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 m^3/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 (m^3 per year)	Life span (year)	Referenced capital investment (AUD)	Capital cost function exponent	O&M costs (% of capital costs)	GHG emissions (kg per m^3)
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 (m^3)	Electricity (MJ)	Labour hours (hrs)	Potable water (m^3)	Influent waste-water (m^3)	Non-drinking potable water (m^3)	Liquid effluent (m^3)

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 (m^3)	Electricity (MJ)	Labour (hours)	Influent waste-water (m^3)	Liquid effluent (m^3)	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 m^3 WW	20	706,000	0.85	4.0	0.0063
	100,000 ton MSW + 15,000,000 m^3 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 (m^3)**	**Energy (MJ)**	**Labour (hours)**	**Influent waste-water (m^3)**	**Liquid effluent (m^3)**	**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 (m^3 per year) or (MW)	Life span (year)	Capital investment (AUD)	Capital cost function exponent	O&M costs (% of capital costs)	GHG emissions (kg per m^3) 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 (m^3)	Electricity (MJ)	Labour hours (hrs)	Potable water (m^3)	Influent waste-water (m^3)	Non-drinking potable water (m^3)	Liquid effluent (m^3)
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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