Infrastructure Transitions Research Consortium

Working paper series

Building national infrastructure networks: Process and data assessment report

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Introduction

This document draws together work undertaken as part of Work Stream 2 of ITRC, specifically looking at the data and processing requirements to build national infrastructure networks. The purpose of the document is to give an assessment of the national infrastructure networks that need to be constructed and identifies which datasets collected within the National Infrastructure Asset Database can be used to represent different features of the different networks. Furthermore the document identifies where data is missing, whether that is missing spatial, attribute or connectivity data for each of the networks. The document then suggests a series of spatial processing steps required to be undertaken to create topologically valid representations of the national infrastructure networks, based on the data identified as being the building blocks of that particular network. The document is split into four main sections; the first section describes each of the networks that are going to be built, whilst the second section follows on from this and looks to assess what datasets within the National Infrastructure Asset Database can be used to build the networks and where data is missing. The third section introduces an interdependency matrix which details, in a qualitative manner, interdependencies that exist between components of the different networks. The third section subsequently attempts to assess how these interdependencies can be created / represented, either as a result of having explicit data defining a particular dependency / interdependency between networks, or how a particular proxy or first pass approximation can be used. Finally the fourth section introduces a series of processing steps to be performed to ensure that a topologically and spatially valid representation of each of the networks is produced.

Network descriptions

Energy

The energy networks that are to be represented and built are currently only the gas and electricity networks. These are generally considered the most heavily employed energy distribution networks that UK society relies upon. The two networks themselves are analogous to each other, in that both comprise national and regional components; the National Transmission System for gas, and the national grid for electricity, both of which are operated by National Grid and these then respectively subsequently connect to local or regional distribution systems that operate beneath these trunk systems. As a result of these similarities, each of the electricity and gas networks will be modelled in a similar way i.e. creating a separate national scale transmission network for each that will represent the larger diameter pipelines within the gas network, or the high-voltage transmission lines within the electricity network. Following this, numerous regional distribution networks will be created for both electricity and gas.

Transport

The main transport networks that are to be initially constructed are the road and national rail networks. Within the UK, these represent the most highly used [REF] transport networks, if the light rail networks such as subways and tube systems are considered separately. However the road network representation will be limited to major trunk roads, motorways, and primary roads initially; this has been decided both to reduce the number of features within the road networks to model. Finally a UK-based, domestic flight air traffic network will be built based on data obtained from the OpenFlights database (Airport, airline and routes data: OpenFlights , 2012) and the Civil Aviation Authority database (Authority, 2012).

Water / Wastewater

The water distribution network will be constructed using the reservoir, lake and river data available from the Ordnance Survey's Meridian 2 and Strategi products. Additionally a set of water pumping stations will be included, however currently there is no indication of how the water pumping stations are connected together, or to water bodies themselves.

The waste water treatment and distribution network will be constructed using the available urban waste water treatment works and discharge points from the Urban Waste Water Treatment Directive (Waterbase - UWWTD: Urban Waste Water Treatment Directive, 2011). A direct link will be created between each treatment work and each appropriate discharge point to represent the return of treated water back to the water network.

Solid Waste

The solid waste network within the UK can largely be considered to include waste processing/reprocessing, disposal and storage sites, recycling centres and landfill sites. Both commercial/industrial and residential waste is largely transported from the waste generation source site to the storage/disposal/processing site via the road network [REF]. Furthermore the disposal of domestic waste collected by local authorities or contracted waste disposal contractors, such as Veolia, is conducted using optimized routing to ensure the waste disposal operatives are utilising the shortest paths along a road network.

Network data and gap analysis

This section of the report will look to identify the various individual networks that will be constructed from and with the use of the data stored in the National Infrastructure Asset Database. The section is split in to sectors, with illustrations and definition of what data will be used to build the network. Finally each network will be assessed for missing data, whether that is attribution, spatial location or connectivity.

Energy

The following two sections will detail which datasets, available from the National Infrastructure Asset Database, will be used to build the networks to represent the gas and electricity networks. This will include, as identified within the individual network description section, building separate networks for the national transmission and regional distribution components.

Gas (National Transmission System):

The operation of the national gas transmission system is primarily conducted by the National Grid within the UK, and can be seen in Figure.1, with the actual components making up the network visible in Figure.2. Figure.2 has been created utilising the datasources identified in Table.1 within a GIS environment (Quantum GIS Wroclaw 1.7). The table illustrates that the majority of data comes directly from the National Grid.

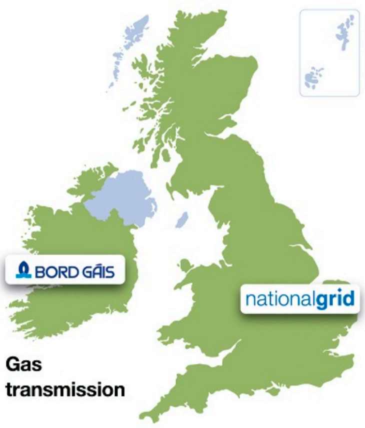


Figure 1 - National Gas Transmission System Operators, UK (Gas Transmission Map, 2011)

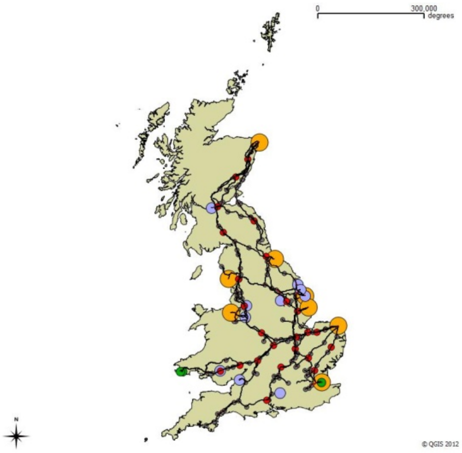


Figure 2 - National Gas Transmission System Components, UK.

NetworkName	Feature Count	Datasource	GeometryType	Nodes/Edges	Attributes Available	Issues
Gas: Transmission (conducted by National Grid)	254	National Grid: Gas Pipeline Feeder	MULTILINESTRING/LINESTRING	Edge	Pipe Name (Inspecti_1, Pipe_Name)	Not all geometry connects to associated gas compressors; connectivity data encoded within strings in inspecti_1 and pipe_name fields; No indication of capacity /pressures
	25	National Grid: Gas	MULTIPOLYGON /POLYGON	Node	Site Name (site_name),	Not all geometry connects to

		Site (compressors)			Site Type (site_type)	pipelines
	3	National Grid: LNG Operators	MULTIPOLYGON /POLYGON	Node	Name	Not all geometry connects to pipelines
	10	National Grid: Gas Storage	MULTIPOLYGON /POLYGON	Node	Name	Not all geometry connects to pipelines
	8	National Grid: Gas Terminals	MULTIPOLYGON /POLYGON	Node	Name	Not all geometry connects to pipelines
	7330	Ordnance Survey Points of Interest: Gas Features	POINT	Node	Type (name(gas compressor station, governor, holder, depot, valve, regulator, works)	Lacks connectivity data

Table 1 - Data layers stored within the National Infrastructure Asset Database, Newcastle, to be used for the generation of the national gas transmission system

Gas (Regional Distribution System(s)):

The overall governance and management of the regional gas distribution systems is split across 5 organisations within the UK, and can be seen in Figure.3.

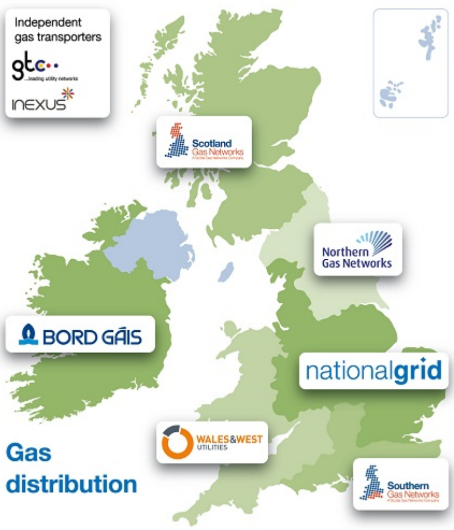


Figure 3 - Regional Gas Distribution System Operators, UK (Gas Distribution Map, 2011)

Regional Distribution Operator: Scotland Gas Networks (Scotland)

There is currently no data within the National Infrastructure Asset Database representing the network operated by Scotland Gas Networks. Scotland Gas Networks are not currently partners of the ITRC project.

Regional Distribution Operator: Northern Gas Networks (Borders and North East)

There is currently no data within the National Infrastructure Asset Database representing the network operated by Northern Gas Networks. Northern Gas Networks are not currently partners of the ITRC project.

Regional Distribution Operator: National Grid

There is no freely-accessible regional distribution data available from the National Grid regarding their regional distribution activities. However, National Grid are partners on the ITRC project.

Regional Distribution Operator: Southern Gas Networks (South East)

There is currently no data within the National Infrastructure Asset Database representing the network operated by Southern Gas Networks. Southern Gas Networks are not currently partners of the ITRC project.

Regional Distribution Operator: Wales and West Utilities (Wales and West Midlands)

There is currently no data within the National Infrastructure Asset Database representing the network operated by Wales and West Utilities. Wales and West Utilities are not currently partners of the ITRC project.

In summary, there is currently no data available to represent and therefore model the regional distribution gas systems operated by the afore-mentioned companies. This is also the case for National Grid, even though the transmission network data is freely and publicly available (National Grid Shapefiles, 2012)

Electricity (National Transmission System):

The operation of the national electricity transmission system is primarily conducted by the National Grid within the UK, but there are three other operators; Scottish and Southern Energy, SP Energy Networks, and Northern Ireland Electricity. Their areas of responsibility can be seen in Figure.4, with the actual components making up the network National Grid owned section of the network, visible in Figure.5.

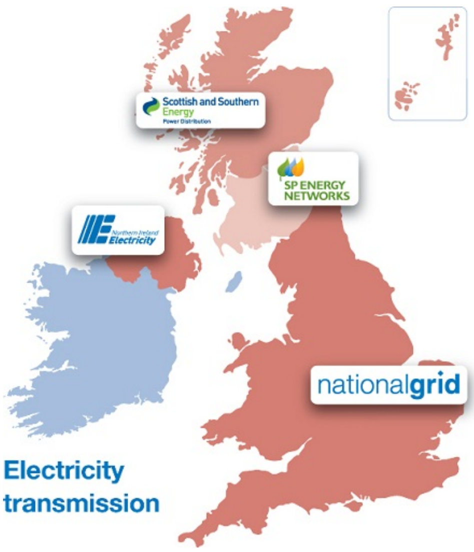


Figure 4 - National Electricity Transmission System Operators, UK (Electricity Transmission Map, 2011)

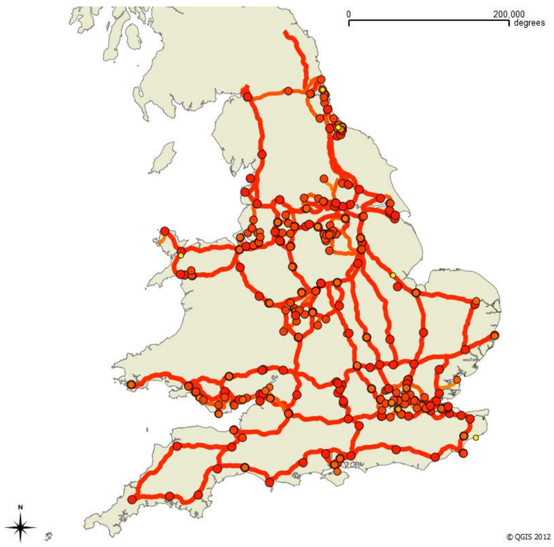


Figure 5 - National Grid owned and operated National Electricity Transmission System Components

Table.2 details the list of datasets available from the database that can be utilised to generate the national electricity transmission system, including the energy production sites that help generate the electricity.

NetworkName	Feature Count	Datasource	GeometryType	Nodes/Edges	Attributes Available	Issues
Electricity: Transmission	3094	Ordnance Survey: Energy Production Sites	POINT	Node	Name (name - filters to stations, wind and turbines)	Lacking connectivity information to national grid
	13482	Ordnance Survey VectorMap District: Electricity Transmission Line	MULTILINESTRING/LINESTRING	Edge		No attribution
	536	National Grid: Line	MULTILINESTRING/LINESTRING	Edge	Operating Voltage (operating_)	Not all geometry connected to substation sites; Text field for operating voltage
	5816	National Grid: Cable	MULTILINESTRING/LINESTRING	Edge	Operating Voltage (operating_)	Text field for operating voltage
	462	National Grid: Substation Site	MULTIPOLYGON/POLYGON	Node	Site Name (notes1), Operating Voltage (operating_)	Text field for operating voltage
	99412	Ordnance Survey Points of Interest: Electrical Features	POINT	Node	Type(name(electricity pole, electricity poles, electricity substation, electricity switchin, electricity transfor, pylon)	
	382	Ordnance Survey Points of Interest: Energy Production	POINT	Node		

	370	DECC Operational Power Stations May 2011	POINT	Node	Station name, Fuel Type, Capacity, Expected Closure Date, Water Usage, Cold Water Source, Cold Water Intake Position	Lacks connectivity data from generation sites to the national grid
	131	Ordnance Survey Refineries: Oil	POINT	Node	Name	Lacks connectivity and attribute data

Table 2- Data layers stored within the National Infrastructure Asset Database, Newcastle, to be used for the generation of the national electricity transmission system

Electricity (Regional Distribution System(s)):

The overall governance and management of the regional electricity distribution systems is split across 5 organisations within the UK, and can be seen in Figure.7.

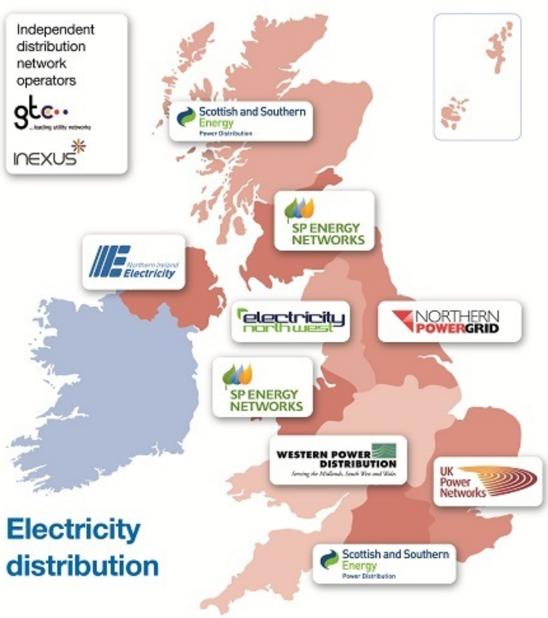


Figure 6 - Regional Electricity Distribution System Operators, UK (Electricity Distribution Map, 2012)

Regional Distribution Operator: Electricity North West (North West England)

Figure.7 illustrates the features within the Electricity North West regional electricity distribution network. The map contains data covering the Lake District, Lancashire and more southern areas.

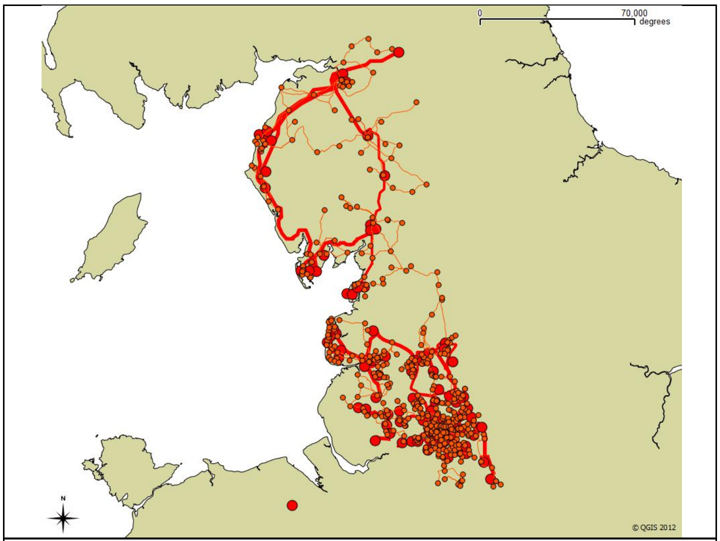


Figure 7 - Electricity North West Regional Distribution Network Components, UK

Table.3 details the list of available data from the National Infrastructure Asset Database that can be utilised to build a regional distribution network based on data supplied by Electricity North West.

NetworkName	Feature Count	Datasource	GeometryType	Nodes/Edges	Attributes Available	Issues
Electricity: Distribution (North West Case Study Area)	1015	Electricity North West: 33kV Line	MULTILINESTRING/ LINESTRING	Edge	Operating Voltage (voltage)	Positional accuracy as georeferenced from OS 1:50000 Gazetteer; Many small disconnected components;
	846	Electricity North West: Substation Site?	POINT	Node		Geometry often not connected to 33kV line
	468	Electricity North West: 132kV Line	MULTILINESTRING/ LINESTRING	Edge	Operating Voltage (voltage)	Positional accuracy as georeferenced from OS 1:50000 Gazetteer; Many small

						disconnected components;
	184	Electricity North West: Substation Site?	POINT	Node		Geometry often not connected to 132kV line
	187719	Ordnance Survey: Electricity Substations	POINT	Node	Toid	Very large set; no connectivity data; no operating voltage;

Table 3- Data layers stored within the National Infrastructure Asset Database, Newcastle, to be used for the generation of the Electricity North West regional distribution systems

Regional Distribution Operator: Scottish and Southern Energy (Scotland, Southern England)

There is currently no data within the National Infrastructure Asset Database representing the network operated by Scottish and Southern Energy. However, Scottish and Southern Energy are partners on the ITRC project.

Regional Distribution Operator: SP Energy Networks (Scotland, Borders, Northern Wales)

There is currently no data within the National Infrastructure Asset Database representing the network operated by SP Energy Networks. SP Energy Networks are not currently partners of the ITRC project.

Regional Distribution Operator: Northern Power Grid (Yorkshire and North East)

There is currently no data within the National Infrastructure Asset Database representing the network operated by Northern Power Grid. Northern Power Grid are not currently partners of the ITRC project.

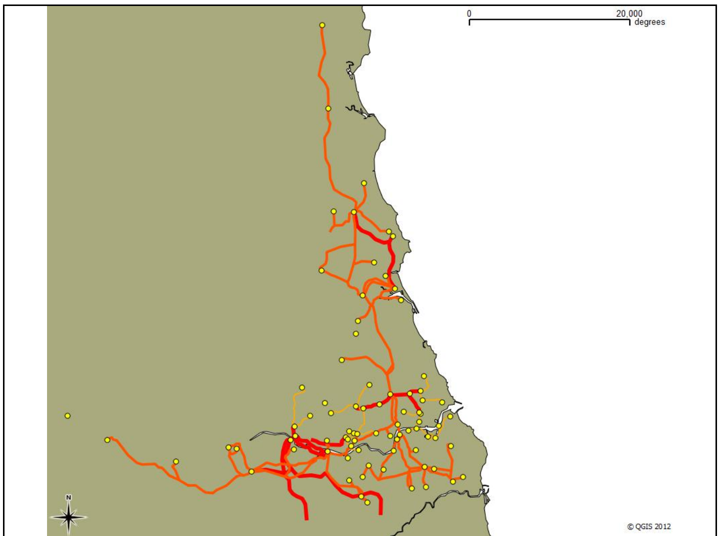


Figure 8 - Northern Electric Distribution Ltd. Regional Distribution Network Components, UK

However Northern Electric Distribution Limited (NEDL) data from 1999 has been sourced from a previous project and stored within the energy section of the database. Currently permission to use this data in this manner has NOT been granted. The data itself can be seen in Figure.8.

Table.4 details the list of available data that can be used to generate the NEDL network.

NetworkName	FeatureCount	Datasource	Geometry Type	Nodes/ Edges	Attributes Available	Issues
Electricity: Distribution (Northern Electric Distribution Limited (NEDL), North East, UK)	83	NEDL Primary Substations	POINT	Node	No attributes available	No permission currently granted for usage, dates to 1999, lacks attribute data, many small disconnected components, geometry often not connected to line features
	10	NEDL 132 kV	MULTILINESTRING/ LINESTRING	Edge	No attributes available	No permission currently granted for usage, dates to 1999, lacks attribute data, many small disconnected components, geometry often not connected to point features
	46	NEDL 66kV	MULTILINESTRING/ LINESTRING	Edge	No attributes available	No permission currently granted for usage, dates to 1999, lacks attribute data, many small disconnected components, geometry often not connected to point features
	16	NEDL 33kV	MULTILINESTRING/ LINESTRING	Edge	No attributes available	No permission currently granted for usage, dates to 1999, lacks attribute data, many small disconnected components, geometry often not connected to point features

Table 4 - Data layers stored within the National Infrastructure Asset Database, Newcastle, to be used for the generation of the NEDL regional electricity distribution network

Regional Distribution Operator: Western Power Distribution (Midlands, Central and Southern Wales, South West England)

There is currently no data within the National Infrastructure Asset Database representing the network operated by Western Power Distribution. Western Power Distribution are not currently partners of the ITRC project.

Regional Distribution Operator: UK Power Networks (South East England)

There is currently no data within the National Infrastructure Asset Database representing the network operated by UK Power Networks. UK Power Networks are not currently partners of the ITRC project.

Regional Distribution Operator: Northern Ireland Electricity

There is currently no data within the National Infrastructure Asset Database representing the network operated by UK Power Networks. UK Power Networks are not currently partners of the ITRC project.

Transport

Road Network

NetworkName	FeatureCount	Datasource	GeometryType	Nodes/ Edges	Attributes Available	Issues
Transport: Road	135790	OS Meridian 2 A Roads	MULTILINESTRING/LINESTRING	Edge	Road number (number), Road name (road_name), OSODR	Integration with Transport CDAM - using common network representation
	81725	OS Meridian 2 B Roads	MULTILINESTRING/LINESTRING	Edge	Road number (number), Road name (road_name), OSODR	
	1020443	OS Meridian 2 Minor Roads	MULTILINESTRING/LINESTRING	Edge	Road number (number), Road name (road_name), OSODR	
	3854	OS Meridian 2 Motorway	MULTILINESTRING/LINESTRING	Edge	Road number (number), Road name (road_name), OSODR	
	17242	OS Meridian 2 Roundabout	POINT	Node		
	2395340	OS Meridian 2 Road Node	POINT	Node		
	30897	OS Strategi A Roads	MULTILINESTRING/LINESTRING	Edge	Road number (number0)	
	32705	OS Strategi B	MULTILINESTRING/LINE	Edge	Road	

		Roads	STRING		number (number0)	
	156453	OS Strategi Minor Roads	MULTILINESTRING/LINE STRING	Edge	Number (number), Name (name)	
	2233	OS Strategi Motorway	MULTILINESTRING/LINE STRING	Edge	Road number (number0)	
	22653	OS Strategi Primary Roads	MULTILINESTRING/LINE STRING	Edge	Road number (number0)	
	3031260	OS VectorMap District Road	MULTILINESTRING/LINE STRING	Edge	Road number (dftnumber) , Road Classificatio n (classifica)	

Table 5 - Data layers stored within the National Infrastructure Asset Database, Newcastle, to be used for the generation of the road network within the UK

Rail Network

NetworkName	Feature Count	Datasource	GeometryType	Nodes/Edges	Attributes Available	Issues
Transport: Rail	8495	OS Meridian 2 Rail Line	MULTILINESTRI NG/LINESTRING	Edge		Integration with Transport CDAM - using common network representatio n
	2526	OS Meridian 2 Station Point	POINT	Node		
	12199	OS Strategi Railway	MULTILINESTRI NG/LINESTRING	Edge		
	3348	OS VectorMap District Railway Station	POINT	Node	Classificatio n	
	68919	OS VectorMap District Railway Track	MULTILINESTRI NG/LINESTRING	Edge		
	1070	OS VectorMap District Railway Tunnel				
	12180	OS Points of Interest: Signalling Facilities	POINT	Node	Type (name (signal lights, signal post, signal box))	NW Coverage Only currently;Onl y name attribute available

Table 6 - Data layers stored within the National Infrastructure Asset Database, Newcastle, to be used for the generation of the rail network within the UK

Air Network

NetworkName	Feature Count	Datasource	GeometryType	Nodes/Edges	Attributes Available	Issues
Transport: Air	N/A	OpenFlights Airlines (all)	NO GEOMETRY		airlineid, name, alias, iata_code, icao_code, callsign, country, active	Currency
	161	OpenFlights Airports (UK only)	POINT	NODE	airportid, name, city, country, iata_faa_c, icao_code, latitude, longitude, altitude, timezone, dst	Currency
	353	OpenFlights Routes (UK only)	MULTILINESTRING/LINESTRING	EDGE	airline, airlineid, source_airport, source_airport_id, destination_airport, destination_airport_id, codeshare, stops, equipment	Currency
	60	OS_Airports	POINT	NODE	number, name, easting, northing, county	No route information available

Table 7 - Data layers stored within the National Infrastructure Asset Database, Newcastle, to be used for the generation of the air traffic network in the UK

Water

Network Name	Feature Count	Datasource	GeometryType	Nodes/ Edges	Attributes Available	Issues
Water: Distribution	11367	Ordnance Survey Reservoirs	POINT	Node	Name (name)	No capacity information
	6426	OS Meridian 2 Lake Regions	POLYGON	Node	Name (name)	No capacity information
	73263	OS Meridian 2 River	MULTILINESTRING/LINESTRING	Edge	Name (name)	
	5978	OS Strategi Lake Regions	POLYGON	Node		No capacity information
	55125	OS Strategi River	MULTILINESTRING/LINESTRING	Edge	Type (legend e.g. canal, minor river), Name (name)	
	31669	OS Water Pumping Stations	POINT	Node	Type (name e.g. Pump, Wind Pump, Hydraulic Asset…)	Generally lacking all pipe work information, including transfer pipes between water resource zones, no capacity or pumping rate information

Table 8 - Data layers stored within the National Infrastructure Asset Database, Newcastle, to be used for the generation of the water distribution network in the UK

Waste water

NetworkName	Feature Count	Datasource	GeometryType	Nodes/ Edges	Attributes Available	Issues
WasteWater: Treatment	1760	Urban Waste Water Treatment: Works	POINT	Node	Organic Design Capacity (uwwCapacity)	Lacking connectivity information to
	1728	Urban Waste Water Treatment: Discharge Points	POINT	Node	Load Entering Works (uwwloadent)	Needs a physical link creating between the treatment works and the discharge points
	2602	Ordnance Survey Points of Interest: Waste, Storage, Processing, Disposal: Sewage Features	POINT	Nodes	Type(name(including…beds, farms, pumps, treatment works, works)	NW Coverage Only currently;Only name attribute available
	1180	Ordnance Survey Points of Interest: Waste, Storage, Processing, Disposal: Slurry Features	POINT	Nodes	Type(name(including…beds, ponds)	NW Coverage Only currently;Only name attribute available
	478	Ordnance Survey Points of Interest: Waste, Storage, Processing, Disposal: Sludge Features	POINT	Nodes	Type(name(including…beds, lagoons, pits, ponds, tanks)	NW Coverage Only currently;Only name attribute available

Table 9 - Data layers stored within the National Infrastructure Asset Database, Newcastle, to be used for the generation of the waste water network in the UK

Solid Waste

Network Name	FeatureCount	Datasource	GeometryType	Nodes/ Edges	Attributes Available	Issues
Solid Waste Collection / Disposal	108	Ordnance Survey Points of Interest: Recycling Centres	POINT	Nodes	Type (name(recycling centres, waste reception centre…))	NW Coverage Only currently;Only name attribute available
	2314	Ordnance	POINT	Nodes	Type(name(amenity	NW Coverage

		Survey Points of Interest: Refuse Disposal Facilities			site/tip, household waste disposal, incinerator, landfill power generator, landfill site, refuse tip, slag heap…)	Only currently;Only name attribute available
	7954	Ordnance Survey Points of Interest: Waste, Storage, Processing, Disposal	POINT	Nodes	Type(name(sludge/slurry pits/ponds, sewage works/tanks, pumps overflows, settling tanks/beds	NW Coverage Only currently;Only name attribute available

Table 10 - Data layers stored within the National Infrastructure Asset Database, Newcastle, to be used for the generation of the solid waste network

Interdependency Matrix

The following section details the interdependency matrix developed as a result of analysing the *physical/geographic* interdependencies that exist between each of the networks identified. Please note that at this stage the *cyber* and *logical* interdependencies, as identified by (Rinaldi, Peerenboom, & Kelly, 2001), are not being considered. Furthermore there is no consideration at this stage of internal interdependencies, where by features that exist within the same network are dependent upon each other. In addition, where a dependency exists on either the electricity *or* gas regional distribution networks, it is assumed that this dependency also exists on the higher level, respective transmission networks.

	Network A:									
Network B:	**Energy: National Gas Transmission**	**Energy: Regional Gas Distribution**	**Energy: National Electricity Transmission**	**Energy: Regional Electricity Distribution**	**Water: Water Distribution**	**Waste Water: Treatment**	**Transport: Road**	**Transport: Rail**	**Transport: Air**	**Solid Waste: Collection / Treatment**
Energy: National Gas Transmission		1	1	1	1	?	1	1	0	0
Energy: Regional Gas Distribution	1		1	1	1	?	1	1	0	0
Energy: National Electricity Transmission	1	1		1	1	?	1	1	0	0
Energy: Regional Electricity Distribution	0	0	1		1	?	1	?	0	0
Water: Water Distribution	0	0	1	1		1	1	0	0	0
Waste Water: Treatment	0	0	1	1	1		1	0	0	0
Transport: Road	0	0	1	1	0	0		0	0	0
Transport: Rail	0	0	1	1	0	0	0		0	0
Transport: Air	1	1	1	1	1	1	1	0		1
Solid Waste: Collection / Treatment	0	0	1	1	0	1	1	0	0	

Table 11 - Physical interdependencies identified between the different national infrastructure networks

1 = dependency exists (Network B is dependent on Network A)

0 = no dependency exists

? = unknown if a dependency exists

Energy

Gas (National Transmission System):

	SITES	DESCRIPTION
Gas Transmission Dependency on Gas Distribution		
Energy: National Gas Transmission (including terminals, compressors, storage and LNG sites)	Offtakes	Controls gas flows in to the gas distribution network
Dependency on		
Energy: Regional Gas Distribution *		
Gas Transmission Dependency on Electricity		
Energy: National Gas Transmission (including terminals, compressors, storage and LNG sites)	UK Gas Compressors LNG Sites Import Terminals Storage Sites	SCADA Power to gas assets and facilities (including compressors, storage and lng sites)
Dependent on		
Energy: National Electricity Transmission (including generation sites)		
Energy: National Gas Transmission (including terminals, compressors, storage and LNG sites)		
Dependent on		
Energy: Regional Electricity Distribution (applicable to all regions)		
Gas Transmission Dependency on Water		
Energy: National Gas Transmission (including terminals, compressors, storage and LNG sites)	UK Gas Compressors Manned gas assets	Water used in potential combustion engine for running compressor Water supply for operations/buildings at terminals, compressors, storage and LNG sites (not necessaily for gas transmission) Water usage for emission reduction at generation sites
Dependent on		
Water:Water Distribution		
Gas Transmission Dependency on Roads		
Energy: National Gas Transmission (including terminals, compressors, storage and LNG sites)	Co-located assets with 3rd-party owned features	Co-location of gas transmission assets with features owned by 3rd parties e.g. Network Rail, Highways Agency etc.

Dependent on	All assets requiring direct operation / maintenance	Access to gas transmission assets for operation and maintenance Transporting LNG (cryogenic tanks) to remote parts of the network
Transport: Road		
Gas Transmission Dependency on Rails		
Energy: National Gas Transmission (including terminals, compressors, storage and LNG sites)	Co-located assets with 3rd-party owned features	Co-location of gas transmission assets with features owned by 3rd parties e.g. Network Rail, Highways Agency etc.
Dependent on	All assets requiring direct operation / maintenance	Access to gas transmission assets for operation and maintenance Transporting LNG (cryogenic tanks) to remote parts of the network
Transport: Rail		

Table 12 - Qualitative assessment of dependencies existing between the national gas transmission system and other networks

Gas (Regional Distribution Systems(s)):

	SITES	DESCRIPTION
Gas Distribution Dependency on Gas Transmission		
Energy: Regional Gas Distribution *	Offtakes Pressure Reduction Stations	Gas supply for distribution Gas Regulation from Gas Terminal
Dependent on		
Energy: National Gas Transmission (including generation, terminals, storage and LNG sites)		
Gas Distribution Dependency on Electricity		
Energy: Regional Gas Distribution *	Offtakes Pressure Reduction Stations Governors	SCADA Power to gas assets and facilities
Dependent on		
Energy: National Electricity Transmission (including generation sites)		
Energy: Regional Gas Distribution *		
Dependent on		
Energy: Regional Electricity Distribution (applicable to all regions)		
Gas Distribution Dependency on Water		
Energy: Regional Gas Distribution *	Manned gas assets	Water supply for operations/buildings at pressure reduction stations
Dependent on		
Water:Water Distribution		
Energy: Regional Gas Distribution *		
Dependent on		
Waste Water: Treatment		
Gas Distribution Dependency on Roads		
Energy: Regional Gas Distribution	Gas Distribution Assets e.g. Pressure Reduction Stations, Gas Governors	Co-location of gas transmission assets with features owned by 3rd parties e.g. Highways Agency etc. Access to gas transmission assets for operation and maintenance
Dependent on		
Transport: Road		

Gas Distribution Dependency on Rail Energy: Regional Gas Distribution Dependent on Transport: Rail	Gas Distribution Assets e.g. Pressure Reduction Stations, Gas Governors	Co-location of gas transmission assets with features owned by 3rd parties e.g. Network Rail etc.

Table 13 - Qualitative assessment of dependencies existing between the regional gas distribution systems and other networks

Electricity (National Transmission System):

	SITES	DESCRIPTION
Electricity transmission Dependency on Gas		
Energy: National Electricity Transmission (including generation sites)	Electricity Generation Sites (CCGT, Gas, GasOil Power Stations)	Gas Supply to Combined Cycle Gas Turbine Power Stations (taken off at approximately 175 major offtakes in the UK, direct to power stations / industrial partners)
Dependent on		
Energy: National Gas Transmission (including terminals, compressors, storage and LNG sites)		
Energy: National Electricity Transmission (including generation sites)		
Dependent on		
Energy: Regional Gas Distribution *		
Electricity Transmission dependent on Electricity Distribution		
Energy: National Electricity Transmission (including generation sites)	400, 275, 132 kV substations	SCADA Main electricity supply escape points from transmission to distribution networks
Dependent on		
Energy: Regional Electricity Distribution (applicable to all regions)		
Electricity Transmission dependent on Water Distribution		
Energy: National Electricity Transmission (including generation sites)	Energy/Power generation sites Underground electricity cables	Cooling
Dependent on		
Water: Water Distribution		
Electricity Transmission dependent on Transport Road		
Energy: National Electricity Transmission (including generation sites)	Electricity Transmission Assets	Access to electricity transmission assets for operation and maintenance

Dependent on Transport: Road		
Electricity Transmission dependent on Transport Rail		
Energy: National Electricity Transmission (including generation sites) Dependent on Transport: Rail	Energy/Power generation sites	Delivery of fuel e.g. coal

Table 14 - Qualitative assessment of dependencies existing between the national electricity transmission system and other networks

Electricity (Regional Distribution System(s)):

	SITES	DESCRIPTION
Electricity distribution dependency on electricity transmission		
Energy: Regional Electricity Distribution (applicable to all regions)	400, 275, 132 kV substations	Main electricity supply
Dependent on		
Energy: National Electricity Transmission (including generation sites)		
Electricity distribution dependency on Water Distribution		
Energy: Regional Electricity Distribution (applicable to all regions)	Underground electricity cables	Cooling
Dependent on		
Water: Water Distribution		
Electricity distribution dependency on Roads		
Energy: Regional Electricity Distribution (applicable to all regions)	Substation locations / Manned electricity distribution assets	Access to and from substations for operation and maintenance of distribution features
Dependent on		
Transport: Road		
Electricity distribution dependency on Rail		
Energy: Regional Electricity Distribution (applicable to all regions)	Substation locations / Manned electricity distribution assets	Access to and from substations for operation and maintenance of distribution features
Dependent on		
Transport: Rail		

Table 15 - Qualitative assessment of dependencies existing between the regional electricity distribution systems and other networks

Transport

Road:

	SITES	DESCRIPTION
Transport Road dependency on Electricity	Street Lighting, Signage Roads, Intersections, Roundabouts	SCADA Traffic Monitoring services Signage Power
Transport: Road		
Dependent on		
Energy: National Electricity Transmission (including generation sites)		
Transport: Road		
Dependent on		
Energy: Regional Electricity Distribution (applicable to all regions)		

Table 16 - Qualitative assessment of dependencies existing between the road network and other networks

Rail:

	SITES	DESCRIPTION
Transport Rail dependency on Electricity	Signals Overhead Railway Cables Road / Rail Intersections Stations including signage	SCADA Rail Monitoring services Power to rail network assets
Transport: Rail		
Dependent on		
Energy: National Electricity Transmission (including generation sites)		
Transport: Rail		
Dependent on		
Energy: Regional Electricity Distribution (applicable to all regions)		

Table 17 - Qualitative assessment of dependencies existing between the rail network and other networks

Air:

	SITES	DESCRIPTION
Transport Air dependency on Gas		
Transport: Air	Airports, airfields, air traffic control, air traffic monitoring, terminals	Space heating of air traffic assets, including airports and air traffic control centres
Dependent on		
Energy: National Gas Transmission (including terminals, compressors, storage and LNG sites)		
Transport: Air		
Dependent on		
Energy: Regional Gas Distribution *		
Transport Air dependency on Electricity		
Transport: Air	Airports, airfields, air traffic control, air traffic monitoring, terminals	Power for operation and maintenance of air traffic-related network features SCADA
Dependent on		
Energy: National Electricity Transmission (including generation sites)		
Transport: Air		
Dependent on		
Energy: Regional Electricity Distribution (applicable to all regions)		
Transport Air dependency on Water Distribution		
Transport: Air	Airports, airfields, air traffic control, air traffic monitoring, terminals	Water supply for airports/airfields for operation and use by consumers
Dependent on		
Water: Water Distribution		
Transport Air dependency on Waste Water		
Transport: Air	Airports, airfields, air traffic control, air traffic monitoring, terminals	Subsequent removal, processing, treatment of waste water from operational sites
Dependent on		
Waste Water: Treatment		

Transport Air dependency on Roads	Airports, airfields, air traffic control, air traffic monitoring, terminals	Delivery of aviation fuel Access for operation and maintenace of equipment
Transport: Air		
Dependent on		
Transport: Roads		

Table 18 - Qualitative assessment of dependencies existing between the air network and other networks

Water

	SITES	DESCRIPTION
Water distribution dependent on Electricity		
Water: Water Distribution	Water Pumping Stations	Powering / Operating Water Pumping Stations SCADA Control of Water Pumping Stations
Dependent on		
Energy: National Electricity Transmission (including generation sites)		
Water: Water Distribution		
Dependent on		
Energy: Regional Electricity Distribution (applicable to all regions)		
Water distribution dependent on Waste Water		
Water: Water Distribution	Water Treatment / Sewerage works (although this forms part of the waste water network)	Re-introduction of clean water
Dependent on		
Waste Water: Treatment		
Water distribution dependent on Transport		
Water: Water Distribution	Water Pumping Stations / Manned water network assets	Access to water distribution features for operation and maintenance activities
Dependent on		
Transport: Roads		

Table 19 - Qualitative assessment of dependencies existing between the water distribution network and other networks

Wastewater

	SITES	DESCRIPTION
Waste water treatment / distribution dependent on Electricity		
Waste Water: Treatment Dependent on	Waste water treatment facilities / sewerage works	Power for waste water treatment assets and facilities
Energy: National Electricity Transmission (including generation sites)		
Waste Water: Treatment		
Dependent on		
Energy: Regional Electricity Distribution (applicable to all regions)		
Waste water treatment / distribution dependent on Water		
Waste Water: Treatment	Waste Water Treatment Sites	Reintegration of waste water outputs back into the water distribution network
Dependent on		
Water: Water Distribution		

Table 20 - Qualitative assessment of dependencies existing between the waste water distribution/redistribution network and other networks

Solid Waste

	SITES	DESCRIPTION
Solid Waste Dependency on Electricity		
Solid Waste: Collection / Treatment	Refuse Disposal Facilities Recycling Centres Waste Storage / Processing	Power to waste collection / disposal sites and recycling facilities
Depends on		
Energy: National Electricity Transmission (including generation sites)		
Solid Waste: Collection / Treatment		
Depends on		
Energy: Regional Electricity Distribution (applicable to all regions)		
Solid Waste Dependency on Waste Water Treatment		
Solid Waste: Collection / Treatment	Refuse Disposal Facilities Recycling Centres Waste Storage / Processing	Removal of waste water products generated as a result of solid waste treatment
Depends on		
Waste Water: Treatment		
Solid Waste Dependency on Roads		
Solid Waste: Collection / Treatment	Waste Collection Points	Waste collection / recycling collection (commercial, industrial, residential) and transport to waste disposal / processing facilities
Depends on		
Transport: Roads		

Table 21 - Qualitative assessment of dependencies existing between the solid waste disposal / processing network and other networks

Data Processing

The purpose of this section is to detail the necessary processing steps that need to be undertaken to build the relevant National Infrastructure (NI) networks. These steps will detail how to build the topologically and spatially valid National Infrastructure networks from the available data; the document will then move on to explain how any dependencies identified between different networks can be calculated or quantified, in the absence of real world data to depict these dependencies. The section is split by sector, and then each network within each sector is considered separately. Despite each of the networks being built from different source datasets, many of the datasets to be used to build the networks suffer from similar issues including lack of connectivity data between point or node datasets, and also a lack of **attribute**, **capacity** and **flow** data. Finally some of the networks identified have no data available to represent them, and this is particularly the case for the regional electricity and gas distribution networks. The data scarcity seen here is generally due to the commercial sensitivity of the regional distribution network data.

The processing steps to undertake for each network to be created are similar in nature. In order to retrieve the most topologically and spatially valid representation for each network in each sector the following steps must broadly be followed (however each dataset used within each network representation may require specific processing steps):

1) Identify and uniquely name the networks that are to be created. This can help to understand how many networks and subsequent datasets will require processing but also helps to understand where networks may be disaggregated rather than aggregated e.g. generating an electricity transmission network separately from the regional distribution networks.

2) Identify the data sets and sources to be used to best represent particular node or edge features within a specific network e.g. DECC_OperationalPowerStationsMay2011 for operational power stations that generate electricity, or OS_EnergyProductionSites used to represent energy generation sites that generate electricity for transmission and distribution.

3) Convert the data sets representing node features in to points or centroid representations. Whilst this may abstract away from the true spatial representation of the feature, for ease of understanding and also interacting with a feature it is more straightforward to have this represented as a point. This approach is also more aligned with standard node and edge components found within network and graph theory. Furthermore this prevents a situation where multiple nodes effectively represent the same component, specifically in the cases where multiple edges appear to be connected to a single node. Figure.9 and 10 illustrates this point:

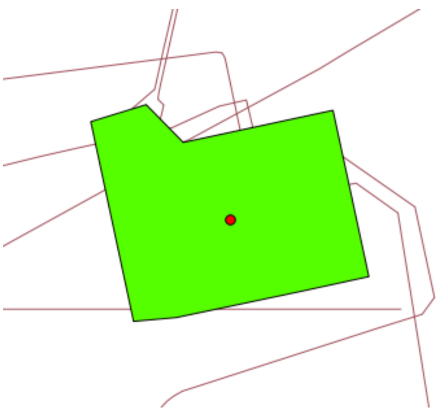


Figure 9 – representing a site as a single node.

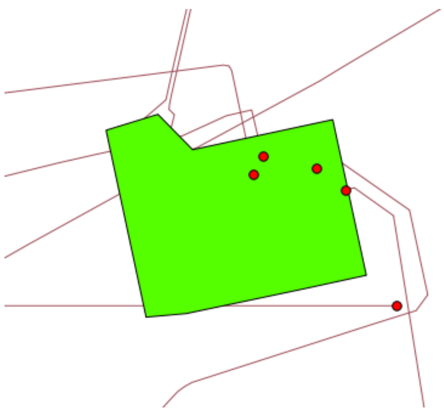


Figure 10 – representing a site as multiple nodes where connections end. Albeit this approach is more accurate, the result is duplication of node data

4) Interrogate the edge data sets spatial validity. The edges themselves may not be *snapped* on to the correct nodes (spatially) e.g. a transmission line not connecting to a substation . This step would also include the identification of floating or wholly disconnected edges and may result in their complete removal from the dataset, or adjustment to correct for their lack of connectivity (spatially). Figure.11 illustrates an example of this problem as found in the National Grid Gas Transmission Network

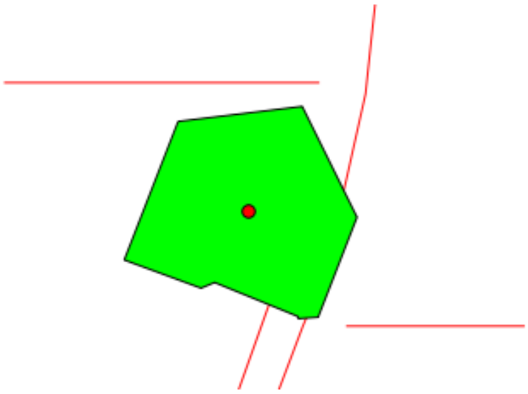


Figure 11 - Disconnected features / floating edges

5) Interrogate and investigate the edge data set to ensure that it is topologically valid, either based on ensuring during step 4 that each edge end is snapped to a node, or by searching the attributes of the edge data for indications as to how they connect to nodes. This step essentially ensures that if there is no data available to infer correct topology then the next best representation is that those nodes and edges that are spatially proximate are coupled; alternatively it ensures that through the investigation of node and edge attributes that the correct edges join to the correct nodes

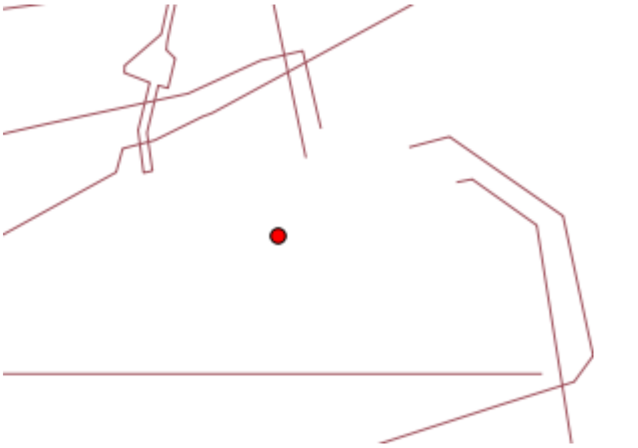


Figure 12 - Disconnected and floating edges identified within the National Gas Transmission Network Data from National Grid

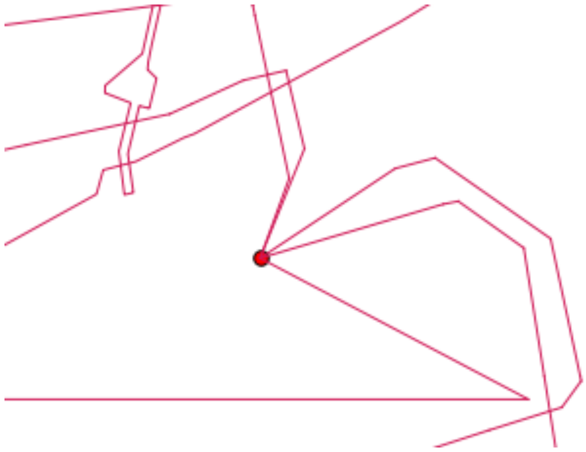


Figure 13 - Connecting floating edge end points to either the nearest node, or a node based on matching attribute values

6) Having performed some alterations during step 5 as seen in Figure.13, there may still be parts of the network where data is missing. For example this could be because of poor digitisation and representation of the network features within the chosen datasets, or because additional nodes may exist in the network that had not previously been considered. This may lead to additional data being required to compensate. For example Figure.14 and Figure.15 illustrates how despite inferring connectivity between edges and nodes within the National Grid Gas Transmission Network, there are still some missing data, and hence the floating edges. These missing data can be manually registered or inferred through the use of other datasets.

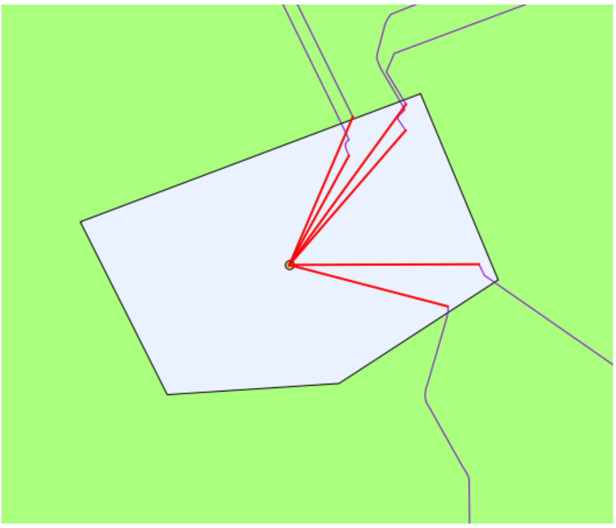


Figure 14 - Connectivity inferred between appropriate gas transmission pipeline (edges) and gas compressors (nodes)

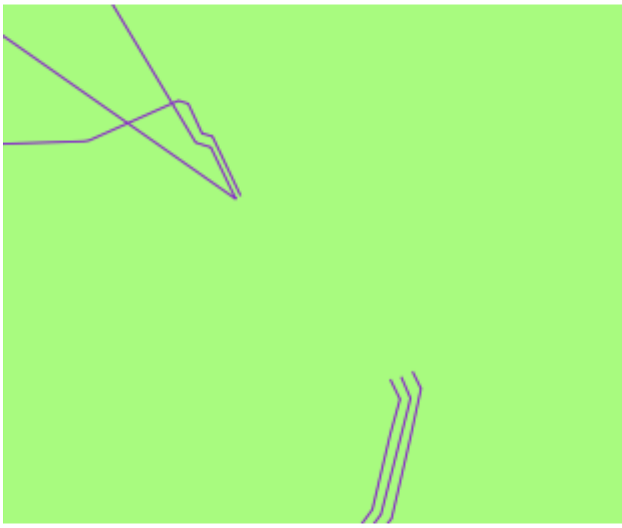


Figure 15 - Following the same process undertaken as in Figure.14, this illustrates how data can still be missing (St.Fergus Gas Terminal)

For example, Figure.16 illustrates (yellow) all the OS Points of Interest Gas Features that lie within 1000m of the National Gas Transmission edge dataset. It can be assumed that these features do lie ***on*** the network i.e. the National Gas Transmission edges probably connect to these yellow features in some way.

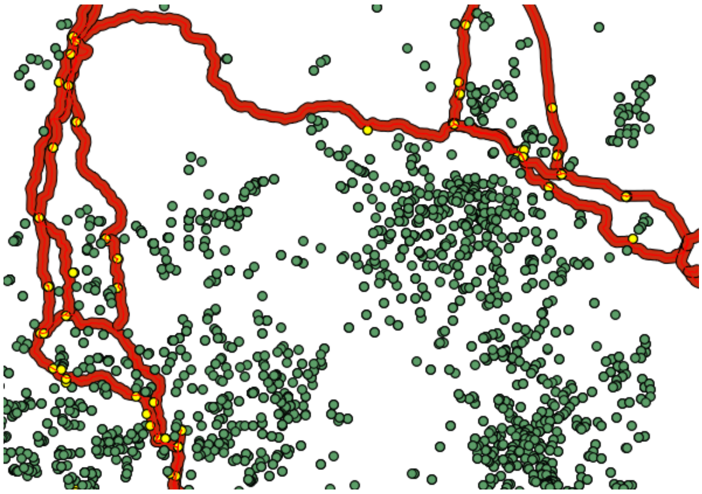


Figure 16 - example of extracting data from alternative sources to complement other data sources for network construction

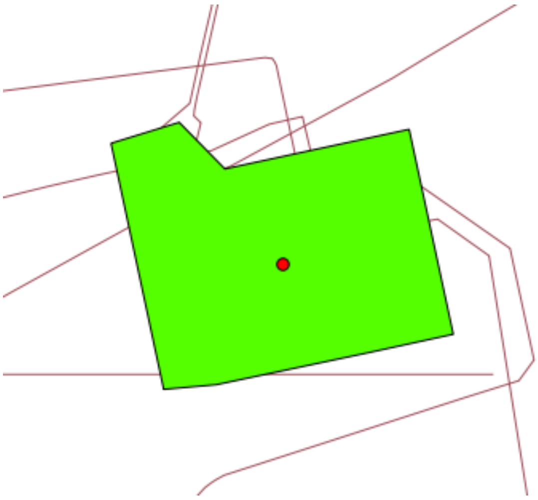
6) If following the investigation of the attributes of the edge datasets, there is a linkage between that attribute and attributes of the node dataset, it may be possible to begin to infer flow or directionality within the network. For example within the National Gas Transmission dataset the attribute "***Pipe_name***" contains this type of directionality in the form of stating where gas flows from and to e.g. FM24 - Auchnagatt to Udny Green. This data can be used to build directionality in to the final network representation.

Energy

Gas: National Transmission System

Network Construction

1) Convert Gas Site data to centroids: Each gas site will be modelled as a single node, with each pipeline connecting to a single point i.e. the gas site centre/centroid. This is opposed to having multiple nodes representing the point on the gas site boundary where each connecting edge crosses the boundary or even just the end of the edge, all with the same attributes. Figure.x demonstrates the gas sites as centroids, whereas figure.x represents the alternative multiple node case:



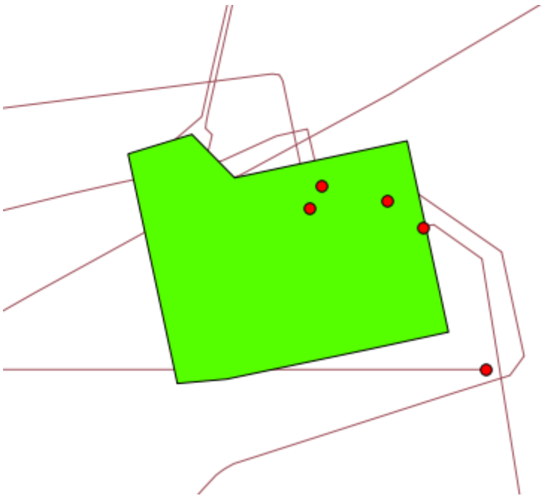


Figure.x – representing a gas site as a single node. This is the more straightforward and simple approach.	**Figure.x** – using the edge end points of connecting edges to a gas site to represent the gas site.

2) Identify and isolate disconnected edges that do not appear to connect to or from any node, or appear residual i.e. both ends of the edge are *close* together, but also *far* from a Gas Site. Figure.x demonstrates this:

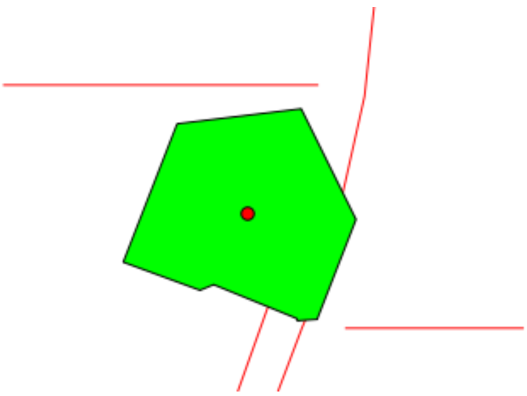


Figure.x – wholly disconnected edges (top left and bottom right)

3) Using the functions available from the network interdependency database schema, attempt to adjust the Gas Pipeline Feeder geometry such that it physically connects to the appropriate gas sites. This can be done simply by proximity, or by using the relationship between attributes identified in table.1. See figure.x for demonstration of the problem faced by non-connecting / hanging edge geometries within the Gas Pipeline Feeder data:

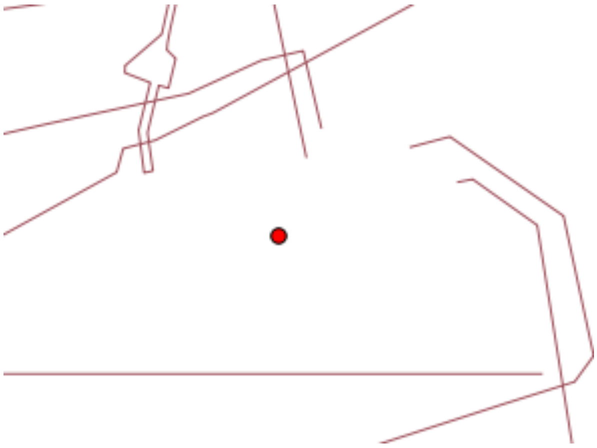


Figure.x – example of hanging edges of Gas_Pipeline_Feeder not connecting to gas site centroids.

The functions (currently) within the network interdependency database to perform such operations are:

ni_data_proc_connect_hanging_edges_to_nodes_in_search - connects edges "ends" to each node that are within a specified search distance of each node.

ni_data_proc_connect_hanging_edges_to_node_like - connects always **edge "ends"** to each node that are related by some relationship between two attributes; one attribute in the nodes table, and one attribute in the edges table.

ni_data_proc_connect_nodes_to_point_on_nearest_edge_in_search - connects the closest point on an edge to a node provided it lies within a specified search distance of each node

ni_data_proc_connect_nodes_to_point_on_nearest_edge_like - connects **the nearest point on an edge (which may or may not be an edge end)** to each node that are related by some relationship between two attributes; one attribute in the nodes table, and one attribute in the edges table.

The result of running such tools would be something similar to figure.x:

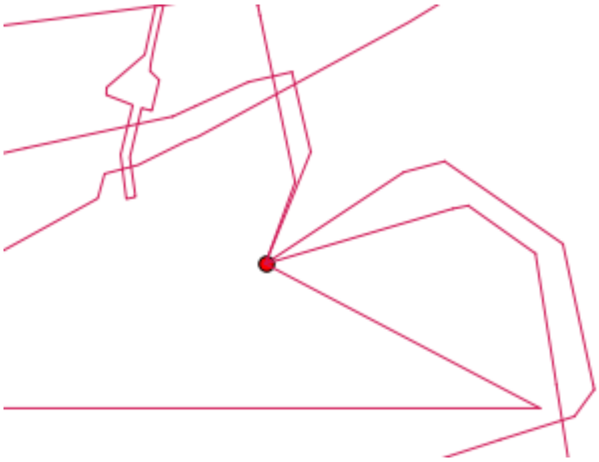


Figure.x – Connecting Gas Pipeline Feeder features (edge ends) to correct Gas Site (centroid)

The aim of performing these operations is to ensure both topologically and geographically that the correct Gas Pipeline Feeder edges are connected to the correct Gas Sites.

4) From the resulting geometries output from step 4, check each edge is fully connected between two nodes i.e. the edge is not only connected to node at either end, but is fully connected in between; not only do some of the edges not connect to the appropriate Gas Site (node), some of the edges have been poorly digitised or recorded and so there are gaps that appear along the edge length. See figure.x for further details of this:

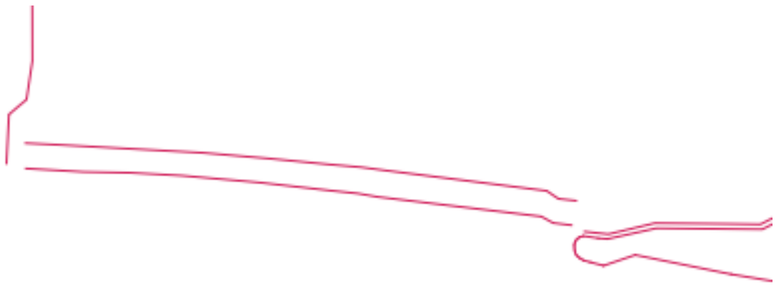


Figure.x – example of edges that do not connect to each other.

5) Contact National Grid via plantprotection@uk.ngrid.com to determine if other attributes within the National Grid datasets can be used to infer a level of connectivity, and also retrieve metadata regarding the other currently undefined attributes.

6) Determine from the available attribute lists of both the gas pipeline data and gas site data which can be used to infer connections between the two data sets.

Gas Pipeline Feeder	Gas Sites
Inspecti_1 / Pipe_name e.g. FM06 - Burton Agnes to Paull	Site_name e.g. Burton Agnes

Table.1 – comparison of attributes between Gas Pipeline Feeder and Gas Site datasets.

7) Filter the inspecti_1 / pipe_name attribute of the Gas Pipeline Feeder dataset to extract all unique *to* and *from* points. This may help to identify missing node features. The missing end nodes can be seen in figure.x.

Figure.x – missing nodes from Gas Site dataset (St. Fergus Terminal is located at the end of these edges)

8) Derive missing nodes from alternative datasets including Ordnance Survey Points of Interest Gas Features, and newly digitised National Grid Gas Terminals. Figure.x shows how features from the Gas Features (code: 06340437) component of the Points of Interest dataset could replace these missing features or complement the dataset.

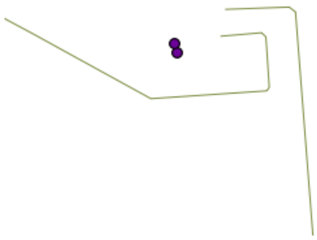


Figure.x – FM15 – Lupton to Bretherton (left) and FM15 – Bretherton to Warburton (right), with the points being Gas Valve Compounds from OS Points of Interest data.

The missing nodes could be incorporated in to a ***separate*** layer representing ***other*** features i.e. other than gas compressors (which is what the Gas Sites dataset represents), but could then be built in to the Gas Transmission network. For example, figure.8 illustrates (yellow) all the OS Points of Interest Gas Features that lie within 1000m of the Gas Pipeline Feeder dataset. It can be assumed that these features do lie ***on*** the network i.e. the Gas Pipeline Feeder features probably connect to these yellow features in some way.

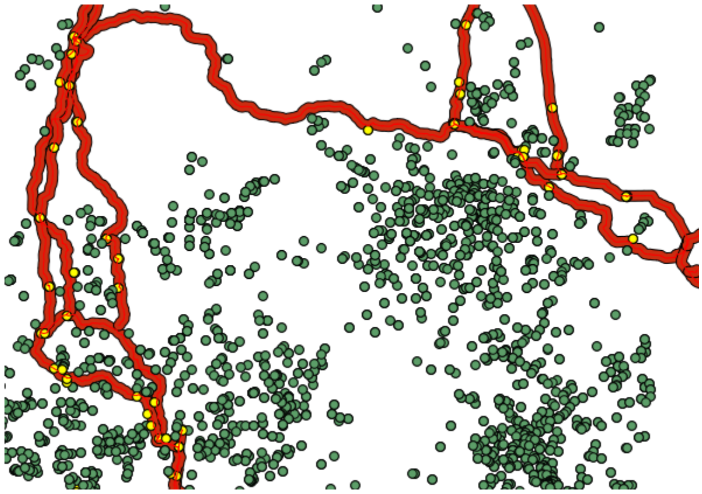


Figure.8 – example of extracting data from other data sources to complement the Gas Transmission network, or populate where there are gaps.

9) Begin to infer directionality of the network based on the data supplied in the edge attributes (Inspecti_1 / Pipe_name) of Gas Pipeline Feeder e.g. FM24 – Auchnagatt to Udny Green helping to denote flow direction.

10) Build Gas Transmission network in network interdependency database schema using Python wrapper and built in database functions, following completion of the previous steps.

These steps represent a broad approach to converting the various National Transmission Gas network data sets in to a network-based topological representation. However please note that these steps are not exhaustive and represent only a mapping of the generic steps to a specific case.

Representing Interdependencies

Calculating and representing dependencies between electricity and gas transmission networks.

In order to represent the dependency of the national gas transmission system on the electricity transmission and distribution networks, a nearest neighbour approach will be used due to the lack of formal connectivity data available between the assets of the gas transmission network and the corresponding electricity network. Some of the dependencies represented are simply due to the need for power, water and heating for assets and facilities that are attended and operated by humans (for comfort purposes), whilst others exist because there is a physical or geographic dependency on a feature from a different network, other than satisfying the needs of humans.

Using Ordnance Survey supplied Electricity Substation data

- Closest electricity substation (taken from the OS supplied electricity sub station set) to each gas compressor (taken from derived National Grid compressors data) e.g.

```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('derived_nationalgrid_gas_compressors',
'gid', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom',
'closest_elecsubstation_to_gas_compressor', false)f( node_A_id integer,
node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line
geometry, node_AB_distance numeric, gid integer, gdo_gid numeric(10,0),
site_type varchar(12), site_name varchar(30), mims_asset varchar(12),
mims_delet numeric(10,0), notes1 varchar(40), status varchar(1), action_dtt
date, action_use varchar(30), action_typ varchar(1), orig_fid integer, geom
geometry);
```

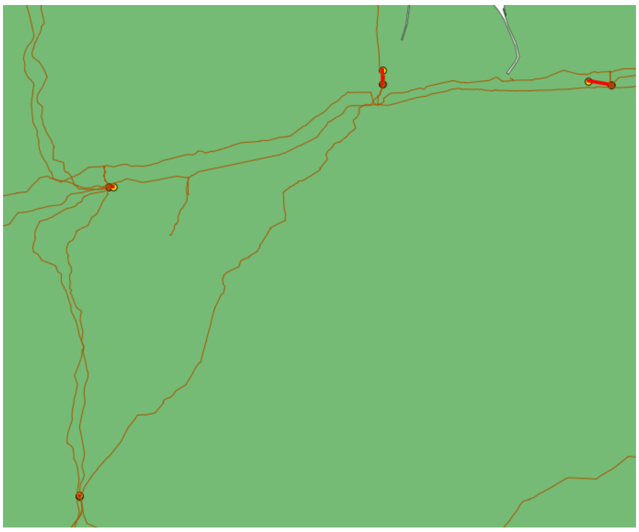


Figure 17 - The closest (red link) electricity substation (yellow) to each gas compressor (brown) of the National Grid Gas Transmission System (brown links)

- Closest electricity substation (taken from the OS supplied electricity sub station set) to each gas LNG operator (taken from derived National Grid LNG operators data)

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('derived_nationalgrid_gas_lngoperators'
, 'gid', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom',
'closest_elecsubstation_to_gas_lng_operator', false)f( node_A_id integer,
node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line
geometry, node_AB_distance numeric, gid integer, id integer, "name" varchar
(50), geom geometry);
```

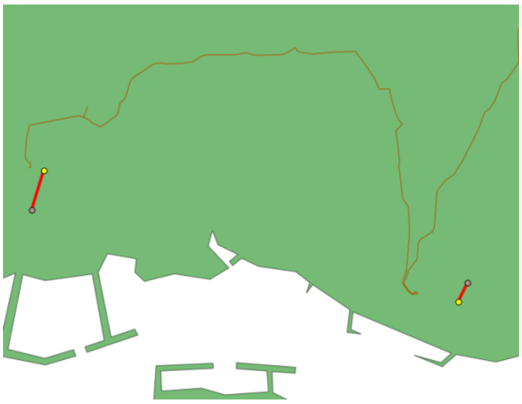


Figure 18 - The closest (red link) electricity substation (yellow) to each gas LNG operator (brown) of the National Gas Transmission System (brown links)

- Closest electricity substation (taken from the OS supplied electricity sub station set) to each gas storage site (taken from derived National Grid gas storage site data)

  e.g.
  ```
  SELECT * FROM
  ni_find_nearest_nodeB_to_nodeA_using_nn('derived_nationalgrid_gas_storage',
  'gid', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom',
  'closest_elecsubstation_to_gas_storage_site', false)f( node_A_id integer,
  node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line
  geometry, node_AB_distance numeric, gid integer, id integer, "name" varchar
  (50), geom geometry);
  ```

Figure 19 - The closest (red link) electricity substation (yellow) to each gas storage site (brown) of the National Gas Transmission System (brown links)

- Closest electricity substation (taken from the OS supplied electricity sub station set) to each gas terminal (taken from derived National Grid gas terminal data)

  e.g.
  ```
  SELECT * FROM
  ni_find_nearest_nodeB_to_nodeA_using_nn('derived_nationalgrid_gas_terminals',
  'gid', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom',
  'closest_elecsubstation_to_gas_terminal', false)f(node_A_id integer,
  node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line
  geometry, node_AB_distance numeric, gid integer, id integer, "name" varchar
  (50), geom geometry);
  ```

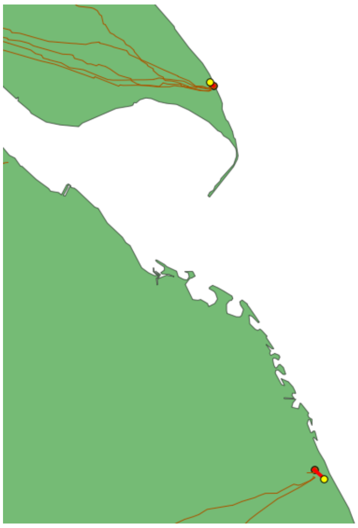


Figure 20 - The closest (red link) electricity substation (yellow) to each gas terminal site (brown) of the National Gas Transmission System (brown links)

Using National Grid supplied Electricity Substation data

- Closest electricity substation (taken from the National Grid supplied sub station set) to each gas compressor (taken from derived National Grid compressors data)

  e.g.
  ```
  SELECT * FROM
  ni_find_nearest_nodeB_to_nodeA_using_nn('derived_nationalgrid_gas_terminals',
  'gid', 'geom',
  'nationalgrid_substation_site_centroids_derived_operating_voltag', 'gid',
  'geom', 'closest_natgridelecsubstation_to_gas_terminal', false) f(node_A_id
  integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry,
  node_AB_line geometry, node_AB_distance numeric, substation varchar(100),
  operating_ varchar(100), gdo_gid numeric, action_dtt date, action_use
  varchar(30), action_typ varchar(1), status varchar(1), notes1 varchar(40),
  mims_asset varchar(12), mims_delet varchar(1), operatingv integer, orig_fid
  integer, geom geometry);
  ```

Figure 21 - The closest (red link) electricity substation (pink) to each gas compressor (brown) of the National Grid Gas Transmission System (brown links)

- Closest electricity substation (taken from the National Grid supplied sub station set) to each gas LNG operator (taken from derived National Grid LNG operators data)

  e.g.
  ```
  SELECT * FROM
  ni_find_nearest_nodeB_to_nodeA_using_nn('derived_nationalgrid_gas_lngoperators
  ', 'gid', 'geom',
  'nationalgrid_substation_site_centroids_derived_operating_voltag', 'gid',
  'geom', 'closest_natgridelecsubstation_to_gas_lngoperators', false) f(node_A_id
  ```

```
integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry,
node_AB_line geometry, node_AB_distance numeric, gid integer, id integer,
"name" varchar (50), geom geometry);
```

Figure 22 - The closest (red link) electricity substation (yellow) to each gas lng operator (brown) of the National Gas Transmission System

- Closest electricity substation (taken from the National Grid supplied sub station set) to each gas storage site (taken from derived National Grid gas storage site data)

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('derived_nationalgrid_gas_storage',
'gid', 'geom',
'nationalgrid_substation_site_centroids_derived_operating_voltag', 'gid',
'geom', 'closest_natgridelecsubstation_to_gas_storage_site', false)f( node_A_id
integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry,
node_AB_line geometry, node_AB_distance numeric, gid integer, id integer,
"name" varchar (50), geom geometry);
```

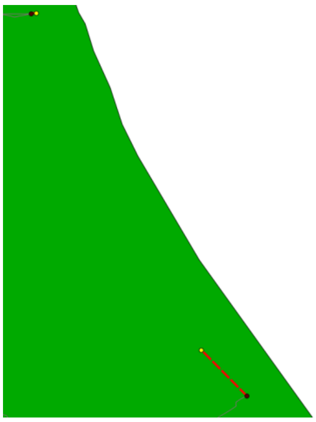


Figure 23 - The closest (red link) electricity substation (yellow) to each gas storage site (brown) of the National Gas Transmission System

- Closest electricity substation (taken from the National Grid supplied sub station set) to each gas terminal (taken from derived National Grid gas terminal data)

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('derived_nationalgrid_gas_terminals',
'gid', 'geom',
'nationalgrid_substation_site_centroids_derived_operating_voltag', 'gid',
'geom', 'closest_natgridelecsubstation_to_gas_terminal', false)f(node_A_id
integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry,
node_AB_line geometry, node_AB_distance numeric, gid integer, id integer,
"name" varchar (50), geom geometry);
```

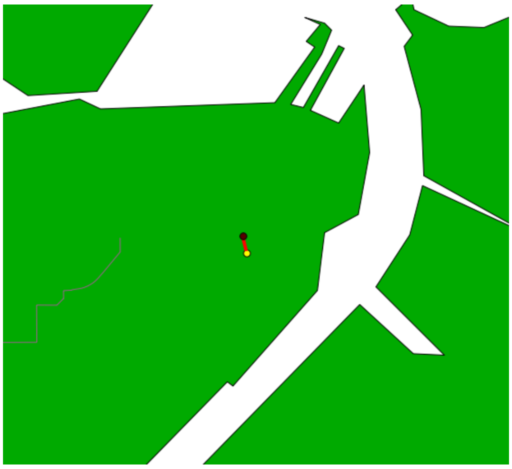


Figure 24 - The closest (red link) electricity substation (yellow) to each gas terminal site (brown) of the National Gas Transmission System

Calculating and representing dependencies between water distribution and gas transmission networks:

In order to represent the dependency of the national gas transmission network on the water distribution network, a nearest neighbour approach will be used due to the lack of connectivity data available.

- Closest water pumping station (taken from OS supplied water pumping stations set) to each gas compressor

```
e.g. SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('derived_nationalgrid_gas_compressors',
'gid', 'geom',  'OS_WaterPumpingStations', 'gid', 'geom',
'closest_waterpumpstation_to_gas_compressor', false)f( node_A_id integer,
node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line
geometry, node_AB_distance numeric, gid integer, gdo_gid numeric(10,0),
site_type varchar(12), site_name varchar(30), mims_asset varchar(12),
mims_delet numeric(10,0), notes1 varchar(40), status varchar(1), action_dtt
date, action_use varchar(30), action_typ varchar(1), orig_fid integer, geom
geometry);
```

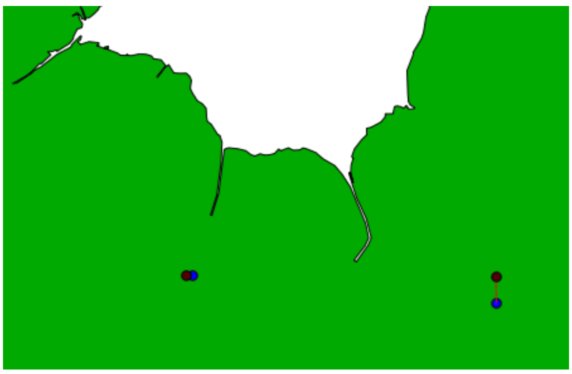


Figure 25 - The closest (red link) water pumping station (blue) to each gas compressor site (brown) of the National Gas Transmission System

- Closest water pumping station (taken from OS supplied water pumping stations set) to each LNG operator

```
e.g. SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('
derived_nationalgrid_gas_lngoperators', 'gid', 'geom',
'OS_WaterPumpingStations', 'gid', 'geom',
'closest_waterpumpstation_to_gas_lngoperator', false)f( node_A_id integer,
node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line
geometry, node_AB_distance numeric, gid integer, id integer, "name" varchar
(50), geom geometry);
```

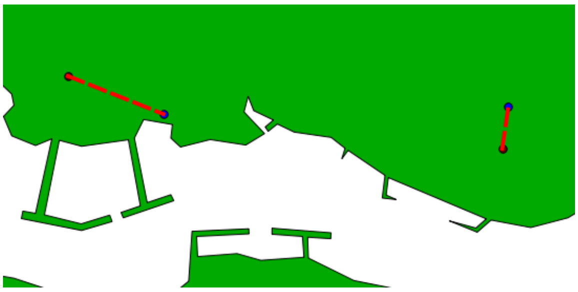


Figure 26 - The closest (red link) water pumping station (blue) to each gas LNG operator (brown) of the National Gas Transmission System

- Closest water pumping station (taken from OS supplied water pumping stations set) to each gas storage site

```
e.g. SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('
derived_nationalgrid_gas_storage', 'gid', 'geom',  'OS_WaterPumpingStations',
'gid', 'geom', 'closest_waterpumpstation_to_gas_storage_site', false)f(
node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom
geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, id
integer, "name" varchar (50), geom geometry);
```

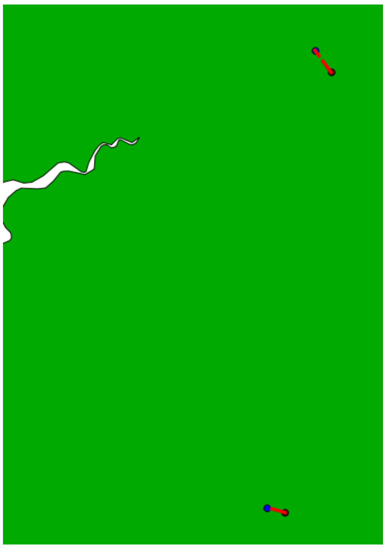


Figure 27 - The closest (red link) water pumping station (blue) to each gas storage site (brown) of the National Gas Transmission System

- Closest water pumping station (taken from OS supplied water pumping stations set) to each gas terminal

```
e.g. SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('
derived_nationalgrid_gas_terminals', 'gid', 'geom',  'OS_WaterPumpingStations',
'gid', 'geom', 'closest_waterpumpstation_to_gas_terminal', false)f( node_A_id
```

```
integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry,
node_AB_line geometry, node_AB_distance numeric, gid integer, id integer,
"name" varchar (50), geom geometry);
```

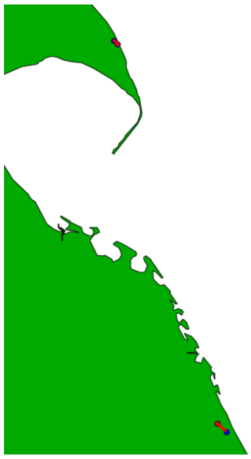


Figure 28 - The closest (red link) water pumping station (blue) to each gas storage terminal (brown) of the National Gas Transmission System

Calculating and representing dependencies between road network and gas transmission networks:

The interdependencies referred to within the interdependency matrix between the gas transmission and road networks are, in general, considered geographic in nature. For example these can include assets that are part of the gas transmission network, but are co-located along a road, or bridge. Secondly, access to gas transmission assets can also be considered a geographic dependency between the road network and the individual asset, facilitating operation and maintenance of assets that are permanently manned, or those requiring access for maintenance on an ad-hoc or temporary basis. Finally the transportation of gas tanks to parts of the gas transmission network is also dependent upon the road network.

Currently there is a lack of formal data available within the National Infrastructure Asset Database to represent these geographic dependencies. The grade separation data available within the Ordnance Survey ITN and Meridian 2 datasets could be utilised to determine the locations of bridges within the road network. In order to make an assessment of the dependency on the road network for asset access, a calculation of the nearest accessible road link to each asset could be employed. These links would represent the dependent links between the gas transmission network and the road network, as they could act as the sole conduits for access to the particular asset. Furthermore, additional information is required to understand which gas transmission assets are reliant on gas tanks / LNG tanks during their operation. This information could then be used to create network paths across the road network to represent the supply route to each asset.

Calculating and representing dependencies between rail network and gas transmission networks:

There is a lack of formal interdependency data available within the National Infrastructure Asset Database to represent interdependencies between the rail and gas networks. Similarly to the dependencies / interdependencies that have been described as existing between the road and the gas transmission network (see previous section), there is also a set of analogous dependencies between the gas transmission network assets, and the rail network. These again include areas of asset co-location, such as on bridges, as well as the use of the rail network for transportation of LNG. An additional useful piece of information would be to understand the routes and frequency of use of gas tank distribution throughout the rail network, which could then be used to create network paths. These can then be considered to be a set of dependent links between the two networks.

Gas: Regional Distribution System

Network Construction

There is currently no data available within the National Infrastructure Asset Database to represent the regional gas distribution systems. However the approaches to be applied to the regional distribution electricity networks could also be applied to the regional gas distribution networks as there are similarities in the organisation of both gas and electricity networks. The regional gas distribution operators will need to be contacted with respect to accessing their underlying network data.

Representing Interdependencies

Currently due to a lack of regional gas distribution network data, it is not possible to denote how dependencies on other networks will be calculated and represented. Initially, using spatial proximity between node sets, as suggested in the construction notes for other networks, could be employed. For example these could be generated between the pressure reduction sites and / or regulators where pressure from the National Gas Transmission System is reduced to flow within the Regional Gas Distribution System.

Electricity: National Transmission System

Network Construction

This section describes how the National Grid Transmission System will be constructed as a network model. There are currently two separate sets of guidelines for handling the different datasets representing energy generation sites outlined here; one that deals with all energy generation sites as supplied by the Ordnance Survey, and a second that deals with the DECC operational power stations, as of May 2011. The links created essentially join the generation site to a point on the grid, via a substation.

1a) Find the closest OS Energy Production Site to each substation point – defines a link (non-dependent/non-interdependent link) between site of electricity generation and its export in to the grid. This would return a link between the energy generation site and a substation of *any* operating voltage.

All energy production sites:

e.g.
```
SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OS_EnergyProductionSites', 'gid', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom', 'closest_ess_to_energyproductionsite_powerstations_derivedtype', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, oid_ character varying(254),  objectid numeric(10,0),  unique_ref numeric(10,0),  "name" character varying(254),  easting numeric,  northing numeric,  county character varying(254),  postcode character varying(254),  "type" character varying(50),  geom geometry);
```

Power stations only:

e.g.
```
SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OS_EnergyProductionSites_PowerStations_DerivedType', 'gid', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom', 'closest_ess_to_energyproductionsite_powerstations_derivedtype', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, oid_ character varying(254),  objectid numeric(10,0),  unique_ref numeric(10,0),  "name" character varying(254),  easting numeric,  northing numeric,  county character varying(254),  postcode character varying(254),  "type" character varying(50),  geom geometry);
```

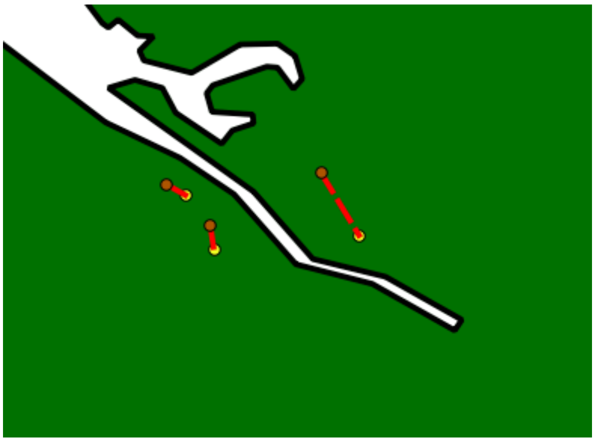


Figure 29 - Closest (red link) electricity sub station (yellow dot) to each power station from Ordnance Survey-supplied energy production sites

The following queries would look to return a link between the energy generation sites, and the National Grid owned Transmission substations of 400kV, 275kV, and 132kV respectively:

<INSERT FIGURE OF CLOSEST SUBSTATION 400KV SUBSTATION TO EACH ENERGY PRODUCTION SITE>

e.g.
```
SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OS_EnergyProductionSites', 'gid', 'geom', 'nationalgrid_substation_site_derived_operating_voltage_400kv, 'gid', 'geom', 'closest_natgrid_400kV_to_energyproductionsite', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, oid_ character varying(254), objectid numeric(10,0), unique_ref numeric(10,0), "name" character varying(254), easting numeric, northing numeric, county character varying(254), postcode character varying(254), geom geometry);
```

<INSERT FIGURE OF CLOSEST SUBSTATION 275KV SUBSTATION TO EACH ENERGY PRODUCTION SITE>

e.g.
```
SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OS_EnergyProductionSites', 'gid', 'geom', ' nationalgrid_substation_site_derived_operating_voltage_275kv, 'gid', 'geom', 'closest_natgrid_275kV_to_energyproductionsite', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, oid_ character varying(254), objectid numeric(10,0), unique_ref numeric(10,0), "name" character varying(254), easting numeric, northing numeric, county character varying(254), postcode character varying(254), geom geometry);
```

<INSERT FIGURE OF CLOSEST SUBSTATION 132KV SUBSTATION TO EACH ENERGY PRODUCTION SITE>

e.g.
```
SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OS_EnergyProductionSites', 'gid', 'geom', ' nationalgrid_substation_site_derived_operating_voltage_132kv, 'gid', 'geom', 'closest_natgrid_132kV_to_energyproductionsite', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, oid_ character varying(254), objectid numeric(10,0), unique_ref numeric(10,0), "name" character varying(254), easting numeric, northing numeric, county character varying(254), postcode character varying(254), geom geometry);
```

1b) Find the closest DECC OperationalPowerStation to each substation point – defines a link (non-dependent/non-interdependent link) between power station and its export to the grid. This would return a link between the DECC OperationalPowerStation and a substation of *any* operating voltage.

e.g. SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OperationalPowerStationsMay2011_OSGB36', 'gid', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom', 'closest_ess_to_decc_operationalpowerstationsmay2011', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, oid_ character varying(254), objectid numeric(10,0), unique_ref numeric(10,0), "name" character varying(254), easting numeric, northing numeric, county character varying(254), postcode character varying(254), geom geometry);

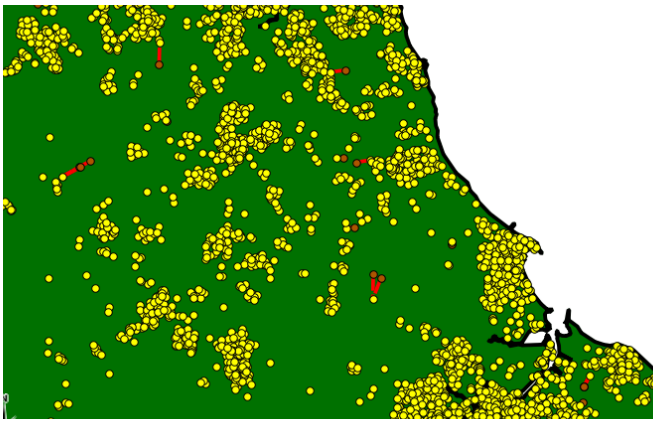


Figure 30 - Closest (red link) electricity substation (yellow dots) to each DECC operational power station (brown dot)

The following queries would look to return a link between the DECC OperationalPowerStation, and the National Grid owned Transmission substations of 400kV, 275kV, and 132kV respectively:

e.g. SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OS_ DECC_OperationalPowerStationsMay2011, 'gid', 'geom', ' nationalgrid_substation_site_derived_operating_voltage_400kv, 'gid', 'geom', 'closest_natgrid_400kV_to_decc_operationalpowerstation', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, oid_ character varying(254), objectid numeric(10,0), unique_ref numeric(10,0), "name" character varying(254), easting numeric, northing numeric, county character varying(254), postcode character varying(254), geom geometry);

<INSERT FIGURE OF CLOSEST 400KV NATIONAL GRID SUBSTATION TO EACH DECC OPERATIONAL POWER STATION>

e.g. SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OS_ DECC_OperationalPowerStationsMay2011, 'gid', 'geom', ' nationalgrid_substation_site_derived_operating_voltage_275kv, 'gid', 'geom', 'closest_natgrid_275kV_to_decc_operationalpowerstation', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, oid_ character varying(254), objectid numeric(10,0), unique_ref numeric(10,0), "name" character varying(254), easting numeric, northing numeric, county character varying(254), postcode character varying(254), geom geometry);

<INSERT FIGURE OF CLOSEST 275KV NATIONAL GRID SUBSTATION TO EACH DECC OPERATIONAL POWER STATION>

e.g. SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OS_ DECC_OperationalPowerStationsMay2011, 'gid', 'geom', '

```
nationalgrid_substation_site_derived_operating_voltage_132kv, 'gid', 'geom',
'closest_natgrid_132kV_to_decc_operationalpowerstation', false) f(node_A_id integer,
node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry,
node_AB_distance numeric, gid integer,  oid_ character varying(254),  objectid
numeric(10,0),  unique_ref numeric(10,0), "name" character varying(254),  easting
numeric,  northing numeric,  county character varying(254),  postcode character
varying(254),  geom geometry);
```

<INSERT FIGURE OF CLOSEST 132KV NATIONAL GRID SUBSTATION TO EACH DECC OPERATIONAL POWER STATION>

CAN ONLY INCLUDE THOSE GENERATION SITES / POWER STATIONS THAT LIE ON OR WITHIN X DISTANCE OF THE TRANSMISSION NETWORK – these sites are likely to be directly connected / co-located as the substations in the transmission network e.g.

Co-location of substations in National Grid Transmission System, and DECC_OperationalPowerStation (or using energy production sites from OS)

1) Convert the SUBSTATION_SITE dataset in to centroids.

NOTE: There is no need to convert either the Ordnance Survey supplied Energy Production Sites or the DECC_OperationalPowerStation datasets to centroids, as they only exist as point datasets.

2) Combine the National Grid Line and Cable datasets in to a single file with an additional attribute denoting whether a particular line feature is a line or cable. The purpose of performing this task is to ensure that only a single link layer is being dealt with when considering the whole National Grid Electricity Transmission Network. This step will also merge the attribute tables of the two datasets.

3) Interrogate both the resultant centroid data set representing National Grid Transmission substations (using attribute Operating_ to denote operating voltage) generated from step 1 and the corresponding transmission lines/cables (using Operating_ to denote maximum and minimum operating voltage) generated in step 2 to determine connectivity of the network. These two attributes found in the different datasets can be used to determine which transmission lines should connect to which substation.

4) Using the knowledge gained within step 3, utilise the data pre-processing tools available to connect spatially, the correct substations with the appropriate transmission lines within the network. For example the following tool within the database could be utilised to connect the transmission lines to the substations.

ni_data_proc_connect_nodes_to_point_on_nearest_edge_like - connects **the nearest point on an edge (which may or may not be an edge end)** to each node that are related by some relationship between two attributes; one attribute in the nodes table, and one attribute in the edges table.

This step would need to be repeated for each substation set identified and the transmission line features output as a result of step 2 i.e. repeat the step to infer connections for the Ordnance Survey supplied substations, as well as substations of different operating voltage as detailed in the National Grid Substation Site data (see step 1), and the transmission lines themselves.

MORE NEEDED HERE

Representing Interdependencies

Calculating and representing dependencies between the National Grid-owned electricity transmission network and the national gas transmission network:

The gas-only operational power stations can be filtered from the DECC OperationalPowerStations dataset using the following SQL query. The purpose of doing this would be to ensure that when calculating an interdependency between the electricity transmission network and the gas transmission network, that only the power stations utilising gas are considered. However this query assumes that all gas-fuelled power stations receive gas from the National Transmission network. As this may not be the case, further knowledge is required to understand which of the gas-based power station types require gas delivered by the National Gas Transmission network to operate, and which receive gas via another means e.g. tanks.

DECC_OperationalPowerStations (gas, gas CHP, gas oil, gas oil/kerosene, gas turbine, gas/coal/oil, gas/gas oil CHP, gas/oil, gas/oil/OCGT):

e.g.
```
CREATE TABLE "DECC_OperationalPowerStationsMay2011_Gas" AS SELECT
DISTINCT(decc.fuel_type) as fuel_type_, decc.* FROM
"DECC_OperationalPowerStationsMay2011" as decc WHERE decc.fuel_type LIKE '%gas%'
OR decc.fuel_type LIKE '%OCGT%' OR decc.fuel_type LIKE '%CCGT%';
```

The result of this query can be utilised to help generate an interdependency link between the National Grid Gas Transmission Network that delivers gas to power stations that are connected to the National Grid Electricity Transmission Network.

Calculating and representing dependencies between the National Grid-owned electricity transmission network and the regional electricity distribution networks:

In order to understand further the links between the national electricity network and the regional distribution networks, additional information is required regarding the locations of substations acting as part of each regional distribution network. In order to establish this link, the following steps can be followed to extract the highest value substations from a regional distribution network, and the lowest value substations from the national transmission network as this is likely to represent the points at which a regional distribution network connects to the national network.

1) Retrieve all substations equal to the lowest value, by operating voltage, of the National Grid Electricity Transmission network:

e.g. SELECT MIN (national_substations.operatingv) FROM nationalgrid_substation_site_centroids_derived_operating_voltag as national_substations

e.g. SELECT DISTINCT(national_substations.operatingv), national_substations.* FROM national_grid_substation_site_centroids as national_substations WHERE national_substations.operatingv = MIN(national_substations.operatingv);

2) Retrieve all substations with the highest operating voltage within each regional electricity distribution network:

e.g. SELECT MAX(operatingv) FROM <insert_regional_distribution_substation_table> as regional_substations

e.g. SELECT DISTINCT(regional_substations.operatingv), regional_substations.* FROM <insert_regional_distribution_substation_table> as regional_substations WHERE regional_substations.operatingv = MIN(regional_substations.operatingv)

The result of performing these two types of operation would be to generate a node set of the lowest value of operating voltage for national transmission substations, and also a set of the substations from a particular regional distribution network with the highest value of operating voltage. Following generation of these subsets, with each subset operation being repeated for each set of regional distribution substations, it would be possible to generate a link between the national and regional systems. For example we can see here that there is likely to be some level of connectivity between the national electricity transmission network (red) and the regional distribution network (blue), perhaps via a link (purple).

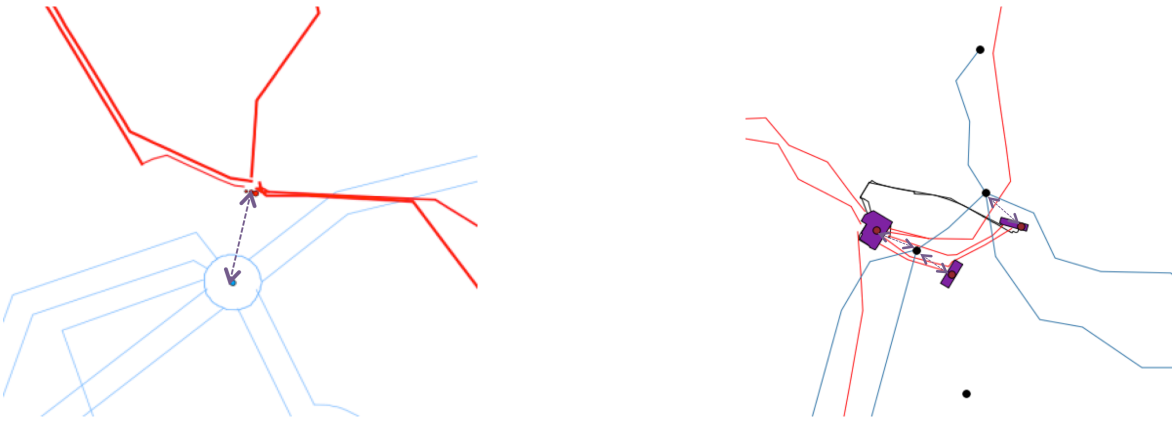


Figure 31 - Regional electricity distribution (blue), national electricity transmission (red), dependent links between the two (purple)

Calculating and representing dependencies between the National Grid-owned electricity transmission network and water distribution networks:

- Closest water pumping station (taken from OS supplied water pumping stations set) to each energy production site (OS supplied)

  e.g.
  ```
  SELECT * FROM
  ni_find_nearest_nodeB_to_nodeA_using_nn('OS_EnergyProductionSites', 'gid',
  'geom', 'OS_WaterPumpingStations', 'gid', 'geom',
  closest_wps_to_eps_powerstations_derivedtype', false) f(node_A_id integer,
  node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line
  geometry, node_AB_distance numeric, gid integer, oid_ character varying(254),
  objectid numeric(10,0),  unique_ref numeric(10,0),  "name" character
  varying(254),  easting numeric,  northing numeric,  county character
  varying(254),  postcode character varying(254),  "type" character varying(50),
  geom geometry);
  ```

  <INSERT FIGURE OF CLOSEST WATER PUMPING STATION TO EACH OS-SUPPLIED ENERGY PRODUCTION SITE>

- Closest water pumping station (taken from OS supplied water pumping stations set) to each energy production site with derived power type

e.g. `SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OS_EnergyProductionSites_PowerStations_DerivedType', 'gid', 'geom', 'OS_WaterPumpingStations', 'gid', 'geom', closest_wps_to_eps_powerstations_derivedtype', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, oid_ character varying(254), objectid numeric(10,0), unique_ref numeric(10,0), "name" character varying(254), easting numeric, northing numeric, county character varying(254), postcode character varying(254), "type" character varying(50), geom geometry);`

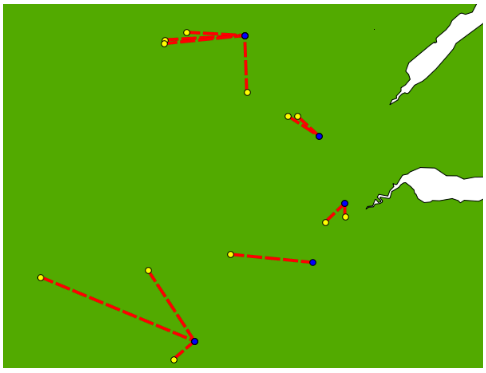


Figure 32 - Closest (red link) water pumping station (blue dot) to each Ordnance Survey-supplied Energy Production Site (yellow dot)

- Closest water pumping station (taken from OS supplied water pumping stations set) to each DECC operational power station (DECC supplied)

e.g. `SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('DECC_OperationalPowerStationsMay2011', 'gid', 'geom', 'OS_WaterPumpingStations', 'gid', 'geom', 'closest_wps_to_decc_operationalpowerstationsmay2011', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, co_name varchar(254), station_na varchar(254), fuel_type varchar(254), capacity numeric(10,0), com_year numeric(10,0), lat numeric, lng numeric, expct_clos smallint, water_use double precision, cldwatrsou varchar(50), cldwtrinpo varchar(50), geom geometry);`

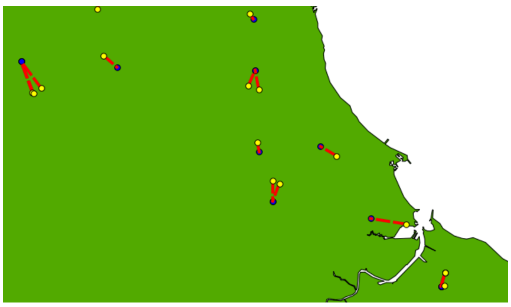


Figure 33 - Closest (red link) water pumping station (blue dot) to each DECC Operational Power Station, May 2011.

Calculating and representing dependencies between the National Grid-owned electricity transmission network and the road network:

- Link between OS supplied energy production sites and OS Meridian road node / roundabout

  e.g. SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('', 'gid', 'geom', '', 'gid', 'geom', '<INSERT_OUTPUT_TABLE_NAME>', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, …, geom geometry);

- Link between DECC OperationalPowerStations May 2011 and OS Meridian road node / roundabout

  e.g. SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('', 'gid', 'geom', '', 'gid', 'geom', '<INSERT_OUTPUT_TABLE_NAME>', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, …, geom geometry);

Calculating and representing dependencies between the National Grid-owned electricity transmission network and the rail network:

e.g. SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('', 'gid', 'geom', '', 'gid', 'geom', '<INSERT_OUTPUT_TABLE_NAME>', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, …, geom geometry);

Electricity: Regional Distribution System

Network Construction

Currently there are only a handful of datasets that are stored within the National Infrastructure Asset Database that can be used to represent regional electricity distribution systems. These have been identified in Table.3 and Table.4, to represent networks owned by Electricity North West and NEDL.

Electricity North West

1) The substation data, split by voltage, should be converted to points.

2) The data as identified in table.3 is split into multiple layers describing the substations of different voltages, and distribution lines of different voltages. For each of the substation data layers assign the appropriate voltage value as an attribute of each substation i.e. 33kV, 132kV.

3) Similarly to step 2, assign voltage values as an attribute of all distribution lines i.e. 33kV, 132kV. This will need to be done for each distribution layer, of which there are four.

4) Merge the substations layers in to a single substation (node) data layer.

5) Merge the distribution line layers in to a single distribution line (edge) data layer.

NOTE: Steps 4 and 5 should be conducted after the attribute tables of each layer have been checked that they are consistent. Effectively only the assigned voltages, performed in steps 2 and 3, should exist as attributes of either the substation or distribution line layers.

6) Once the distribution line layers have been merged, the resulting data layer should be checked to ensure that any erroneous edges, present as a result of the data conversion techniques employed, should be removed. Figure.17 illustrates this problem, arising from converting GeoPDF data to ESRI Shapefile formats, via AutoCAD .dxf format:

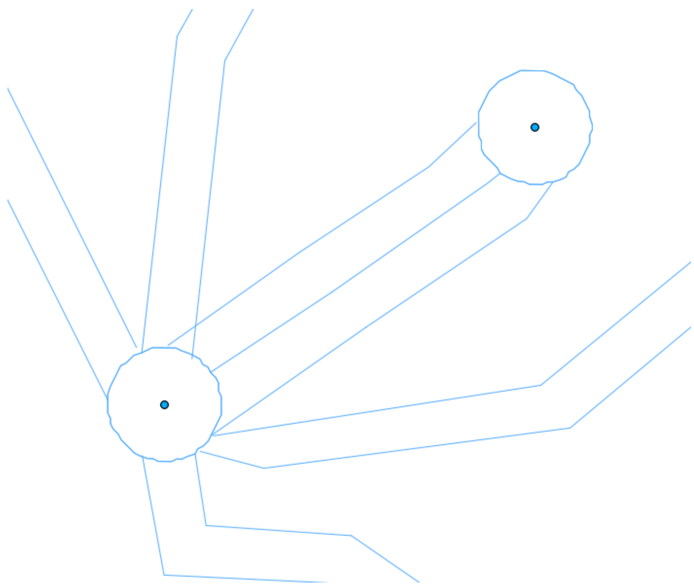


Figure 34 - Double circuit edges within Electricity North West regional distribution network, misrepresented as rings around substation

7) Once the erroneous lines have been removed the dataset, the edges will not be spatially connected to the appropriate substations. At this point the attribute tables of the substation and distribution line layers should be interrogated to try and identify any common attribute that will help to denote some level of connectivity within the network. If no such attribute pairing exists between the different layers, then the next best approximation is to use the spatial proximity of distribution line end points and substations. The result of doing this should be a spatially valid representation of the network.

8) If attributes can be matched between the substations and distribution line datasets, then this pairing should subsequently be investigated for its use in inferring directionality along the distribution lines.

Northern Electric Distribution Limited

1) Assign the appropriate voltage values to each distribution line dataset representing the different voltages in the network, as a new attribute.

2) Merge the different distribution line datasets together to form a single distribution line dataset, with an attribute denoting the voltage of each line/edge.

NOTE: When merging the lines together it is sensible to ensure that the attribute tables of the different datasets are the same. Effectively this will be to ensure that only the voltage value remains.

3) Assign the appropriate voltage values to each substation within the NEDL substation layer, as a new attribute. There is no need to merge this data because only a single layer exists for all NEDL substations.

Representing Interdependencies

At present there are effectively only two datasets that can be utilised to represent a regional electricity distribution networks, and they include the Electricity North West, and NEDL example datasets. However the processes for formulating a representation of a dependency broadly applies to all regional networks, whether data exists currently for the network or not.

Calculating and representing dependencies between the regional electricity distribution networks and the National Grid-owned electricity transmission:

- Closest 400, 275 (or potentially 132) kV substation to highest voltage substation within each regional electricity distribution network

```
400kV

SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('','','geom', '', '', 'geom',
<insert_output_table_name>_400kV', false) f( node_A_id integer, node_A_geom geometry,
node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance
numeric, …, geom geometry);
```

<INSERT FIGURE WHERE NATIONAL GRID ELECTRICITY TRANSMISSION STEPS DOWN TO 400kV REGIONAL ELECTRICITY DISTRIBUTION FROM 400Kv TRANSMISSION>

```
275kV

SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('','','geom', '', '', 'geom',
<insert_output_table_name>_275kV', false) f( node_A_id integer, node_A_geom geometry,
node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance
numeric, …, geom geometry);
```

<INSERT FIGURE WHERE NATIONAL GRID ELECTRICITY TRANSMISSION STEPS DOWN TO 275kV REGIONAL ELECTRICITY DISTRIBUTION FROM 275Kv TRANSMISSION>

```
132kV

SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('','','geom', '', '', 'geom',
<insert_output_table_name>_132kV', false) f( node_A_id integer, node_A_geom geometry,
node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance
numeric, …, geom geometry);
```

<INSERT FIGURE WHERE NATIONAL GRID ELECTRICITY TRANSMISSION STEPS DOWN TO 132kV REGIONAL ELECTRICITY DISTRIBUTION FROM 132Kv TRANSMISSION>

Calculating and representing dependencies between the regional electricity distribution networks and the water distribution network:

- Closest electricity cables (often underground) to each water pumping station used for cooling the cables

```
SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('','','geom', '', '', 'geom',
<insert_output_table_name>', false) f( node_A_id integer, node_A_geom geometry,
node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance
numeric, …, geom geometry);
```

Calculating and representing dependencies between the regional electricity distribution networks and the road network:

- Calculate closest road access point to each substation and/or network asset feature
    - Ordnance Survey Supplied Substations to OS Meridian road node / roundabout

SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OS_ElectricitySubStations', 'gid', 'geom', 'os_meridian_2_rndabout_point', 'code', 'geom', 'closest_electricity_substation_os_meridian_2_rndabout', false) f (node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, …, geom geometry);

- ENW 132, 33kV substations for all ENW regions to OS Meridian road node / roundabout

SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('', 'gid', 'geom', 'os_meridian_2_rndabout_point', 'code', 'geom', 'closest_enw_substation_os_meridian_2_rndabout', false) f (node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, …, geom geometry);

- What about other features found in the regional distribution networks

Calculating and representing dependencies between the regional electricity distribution networks and the rail network:

- Calculate closest rail station to each substation and/or network asset feature

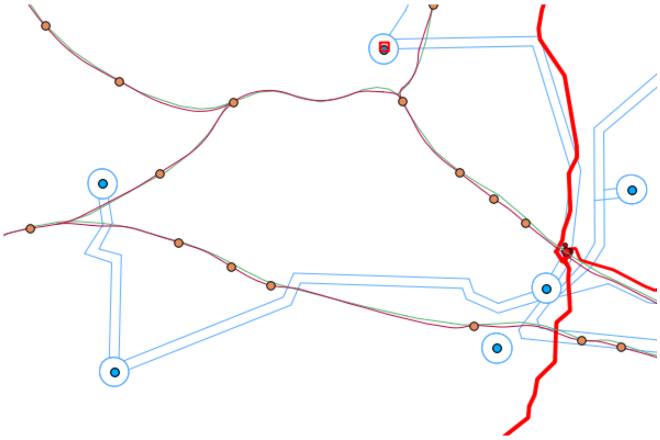


Figure 35 - proximity of rail stations (orange dots) to regional electricity distribution assets (blue dots)

Transport

Road:

NetworkX constructs the network from the edges only

Optional points table (match between node and geometry of node created from edges)

Network Construction

Representing Interdependencies

Calculating and representing dependencies between road features and electricity transmission and distribution networks via substations (using Ordnance Survey supplied substations):

-to help determine how electricity is supplied to the road network for signage, monitoring etc

> e.g. SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('', 'gid', 'geom', '', 'gid', 'geom', '<INSERT_OUTPUT_TABLE_NAME>', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, …, geom geometry);

Calculating and representing dependencies between coach stations and regional electricity distribution via electricity substations (using Ordnance Survey supplied substations):

In order to represent the dependency of coach stations on the electricity transmission and distribution networks, a nearest neighbour approach will be used due to the lack of connectivity data available detailing how coach stations receive their power from either the national transmission or regional distribution networks. Power is required for the safe operation and delivery of bus and coach services to and from each coach station.

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('naptan_coachreferences','gid','geom',
'OS_ElectricitySubStations', 'gid', 'geom', 'closest_elecsubstation_to_coach_station',
false) f( node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom
geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, atcocode
character varying(254), operatorre character varying(254), nationalco character
varying(254), "name" character varying(254), namelang character varying(254), longname
character varying(254), longnamela character varying(254), gridtype character
varying(254), easting numeric(10,0), northing numeric(10,0), creationda character
varying(254), modificati character varying(254),  revisionnu numeric(10,0), modifica_1
character varying(254), geom geometry);
```

<INSERT FIGURE OF CLOSEST ELECTRICITY SUB STATION AND EACH COACH STATION>

Rail:

Network Construction

NetworkX constructs the network from the edges only

Optional points table (match between node and geometry of node created from edges)

Representing Interdependencies

Calculating and representing dependencies between rail line and electricity distribution via electricity substations (using Ordnance Survey supplied substations) to understand how electrified sections of the rail network receive their power.

In order to represent the interdependencies that exist between the rail network and the regional electricity distribution network(s), additional data is required to represent the locations where electricity from the regional distribution network(s) is supplied to the rail network. Furthermore, an understanding of what sections of the rail network are electrified at present is also required. In the absence of this data, an alternative source of information that could be used is the interval or frequency of substations along an electrified section of the railway. Further to this, knowledge of the general distance between a railway line and a substation powering it would be complementary. By combining these pieces of information together, a search function could be generated to determine which substation *may* be used to power the railway. This operation would follow these steps:

1) Determine interval of substations e.g. 500m

2) Determine sections of railway that are electrified

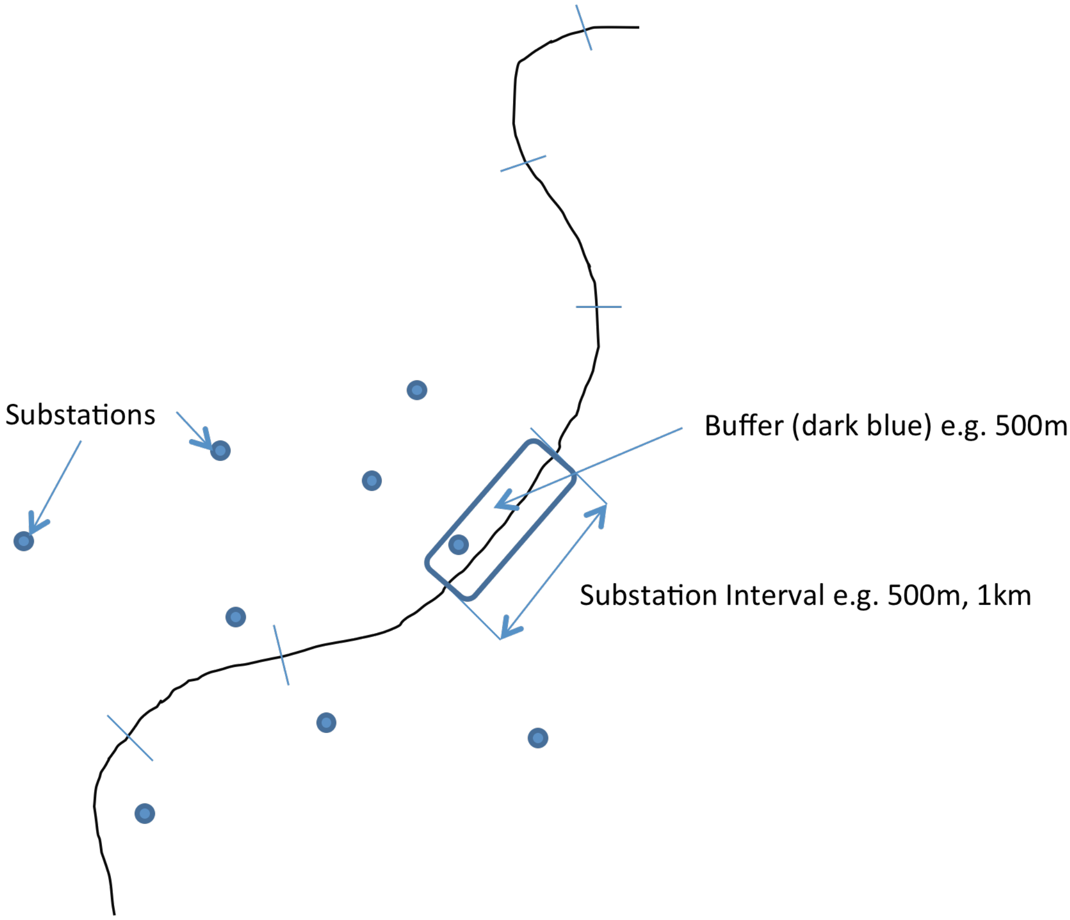
3) For each electrified section of the railway, split the section by the interval, in to a series of sub-sections.

4) For each sub-section create a buffer of set distance, based upon the likely separation of the railway and the powering substation. Alternatively if there is no maximum or average distance knowledge available, a buffer of ever-increasing distance could be used.

5) Once the buffer is created, this can be intersected with the available substation data (filtered to required rating).

6) Calculate the closest point within each buffer to the railway section, and generate a line between these points.

The graphical representation of this process can be seen in Figure.x



For example figure.x illustrates the result of running the afore-mentioned type of function to determine which sub station could be supplying power to a particular section of the rail network:

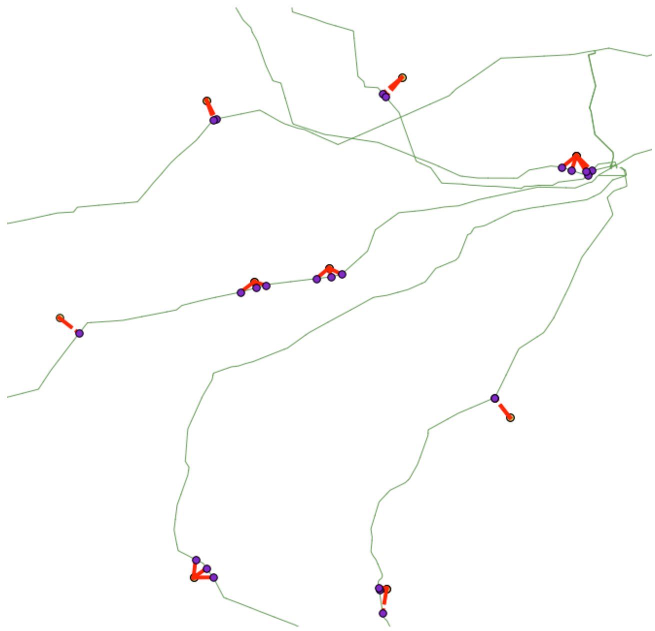


Figure 36 - Substations (yellow dot) possibly supplying power (red dashed line) to electrified sections of the rail network (green line), at various potential connection points (purple dots)

Calculating and representing dependencies between NAPTAN rail stations and regional electricity distribution via electricity substations (using Ordnance Survey supplied substations):

e.g.
```
SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('naptan_railreferences',
'gid', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom',
'closest_elecsubstation_to_railway_station', false) f( node_A_id integer, node_A_geom
geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry,
node_AB_distance numeric, gid integer, atcocode varchar(254), tiplocode varchar (254),
crscode varchar (254), stationnam varchar (254), stationn_1 varchar (254), gridtype
varchar (254), easting numeric(10, 0), northing numeric(10, 0), creationda varchar(254),
modificati varchar(254), revisionnu numeric (10, 0), modifica_1 varchar (254), geom
geometry);
```

<INSERT FIGURE OF CLOSEST ELECTRICITY SUBSTATION TO EACH RAIL STATION>

Calculating and representing dependencies between Ordnance Survey Meridian 2 rail stations and regional electricity distribution via electricity substations (using Ordnance Survey supplied substations):

e.g.
```
SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('os_meridian_2_station_point',
'identifier', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom',
'closest_elecsubstation_to_railway_station', false) f( node_A_id integer, node_A_geom
geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry,
node_AB_distance numeric, code double precision, identifier character(13),  "name"
character(70),  geom geometry)
```

Air:

Network Construction

There are two sets of data available within the National Infrastructure Asset Database that could potentially be used to generate the air transport network; the OpenFlights database for UK only airports and travel (Airport, airline and routes data: OpenFlights , 2012), and the airport and airline statistics available from the Civil Aviation Authority (Authority, 2012). Both of these datasets are similar whereby routes, and some passenger and / or airline information is available between different origin and destination airports. These data can be utilised to create a spatially correct, topological network representation of domestic air travel within the UK.

Representing Interdependencies

Calculating and representing dependencies between airports and the gas transmission/distribution network

There is currently no data available for any of the regional gas distribution networks to help generate a link between the airports and regional gas distribution. The type of connection is likely to exist to provide space heating for airport facilities.

Calculating and representing dependencies between airports and the electricity transmission/distribution network

In order to represent the dependency of airports on the electricity transmission and distribution networks, a nearest neighbour approach will be used due to the lack of connectivity data available detailing how airports receive their power from either the national transmission or regional distribution networks. Not only is power required to operate the facilities within the terminal buildings of airports themselves, it is also required for the operation of aircraft monitoring equipment such as that found in air traffic control towers.

Using Ordnance Survey supplied Airports and Ordnance Survey supplied electricity sub stations

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('OS_Airports','gid','geom',
'OS_ElectricitySubStations', 'gid', 'geom',
'closest_elecsubstation_to_os_airports', false) f( node_A_id integer, node_A_geom
geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry,
node_AB_distance numeric, gid integer, oid_ varchar(254), number_ numeric, "name"
varchar(254), easting numeric, northing numeric, county varchar(254), geom
geometry);
```

Figure 37 - Closest (red link) electricity sub station (blue dot) to each Ordnance Survey supplied airport (yellow dot)

Using OpenFlights.org supplied UK only airports and Ordnance Survey supplied electricity sub stations

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('openflights_airports_uk_only','airportid'
,'geom','OS_ElectricitySubStations', 'gid',
'geom','closest_elecsubstation_to_openflights_uk_airports',false)f( node_A_id
integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry,
node_AB_line geometry, node_AB_distance numeric, airportid integer, "name"
```

```
character(254), city character(254), country character(254), iata_faa_c
character(10), icao_code character(10), latitude double precision, longitude
double precision, altitude double precision, timezone double precision, dst
character(5), geom geometry);
```

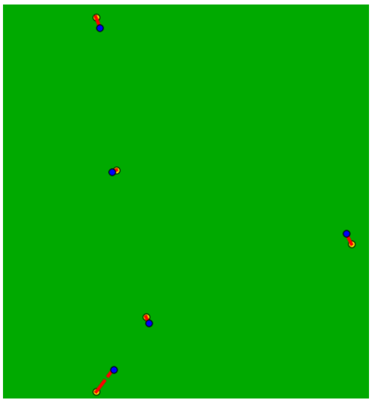


Figure 38 - Closest (red link) electricity sub station (blue dot) to each Openflights airports (yellow dot)

Calculating and representing dependencies between airports and the water distribution network

In order to represent the dependency of airports on the water distribution network, a nearest neighbour approach will be used. Water is supplied to airports both for use by aircraft, as well as the operation and maintenance of air traffic features including supply to terminal buildings.

Using Ordnance Survey supplied Airports and Ordnance Survey supplied water pumping stations

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('OS_Airports','gid','geom','OS_WaterPumpin
gStations','gid','geom','closest_waterpumpingstation_to_os_airports',false)f(
node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry,
node_AB_line geometry, node_AB_distance numeric, gid integer, oid_ varchar(254),
number_ numeric, "name" varchar(254), easting numeric, northing numeric, county
varchar(254), geom geometry);
```

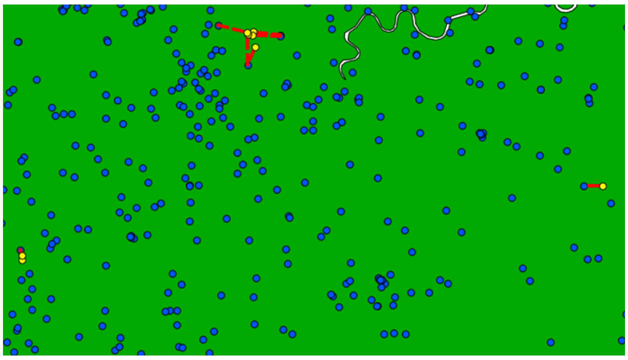


Figure 39 - Closest (red link) water pumping station (blue dot) to each Ordnance Survey-supplied airport (yellow dot)

Using OpenFlights.org supplied UK only airports and Ordnance Survey supplied water pumping stations

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('openflights_airports_uk_only','airportid'
,'geom','OS_WaterPumpingStations','gid','geom','closest_waterpumpingstation_to_ope
nflights_uk_airports',false)f( node_A_id integer, node_A_geom geometry, node_B_id
integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric,
airportid integer, "name" character(254), city character(254), country
character(254), iata_faa_c character(10), icao_code character(10), latitude double
```

```
precision, longitude double precision, altitude double precision, timezone double
precision, dst character(5), geom geometry);
```

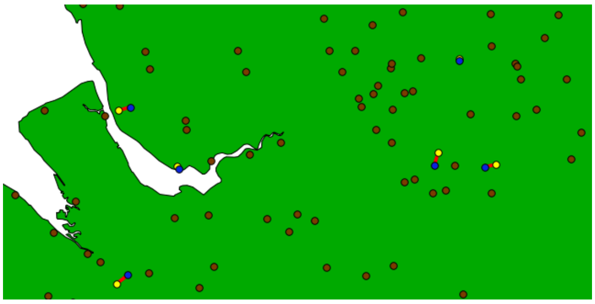


Figure 40 - Closest (red link) water pumping station (blue dot) to each Openflights airport (yellow dot)

<INSERT FIGURE OF CLOSEST WATER PUMPING STATION TO AIRPORT – FROM OPENFLIGHTS>

Calculating and representing dependencies between airports and the wastewater treatment network

In order to represent the dependency of airports on the waste water distribution network, a nearest neighbour approach will be used. Waste water generated at airport sites needs to be removed and treated.

Using Ordnance Survey supplied Airports and Urban Waste Water Database Treatment Works

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('OS_Airports','gid','geom',
'UWWTW_T_UWWTPS_UK_ONLY_OSGB', 'gid', 'geom',
'closest_wastewatertreatmentworks_to_os_airports', false) f( node_A_id integer,
node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line
geometry, node_AB_distance numeric, gid integer, oid_ varchar(254), number_
numeric, "name" varchar(254), easting numeric, northing numeric, county
varchar(254), geom geometry);
```

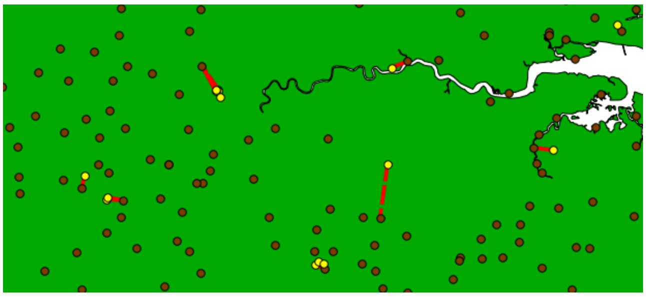


Figure 41 - Closest (red link) waste water treatment works (brown dot) to each Ordnance Survey-supplied airports (yellow dot)

Using OpenFlights.org supplied UK only airports and Urban Waste Water Database Urban Waste Water Treatment Works

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('openflights_airports_uk_only','airportid'
,'geom', 'UWWTW_T_UWWTPS_UK_ONLY_OSGB', 'gid', 'geom',
'closest_wastewatertreatmentworks_to_openflights_uk_airports',false)f( node_A_id
integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry,
node_AB_line geometry, node_AB_distance numeric, airportid integer, "name"
character(254), city character(254), country character(254), iata_faa_c
character(10), icao_code character(10), latitude double precision, longitude
double precision, altitude double precision, timezone double precision, dst
character(5), geom geometry);
```

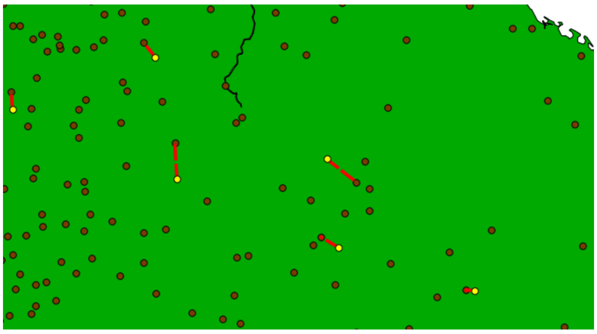


Figure 42 - Closest (red link) waste water treatment works (brown dot) to each Openflights supplied airports (yellow dot)

<INSERT FIGURE OF CLOSEST WASTE WATER TREATMENT WORKS TO EACH AIRPORT OF OPENFLIGHTS DATA>

Water

Network Construction

- Reservoirs, OS (Meridian 2 and Strategi) lakes/rivers layers
- Try loading rivers in to NetworkX

Representing Interdependencies

Calculating and representing dependencies between water pumping stations and electricity sub stations

In order to represent the dependency of the water distribution network on the electricity transmission and distribution networks, a nearest neighbour approach will be used due to the lack of connectivity data available detailing how water pumping stations receive their power. Water pumping stations require power both for their operation when manned, but also to allow remote operation and maintenance via SCADA systems.

e.g.
```
SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('OS_WaterPumpingStations',
'gid', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom',
'closest_elecsubstation_to_pumping_station', false) f( node_A_id integer, node_A_geom
geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry,
node_AB_distance numeric, gid integer, oid_ varchar(254), objectid numeric(10, 0),
unique_ref numeric(10, 0), "name" varchar(254), easting numeric, northing numeric,
county varchar(254), postcode varchar(254), geom geometry);
```

The addition of further information regarding how power is served to water pumping stations may require adjustment of this query to only perform the operation on substations of a particular voltage i.e. power supplied to water pumping stations is only received from substations of a set voltage.

The result of this type of query can be seen in figure.x. The yellow markers indicate electricity sub stations, whilst the blue markers indicate water pumping stations, with the red line between them inferring delivery of power to the pumping station from the sub station based purely on proximity.

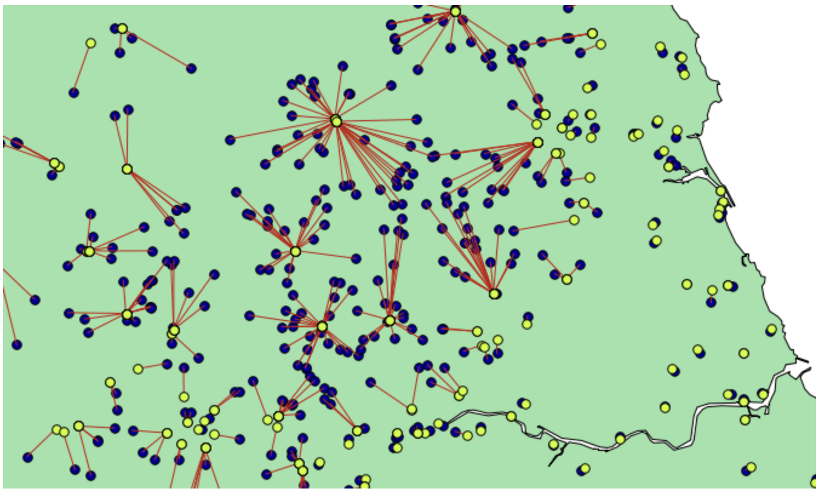


Figure 43 - Inferring interdependency between a water pumping station and electricity sub station

Waste water

Network Construction

- Need to get hold of any water resource zone transfer pipelines / networks

- Reservoirs, OS (Meridian 2 and Strategi) lakes/rivers layers
- Try loading rivers in to NetworkX
-

The linkages between the waste water treatment works and the related discharge points within the Waste Water Treatment Works Directive Data (Waterbase - UWWTD: Urban Waste Water Treatment Directive, 2011), can be created in two ways;

Nearest neighbour calculation

This approach will calculate the closest discharge point to every waste water treatment works from the available data.

E.g. `SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('UWWTW_T_UWWTPS_UK_ONLY_OSGB', 'gid', 'geom', 'UWWTW_T_DischargePoints_UK_ONLY_OSGB36', 'gid', 'geom', 'closest_uwwtw_t_discharge_point_to_waste_water_treatment_works', false)f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, uwwid double precision, uwwstate double precision, rptmstatek varchar(254), aggid double precision, uwwcode varchar(254), uwwname varchar(254), uwwcollect double precision, uwwdateclo varchar(254), uwwhistori varchar(254), uwwlatitud double precision, uwwlongitu double precision, uwwnuts double precision, uwwloadent double precision, uwwcapacit double precision, uwwprimary smallint, uwwseconda smallint, uwwothertr smallint, uwwnremova smallint, uwwpremova smallint, uwwuv smallint, uwwchlorin smallint, uwwozonati smallint, uwwsandfil smallint, uwwmicrofi smallint, uwwother smallint, uwwspecifi varchar(254), uwwbod5per double precision, uwwcodperf double precision, uwwtssperf double precision, uwwntotper double precision, uwwptotper double precision, geom geometry);`

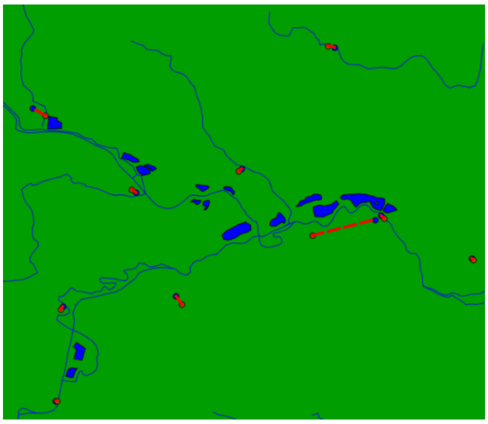


Figure 44 - Closest (red link) discharge point (blue dot) to each waste water treatment works (brown dot)

*Using the linkage between the **uwwid** attribute of the discharge point data, and the **uwwid** attribute of the waste water treatment works data*

e.g. `SELECT * FROM ni_link_nodeB_to_nodeA_by_attribute('UWWTW_T_UWWTPS_UK_ONLY_OSGB', 'uwwid', 'geom', 'uwwid', 'nodeset_A_', 'UWWTW_T_DischargePoints_UK_ONLY_OSGB36', 'dcpid', 'geom', 'uwwid', 'nodeset_B_', 'uwwtw_t_uwwtps_link_uwwtw_discharge_points_Feb2011', False) f(nodeset_A_gid integer, nodeset_A_uwwid double precision, nodeset_A_uwwstate double precision, nodeset_A_rptmstatek character varying(254), nodeset_A_aggid double precision, nodeset_A_uwwcode character varying(254), nodeset_A_uwwname character varying(254), nodeset_A_uwwcollect double precision, nodeset_A_uwwdateclo character varying(254), nodeset_A_uwwhistori character varying(254), nodeset_A_uwwlatitud double precision, nodeset_A_uwwlongitu double precision, nodeset_A_uwwnuts double precision,`

```
nodeset_A_uwwloadent double precision, nodeset_A_uwwcapacit double precision,
nodeset_A_uwwprimary smallint, nodeset_A_uwwseconda smallint, nodeset_A_uwwothertr
smallint, nodeset_A_uwwnremova smallint, nodeset_A_uwwpremova smallint, nodeset_A_uwwuv
smallint, nodeset_A_uwwchlorin smallint, nodeset_A_uwwozonati smallint,
nodeset_A_uwwsandfil smallint, nodeset_A_uwwmicrofi smallint, nodeset_A_uwwother
smallint, nodeset_A_uwwspecifi character varying(254), nodeset_A_uwwbod5per double
precision, nodeset_A_uwwcodperf double precision, nodeset_A_uwwtssperf double precision,
nodeset_A_uwwntotper double precision, nodeset_A_uwwptotper double precision,
nodeset_A_geom geometry, nodeset_B_gid integer, nodeset_B_dcpid double precision,
nodeset_B_dcpstate double precision, nodeset_B_rptmstatek character varying(254),
nodeset_B_uwwid double precision, nodeset_B_dcpcode character varying(254),
nodeset_B_dcpname character varying(254), nodeset_B_dcpnuts double precision,
nodeset_B_dcplatitud double precision, nodeset_B_dcplongitu double precision,
nodeset_B_dcpwaterbo double precision, nodeset_B_dcpirrigat double precision,
nodeset_B_dcptypeofr double precision, nodeset_B_rcaid double precision,
nodeset_B_dcpsurface double precision, nodeset_B_dcpwater_1 character varying(254),
nodeset_B_dcpnotaffe character varying(254), nodeset_B_dcpmsprovi character
varying(254), nodeset_B_dcpcomacce character varying(254), nodeset_B_dcpgroundw
character varying(254), nodeset_B_dcpreceivi character varying(254),
nodeset_B_dcpwfdsubu character varying(254), nodeset_B_dcpwfdrbd character varying(254),
nodeset_B_dcpremarks character varying(254), nodeset_B_dcpwfdrbdr date,
nodeset_B_dcpwater_2 date, nodeset_B_dcpgroun_1 character varying(254),
nodeset_B_dcprecei_1 date, nodeset_B_dcpwfdsu_1 character varying(254), nodeset_B_geom
geometry, node_A_id double precision, node_A_attr double precision, node_A_geom
geometry, node_B_id double precision, node_B_attr double precision, node_B_geom
geometry, node_AB_line geometry, node_AB_distance numeric);
```

The result of running such a query can be seen in figure.x. This illustrates the links between each waste water treatment work and their respective discharge point back to a particular water course. The treatment works are shown in light green, whilst the discharge points are shown in dark blue.

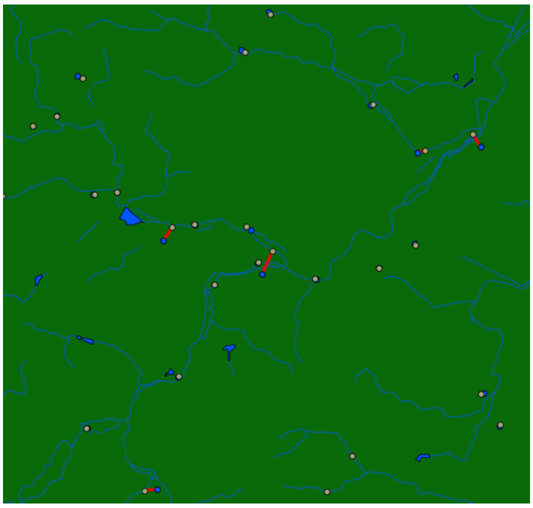


Figure 45 - Link between Urban Waste Water Treatment Works and their respective discharge points

Representing Interdependencies

Calculating and representing dependencies between waste water treatment works and electricity sub stations

In order to represent the dependency of the waste water treatment network on the electricity transmission and distribution networks, a nearest neighbour approach will be used due to the lack of connectivity data available detailing how waste water treatment works receive their power.

e.g. `SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('UWWTW_T_UWWTPS_UK_ONLY_OSGB', 'gid', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom', 'closest_elecsubstation_to_waste_water_treatment_works', false) f(node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, uwwid double precision, uwwstate double precision, rptmstatek varchar(254), aggid double precision, uwwcode varchar(254), uwwname varchar(254), uwwcollect double precision, uwwdateclo varchar(254), uwwhistori varchar(254), uwwlatitud double precision, uwwlongitu double precision, uwwnuts double precision, uwwloadent double precision, uwwcapacit double precision, uwwprimary smallint, uwwseconda smallint, uwwothertr smallint, uwwnremova smallint, uwwpremova smallint, uwwuv smallint, uwwchlorin smallint, uwwozonati smallint, uwwsandfil smallint, uwwmicrofi smallint, uwwother smallint, uwwspecifi varchar(254), uwwbod5per double precision, uwwcodperf double precision, uwwtssperf double precision, uwwntotper double precision, uwwptotper double precision, geom geometry);`

<INSERT DIAGRAM OF CLOSEST WASTE WATER TREATMENT WORKS TO EACH ELECTRICITY SUB STATION>

Solid Waste

Network Construction

The solid waste network will utilise the available waste site data available from features within the Ordnance Survey Points of Interest data, including:

- recycling, reclamation and disposal (Points of Interest – 02120196)
- medical waste disposal services (Points of Interest – 05290361)
- refuse disposal facilities (Points of Interest - 06340440)
- recycling centres (Points of Interest - 06340462)
- waste, storage, processing, disposal (Points of Interest - 06340441)

These features will form the likely destinations of a large amount of the waste generated within the UK, with local refuse collection sites operating as the likely origins of the waste. The road network generated as part of the networks developed for the transport sector will be utilised to traverse shortest paths between the refuse collection sites and the likely disposal points i.e. those listed above. However specific consideration may need to be taken against industrial or commercial sites that generate large amounts of waste and have to dispose of this in a specific way or at a specific site. For example, medical waste generated from hospitals or medical centres can only be disposed of at specific sites capable of dealing with medical waste. In general further consultation with researchers within the solid waste sector is required to understand how different types of waste can be disposed of. These two considerations will influence how shortest paths are generated between origins and destinations across the road network, as waste may not be able to be treated at any of the sites mentioned.

In addition, this approach will, in general, handle the commercial and industrial aspects of solid waste collection and disposal. In order to address the collection of waste generated from residential sources, a proxy for the origins in the network is required to avoid creating thousands of networks representing the path taken by waste collected at the kerbside to disposal and / or land fill sites. There are alternative administrative boundaries available within the UK that could be utilised to represent the origin of residential waste collection i.e. assuming that all solid waste collection from residential sources originates from the centroid of each of the administrative boundaries from the chosen set. However further information is required to understand which boundary set would be most suitable in terms of understanding at what geographic level residential waste collection is handled e.g. ward, district, borough, county. Table 22 gives an overview of the types of boundary that exist within England and the number of features within each set:

Description	FeatureCount (England Only)
Government Office Regions	9
Counties	47
Districts + Districts in unitary authorities	335 + 55 (390)
Lower level super output areas + lower level super output areas in unitary authorities	27102 + 5431 (32533)
Middle level super output areas + middle level super output areas in unitary authorities	5696 + 1125 (6821)
Output areas + output areas in unitary authorities	138240 + 27491 (165731)
Wards	7619

Table 22 - Examples of potential administrative boundaries to be used as proxy for origins in residential waste collection

Representing Interdependencies

Calculating and representing dependencies between the solid waste sector disposal/processing sites and the regional electricity distribution networks:

In order to represent the dependency of the solid waste sector network on the regional electricity distribution network, a nearest neighbour approach will be used. Electricity is required at many of the solid waste assets including recycling centres, refuse / disposal facilities and processing plants to power the sites and machinery themselves, whilst also provided power for employees working at these sites.

Using Ordnance Survey supplied Electricity Substation data

- Closest electricity substation to each Ordnance Survey supplied Points of Interest Recycling Centres

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('derived_poi_recycling_centres',
'unique_reference_number', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom',
'closest_ess_to_poi_recycling_centres', false) f( node_A_id character(20),
node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line
geometry, node_AB_distance numeric,  topographic_toid_version character(20),
pointx_classification_code character(20),  qualifier_type character(20),
feature_easting character(20),  date_of_supply character(20),  itn_easting
character(20),  itn_toid_version character(20),  itn_northing character(20),
postcode character(20),  "name" character(20),  provenance character(20),
positional_accuracy_code character(20),  address_detail character(20),
feature_northing character(20),  url character(20),  unique_reference_number
character(20),  brand character(20),  topographic_toid character(20),  locality
character(20),  distance character(20),  qualifier_data character(20),
street_name character(20),  telephone_number character(20),  geographic_county
character(20),  itn_toid character(20),  verified_address character(20),  geom
geometry);
```

Figure 46 - Closest (red link) electricity sub station (yellow dot) to each Ordnance Survey Points of Interest (green dot) - NW only

- Closest electricity substation to each Ordnance Survey supplied Points of Interest Refuse and Disposal Facilities

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('derived_poi_refuse_disposal_facilities',
' unique_reference_number', 'geom', 'OS_ElectricitySubStations', 'gid', 'geom',
'closest_elecsubstation_to_poi_disposal_facilities', false) f( node_A_id
character(20), node_A_geom geometry, node_B_id integer, node_B_geom geometry,
```

```
node_AB_line geometry, node_AB_distance numeric,  topographic_toid_version
character(20),  pointx_classification_code character(20),  qualifier_type
character(20),  feature_easting character(20),  date_of_supply character(20),
itn_easting character(20),  itn_toid_version character(20),  itn_northing
character(20),  postcode character(20),  "name" character(20),  provenance
character(20),  positional_accuracy_code character(20),  address_detail
character(20),  feature_northing character(20),  url character(20),
unique_reference_number character(20),  brand character(20),  topographic_toid
character(20),  locality character(20),  distance character(20),  qualifier_data
character(20),  street_name character(20),  telephone_number character(20),
geographic_county character(20),  itn_toid character(20),  verified_address
character(20),  geom geometry);
```

<INSERT FIGURE OF CLOSEST SUB STATION TO POINTS OF INTEREST REFUSE AND DISPOSAL FACILITIES>

-Closest electricity substation to each Ordnance Survey supplied Points of Interest Waste Storage and Processing Facilities

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('derived_poi_waste_storage_processing_disp
osal', 'unique_reference_number', 'geom', 'OS_ElectricitySubStations', 'gid',
'geom', 'closest_elecsubstation_to_poi_waste_storage_processing_disposal', false)
f( node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom
geometry, node_AB_line geometry, node_AB_distance numeric,  gid integer,  oid_
character varying(254),  os_toid character varying(254),  easting numeric,
northing numeric,  geom geometry);
```

<INSERT FIGURE OF CLOSEST SUB STATION TO POINTS OF INTEREST WASTE STORAGE AND PROCESSING FACILITIES>

Calculating and representing dependencies between the solid waste sector disposal/processing sites and the waste water treatment and redistribution networks:

In order to represent the dependency of the solid waste sector network on the waste water treatment and redistribution network, a nearest neighbour approach will be used. Waste disposal and processing sites can produce waste water as a by product of the processing undertaken on waste products, and this therefore needs to be removed and treated, which is dependent on the waste water network.

- Closest Urban Waste Water Treatment Works to each Ordnance Survey supplied Points of Interest Recycling Centres

e.g.
```
SELECT * FROM
ni_find_nearest_nodeB_to_nodeA_using_nn('UWWTW_T_UWWTPS_UK_ONLY_OSGB', 'gid',
'geom', 'derived_poi_recycling_centres', 'gid', 'geom',
'closest_urban_waste_water_treatment_works_to_poi_recycling_centre', false) f(
node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry,
node_AB_line geometry, node_AB_distance numeric, gid integer, uwwid double
precision, uwwstate double precision, rptmstatek varchar(254), aggid double
precision, uwwcode varchar(254), uwwname varchar(254), uwwcollect double
precision, uwwdateclo varchar(254), uwwhistori varchar(254), uwwlatitud double
precision, uwwlongitu double precision, uwwnuts double precision, uwwloadent
double precision, uwwcapacit double precision, uwwprimary smallint, uwwseconda
smallint, uwwothertr smallint, uwwnremova smallint, uwwpremova smallint, uwwuv
smallint, uwwchlorin smallint, uwwozonati smallint, uwwsandfil smallint,
uwwmicrofi smallint, uwwother smallint, uwwspecifi varchar(254), uwwbod5per double
```

```
precision, uwwcodperf double precision, uwwtssperf double precision, uwwntotper double precision, uwwptotper double precision, geom geometry);
```

<INSERT FIGURE OF CLOSEST WASTE WATER TREATMENT WORKS FOR EACH RECYCLING CENTRES>

- Closest Urban Waste Water Treatment Works to each Ordnance Survey supplied Points of Interest Refuse and Disposal Facilities

e.g.
```
SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('UWWTW_T_UWWTPS_UK_ONLY_OSGB', 'gid', 'geom', 'derived_poi_refuse_disposal_facilities', 'gid', 'geom', 'closest_urban_waste_water_treatment_works_poi_disposal_facilities', false) f( node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, uwwid double precision, uwwstate double precision, rptmstatek varchar(254), aggid double precision, uwwcode varchar(254), uwwname varchar(254), uwwcollect double precision, uwwdateclo varchar(254), uwwhistori varchar(254), uwwlatitud double precision, uwwlongitu double precision, uwwnuts double precision, uwwloadent double precision, uwwcapacit double precision, uwwprimary smallint, uwwseconda smallint, uwwothertr smallint, uwwnremova smallint, uwwpremova smallint, uwwuv smallint, uwwchlorin smallint, uwwozonati smallint, uwwsandfil smallint, uwwmicrofi smallint, uwwother smallint, uwwspecifi varchar(254), uwwbod5per double precision, uwwcodperf double precision, uwwtssperf double precision, uwwntotper double precision, uwwptotper double precision, geom geometry);
```

<INSERT FIGURE OF CLOSEST WASTE WATER TREATMENT WORKS TO EACH POI REFUSE DISPOSAL FACILITIES>

- Closest Urban Waste Water Treatment Works to each Ordnance Survey supplied Points of Interest Waste Storage and Processing Facilities

e.g.
```
SELECT * FROM ni_find_nearest_nodeB_to_nodeA_using_nn('UWWTW_T_UWWTPS_UK_ONLY_OSGB', 'gid', 'geom', 'derived_poi_waste_storage_processing_disposal', 'gid', 'geom', 'closest_urban_waste_water_treatment_works_poi_waste_storage_processing_disposal', false) f( node_A_id integer, node_A_geom geometry, node_B_id integer, node_B_geom geometry, node_AB_line geometry, node_AB_distance numeric, gid integer, uwwid double, uwwstate double, rptmstatek varchar(254), aggid double, uwwcode varchar(254), uwwname varchar(254), uwwcollect double, uwwdateclo varchar(254), uwwhistori varchar(254), uwwlatitud double, uwwlongitu double, uwwnuts double, uwwloadent double, uwwcapacit double, uwwprimary smallint, uwwseconda smallint, uwwothertr smallint, uwwnremova smallint, uwwpremova smallint, uwwuv smallint, uwwchlorin smallint, uwwozonati smallint, uwwsandfil smallint, uwwmicrofi smallint, uwwother smallint, uwwspecifi varchar(254), uwwbod5per double, uwwcodperf double, uwwtssperf double, uwwntotper double, uwwptotper double, geom geometry);
```

<INSERT FIGURE OF CLOSEST WASTE WATER TREATMENT WORKS TO EACH POI WASTE STORAGE / PROCESSING FACILITIES>

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