |
| **aerated lagoon** | 0 | -5.99 | -0.0063 | 0 | -1 | 0 | 1 |
| **decentralized activated sludge system** | 0 | -0.36 | -0.004 | 0 | -1 | 0 | 1 |
| **faecal sludge polymer separation drying plant** | 0 | -1 | -0.2 | 0 | -1 | 0 | 0.86 |
| **Desalination** | -1 | -28.5 | -0.001 | 0.41 | 0 | 0 | 0 |

## Part C: Modelling basis of energy technologies

**Table C1**. Detailed modelling basis of energy technologies [16]

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment technology** | **Referenced capacity****(MW)** | **Life span (year)** | **Referenced capital investment (AUD)** | **Capital cost function exponent** | **O&M costs (% of capital costs)** | **GHG emissions (kg per MJ)** |
|
| **Solar P-si-ground** | 5 | 20 | 21372000 | 0.61 | 4.4 | 0.0337 |
| **Solar thermal trough** | 12.5 | 20 | 172590000 | 0.61 | 3.7 | 0.0273 |
| **Hydro small** | 0.5 | 20 | 7270000 | 0.73 | 3.6 | 0.00657 |
| **Coal IGCC** | 80 | 20 | 1935206000 | 0.74 | 4.4 | 1.648 |
| **Gas CCGT** | 62.5 | 20 | 339154000 | 0.79 | 3.8 | 0.612 |
| **Nuclear SPWR** | 75 | 20 | 1268837000 | 0.72 | 4.2 | 0.0256 |
| **Wind onshore** | 0.75 | 20 | 5792000 | 0.65 | 3.7 | 0.0097 |
| **Hydro large** | 295 | 20 | 3107713000 | 0.69 | 4.0 | 0.00676 |
| **Biofuel** | 9.5 | 20 | 310840000 | 0.60 | 3.9 | 0.0105 |
| **Wind offshore** | 0.9 | 20 | 18413000 | 0.73 | 4.0 | 0.00297 |
| **Coal IGCC-CCS** | 125 | 20 | 3299500000 | 0.80 | 4.0 | 0.33 |
| **Gas CCGT-CCS** | 62.5 | 20 | 523750000 | 0.69 | 4.5 | 0.122 |

**Table C2**. Resource mass and energy balance of energy technologies

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Technology/ Resources** | **Raw source water (m3)** | **Electricity (MJ)** | **Labour (hours)** | **Influent waste-****water (m3)** | **Liquid effluent (m3)** | **Biosolid/ organics (kg)** | **Agro-****waste (kg)** |
| **Solar P-si-ground** | -0.00010515 | 1 | -0.0230 | 0 | 0 | 0 | 0 |
| **Solar thermal trough** | -0.0003575 | 1 | -0.0164 | 0 | 0 | 0 | 0 |
| **Hydro small** | 0 | 1 | -0.0068 | 0 | 0 | 0 | 0 |
| **Coal IGCC** | -0.0004332 | 1 | -0.0320 | 0 | 0 | 0 | 0 |
| **Gas CCGT** | -0.000268133 | 1 | -0.0300 | 0 | 0 | 0 | 0 |
| **Nuclear SPWR** | -0.001215537 | 1 | -0.0210 | 0 | 0 | 0 | 0 |
| **Wind onshore** | -2.83906E-05 | 1 | -0.0026 | 0 | 0 | 0 | 0 |
| **Hydro large** | 0 | 1 | -0.0280 | 0 | 0 | 0 | 0 |
| **Biofuel** | -0.000433219 | 1 | -0.0257 | 0 | 0 | 0 | 0 |
| **Wind offshore** | -0.00002839 | 1 | -0.0078 | 0 | 0 | 0 | 0 |
| **Coal IGCC-CCS** | -0.0006971 | 1 | -0.0263 | 0 | 0 | 0 | 0 |
| **Gas CCGT-CCS** | -0.000541524 | 1 | -0.0262 | 0 | 0 | 0 | 0 |

## Part D: Modelling basis of WtE technologies

**Table D1**. Detailed modelling basis of waste treatment technologies [7-9]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment technology** | **Referenced capacity****(per year)** | **Life span (year)** | **Referenced capital investment (AUD)** | **Capital cost function exponent** | **O&M costs (% of capital costs)** | **GHG emissions (per unit capacity)** |  |
|
| **Large AD**  | 3,430 dry ton biosolid | 20 | 47,000,000 | 0.85 | 4.7 |  0.545 |  |
| 365,000 m3 WW | 20 | 706,000 | 0.85 | 4.0 | 0.0063 |  |
| 100,000 ton MSW + 15,000,000 m3 WW | 20 | 18,500,000 | 0.85 | 4.0 | 0.0112 |  |
| 100,000 ton MSW | 20 | 174,000,000 | 0.85 | 4.5 | 0.846 |  |
| 100,000 ton agro-waste /other organic wastes | 20 | 128,013,000 | 0.85 | 4.5 | 0.12 |  |
| **Decentralised AD**  | 10,000 dry ton biosolid | 15 | 3,000,000 | 0.85 | 4.5 | 0.741 |  |
| 10,000 dry ton MSW | 15 | 3,000,000 | 0.85 | 4.5 | 0.741 |  |
| 10,000 ton agro-waste/other organic wastes | 15 | 2,500,000 | 0.85 | 4.5 | 0.040 |  |
| **Fluid-bed Gasification** | 10,000 dry ton biosolid or wastes | 25 | 106,400,000 | 0.68 | 4.0 | 0.841 |  |
| **Plasma Gasification** | 10,000 dry ton biosolid or wastes | 25 | 105,300,000 | 0.67 | 4.0 | 0.824 |  |
| **Pyrolysis** | 36,000 dry ton biosolid or wastes | 25 | 15,157,000 | 0.80 | 3.2 | 0.794 |  |
| **Incineration** | 216,000 dry ton biosolid or wastes | 25 | 81,469,000 | 0.85 | 3.0 | 0.877 |  |
| **Syngas Upgrade** | 500,000 GJ | 15 | 7,480,000 | 0.82 | 3.0 | 0.120 |  |
| **Biogas Upgrade** | 50,000 GJ | 15 | 1,300,000 | 0.82 | 3.0 | 0.140 |  |

\*AD: anaerobic digestion. WW: wastewater. MSW: municipal solid waste. agro-waste: agricultural waste. AD with THP: anaerobic digestion with thermal hydrolysis process.
Note that AD with THP data are taken from the draft of Hunter Water-Planning Technical Advice and other technologies data are based on literature.

As part of the FEW2 nexus, allocation of WtE technologies also incurs the consumption or demand of other resources. A well-defined material and energy balance matrix are used as the basis of RTN optimization. *Table C2* shows the connections between WtE technologies and various resources. A negative sign indicates input of corresponding resources and positive sign indicates output. Related resources can be imported/exported, or they can be supplied/consumed by the existing technologies that are set up in business as usual scenario.

**Table D2**. Resource mass and energy balance of WtE technologies

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Technology/ Resources** | **Raw source water (m3)** | **Energy (MJ)** | **Labour (hours)** | **Influent waste-****water (m3)** | **Liquid effluent (m3)** | **Biosolid/ organics (kg)** | **Agro-****waste (kg)** |
| **large AD co** | 0 | 32.4 | -0.0233 | -1 | 0.98 | -6.259 | 0 |
| **large AD WW** | 0 | 28.7 | -0.0160 | -1 | 0.98 | 0 | 0 |
| **large AD** | 0 | 4.46 | -0.0059 | 0 | 0 | -1 | 0 |
| **large AD agro** | 0 | 1.02 | -0.0011 | 0 | 0 | 0 | -1 |
| **farm AD** | 0 | 4.86 | -0.0089 | 0 | 0 | -1 | 0 |
| **farm AD agro** | 0 | 1.11 | -0.0012 | 0 | 0 | 0 | -1 |
| **incinerator** | 0 | 0.994 | -0.0024 | 0 | 0 | -1 | 0 |
| **pyrolysis** | -0.0816 | 1.6 | -0.0073 | 0 | 0 | -1 | 0 |
| **plasma** | -0.06 | 2.36 | -0.0284 | 0 | 0 | -1 | 0 |
| **fluid-bed** | -0.06 | 2.34 | -0.0067 | 0 | 0 | -1 | 0 |
| **plasma agro** | -0.06 | 0.983 | -0.0067 | 0 | 0 | -1 | 0 |
| **fluid-bed agro** | -0.06 | 0.983 | -0.0067 | 0 | 0 | -1 | 0 |

As mentioned above, the transformation from biogas/syngas to electricity incurs certain energy losses. Specifically, electrical conversion efficiency in AD is 20.35% with 15.7% and 8.1% of the generated electrical power consumed in the large-scale and farm-scale operation respectively in this model. Similarly, gasification technologies has a conversion efficiency of 18.8% from syngas to electricity. The energy loss of gas transmission is at 1% - 2%, which is lower compared to electricity transport (5% - 8%) [17, 18]. The model fully comprehends this difference and accounts it in RTN optimization, using system-wide performance indicators.

Biosolids, municipal solid wastes, agricultural wastes and other organic wastes can be transported in the model. No waste loss is assumed for transportation. The additional price incurred is set as regular truck price (9.08 cents per km per tonne) based on distances between regions as well as the mass of transported waste [19, 20]. The distance used is estimated by the map distance between the centres of two regions.

The input waste streams are assumed to leave the system through recycle/recovery and landfill at different prices. The biosolids disposal cost via land application program is included in the system based on cost data provided by Hunter Water. Other than biosolids, MSW has a landfill levy of $78.20 per tonne in 2016 [21].

For other organic feedstocks including agricultural waste that are identified in MRA’s reports [6], it is understood that depending on specific feedstock types, various treatment facilities are currently available to accept organic wastes with certain gate fee, which is unclear at this time point. In that case, post-consumer waste is assumed to be landfilled according to MRA [6]. Other organic wastes are assumed to be recovered with certain gate fees charged by waste processors. The assumptions for gate fees of various feedstocks is listed in below table.

**Table D3**. Feedstock gate fee or landfill price (AUD) [22]

|  |  |
| --- | --- |
| **MSW - Landfill** | $78.20 |
| **Forestry** | $78.20 |
| **Commercial and Industrial**  | $135.70 |
| **Post-consumer food waste** | $78.20 |
| **Manure** | $25 |
| **Other organic wastes** | $10 |

Both landfill levy fee and gate fee are modelled as competitors of WtE facilities. Potential avoided landfill costs and gate fees to processors by our WtE facilities will be calculated.

Key policy factors such as carbon credit price and feed-in tariff (FIT) could drive the optimization towards certain directions, which will be discussed in the next scenario. In this scenario, natural gas and electricity price is set at average market value ($0.19 per litre for gas and $0.16 per kWh for electricity). Carbon credit price and FIT are both set at zero in this scenario.

## Part E: Modelling basis of Existing Facilities in BAU scenario

**Table E1**. Existing facilities modelled in business as usual scenario.

|  |  |  |
| --- | --- | --- |
| Grahamstown\_wtp | Boulder\_Bay\_wwtw | Shortland\_wwtw |
| Dungog\_wtp | Clarence\_Town\_wwtw | Toronto\_wwtw |
| Lemon\_Tree\_Passage\_wtp | Edgeworth\_wwtw | Karuah\_wwtw |
| Anna\_Bay\_wtp | Morpeth\_wwtw | Kearsley\_wwtw |
| Nelson\_Bay\_wtp | Paxton\_wwtw | Tanilba\_Bay\_wwtw |
| Gresford\_Water\_wtp | Dora\_Creek\_wwtw | Bayswater\_power\_station |
| Branxton\_wwtw | Dungog\_wwtw | Eraring\_power\_station |
| Burwood\_Beach\_wwtw | Farley\_wwtw | Liddell\_power\_Station |
| Cessnock\_wwtw | Kurri\_Kurri\_wwtw | Vales\_Point\_B power station |
| Belmont\_wwtw | Raymond\_Terrace\_wwtw |  |

\*wtp stands for water treatment plant. wwtw stands for wastewater treatment work.

Existing facilities in the same region are then combined as shown in Table E2.

**Table E2**. Detailed modelling basis of existing technologies [2, 10-12]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment technology** | **Capacity****(m3 per year) or (MW)** | **Life span (year)** | **Capital investment (AUD)** | **Capital cost function exponent** | **O&M costs (% of capital costs)** | **GHG emissions (kg per m3) or (kg per MJ)** |  |
|
| **Port Stephens wtp** | 52195000 | 20 | - | - | 4.0 | 0.017 |  |
| **Dungog all wtp** | 16535000 | 20 | - | - | 4.0 | 0.017 |  |
| **Lake Macquarie wwtp** | 10488000 | 20 | - | - | 4.0 | 0.04 |  |
| **Newcastle wwtp** | 10529000 | 20 | - | - | 4.0 | 0.04 |  |
| **Port Stephens wwtp** | 3201000 | 20 | - | - | 4.0 | 0.04 |  |
| **Maitland wwtp** | 3192000 | 20 | - | - | 4.0 | 0.04 |  |
| **Cessnock wwtp** | 1690000 | 20 | - | - | 4.0 | 0.04 |  |
| **Branxton wwtp** | 234000 | 20 | - | - | 4.0 | 0.04 |  |
| **Dungog wwtp** | 136000 | 20 | - | - | 4.0 | 0.04 |  |
| **Muswell- brook ps** | 4691 | 20 | - | - | 4.0 | 1.648 |  |
| **Lake Macquarie ps** | 4200 | 20 | - | - | 4.0 | 1.648 |  |

**Table E3**. Resource mass and energy balance of existing facilities [10-12]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Technology/ Resources** | **Raw source water (m3)** | **Electricity (MJ)** | **Labour hours (hrs)** | **Potable water (m3)** | **Influent waste-water****(m3)** | **Non-drinking potable water (m3)** | **Liquid effluent****(m3)** |
| **Port Stephens wtp** | -1 | 0 | -0.002 | 0.573 | 0 | 0.427 | 0 |
| **Dungog all wtp** | -1 | 0 | -0.002 | 0.573 | 0 | 0.427 | 0 |
| **Lake Macquarie wwtp** | 0 | 0 | -0.02 | 0 | -1 | 0.0608 | 0.939 |
| **Newcastle wwtp** | 0 | 0 | -0.02 | 0 | -1 | 0.0967 | 0.903 |
| **Port Stephens wwtp** | 0 | 0 | -0.02 | 0 | -1 | 0.0307 | 0.969 |
| **Maitland wwtp** | 0 | 0 | -0.02 | 0 | -1 | 0.0339 | 0.966 |
| **Cessnock wwtp** | 0 | 0 | -0.02 | 0 | -1 | 0.0849 | 0.915 |
| **Branxton wwtp** | 0 | 0 | -0.02 | 0 | -1 | 0.7676 | 0.232 |
| **Dungog wwtp** | 0 | 0 | -0.02 | 0 | -1 | 1 | 0 |
| **Muswell- brook ps** | 0 | 1 | 0 | 0 | -1 | 0 | 0 |
| **Lake Macquarie ps** | 0 | 1 | 0 | 0 | -1 | 0 | 0 |

## Part F: Model size indicators

**Table F1**. Model running time and variable counts in different scenarios

|  |  |  |  |
| --- | --- | --- | --- |
| **Scenarios** | **No. of Variables** | **No. of Constraints** | **Solving time (s)** |
| **BAU** | 17,860 | 13,340 | 10 |
| **Water** | 17,860 | 13,340 | 10 |
| **Energy** | 17,860 | 13,340 | 30 |
| **Waste-to-Energy** | 23,780 | 17,885 | 15 |
|  |  |  |  |

## Part G: Present value analysis assumptions

The present value analysis is based on following assumptions:

* Present values of cost are calculated for year 2016 to 2036, including capital costs and operating costs.
* Landfill levy and gate fee avoided, as well as the equivalent revenue of energy generated from 2016 to 2036 for savings in terms of NPV over 20 years.
* Revenue of energy generated is calculated based on the predicted price of gas or electricity at each year from 2016 to 2036.
* Discount rate of 7% per annum.
* The effect of tax and depreciation is not considered in the analysis.
* The costs for each year are based on the already installed WtE technologies in that year.
* Construction of all facilities is assumed to take one year.

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