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Data Specification

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This report has been compiled for The Department for International Development (DFID) and Cities Alliance by Imperial College London (ICL) and the Institute for Integrated Economic Research (IIER) for The Ecological Sequestration Trust.

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Future Cities Africa – Resilience.IO Platform:

Resource Economic Human Ecosystem Model Prototype

Data Specifications

Draft

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Rembrandt Koppelaar (IIER)
Hannes Kunz (IIER)
Nilay Shah (ICL)
James Keirstead (ICL)

1. Overview

This document describes the data specification of the resource-economic human ecosystem model under development from a data structure and needs analysis. The prototype model is developed as part of the Department for International Development (DfID) funded Future Cities Africa (FCA) project and is to become a core component of the **resilience.io** platform of the Ecological Sequestration Trust (the Trust). This document is an 'evolving' document and will be updated periodically throughout the project. Comments on the document can be sent to Rembrandt Koppelaar (koppelaar@iier.ch) and Stephen Passmore (Stephen.passmore@ecosequestrust.org).

1.1 Project Goals

The development vision is for an open source model to become available to city-regions across the world including deployment for African cities. The model is to provide in-depth insights in a substantial portion of available resources and wastes in city-regions inclusive of their metropolian area and supply hinterland, and how policy and technology decisions can positively or negatively affect resource flows, expressed in terms of social, economic, and environmental performance indicators. The model architecture is designed to enable decision-makers and key stakeholders to make better city-wide policies, plans, investments and interventions.

At the end of the project in month 18 the model will be at the level of prototype software, to enable the project team to demonstrate its overall functionality at an individual sector level, and to provide insights in how scaling of the model will provide for cross-sector real life application in city metropolitan areas and their supply hinterland, contingent upon additional funding necessary to secure required local data inputs and create modifications to move from prototype demonstration to functional use.

The framework is to be built for flexible adaptation to different city-region contexts from both a socio-economic and resource perspective, such that a bespoke model for each city and its hinterland can be developed, given that the required data collection effort to incorporate local specifics take place.

1.2 Purpose of this specification

The data specifications describes the data elements of the prototype model, which create a computer representation of the real world. It serves to inform the resource, human, economic, ecosystems model by outlining the structure of large data elements (objects), and the smaller data elements to which they relate (properties). For example, a parent in modelling terms can be described as an ‘object’, with the ‘property’ of having a child, among other properties. The data specifications form the basis to describe the technical specifications (milestone 4), by formulating model data elements as objects together with their properties. The change in these objects and properties in time and space are captured by interactions which are formulated as a set of relationships in the technical specifications. As such the data and technical specifications when implemented in computer code bring the sector (or economy) of a city-region to ‘life’ as a computer model (they represent the world in objects and describe the change therein).

The data specifications also inform the approach to build a local version of the model. A first outline is created of overall and local data needs to build the model. The approach on how to collect local data is described in the data collection strategy (milestone 7), which serves to provide structured guidelines to setup a local model, using a standardized approach. For example, the data collection strategy in milestone 7 will describe how population surveys, census data, and satellite data, are brought together to provide values for the data types outlined in these data specifications .

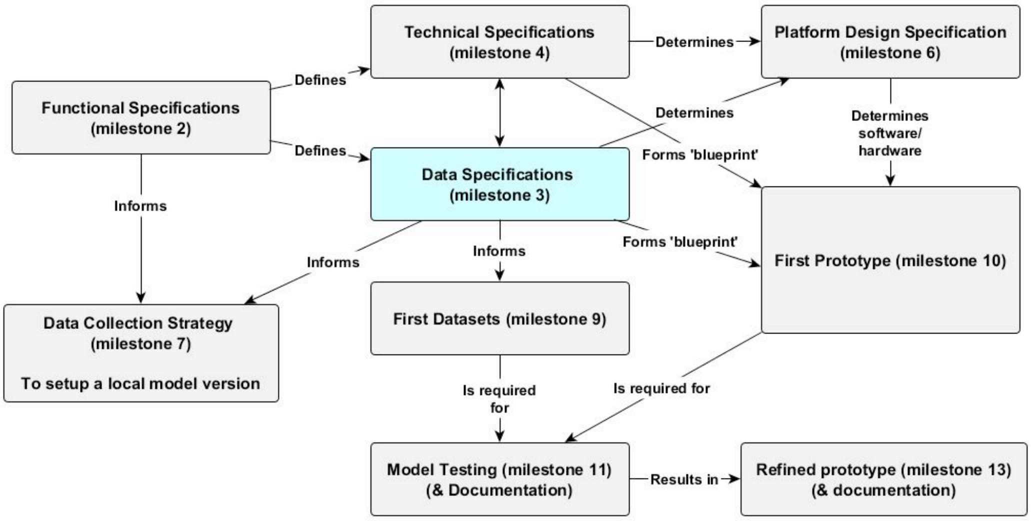

Fig. 1.1 - Relationship between data specifications and other milestones of the decision-making model development component of the FCA project.

1.3 Document Overview

The document is outlined on the basis of ‘generalized’ objects that serve to represent space, people, buildings, machines, animals and other aspects of the real world. These objects and the properties that they exhibit, such as their type and weight, are described. For each property of an object defined in this document, either a data value will be collected, or a value calculation will be created, to build the ‘modelled’ world in the computer.

The documentation is built around four key objects, **space, entities, processes,** and **agents**, which are summarised in section 3. Additional details for each of the components are outlined respectively in sections 4, 5, 6, and 7 in terms of describing what the object type entails, what data is related, and how they can be described as potential model data tables of the database to be built. Significant further detail is added in these sections on overall data structures and meta-data, including a first data dictionary with respective data tables. The actual implementation is subject to revision, so as to decide whether relational tables will be used or not. Further details of this will be explored in the platform design specifications, which forms milestone 6 of the FCA decision-making model prototype development.

An illustration of how a modelled sector relates to process object data is outlined in sections 8 and 9, where an example is provided on the development of the sugar cane sector in Ghana, and how this would transform the Greater Accra Metropolitan Area (GAMA) city-region’s sugar imports and inland transportation, inclusive of bagasse and molasses by-products, and their conversion into electricity and ethanol. After the illustration model data input requirements are discussed and outlined in section 10 split by each type of object (space, entity, process, and agent). The report ends with an outline of standardised practices of data treatment to be incorporated in the data management structure (section 11), and an overview of the integration of data types with international classification standards (section 12).

1.4 Phased development overview

The development of the prototype model is part of a 5 year development split into a number of phases. As a final outcome a user friendly model version is to be released under open source conditions.[1] The Future Cities Africa (FCA) project supports the 18 month development under **phase 1a**, to build a prototype which demonstrates the core functionality of the modeling approach. This document outlines the data specification, including in specific cases developments related to future phases.

In this document, various functionality aspects are attributed to the phases outlined below:

- Phase 1: Prototype providing all relevant functionality and datasets to validate and test the approach using real data (Phase 1a limited to a sector application and with limited capabilities of simulated agents in internal model driven decision making).
- Phase 2: First test implementation of prototype and development of fully scalable first release.
- Phase 3: Full open source/access release with enhanced user interfaces and external interfacing options.

Each phase is aimed at delivering a certain combination of model aspects to ensure the highest possible quality of the final product. An overview of data related aspects and their introduction in particular phases is included in table 1.1 below, as also mentioned in separate places within the text

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[1] "Open-source" has many different interpretations and the precise license terms for the tool have not yet been decided. However our working definition is that "open source" refers to "computer software with its source code made available with a license in which the copyright holder provides the rights to study, change and distribute the software to anyone and for any purpose." (http://en.wikipedia.org/wiki/Open-source_software)

Table 1.1 – Overview of Development Phases and High-Level Scope

Phasing	Phase 1a	Phase 1b	Phase 2	Phase 3+ Enhanced final product
Activity Duration from 1/12/14	0 - 18 months	12 - 30 months depending on time of funding availability	24 - 48 months	48 - 72 months
Scope	Proof of concept based on a functional model covering one important economic sector (e.g. energy)	Proof of concept covering an entire economy (city plus hinterland)	Applicable and reusable model with all relevant functionality for assisted local runs	Optimised open-source/access solution with full documentation and interfaces to external models
Spatial depiction (4 / 4.1)	2D Raster format with height/slope attributes 2D vector objects for special cases		Large sets of 2D vector objects for basic visualisation	Inclusion of 3D space objects for visual purposes
Entity data layers (5 / 5.1)	Material flow based depiction of entities on mass basis (with energy states as applicable)		Limited implementation of substance tracing (molecules, atoms) across entities with change due to processes, including eco-toxicity and human toxicity endpoint impacts	Substance flow tracing with incorporation of relevant elements and toxic compounds (molecules, atoms) using established eco- and human toxicity dose response curves
Ecological Processes (section 6.1.1)	Simple agro-ecosystems (e.g. mono-cropping	Simple terrestrial ecosystems (e.g. pine forests, grasslands)	Complex agro-ecosystems (e.g. combined agricultural-livestock systems)	Complex terrestrial and aquatic ecosystems (e.g. estuaries, rainforests)

	agriculture, mono-grazing) Based on empirical pattern recreation	Based on weather inputs, soil and hydrology flow logic of entities/space	by weather, soil, hydrology flow logic between entities/space, and simple ecosystems (forests, savannahs lakes) by external party model data input-output coupling	by external party model data input-output coupling
Environmental processes (section 6.1.1)	Basic weather (rainfall, sunshine, temperature) based on empirical pattern recreation	Hydrology based on internal flow logic between grid cells	Complex weather (humidity, wind, particles) based on stochastic empirical pattern recreation + climate scenario weather variability data inputs	
Macro-human processes /process blocks (section 6.1.2)	Approximately 50 key process blocks documented	Approximately 120 key process blocks documented	Addition of user additions of process blocks with quality validation and monetary parameters	
Event processes (section 6.1.4)	Manual forcing of parameters based on scenario narrative (capability testing)		Limited implementation of events w. frequency, inferred probability, and impacts (test cases with solid data availability)	Standardised events using risk incl. internal logic impacts effects (dependent on data input for robustness per case)

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3. Prototype Objects

The key to effective model construction is to include the least number of building blocks necessary to represent the real world, for the use cases in question, whilst maintaining the ability to display the behaviour of interest, especially at initial stages. The reasons are improvement in transparency in interpretation and testing, tractability in operating the model, validation, and flexibility in creating model expansions.

The prototype is split up into five large building blocks as defined in the functional specifications. These can subsequently be related to modelled objects which represent entities we observe in the real world that have a rational or subjectively chosen boundary, and properties can be ascribed to these objects that relate to a data value. For example, a pile of cement (object) has a weight (property) of 50 kilograms (value). An understanding of all such properties of an object required to understand what data is required for the model, and as such in this report the prototype model's objects, their properties, and information about the values which define these properties, are described, so as to create a complete first data specification.

In the model there are four 'generic' type objects, **space**, **entities**, **processes**, and **agents**, which form the ability to represent physical change in its interaction with socio-economic behaviour.

The generic description of these four types are:

- **Space**, as a 2D or 3D representation of dimensions in length, width, and height in a grid or as vectors.
- **Entities**, as physical non-human objects with a boundary which exist in space and time (e.g. a machine, a pile of stones, a building, a water body). They can also contain other entities within their structure (e.g. a machine in a building).
- **Agents**, as human (or animal) objects with a set of behaviours which interact with the physical world by carrying out activities, as market participants, and as producers, consumers, and owners (e.g. people, companies).[2]
- **Processes,** as objects that define the relationships of possible changes that can occur in space and time between entity objects and agent objects (e.g. chemical reactions, transportation).

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[2] It could also be used to describe animals if it would be necessary to include animal behaviour.

The four object properties provide for the ability to create the building blocks as outlined in the functional specifications (see figure 3.1 below). Space objects provide the basis for land use mapping and terrain mapping, as the foundation for the resource and infrastructure map building block. The physical components mapped therein, such as infrastructure within the built environment, major ecological features, and stocks of resources, are depicted as entities with their own locational coordinates, providing a physical 'snapshot' of a sector (or the economy) of the city-region and its supply hinterland. Within this structure a process block building block is incorporated based on the process relation between entities, and agents, physically related by energy and material flows and labour hour inputs by a process object. In a similar fashion resource flow networks building blocks become 'alive' by mapping entities and the process objects which operate on these, inclusive of agent objects governed by behavioural rules. Finally, policy decisions as a building block are not described within the data structure as an object as such, but as an operation on particular dataset parameters.

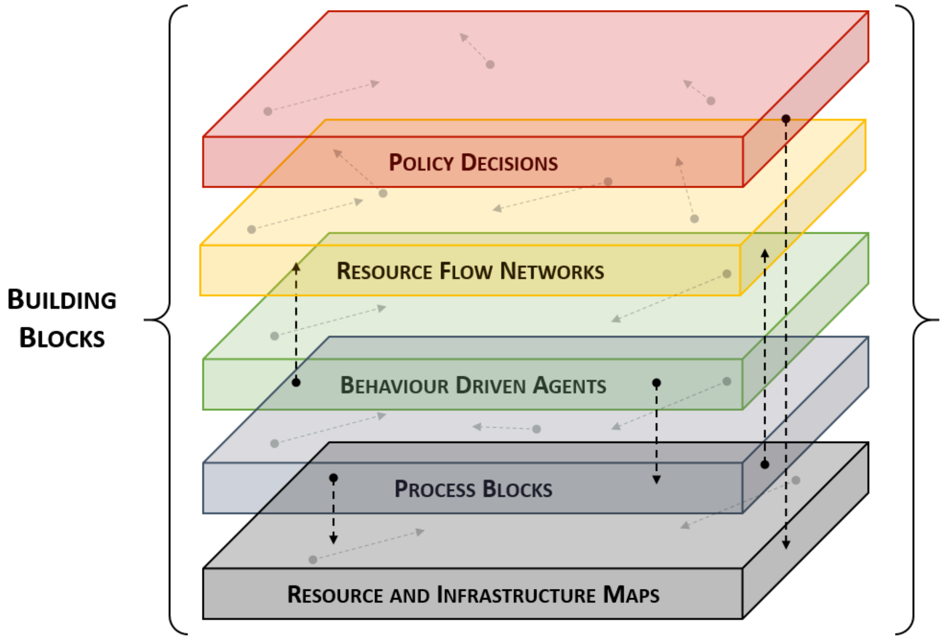

Fig. 3.1 – The building blocks of the Resource-Economic Human Ecosystem

The ‘mechanisms’ by which the objects create resource flows in the model environment, how they represent socio-economic interactions, and how human ecosystems indicators are provided, are to be detailed in the technical specifications (milestone 5 of the FCA program).

In this report the technical data aspects of each type of object are defined, as described in each of the sections 4, 5, 6, and 7 sequentially. First, on the basis of a set of minimum ‘generic’ properties that they need to possess to count as such an entity. Secondly, on the basis of describing individual variants which have additional properties on top of the ‘generic’ object, with the purpose to enable inheritance of properties of ‘generic’ entities. In the use of this procedure, variants can effectively be created using object oriented software engineering inheritance principles.

Prior to outlining the technical aspects, however, a brief overview of key object interrelationships is provided in the next section 3.1, to illustrate conceptually how the four objects are related.

3.1 Object interaction illustration

The **entity** objects in the model represent all the non-human physical objects that exist, from relatively simple homogeneous entities such as a ton of grain or a conveyor belt, to complex heterogeneous mixed entities such as an agricultural field or a part of the atmosphere. Similar to the real world, entities can be directly related based on their occurrence in **space** objects, such as the sawing machinery within a factory, or trees in a forest. The existence of **entity** objects in the model in essence represent a 'snapshot' in time, describing the physical properties of entities that can only change over time if a **process** object operates on the entity. For example, the saw machines as part of a furniture factory are represented by their qualitative and quantitative characteristics, as radial arm saws that weigh 150 kilogram with a volume of 2.8 m^3.

A **process** object for saws describes how such a saw cuts a piece of wood board in a certain timespan, as an input into a series of planks plus sawdust as outputs, including required electricity inputs and heat losses as energy input-outputs. As such properties of process objects are described including the type of **entities** on which it can operate (in this case wood boards) and process detail, e.g. for the saw a cutting speed of 53 meters of wood board per second plus its variability, and power input to output in wattage. The sum of such unit processes within a factory describe the entirety of a 'process block' as a factory, as aggregate input to outputs on a bottom-up basis.

In the case of the furniture factory **process** objects do not operate autonomously, however, and like in the real world require human intervention, which is represented in the model by **agent** objects as clusters of people and companies. People agent objects are defined on the basis of their activities in carrying out work, leisure, sleep, food consumption and so forth, as well as contributing labour inputs, among other properties. For any human-driven **process** objects to operate, labour inputs from **agent** objects are required, similar to any other type of material **entity** objects, defined as the inputs for the **process** to operate. By simulating the work activities of clusters of people as **agent** objects, the model provides for the availability (or lack thereof) by which a **process** object creates change in a set of **entity** objects into another set of entity objects caused by resource conversions. For example, see the conversion of clay/stone entities into brick entities illustrated in figure 3.2 below.

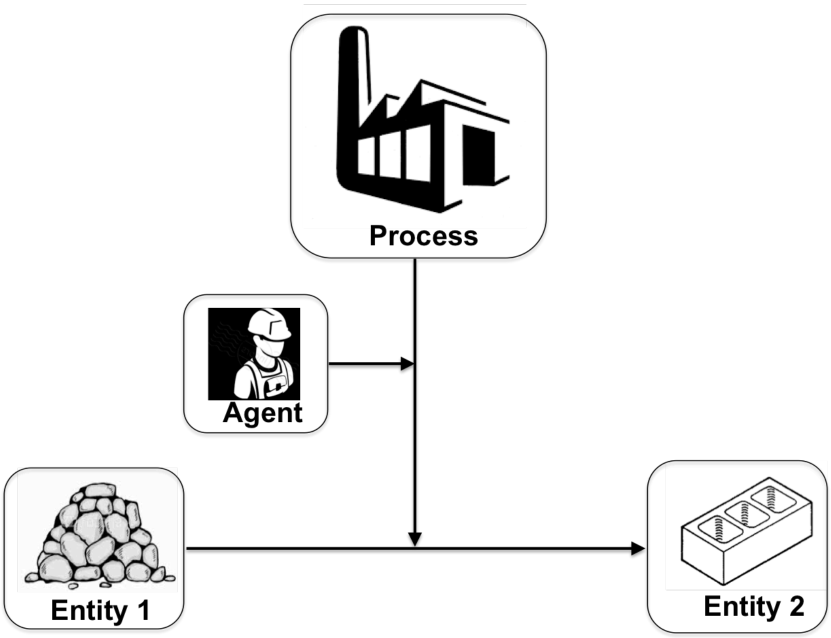

Fig. 3.2 – Agent to entity to process to entity interaction illustration

The occurrence of **process** objects operating on **entities** happens in certain cases without human intervention, such as rainfall in the environment, originating from an atmosphere entity, which describes a state of a part of the atmosphere as a 'snapshot' in time. The output of a rainfall **entity** from a **process** object will flow into various **entity** objects across the landscape including water bodies as hydrosphere entities, the earth's surface as lithosphere entities, and buildings and roads as infrastructure entities.

The resolution of flows that take place across entities in their spatial depiction is resolved using **space** objects, which define the relation and possible movements of entities as physical objects between 'blocks of space', such as in the case of rainfall. As such, specific entity to process to entity relationships can be formulated in the model to occur in space and time, such as a rainfall **entity** object interacting with a lithosphere surface **entity** object through a runoff **process** object, and similarly a rainfall process interacting with a water body **entity** object by an absorption process object occurring within a soil **entity**, as illustrated in figure 3.3 below. This is on the basis that an atmosphere **entity** exists in space above a lithosphere **entity,** given the same latitudinal and longitudinal coordinate as determined by a **space** object relationship.

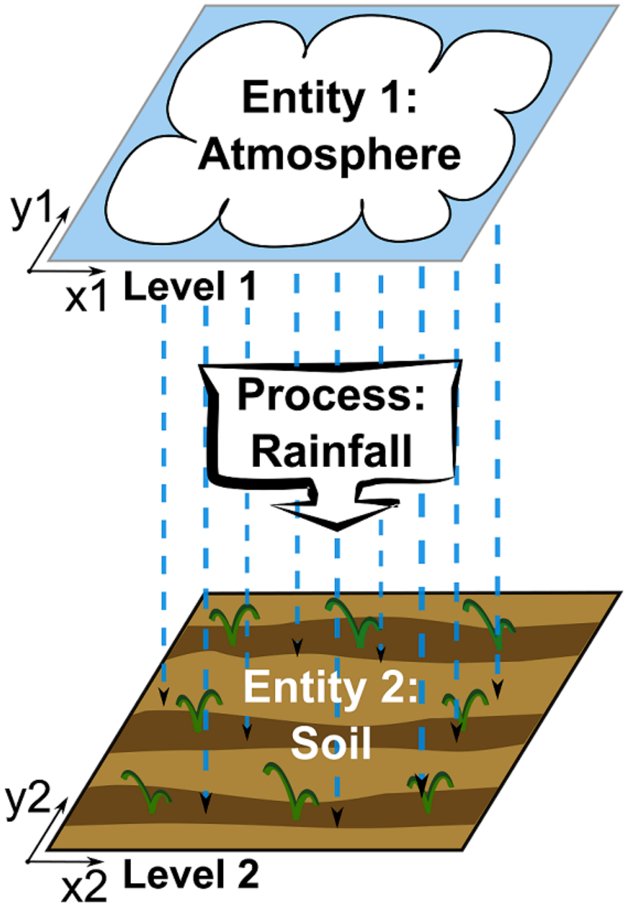

Fig. 3.3 - Entity to process to entity interaction defined by space

The object-property relations of 'existence' is, as per the above, conceptually separated from the object-property relations of 'resource activity' processes in the model, to be defined by chemical, biological, and physical rules, as well as technologies, and the human 'drivers' of a majority of processes as agents.

4. Space Data

In a Geographical Information System (GIS) spatial data can be represented in two formats: raster or vector. Raster data can be represented as an array of numeric values, such as the pixels in a satellite image, and it needs to be geo-referenced before use in a spatial analysis (i.e. aligned to the coordinated reference system being used). Vector data however is inherently spatial and comes in three formats: points (e.g. the centre of a city), lines (e.g. road networks), or polygons (e.g. administrative boundaries). This geometry can be queried if necessary to extract other spatial data such as the bounding box (i.e. minimum and maximum latitude and longitude coordinates) or the centroid of the polygon.

In the prototype the standard **space** object is a 2D vector polygon, as a series of quadrants with their coordinates and associated attributes (table 4.1). The entities and agents are spatially located within this depiction, especially for purposes of identifying resource and population flows across the landscape, from one grid cell to another.

Table 4.1 – Listing of data elements for vector quadrant space objects

Property	Description	Unit	Data type
ID	Polygon cell number	Number	Integer
L1	X-min	Longitude (decimal degrees)	Float
L2	X-max	Longitude (decimal degrees)	Float
A1	Y-min	Latitude (decimal degrees)	Float
A2	Y-max	Latitude (decimal degrees)	Float
z	Additional attributes to be defined during project where applicable		

The additional attributes (z) serve to include particular depictions, such as a land-use, to include data on whether a vector space object is used for purposes such as residential, commercial, industrial or as natural areas. The information can subsequently be used to include restrictions on activities that can take place within grid cells, as well as the addition of height and slope related attributes, so as to include terrain levels and their effects on agricultural land use feasibility, and transportation related terrain impacts.

4.1 Space Object Variants

In the majority of cases the vector quadrant based approach should be sufficient from a model logic perspective with the possibility to extend a vector space object by adding articular attributes. In certain cases a more complex vector object may be necessary, for instance to depict a lake structure or a large park which spans across several quadrants. In that case the generic object depicted in table 4.1 can be expanded on the basis of a bounding box with polygons inside that represent the vector, as shown in table 4.2, following GIS based polygon guidelines.

Table 4.2 – Listing of data elements for complex vector space objects

Property	Description	Unit	Data type*
ID	Vector number	Number	Integer
L1	X-min (for bounding box)	Longitude (decimal degrees)	Float
L2	X-max (for bounding box)	Longitude (decimal degrees)	Float
A1	Y-min (for bounding box)	Latitude (decimal degrees)	Float
A2	Y-max (for bounding box)	Latitude (decimal degrees)	Float
p	Number of polygons	Number	Integer
n	Tot. number of polygon points	Number	Small Integer
f	First point of polygon	Number	Small Integer
g	Polygon number	Number	Small Integer
u	Point number	Number	Small Integer
L3	X-polygon point	Latitude (decimal degrees)	Float
A3	Y-polygon point	Longitude (decimal degrees)	Float
z	Additional attributes to be defined during project where applicable		

*Integers are in databases positive and negative whole numbers which can hold values between -2,147,483,648 and 2,147,483,747, small integers also represent whole numbers with values between -32,768 and 32,767, and floats include both whole numbers plus up to 7 decimal numbers within the range -3.4e+38 and +3.4e+38.

In other specific cases it may be necessary to include a multi-shaped line as a polyline to describe networks, to add network capacity to grid-cells, or for visual purposes. The depiction is possible by using a polyline which is a combination of points in a particular sequence, whose properties can be similarly depicted as for a vector space object (table 4.2), except for being entered in a different data-table with different semantic naming, based on GIS based polyline guidelines.

In future development phases of the model beyond the prototype, further extensions can made by extending the raster cell object or a vector space object, such as to describe 3D by expanding with three dimensional coordinates.

4.2 Space Object Data Relations

Table 4.3 *– Relational tables for space objects*

Table name	**SQUADRANT**					
Attribute	CELLNO	XMIN (L1)	XMAX(L2)	YMIN (A1)	YMAX (A2)	ADDATTRIB (z)
Data type	INT	FLOAT	FLOAT	FLOAT	FLOAT	

Table name	**SCVECTOR**			
Attribute	VECTORNO	POLYNO (p)	TOTPOLY (n)	ADDATTRIB (z)
Data type	INT	TINYINT	TINYINT	

Table name	**SVECTOR POINTS**							
Attribute	POINTNO	XVAL (L)	YVAL (A)	POINTTYPE (1,2,3)	POINTNO (u)	POLYNO	FIRSTP (f)	*VECTORNO*
Data type	INT	FLOAT	FLOAT	TINYINT	TINYINT	TINYINT	TINYINT	INT

4.3 Space Object Data Examples

***Table 4.4** – Examples for raster space objects*

Table name	**SQUADRANT**					
Attribute	CELLNO	XMIN (L1)	XMAX(L2)	YMIN (A1)	YMAX (A2)	ADDATTRIB (z)
	1	5.56499	5.57500	0.19499	0.20500	
	2	5.55500	5.56499	0.18500	0.19499	
	3	5.54500	5.55500	0.17500	0.18500	
	4	5.53500	5.54500	0.16499	0.17500	

***Table 4.5** – Examples for vector space objects*

Table name	**SCVECTOR**			
Attribute	VECTORNO	TOTPOLY (p)	TOTPOINT (n)	ADDATTRIB (z)
Data type	INT	TINYINT	TINYINT	
	1	2	12	

Table name	**SVECTORPOINTS**							
Attribute	POINTID	XVAL (a)	YVAL (l)	POINTTYPE (1,2,3)	POINTNO (u)	POLYNO	FIRSTP (f)	*VECTORNO*
Data type	INT	FLOAT	FLOAT	TINYINT	TINYINT	TINYINT	TINYINT	INT
	1	5.552516	0.1911777	1	0	1	1	1
	2	5.551361	0.1926666	2	0	1	1	1
	3	5.552361	0.1926666	3	1	2	3	1
	4	5.552516	0.1921194	3	2	2	3	1
	5	5.552397	0.1913194	3	3	2	3	1

	6	5.551361	0.1911777	3	4	2	3	1

5. Entity Data

The ‘generic’ **entity** object has five properties. It describes any non-human physical entity that is represented in the model world which contains in it physical elements expressed typically as materials. An entity exists in space at latitudinal (a) and longitudinal coordinates (l), and at a time instance expressed as a time of creation (c), and a time of ending (e), with a 0 ending value if still in existence.

The variants of an entity object are firstly described on a binary basis as to whether they are pool entities or non-pool entities (p). The separation is made to distinguish between ‘containers’ that hold substances or other entities and those that do not.

Pools and non-pools are specifically defined as follows:

- **Pools**, as physical objects with boundaries that form ‘tanks’ with large source or sink properties, by holding other entities in a continuous flux or in relatively constant form (e.g. atmosphere, water bodies, buildings, mineral deposits, soils)
- **Non-pools**, as physical objects existing in space within their own confines without the purpose or ability to store other entities (e.g. machines, consumables).

A further distinction is made by attribution of a main entity type class (y) that identifies the entity variant that holds, as expressed in table 5.1. Also since entities can be related to each other, such as in case of a factory and its machinery, an entity relationship property (ee) is necessary.

Table 5.1 – Listing of Data Elements for Generic Entity Object

Property	Description	Unit	Data type
EN	Entity number	Number	Integer
Y	Entity type	Number	Tiny integer
P	Pool quality	Binary identifier	Tiny integer
C	Creation time	Date (ddmmyyyy)	Integer
E	Ending time	Date (ddmmyyyy)	Integer
L	X-point	Longitude (decimal degrees)	Float
A	Y-point	Latitude (decimal degrees)	Float
EE	Entity relations	Number	Integer
Z	Additional attributes to be defined during project where applicable		

The variants of the generic object are described in the next section 5.1, including the incorporation of physical descriptions of entities by weight and volume.

5.1 Entity Object Variants

The ‘generic’ entity is empty in a sense that it only describes qualitative aspects. In total nine main variants are identified to isolate the various entities that could be represented in the prototype model.

The nine variants, further identified in sub-variants in appendix A and visually depicted in figure 5.1 below, include:

- **Sector entities,** the entities that are defined in the human environment such as factories, farms, malls, road networks, and stadiums.
- **Infrastructure**, the entities that form the built environment as construction, transportation and auxiliary human made objects (can have pool quality), as well
- **Machinery**, the entities that form machines operated by humans either through direct physical labour and/or using energy, as well as entities that can be used to move materials.
- **Consumables**, the entities that are sets of materials produced in human and natural systems, such as timbers, ceramics, woods, building materials etcetera.
- **Biota**, the entities representing physical aspects of plants and animals including trees, shrubs, cows, sheep.
- **Atmosphere**, a set of entities identifying different layers within the earth’s atmosphere, including surface layer, minimum bounding layer, and troposphere (always has pool quality).
- **Lithosphere,** a set of entities that serve to include soil layers in the model, such as the surface, top-soils, sub-soils, and bedrock (can have pool quality).
- **Hydrosphere**, a set of entities to represent waterbodies that form pools which contain water in the human and natural environment (always has pool quality).
- **Biosphere**, a set of entities identifying ecosystems of terrestrial and aquatic types, such as forests, savannah’s, agricultural fields.

In case of biosphere entities, no additional quantitative properties are added, as these depict ecosystems which are purely ‘holders’ of other entities. In all other variants both qualitative and quantitative attributes are added to describe the physical ‘contents’ of the entity.

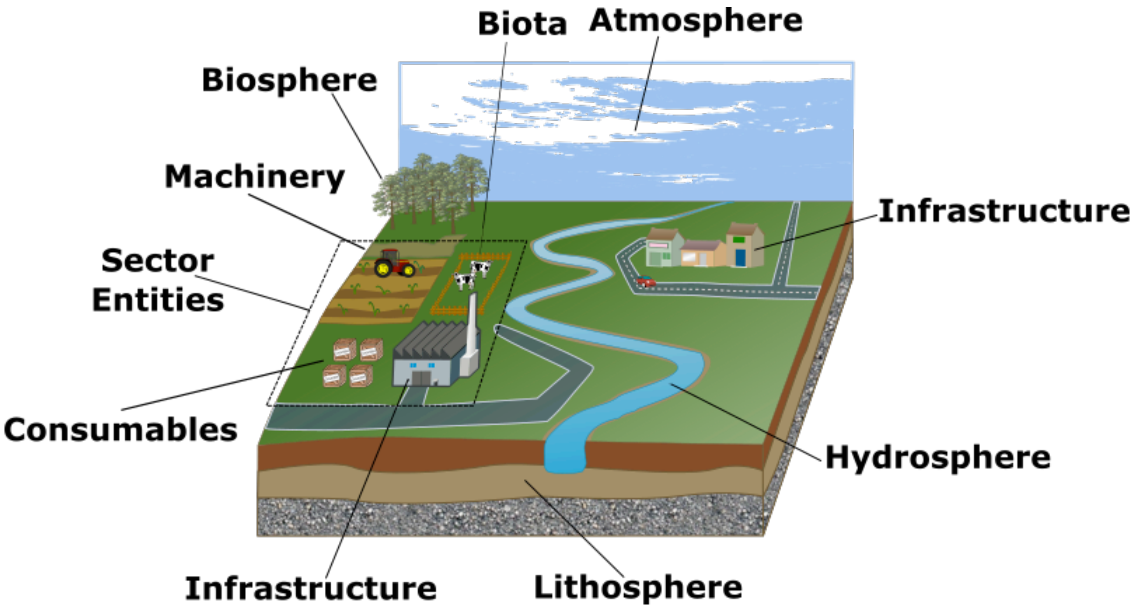

Fig 5.1 – Conceptual visualisation of entities in model prototype

The physical aspects of the majority of entities are described at two levels including:

- **Entity**, as the level that identifies the instance of the entity in its consistence of multiple materials, classified on the basis of sub-variants following the variants described above (see appendix A).
- **Materials**, a complex substance which consists of multiple types of molecules, which can be classified by phase (solid, gas, liquid) and type (e.g. metals, ceramics, composites, polymers)

The exception to this description is the biosphere entity, which is purely a holder of other entities and not physically described at this level, given the lack of usefulness in describing biosphere components in this manner, plus sheer complexity of this entity type given the number of species and their interactions, which is significantly better captured in dedicated ecosystem models. As outlined in the phased development overview (section 1.4) a coupling with such models is to be established in later development stages of the model. This on the basis of data input-outputs from the resource economic human ecosystem model to existing dedicated ecosystem models in existence within a city-region.

The entity and material types are to be qualitatively described by a standardised naming system, as much adhering to standard classifications as possible.[3] Each of these needs to be complemented with quantitative values as to create a resource based view of a city-region (or other sized economy). The inclusion of these properties is carried out on the basis of weight (w) and volume (v) for entities as well as materials. In addition for materials the percentage entity weight share (h), and where applicable the energy state (f), and its form (o), representing an intensive or extensive energy quality, such as the gross thermal value of the materials, or a potential energy state in particular applications (e.g. hydropower). The energy state is included for energy balance calculation purposes in relation to process objects (section 6). In relation a number of extensive material and energy properties are to be incorporated, such as density (kg/m^3) and lower heating values (MJ/kg), for a large series of materials in a systematic manner using the same standardised naming format. With this characterisation it is possible that a material input also functions as an energy input based on its relevant properties.

Similar to the entity relationship property also the association between the entity level and material level needs to be described on the basis of an entity-material relationship property (em). The physical properties are expressed in table 5.2, which forms an additional data-layer for entity objects.

Table 5.2 – Listing of data elements for an entity objects physical layers

Property	Description	Unit	Data type
LN	Layer number	Number	Integer
EN	Entity object number	Number	Integer
R	Layer type	Symbol ('e' or' r')	String
N	Layer name	Name of entity or material	String
EM	Layer relation	Number	Integer
W	Weight	Kilograms	Integer
V	Volume	Cubic meters	Integer
H	Weight share	Percentage	Tiny integer
F	Energy state	Joules	Integer
O	Energy form	Name	String
Z	Additional attributes to be defined during project where applicable		

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[3] In cases where multiple names exist, such as for chemicals, a correspondence table can be added to the data-input feed into the model. For example, di-ammonium phosphate (DAP) one of the most common fertilizers is also referred to as di-ammonium hydrogen phosphate based on the official classification of the international union of pure and applied chemistry.

The approach is setup to be so that flexibility is maintained to describe particular micro-scale substances in future phases of development beyond FCA prototype development.

This especially with the development anticipation to add two important additional layers in phase 2 of model development (see for phasing the section 1.1 overview), based on the flexible design approach:

- **Molecules**, a combination of two or more atoms bonded together (e.g. methane, water, iron).
- **Atoms**, the smallest particle of an element that can exist (e.g. oxygen, hydrogen, sulphur etc.).

The purpose of adding molecules and atoms serves to add the impacts of substances. The importance can be illustrated at a toxicity level, such as the small concentration of an inorganic arsenic molecule which in a water supply or food source can be highly toxic, and needs to be traced when a particular health component would be included in the model to trace toxicity.

Similarly, also at a physical level tracing molecules and atoms is highly relevant. To adequately cover recycling the singular incorporation of only an entity or material level is insufficient, as molecules can accumulate within for example composting or metal recycling. In the latter case for steel recycling, for example, an increase in copper content will reduce the integrity of the steel up to a point that it can no longer be used for cars or steel building constructions. Finally, to adequately carry out material balances the value at a material level is in many cases insufficient due to a lack of descriptive properties and following adequate tracing, such as when dealing with metal alloys, types of clay, or types of glass. For instance, crystal class typically contains 24% lead(ii)oxide, and tracing its estimated content of this molecule then simply noting "leaded glass" or even worse "crystal glass".

In addendum to the above it is not the case that all layers need to be traced at all times, even when molecules and atoms are included in future version, but more so when appropriate in terms of model object-property relations, as well as feasibility given data availability. This anticipating that over time, once the model is setup for a given city-region, more and more details can be incorporated. Obviously, the more detail which needs to be described in a model version the more effort that will be required for data collection.

5.2 Entity Object Meta-Data

The data used to describe entities is purely functionally denoted from a model's perspective, however, for a data quality assessment perspective the incorporation of additional meta-data properties is necessary. An overview of these meta-data types is provided in table 5.3 below. This data is not used in the model for any computation as such, but describe the when, where, and how, of entity entries in their addition to model data tables.

The first aspect is the person (mp) who added the entry into the data-table, or an underlying initial entry sheet, as to be able to trace any errors back to the source of entry point for quality purposes. Second, when the entry was added into the data-table (mt). Third, the actual data source (ms) of the entity data such as an existing database, an aerial photo, a mapping service, a reference book, a peer-review study, a conversational account, and so forth. Fourth, the date at which the original data value was produced as incorporated within the source (mc), and if no timestamp is provided the date of the source itself. And finally, the method (mm) by which the information of the entry was obtained based on a listing of categories to be defined, such as aerial photo mapping, satellite datasets, expert assessment, mass balance flow calculations, stoichiometric calculations, and so forth.

Table 5.3 – Listing of meta-data elements for entity objects

Property	**Description**	**Unit**	**Data type**
ME	Meta data entry number	Number	Integer
EN	Entity number	Number	Integer
LR	Layer related	Binary (y/n)	String
LN	Entity layer number	Number	Integer
MP	Person name and surname	Names	String
MT	Date of entry into database	Date (ddmmyyyy)	Integer
MS	Source	Category	String
MC	Date of data points creation	Date (ddmmyyyy)	Integer
MM	Method	Category	String
Z	Additional attributes to be defined during project where applicable		

5.3 Entity Object Data Relations

Table 5.4 – Relational tables for entity objects

Table name	**EOBJ**								
Attribute	EOBJNO	ETYPE (y)	POOLQ (p)	CREATION (c)	END (e)	LONG (L)	LAT (L)	*ENTITYREL*(ee)*	ADDATTRIB (z)
Data type	INT	TINYINT	STRING (y/n)	INT	INT	FLOAT	FLOAT	INT	

*Recursive relationship with EOBJNO to include entities that relate to entities

Table name	**ELAYERS**							
Attribute	LAYERNO	*EOBJNO*	LAYERTYPE (r)	LAYERNAME (n)	*LREL* (em)	WEIGHT (w)	VOLUME (v)	WEIGHTSHR (h)
Data type	INT	INT	STRING (e/r)	STRING	INT	INT	INT	TINYINT

*Recursive relationship with LAYERNO to include entity to layer relationship at material level

Table name	**EENERGY**				
Attribute	ENERGYNO	ENERGYSTATE (f)	ENERGYFORM (o)	*LAYERNO*	ADDATTRIB (z)
Data type	INT	INT	STRING	INT	

Table name	**EMETA**								
Attribute	METAID	*EOBJNO*	LAYER (LR)	*LAYERNO*	PERSON (MP)	EDATE (MT)	SOURCE (MS)	CDATE(MC)	METHOD (M
Data type	INT	INT	STRING (y/n)	INT	STRING	INT	STRING	INT	STRING

5.4 Entity Object Data Examples

Table 5.4 – Relational tables for entity objects

Table name	**EOBJ**							
Attribute	EOBJNO	ETYPE (y)	POOLQ (p)	CREATION (c)	END (e)	LONG (L)	LAT (L)	*ENTITYREL(ee)*
Data type	INT	TINYINT	STRING (y/n)	INT	INT	FLOAT	FLOAT	INT
	1	1 (Sector entity)	N	09022015	0	5.55252	0.192119	1
	2	2 (infrastructure)	N	09022015	0	5.55252	0.192119	1
	3	3 (Machinery)	N	09022015	0	5.55252	0.192119	1
	4	3 (Machinery)	N	09022015	0	5.55252	0.192119	1
	5	4 (Consumables	N	09022015	0	5.55252	0.192119	1
	6	4 (Consumables)	N	09022015	0	5.55252	0.192119	1

Table name	**ELAYERS**							
Attribute	LAYERNO	*EOBJNO*	LAYERTYPE (r)	LAYERNAME (n)	*LREL* (em)	WEIGHT (w)	VOLUME (v)	WEIGHTSHR (h)
Data type	INT	INT	STRING (e/r)	STRING	INT	INT	INT	TINYINT
	1	1	E	Sugar mill	1	250000	2000	0
	2	2	E	Mill house	2	200000	1500	0
	3	3	E	Cane unloader	3	20000	10	0
	4	3	R	Stainless Steel	3	16000	0	0.8
	5	4	E	Cane cutters	5	14000	20	0
	6	5	E	Sugarcane	6	20000	200	0
	7	6	E	Wet bagasse	7	400	4	0
	8	6	R	Water	6	160	0	0.40
	9	6	R	Cellulose	6	100	0	0.25

	10	6	R	Hemicellulose	6	80	0	0.20

Table name	**EENERGY**			
Attribute	ENERGYNO	ENERGYSTATE (f)	ENERGYFORM (o)	*LAYERNO*
Data type	INT	INT	STRING	INT
	1	354000	Heat content (LHV)	6
	2	6920	Heat content (LHV)	7

Table name	**EMETA**								
Attribute	METAID	*EOBJNO*	LAYER (LR)	*LAYERNO*	PERSON (MP)	EDATE (MT)	SOURCE (MS)	CDATE(MC)	METHOD (M
Data type	INT	INT	STRING (y/n)		STRING	INT	STRING	INT	STRING
	1	1	y	1	Rembrandtkoppelaar	09022015	dummy	09022015	dummy

6. Process Data

Process objects in the model describe all types of resource conversions operating upon entities, inclusive of biological and chemical processes in the natural environment, conversions driven by man-made technologies, or interactions between the two. The described processes serve to enable the accurate simulation of resource flows as related to real-life production of goods and services, by integrating resource, energy, and labour flows into the calculation. In a simplistic fashion the methodology involves the creation of a material and energy balance, including all inputs and outputs such as wastes and emissions, combined with a description of the labour inputs required to create a service or good by operating technologies or from sheer physical labour (see figure 6.1 below).

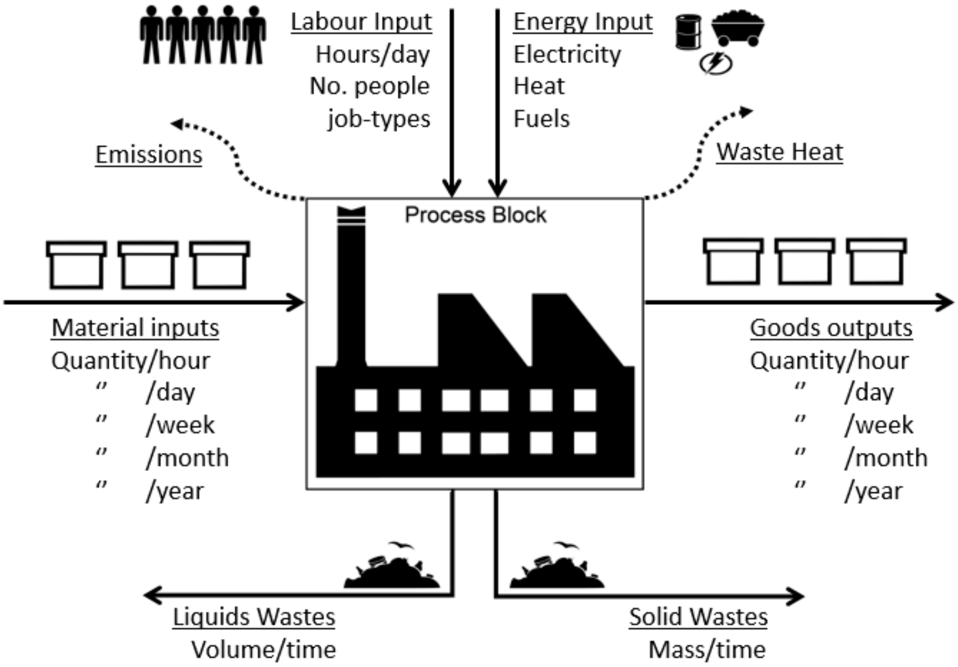

Fig. 6.1 – overview of a process object that forms the basis of representing resource conversions in the model for the production of goods (a similar representation can be made for service outputs)

Similar to entity objects the definition for process objects is made by identifying a set of variants which are hierarchical, in that one object can contain several more disaggregated process objects. The standard process unit of identification in the model is a process object is a ‘process block’ which defines the physical input-output relationship for a large location such as a factory, agricultural field, water treatment plant, transportation network mode, and shopping mall.

The FCA decision-making model prototype will be provided with a first set of 50 process blocks, which define the relationships between input/outputs at this level of aggregation, including from bottom-up estimations the underlying smaller process objects contained therein (described in section 6.1.2).

A ‘generic’ **process** object has four properties outlined in table 6.1 below. The process is defined by a class (y) to outline variants, and with classes by a name to outline class types. A process always has a set of energy input types (ei) and energy output types (eo), defined as conversions between energy forms such as electricity to work plus electricity to heat. Since it is a set multiple such conversions for a single process object can be identified. The conversion takes place at a certain efficiency based on an accompanying energy conversion ratio (et), with an added variability factor between inputs and outputs (ev), in relation to a time duration (Δt). In the course of the project additional attributes will plausibly be added to explain variability in greater detail for purposes of realistic approximations, as defined by the collection and creation of novel process data. In addition certain constraining conditions may be added under which the energy conversion ratio applies, such as minimum or maximum temperatures

Table 6.1 – Listing of generic energy data elements for process objects

Property	**Description**	**Unit**	**Data type**
TI	Process table index	Number	Integer
PI	Process object index	Number	Integer
y	Process object class	Category	String
N	Process object type	Name	String
ei	Energy input types	Category	String
eo	Energy output types	Category	String
ef	Energy conversion factor	Factor	float
ev	Energy conversion variability	Percentage	float
t	Time duration	Time (mmhhdd)	integer
Z	Additional attributes to be defined during project where applicable		

A process object can but does not necessarily need to have material input quantities (mi) or output quantities (mo) including wastes, since some processes are entirely energy driven like sunshine on earth. Moreover some processes only have outputs as they are purely based on driving down existing stock without inputs. Also a process need not to have labour hour inputs (li) or job-types (jt) associated with these inputs as they are entirely naturally driven without human interventions. The job-type affect the related productivity of a process such as crop production, as to incorporate impacts of low versus high-skilled labour.

All these variants at different scales and input/output types based on the generic process object are described in the next section, including the quantitative physical descriptions of input to output relationships.

6.1 Process Object Variants

6.1.1 Environmental processes

The non-human systems in the model vary based on whether they are mostly driven by physical systems, such as the weather, or biota interacting with physical systems, such as a forest, savannah, or an agricultural field. The former are defined by a process object called an ‘**environmental process object’** whilst the latter are referred to as ‘**ecological process object’**. These systems are often complex in that they can only be described adequately on the basis of internal logic by a set of non-linear relationships. The main role in representing these systems within the resource economic model of the human ecosystem, is to incorporate key inputs from natural systems into the human environment, and vice versa outputs from the human environment

The actual modelling of these systems and how extractive inflows from for instance, forests or the dumping of wastes in estuaries, affects them, is not of a direct consideration within this activity. Not because these impacts are not important, but because there are other models that exist which are much better suited to representing ecological and environmental processes. In many cases built in a tailored manner for specific ecosystems and environments.

The aim is therefore to enable the future connection to such models in existence, in the form of data inputs and outputs between models. For example, to use detailed existing models of shallow water lakes within a city-region’s hinterland, with data inputs of particular pollutants given city-region manufacturing sector developments as simulated in the resource economic human ecosystem model, without and with pollution regulation control. And vice versa, to provide as inputs the number of fish developments also taken into account fishing loads, which is obtained as an output of the shallow water lake model in question, that can be translated into an exogenous scenario (e.g. logic taken from ‘outside’ the model set by the user, or in this case modelled from another model), one which is valid within the input values of pollution provided and thereby the validity of the purported sector development.

Within the scope of the first building block towards a prototype model within the FCA program, such connections are enabled especially for purposes of including climate change scenarios and their effects on weather. To this end simple mostly exogenously driven logic of weather patterns, including rainfall, temperature, and sunshine, are included. Both to drive simple agro-ecosystems modelling of crop-growth, as well as for impact estimates of heavy and extreme weather on processes (such as sand road waterlogging), and in the future to facilitate the incorporation of climate change scenarios. An overview of the incorporation of complexity across the model development phases is shown in table 6.2 below.

Table 6.2 - Overview of environmental and ecological process systems and their inclusion in the model outlined by the development phases 1a, 1b, 2 and 3+.

Process object type	System type	Inclusion in model (development phase)
Environmental Process	Basic weather (rainfall, sunshine, temperature)	1a (empirical stochastic pattern recreation)
Ecological Process	Simple Agro-ecosystems (e.g. mono-cropping agricultural fields, grazing areas)	1a (empirical stochastic pattern recreation)
Environmental Process	Hydrology (runoff, run-on, filtration, underground water flows, rivers, streams etc.).	1b (Internal water flow logic between grid cells, entities)
Ecological Process	Simple Terrestrial Ecosystems (e.g. pine forests, grasslands)	1b (empirical stochastic pattern recreation)
Environmental Process	Complex weather (humidity, wind, particles)	2 (empirical stochastic pattern recreation)
Ecological Process	Complex agro-ecosystems (e.g. combined agricultural-livestock systems, rotational cropping systems)	2 (Internal nutrient & water flow logic between grid cells, entities)
Ecological Process	Complex Terrestrial Ecosystems (e.g. rainforests)	2 (external model data input-output coupling)
Ecological Process	Aquatic Ecosystems (e.g. lakes, estuaries)	3+ (external model data input-output coupling)

The operationalization of the three environmental systems of rainfall, sunshine, and temperature, is to be based on pattern recreation of empirical datasets. Historic patterns are taken and their change in the mean value and variability over time and space is analysed. As such a reasonable approximation based on past developments can be made within a plausible range, with a specifically described degree of randomness on a short-term scale within the overall longer term pattern. Ideally the development is done on the basis of data available on a daily basis for a period of over 10 years, so as to generate accurate weather patterns.

The input-output relation of rainfall within this system is to be described on the basis of rainfall as a material output (mo), whose value is driven by a stochastic pattern, using information on the frequency in time (fr), within a specified time period (tp), as defined for the stochastic process object type in table 6.3.

Table 6.3 – Listing of data elements for a stochastic process type

Property	Description	Unit	Data type
PS	Identified for stochastic process	Number	Integer
MO	Material output value	Weight or volume	Integer
FR	Frequency of output value	Ratio	Float
TP	Total period of frequency range	mmyyyy	Integer
Z	Additional attributes to be defined during project where applicable		

In case of sunshine there is no material flow as it consists entirely of photons, and only the energy flow in terms of solar radiation is described. As well as an additional property of the wavelength (wa) across the spectrum of solar radiation, which can be added as an additional attribute to the properties outlined in table 6.3, and with the replacement of material output with energy output values, for purposes of stochastic simulation of sunshine. This since wavelength is important to understand agricultural crop growth and micro-organism growth, and other light dependent processes.

Temperature is defined in a similar way to sunshine on the basis of energy flows only in relation to a temperature medium. In this system, sunshine forms a gross energy input, absorption a net energy input value, and reflection as well as output radiation the energy output values, relative to temperature medium of interest such as the air or soils. It can thereby be simulated on the basis of the data properties outlined as per the generic object with input-output, whereby the temperature medium is included as an energy state (es) following the entity object to process interaction, as outlined in section 3 and section 5. As such, temperature can be defined following the process properties outlined in table 6.1, with addition of process-entity energy state interactions. Such more-detailed interactions in terms of entity to process for rainfall, temperature, and sunshine, are to be defined in the technical specifications.

The simple agro-ecosystems to be included in the FCA model prototype development are to be based on the growth of biomass (b) as a material state defined by the entity object systems, whilst the process is described from an energy and material perspective. This as a relationship of temperature and sunshine as energy related inputs, simplified water inputs (mi) from rainfall, human irrigation, and a ‘tank’ represented soil stock, and material outputs (mo) as harvested biomass. The material system is described in table 6.4 an analogous balance manner as to the energy system described in table 6.1. Similar to temperature a distinction is made between gross sunshine and net absorbed energy inputs, and reflected energy outputs.

Table 6.4 – Listing of generic material data elements for process objects

Property	Description	Unit	Data type
TI	Material table index	Number	Integer
PI	Process object index	Number	Integer
mi	Material input types	Category	String
mo	Material output types	Category	String
mf	Material input/output factor	Factor	float
mv	Material conversion variability	Percentage	float
t	Time duration	Time (mmhhdd)	integer
Z	Additional attributes to be defined during project where applicable		

Any systems of additional complexity, such as detailed water-soil relationships, are to be defined at later stages of model development, as described in table 6.2 above.

6.1.2 Macro-human processes

As stated previously the standard process object is a ‘process block’ which defines the physical input-output relationship for any large location where humans are involved, such as a factory, agricultural field, water treatment plant, distribution centre, transportation network component, shopping mall, or any other location, with the main condition that it is spatially interconnected.[4]

To illustrate the boundaries of a process block as a resource conversion site, a few general examples are listed here, one for each of the fourteen sectors:

- **Agriculture and Seafood**, the flows related to the cultivation, harvesting and post-harvest treatment of apples and pears in an orchard.
- **Agri-food processing**, the flows related to the processing of grains into flour in a food processing plant.
- **Biological processing**, the flows related to the manufacturing of yeasts by an industrial yeast manufacturer.
- **Chemicals manufacturing**, the flows related to the production of fertilizers at a phosphorus, nitrogen, or potassium fertilizer chemicals plant.
- **Construction**, the flows related to erecting a low-rise building within the built environment using light and heavy machinery.
- **Energy generation**, the flows related to the operation, and maintenance of a natural gas fuelled thermal power plant to produce electricity.
- **Forestry**, the flows related to the production of plywood from felled spruce at a secondary wood products manufacturing plant.
- **Human and animal services**, the flows related to the operation of an office building at various levels of occupancy.
- **Human consumption**, the flows related to household consumption of personal and home care products.[5]

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[4] This is spatially operationalised as a set of line segments which are connected end to end forming a closed shape (a polygon).

[5] The human consumption ‘sector’ covers individual unit operations and not complex process blocks as such, and is therefore not taken into consideration in the process block selection.

- **Mechanical manufacturing,** the flows related to the conversion of intermediary materials, such as the production of isolated copper wires from pure copper, or the manufacturing of an engine.
- **Mineral extraction and processing**, an open-pit mine site where copper is extracted from its ore, for subsequent upgrading into concentrated copper of 99%+ purity to use in wires and other applications.
- **Recycling, disposal, remanufacturing**, the flows related to the landfilling or dumping of wastes by truck in the urban environment.
- **Transportation**, the flows related to the movement of truck transportation of goods across a kilometre within urban and rural environments.
- **Water supply**, the flows related to a slow sand filtration water treatment facility which operates by means of gravity deposition of particles.

A process block always includes energy inputs and energy outputs as well as labour hour inputs and job-types, and can form interactions with other process objects such as ecological process objects in case of agricultural fields, by adding or removing materials and energy as inputs and outputs.

Process blocks are from a human and model construction perspective divided based on the fourteen sectors, as outlined above and in section 8, and these vary by type of output and type of processing route including biological, chemical, and physical pathways. A preliminary overview of the 50 process blocks which will possibly be developed during the FCA prototype development, in relation to the fourteen sectors, can be found in Appendix C. The listing is informed by an assessment of the largest resource flows which generically occur across sectors and the economy. The final selection is to be made based on the selected sector for demonstration of functionality within the African context, since this will shift the emphasis of required resource flows to be modelled. In appendix C also a preliminary listing of the 70 additional process blocks envisioned for development in phase 1b is included, which result in the sum of 120 process blocks.

A process block is related to a **sector entit**y, described in section 5.1, which contains the physical state of the entity and other entities which are related to it (e.g. consumables, machinery, infrastructure etc.). The process blocks define how these entities change over time in terms of labour, material, and energy flows and related wastes.

All process blocks, which represent a location such as a factory, are described on the basis of four key aspects:

- First, the **sector entity objects** and its sub-entity objects on which the process operates in a given timespan.
- Second, **the energy** inputs and outputs flow types and their quantities plus relevant energy properties.
- Third**, the material** input and output flows and their quantities plus related material properties.
- Fourth, **the labour inputs** later based on inputs in hours and related job-types related to the labour work being carried out (e.g. process operator, manager).

The material aspects are identified by a material layer with key properties similar to those outlined in table 6.4 including material input and output types, the material input/output factor, conversion variability, and time duration. In addition a number of flow types (mt) are introduced to distinguish between waste outputs and desirable outputs varying by gaseous, liquid, and solid types.

The material related properties for process blocks including these additions on top of table 6.4 are outlined in table 6.5 below. In addition similar to energy certain constraining conditions may be added under which the material conversion ratio applies, such as minimum or maximum quantities of operation.

Table 6.5 – Listing of material data elements for process blocks

Property	Description	Unit	Data type
TI	Material table index	Number	Integer
PI	Process object index	Number	Integer
mi	Material input types	Category	String
mo	Material output types	Category	String
mf	Material input/output factor	Factor	Float
mv	Material conversion variability	Percentage	Float
mt	Material flow type	Category	String
t	Time duration	Time (mmhhdd)	Integer
Z	Additional attributes to be defined during project where applicable		

The labour values are captured in a separate data layer for a process block, as outlined in table 6.6, and include the labour hour inputs (li) related to the process object, the related job-types necessary for carrying out the work (jt), and the number of workers (lw).

Table 6.6 – Listing of generic labour data elements for process blocks

Property	Description	Unit	Data type
JI	Job type index	Number	Integer
PI	Process object index	Number	Integer
LI	Labour hour input value	Labour hour number	Integer
JT	Job types of work	Category	String
LW	Number of workers	Number	Integer
Z	Additional attributes to be defined during project where applicable		

In terms of model logic process blocks are divided into six types of process objects, defined as **'life cycle process objects'**, including transportation, construction, operation, degradation, maintenance, and deconstruction. All these operate on the basis of the input and output properties as described the process block tables above, yet they vary significantly in their effects on entities in the model in space and time. Within model operation a number of these can function on both an irregular discretised basis, as well as a regular continuous basis. For example, for food processing maintenance in terms of cleaning occurs on a daily basis at exact regular intervals, whilst repair maintenance is highly variable in time dependent on wear of components such as engines or pipelines. As such an additional meta-attribute (z) will plausibly to be developed to outline time related occurrence, to be further in the technical specifications (milestone 5 of FCA project).

The six types of life cycle process objects are defined as:

- **Transportation**, a process which transports entities across the model landscape in a time period from one location (space) to another (e.g. a car moving along space within road network entity constraints).
- **Construction**, a process which creates infrastructure sector entities as new physical capital in the model in space during a time-period, or results in significant alteration of existing capital stock (re-construction) (e.g. the development of an agricultural field where prior a forest existed).
- **Operation**, a process which object-property relations to convert resources into desirable outputs such as consumables, materials, machinery, goods, and services (e.g. the conversion of vegetables into canned soups).

- **Degradation**, a process which occurs naturally due to decaying processes such as corrosion, wear and tear, and if not counteracted will affect operation over time inducing capacity reductions and breakdowns (e.g. the breakage of a pipeline).
- **Maintenance**, a process which counteracts degradation to maintain operational status to a defined level (e.g. the replacement of the pipeline section).
- **Deconstruction**, a process which removes entities from the model prototype by demolition or managed deconstruction (e.g. the disassembly of a power plant at the end of its lifetime).

Within process blocks a large set of underlying smaller processes occur that define the object property relations at smaller scales within a location or site such as a factory, field, mall, or distribution centre. These are outlined in the next section.

6.1.3 Micro-human processes

A process block and its life cycle process object types are in essence a large set of processes which are interrelated. Such as for an apple juice factory: the offloading of apples, on-site transportation and their storage, the conversion processes to create apple-juice, and the packaging of the juice and loading into trucks. The inclusion of these detailed levels allows for a significantly richer description of physical flows to significantly improve the validation of modelled resource flows, going beyond the typical aggregate level of input-outputs related to a product such as life cycle analysis.

The four '**micro process object**' variants are defined as:

- **Process unit**, the main process operations that are directly related to the energy/resource conversion. For example, pre-treatment of chemicals and a series of chemical reactions in reaction chambers.
- **Storage unit,** any process operations that operate upon 'micro' pools in terms of storing entities and keeping their contents in a certain material and energy state. For example, a chemicals storage tank.
- **Transit link,** any process operation which serves to transport materials within a process block from one process unit to another or from/to a storage unit.
- **Auxiliary unit**, any additional process operations that is not a direct energy/resource conversion or storage unit or transit link which his necessary for the location to object-property relations from an operations, monitoring, or maintenance perspective. For example, an operational room for a manufacturing plant.

The physical relations of all these units are similarly described as per the properties of object-property relations in table 6.1, 6.5, and 6.6 outlined above, with the exception of an additional properties to relate particular 'micro process object' (p2) to a particular process block (p1) and outline the sequence of micro process objects as they occur therein (so), as outlined in table 6.7.

Table 6.7 – Listing of generic labour data elements for process blocks

Property	Description	Unit	Data type
PS	Process sequence index	Number	Integer
P1	Process block object index	Number	Integer
P2	Micro-process object index	Number	Integer

so	Process sequence	Number	Integer
Z	Additional attributes to be defined during project where applicable		

Within the perspective of a particular process block and its set of micro process objects a division can be into ‘core’ and ‘complementary’ micro objects. This to create a division between process operations which are, and which are not necessary on a physical basis, to produce the output or for end consumption to take place. For example, carbon capture and storage at a power plant, manure composting at an agricultural site, or water treatment at a petroleum refinery.

The distinction of complementary operations is made because there are sites where these processes will be carried out due to regional or country level regulations, or evolution of the set of processes that are installed as per standard industry practices. For example, in certain countries water treatment plants are mandated on-site for particular chemicals plants.

A process block developed in the model in principle only includes core activities. In case a spatial site is identified in constructing the model for a sector (or economy) where complementary activities take place, these are to be incorporated by combining micro process objects within multiple process blocks. For example, by combining the relevant process objects identified within a waste water treatment process block with an oil refining process block, in case of on-site chemical and biological waste-water treatment.

The integration of multiple process blocks requires a scaling of size of resource flows within a realistic approximation taking technology constraints of operations at particular min-max ranges into account, which is to be further investigated during FCA technical specification development (milestone 5).

6.1.4 Event processes

The fourth category of processes to be included in the model relates to unanticipated events which occur at irregular intervals. Such events can cause disruptions of small and large scales in terms of impacts, duration, and spatial region of affect. For example, a transportation strike, a drought or flood, the sudden rise of a competing country undercutting an entire market, or an explosion at a chemicals plant.

In the context of the FCA prototype the capability to simulate disruptive events to is to be tested at a limited scale based on a simple exogenous forcing. The implementation is included on cases relate to a loss of key resource flows that form inputs into the process blocks, and to market disruptions that lead to a significant reduction or increase in export possibilities. For example, a scenario based on a drought in crucial grain producing country resulting in rising prices which are favourable for other exporters of similar or related grains. To simulate such cases an exogenous parameter change is to be tested where prices or flows are manually adjusted.

In the future development phase 2 beyond the prototype for a series of well-studied events a stochastic approach could be taken, similar to the outline in table 6.3 in section 6.1.1. With the caveat that this depends on available data to properly examine frequencies and size impacts of events as to provide for a systematic and empirically valid approach.

6.2 Process Object Meta-Data

The development of process data on an energy, material, and labour basis is the core element that allows for the accurate representation of resource flows within the model environment, and the quality characteristics of provided data including sufficient validation checks is therefore essential. In addition the process data also provides for useful information on its own in relation to the technological state of sectors (or economies), just as the physical depiction of the landscape with entity objects in a systematic manner.

In the data tables meta-data is to be included for these purposes to improve the ability to provide for quality control, and to enhance the data richness for interpretation of the current 'technological' state within the model. The inclusion of quality data is to be provided on a similar basis as for the entity object data, as summarised in table 6.7, by means of logging the person, date of entry, source, date at which the data point was created, and the methodology by which it was generated, using a series of standardised listings that can be used across all types of process datasets.

Table 6.8 – Listing of meta-data elements for process objects meta-data

Property	Description	Unit	Data type
ME	Meta data entry number	Number	Integer
PN	Process number	Number	Integer
MP	Person name and surname	Names	String
MT	Date of entry into database	Date (ddmmyyyy)	Integer
MS	Source	Category	String
MC	Date of data points creation	Date (ddmmyyyy)	Integer
MM	Method	Category	String
Z	Additional attributes to be defined during project where applicable		

The inclusion of meta-data on the technological state is to be defined based on a technological typology of the process blocks and their related datasets, whose properties are summarised in table 6.8 and outlined below.

At a generic level the typology includes variations across categories in four dimensions:

- The **degree of automation (pa)**, as fully manual, semi-manual, semi-automated, and fully automated, describing the extent to which processes are operated by humans or by machinery.
- The **technological modernity (pm)**, as outdated, common, and novel, describing whether the process technique is the one commonly in place today at the majority of sites for the respective output, or is significantly older or newer. For example, novel direct-reduction iron furnaces enable direct pig iron production, which are increasingly replacing the common blast furnace with pre-heating, which on its turn replaced the outdated small scale blast furnace.
- The **turnover of production/consumption (pt)**, as low, medium, and high in volume per unit time, describing the scale of operations and how this scale relates to a city-region.
- The **spatial intensiveness/extensiveness (pi)** of process blocks, as low, medium, and high resource/energy input/output throughputs per unit time, describing the spatial effectiveness and resource use efficacy of the site (e.g. intensive versus extensive farming)

The development of detailed definitions at a qualitative/quantitative level to operationalise these categories for the typology is part of the process block dataset development, as the values will vary by the sector of interest and the respective technology. In other words for each process block these values need to be defined with relevant parameters based on a set of mutually exclusive criteria.

Table 6.9 – Listing of Meta-Data Elements for a technological 'typology'

Property	Description	Unit	Data type
ME	Meta data entry number	Number	Integer
PN	Process number	Number	Integer
PA	Process automation	Categories	String
PM	Technological modernity	Categories	String
PT	Turnover of production	Categories	String
PI	Spatial intensity	Categories	String
Z	Additional attributes to be defined during project where applicable		

6.3 Process Object Data Relations

Table 6.10 – Relational tables for process objects

Table name	**POBJ**									
Attribute	TABLEID	POBJNO	PTYPE (y)	PNAME (n)	EINP (ei)	EOUT (eo)	EIOFACTOR (ef)	EVAR (ev)	TIME (t)	ADDAT (
Data type	INT	INT	STRING	STRING	STRING	STRING	FLOAT	FLOAT	INT	

Table name	**PMAT**							
Attribute	MATNO	*POBJNO*	MINP (mi)	MOUT (mo)	MIOFACTOR (mf)	MVAR (mv)	FLOWTYPE (mf)	TIME (t)
Data type	INT	INT	STRING	STRING	TINYINT	TINYINT	STRING	INT

Table name	**PLABOUR**					
Attribute	LABNO	*POBJNO*	LABOURINP (li)	JOBTYPE (jt)	WORKERNO (lw)	ADDATTRIBUTE (z)
Data type	INT	INT	INT	STRING	INT	STRING

Table name	**PSTOCH**					
Attribute	PSID	PSTYPE	MOUT (mo)	FREQUENCY (fr)	PERIOD (tp)	ADDATTRIBUTE (z)
Data type	INT	STRING	INT	FLOAT	INT	

Table name	**PSEQUENCE**				
Attribute	SEQTABID	PSEQNO	*POBJNO*	*PTYPE (y)*	ADDATTRIB (z)
Data type	INT	TINYINT	INT	STRING	

Table name	**PMETA**							
Attribute	METAID	*POBJNO*	PERSON (MP)	EDATE (MT)	SOURCE (MS)	CDATE(MC)	METHOD (MM)	ADDATTRIB (z)
Data type	INT	INT	STRING	INT	STRING	INT	STRING	

Table name	**PMTECHNOLOGY**						
Attribute	METAID	*POBJNO*	AUTOMATION (pa)	MODERNITY (pm)	PRODTURNOVER (PT)	SPATIALINT (PI)	ADDATTRIB (z)
Data type	INT	INT	STRING	STRING	STRING	STRING	

6.4 Process Object Data Examples

Table 6.11 – Relational tables for process objects

Table name	**POBJ**									
Attribute	TABLEID	POBJNO	PTYPE (y)	PNAME (n)	EINP (ei)	EOUT (eo)	EIOFACTOR (ef)	EVAR (ev)	TIME (t)	ADDAT (z)
Data type	INT	INT	STRING	STRING	STRING	STRING	FLOAT	FLOAT	INT	
	1	1	Process block	Brick manufact.	electricity	mechanical work	0.8	0.06	20	
	2	1	Process block	Brick manufact.	electricity	heat	0.2	0.06	20	
	3	1	Process block	Brick manufact.	liquid fuel	mechanical work	0.35	0.10	20	
	4	1	Process block	Brick manufact.	liquid fuel	heat	0.75	0.10	20	
	5	1	Process block	Brick manufact.	Nat. gas	heat	1.0	0.0	20	
	6	2	Process unit	Water kettle use	electricity	heat	0.85	0.1	40	

Table name	**PMAT**							
Attribute	<u>MATID</u>	*POBJNO*	MINP (mi)	MOUT (mo)	MIOFACTOR (mf)	MVAR (mv)	FLOWTYPE (mt)	TIME (t)
Data type	INT	INT	STRING	STRING	TINYINT	TINYINT	STRING	INT
	1	1	Clay	Bricks	0.98	0.02	Solid produce	20
	2	1	Water	Bricks	0.90	0.05	Solid produce	20
	3	1	Slurry	Bricks	1.00	0.00	Solid produce	20
	4	1	Sand	Bricks	1.00	0.00	Solid produce	20
	5	1	Water	Waste water	0.10	0.05	Liquid wastes	20
	6	1	Clay	Waste water	0.02	0.02	Liquid wastes	20
	7	1	Methane	CO_2	0.75	0.00	Gaseous wastes	20
	8	1	Methane	H_2O	0.25	0.00	Gaseous wastes	20
	9	1	Air (O_2)	CO_2	0.50	0.00	Gaseous wastes	20
	10	1	Air (O_2)	H_2O	0.50	0.00	Gaseous wastes	20

Table name	**PLABOUR**					
Attribute	<u>LABNO</u>	*POBJNO*	LABOURINP (li)	JOBTYPE (jt)	WORKERNO (lw)	ADDATTRIBUTE (z)
Data type	INT	INT	INT	STRING	INT	
	1	1	200	Loading/offloading workers	20	
	2	1	35	Machinery operators	5	
	3	1	14	Process operator	2	
	4	1	9	Floor manager	1	
	5	1	80	Administrative overhead	10	

Table name	**PSTOCH**					
Attribute	PSID	PSTYPE	MOUT (mo)	FREQUENCY (fr)	PERIOD (tp)	ADDATTRIBUTE (z)
Data type	INT	STRING	INT	FLOAT	INT	
	1	Rainfall	25	10	10	
	2	Rainfall	30	60	10	
	3	Rainfall	35	30	10	

Table name	**PSEQUENCE**				
Attribute	SEQTABID	PSEQNO	*POBJNO*	*PTYPE (y)*	ADDATTRIB (z)
Data type	INT	TINYINT	INT	STRING	
	1	1	1	PROCESS BLOCK	

Table name	**PMETA**							
Attribute	METAID	*POBJNO*	PERSON (MP)	EDATE (MT)	SOURCE (MS)	CDATE(MC)	METHOD (MM)	ADDATTRIB (z)
Data type	INT	INT	STRING	INT	STRING	INT	STRING	
	1	1	Rembrandtkoppelaar	09022015	Database X	09022015	Direct measurement	

Table name	**PMTECHNOLOGY**						
Attribute	METAID	*POBJNO*	AUTOMATION (pa)	MODERNITY (pm)	PRODTURNOVER (PT)	SPATIALINT (PI)	ADDATTRIB (z)
Data type	INT	INT	STRING	STRING	STRING	STRING	
	1	1	Fully automated	Common	high	medium	

7. Agent Data

A ‘generic’ **agent** object has three properties. It describes the direct human representation of a cluster of people in the model or a set of human related entities (e.g. companies or institutes) to which behaviour needs to be ascribed. An agent always exists in a time instance (t), similar to an entity, but does not always need to be described in space. It will also always have an agent entity type class (y) to identify the agent variant that holds, and a series of cluster states in which it participates (a) whose object-property relations and variants are explained in the section 7.1.

7.1 Agent Object Cluster Variants

An agent is described by a set of cluster states, under which combinations of properties are defined. The interactions between sets of clusters and their property associations effectuates human-driven process inputs, and thereby change in entities on which processes operate, as well as agent property changes themselves. Clusters are in essence, relevant associations between agent properties for purposes of specific calculations made in the model related to agents. As such individual properties can exist in combinations under multiple clusters varying by applicability.

A first listing of types of cluster states, which can be associated with population and/or company agents, combine into a number of agent properties which are:

- **Activity state (s)**, describes for population agents the occurrence, duration, and locations within a day’s timeframe of activities, which vary locally and can be arranged in a tailored manner. A few generic examples include work, sleep, leisure, education, food consumption, travel, or ‘maintenance’ as personal care or household upkeep, and religious activities.
- **Trade activity state (c),** describes for population and company agents the occurrence of exchange from one agent to another.
- **Life identity state (i),** describes socio-economies qualities such as age, gender, labour force participation, educational and skill states, health status, and well-being status.
- **Agent employment relational state (r),** household membership status, employment status, in relation to a spatial zone.
- **Agent household relational state (h),** describes relationship status, and household membership status.

- **Work identity state (w),** describes work related properties including sector entity work association, and agent work qualification.
- **Entity ownership state (p),** describes agent ownership of entities including sector entities, infrastructure, machinery, and consumables.
- **Internal behavioural states** (u), describes key behavioural parameters affecting trade and purchasing including goods preferences, degree of trust, and population discount rates.
- **Income state (n),** describes agent income and savings.

The split into several cluster states serves to reduce the number of combinations of variables that need to be accounted for, thereby improving the speed of computation. If all properties of the agents would be lumped together, such as employment, income, activity within a time-period, ownership, and so forth, a vast number of clusters would need to be described. For example, if agent relational state (h), work identity states (w), and income states (f) would be lumped together, there could already in a simple case be tens of millions of different small clusters within population agents that need to be described to resolve labour hour supply to process entities. Say there are 1000 different sector entities existing in 300 different spatial zones to which jobs are related, and these jobs can have 6 income levels, 50 savings levels, 4 work qualification levels, and 2 employment states (yes/no), then a total of 720 million different combinations are possible. Whilst limitations could be added to ignore certain subsets of properties to limit possibilities, the number of combinations still remain large.

In contrast, to resolve the need for labour hour inputs into a process block with the split system above, combinations are created of the states above in parallel and in sequence where appropriate. To illustrate, say that first for each weather season a set of 20 possible activity profiles is generated on the basis of the sequences in which the seven activities can take place.[6] Second, from these profiles work activity states (s) that take place on a given day are calculated, as the number of population agents carrying out the activity work for a number of hours in a spatial zone.

The calculation is based on association of an activity profile with an applicable agent employment relation state (r), which combines for example 160 household types, as combinations of employment status and household composition (e.g. singles or couples with/without children etcetera), across the 300 spatial zones, as 48,000 combinations. Say that only 5 out of 20 activity sequences are applicable for each household type, resulting in an examination of 240,000 possibilities to allocate labour hours to each spatial zone to create an activity state (s) as a labour hour pool in a zone.

Third, on the basis of the activity state (s) related to work an association to the work identity state (w) is created to assort to which sector entities the work hours are ascribed. The calculation relates the sector work entity and its spatial zone of existence, on average 3-4 in each zone (described by entity objects), to the labour hour pool in a zone, to the work quality association to the sector entity. Finally, a process object can operate on the sector entity, given the available labour hours with a given quality affecting the productivity of labour, as to generate material and energy input-outputs.

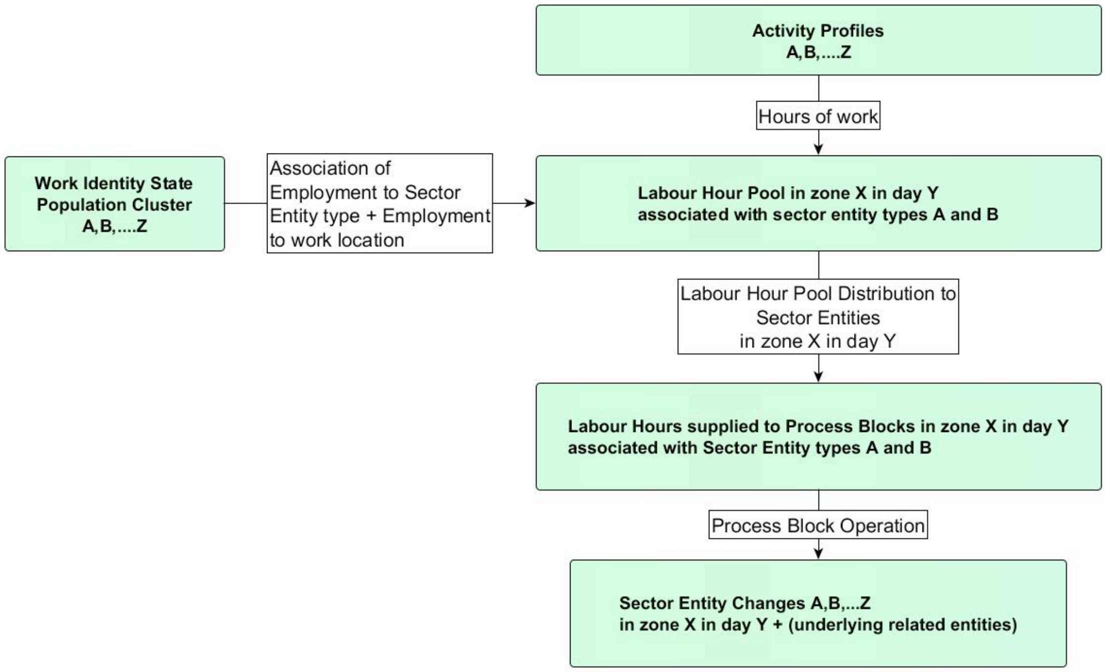

Fig. 7.1 – Population State Cluster association example

The implemented approach of calculation for an activity cluster, as well as any other cluster, can vary significantly in its implementation. A first approach is estimation on the basis of primarily an exogenous allocation, wherein in case of activity clusters daily profiles are pre-calculated and 'loaded' onto agent clusters, which can remain unchanged across model runs, transition from one type to the other, or vary in an alternative mode. A second approach is regular recalculation of the activity profiles themselves. Within the FCA prototype model both approaches are used the particular choice dependent on relevance and applicability, a first overview of implementation approaches is to be outlined in the technical specifications (milestone 5).

By the above an individual population agent thereby is not represented as an individual 'object' but as a participant to one of the state object defined by its membership, which form the effective operational objects within the model. Agent state objects are used to keep track of agent properties and they are altered by socio-economic decisions. Decision algorithms in the model thereby do not operate on the individual agents, but are related to population state clusters, or subsets thereof.

The appropriate clustering of which properties belong together is an iterative process, as part of the technical specifications development (FCA milestone 5), as it relies significantly on the implementation of the algorithms and what makes computational sense. Within the technical specifications development the data specifications on the clustering outline is to be revisited. For purposes of illustrating a particular cluster at this early stage data aspects related to agent activities are outlined in sections 7.2 and 7.3.

7.2 Agent Object Data Relations

Table 7.1 – Relational tables for agent activities as an agent cluster property example

Table name	**AOBJ**				
Attribute	AOBJNO	ATYPE (y)	TIME (t)	*HOUSEHTYPE*	ADDATTRIB (z)
Data type	INT	STRING	INT	INT	

Table name	**HOUSEHTYPE**					
Attribute	HOUSEHTYPE	NOHEADS	HEADREL (y/n)	NOCHILDREN	EMPLOYMENT	ADDATTRIB (z)
Data type	INT	TINYINT	STRING	TINYINT	TYININT	

Table name	**ACTPROFILES**								
Attribute	GENID	PROFID	ACTIVITY	STARTT(t)	ENDT (t)	DAYTYPE	SEASON	*SEQUENCEID* ()	*HOUSEHTYPE (t)*
Data type	INT	INT	STRING		INT	STRING	STRING	INT	STRING

Table name	**AACTIVITYSTATE**				
Attribute	ACTIVITYID	*AOBJNO*	ACTIVITY	DURATION(t)	*GRIDNO*
Data type	INT	INT	STRING	INT	INT

7.3 Agent Object Data Examples

Table 7.2 – Relational tables for agent activities as an agent cluster property example

Table name	**AOBJ**			
Attribute	AOBJNO	ATYPE (y)	*HOUSEHTYPE*	TIME (t)
Data type	INT	STRING	INT	INT
	1	P	1	01012014
	2	P	1	01012014

Table name	**HOUSEHTYPE**					
Attribute	HOUSEHTYPE	NOHEADS	HEADREL (y/n)	NOCHILDREN	EMPLOYMENT	ADDATTRIB (z)
Data type	INT	TINYINT	STRING	TINYINT	TYININT	
	1	1	n	0	1	
	2	2	y	2	2	

Table name	**ACTPROFILES**								
Attribute	GENID	PROFID	ACTIVITY	STARTT (t)	ENDT (t)	DAYTYPE (w/e)	SEASON	*SEQUENCEID*	*HOUSEHTYPE*
Data type	INT	INT	STRING	INT	INT	STRING	STRING	INT	STRING
	1	1	Sleep	2300	0720	E (weekday)	SPRING	1	1
	2	1	Personal care	0720	0740	E (weekday)	SPRING	2	1
	3	1	Food cons	0740	0800	E (weekday)	SPRING	3	1
	4	1	Travel	0800	0900	E (weekday)	SPRING	4	1
	5	1	Work	0900	1330	E (weekday)	SPRING	5	1

	6	1	Foods cons.	1330	1345	E (weekday)	SPRING	6	1
	7	1	Work	1345	1915	E (weekday)	SPRING	7	1
	8	1	Travel	1915	2015	E (weekday)	SPRING	8	1
	9	1	Food cons.	2015	2115	E (weekday)	SPRING	9	1
	10	1	Leisure	2115	2230	E (weekday)	SPRING	10	1
	11	1	Personal care	2230	2300	E (weekday)	SPRING	11	1

Table name	**AACTIVITYSTATE**				
Attribute	ACTIVITYID	*AOBJNO*	ACTIVITY	DURATION(m)	*QUADRANTNO*
Data type	INT	INT	STRING	INT	INT
	1	2	WORK	270	52
	2	1	TRAVEL	60	65

8. Model Sector Classification

The framework of the prototype model is developed on the basis of 14 main sectors to which all productive and consumptive activities can be allocated on a mutually exclusive basis (figure 8.1 below). These have been selected on the basis of relative similarity of physical/biological/chemical processing and human output use of activities carried out in the main sectors. In relation to these sectors the set of 50 process blocks is to be developed with the focus of a specific sector application (discussed in section 9).

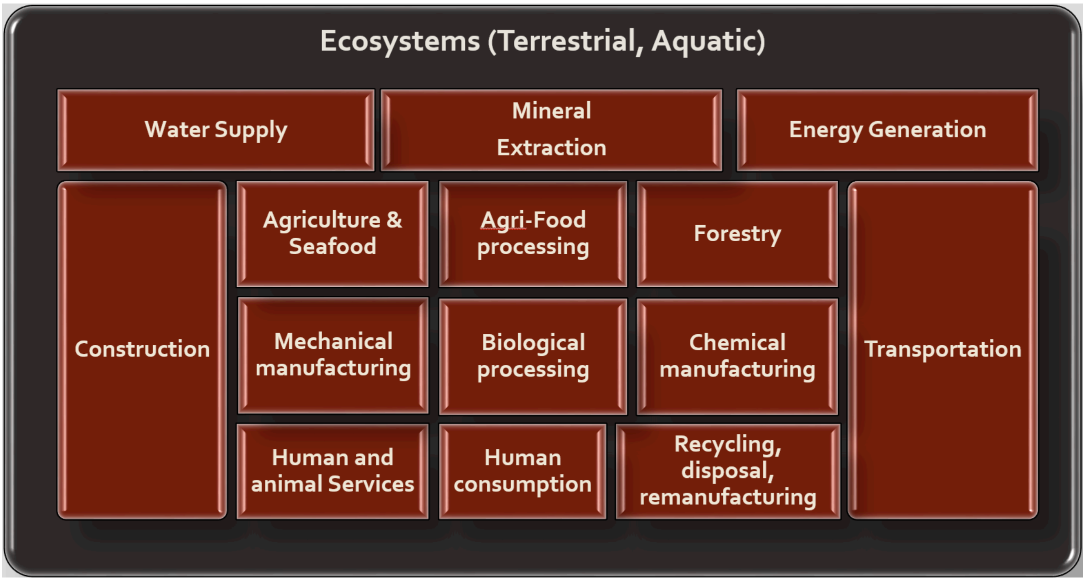

Fig. 8.1 – The fourteen sectors of the human ecosystem within the greater environment.

The sector framework is built as to make it possible to identify individual sub-sectors in a flexible manner within this system, such that in a full scale version of the model variations can be incorporated using local systems in a country or city region, such as the Ghana Standard Industrial Classification[7], and by following international guidelines.[8] The importance of flexibility to create a structure that can match existing local structures of sector divisions is twofold. Firstly, because existing data collection efforts follow structures and classification standards which are already in place. Secondly, because there will be familiarity with existing sector division structures in a city-region on a decision-making level.

By this flexible mode transportation, for instance, could be subdivided into land, water, and air transport, postal and courier activities, and warehousing and support activities. Alternatively a particular service sector could include postal and courier activities, as opposed to the transportation sector, if this matches better with existing decision needs.

Similarly, water supply could be subdivided in collection, treatment and supply, sewerage, and water treatment waste output collection and remediation. Alternatively water sector waste output treatment could be placed under recycling, disposal, and remanufacturing, and so forth.

8.1 Process Block Selection from Sector Application

The selection of the fifty process blocks to be developed under the FCA prototype is to be carried out on a well-informed basis. The aims are to cover an as significant portion of energy/resource flows related to a sector (and the economy) as possible, and to provide for universal applicability including the African cities context. To this end within a sector application the underlying dependencies of infrastructure, machineries, and consumables are to be covered across their supply chains. As such not only an understanding from the operational perspective within the sector itself, such as water treatment plant operation for a water sector related operation, but also how the machinery that is used within the water treatment plant is constructed, and the materials that go into the machinery, are to be included.

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[7] Ghana Statistics, 2008. Ghana Industrial Standard Classification. [online]. Available at: http://goo.gl/9q9Rzt

[8] For example, the United Nations Statistics Division ISIC Rev. 4 (International Standard Industrial Classification of All Economic Activities)

As stated previously a preliminary overview of the 50 process blocks which forms a basis of selection during the FCA prototype development can be found in Appendix C. The final selection is to be made based on the selected sector for demonstration of functionality within the African context, since this will shift the emphasis of required resource flows to be modelled. The process blocks in this listing have been based on a set of criteria, which can be applied generically at any economic scale, and thus also for a given city-region once a model instance is created, as to create prioritization in process block development.

The set of criteria used is as follows:

- **Energy inclusiveness criterion**, selection of all significant energy source process blocks related to the sector, to create an as complete description of energy flows as feasible, and their related GHG Emissions.
- **Water inclusiveness criterion**, selection of process blocks to be able to cover all typical streams of water sources related to the sector, including source water and waste water.
- **Resource flow importance,** selection of process blocks that form a large contribution to resource flows related to a sector (and economy) in terms of material weight and volume.
- **Supply chain criterion,** selection of process blocks that provide for the underlying infrastructure, machinery, and consumables within the sectors entities (see section 5).
- **Sector diversity criterion**, selection of a minimum of one process blocks within each of the main 14 sectors to have an expandable base to build upon and ensure methodological robustness.

The sector diversity is part of the phased development plan of the model as to provide a minimum base for each sector to build upon. In addition to these criteria the selected sector to be developed for demonstration of functionality is to be taken into account, as outlined in the next section.

9. Sector Selection Criteria

The sector to be developed relates to the provisioning of a particular utility or goods output with its by-products and waste outputs, which fall within the 14 sectors as described above. For example, the supply chain to produce sugar and the utilisation of its by-products (molasses and bagasse) for electricity and ethanol as described in section 9.2. Thereby the sector selection implies an important sub-set of activities spanning across the 14 sectors described in section 8, such as energy generation, agricultural and seafood, agri-food, and water supply, for representation in the model. The ‘reconstruction’ of a sector in the model prototype for a demonstration of functionality requires a minimum of five key elements:

- **Sector Importance,** the sector should be of importance in relation to the size of the city-region and its resource flows, and the local livelihood of inhabitants. For example, the food sector which is a significant part both aspects within African city-regions (as opposed to say the automotive manufacturing sector)
- **Sector description**, the sector needs to be well described in its scope, boundary, and activities.
- **Data requirements**, sufficient data needs to be available to generate a reasonable model representation, with a minimum of five years available.
- **Number of activity locations**, the majority of activities in the sector should be occurring in a limited number of point sources, as to create a feasible representation which is sufficiently robust within the constraints of prototype building.
- **Resource based sector**, the sector should be primarily resource driven, as opposed to a service driven sector, due to present constraints on the accuracy of describing service based sectors from a resource perspective.[9]

Below each of these five points are described in more detail in subsequent order of their listing.

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[9] There is only limited external research available of the resource flows related to services, for example the actual resource footprint related to a megabyte of internet bandwidth or the resource cost of producing a movie. Whilst such capabilities are to be developed within the phased model development, choosing such a sector for a demonstration of functionality is not suitable under these present limitations.

The **sector importance** outlines that the sector represents a significant portion of local economic activity in the city-region in terms of production and consumption, and thereby of resource flows as well as economic welfare. This can be measured on the basis of its value added contribution to GDP and/or its estimated number of people involved in the sector in case of sectors within the 'informal economy', as well as the size of imports/exports related to the sector, which can be analysed using data available from the International Trade Centre TradeMap database, as it contains detailed trade data for all countries in Africa differentiated across 99 sub-sector types.[10]

The **sector description** requirement of the sector in its scope, boundary, and activities, implies that a coherent set of similar activities are carried out therein, that these are well understood and can thus both be qualitatively and quantitatively described as they are currently being carried out. For example, in case of 'manufacturing' as a sector the scope is not clear of what activities are carried out, whilst a scope around the 'manufacturing of beverages' provides for a clear boundary. Subsequently, this can be further divided in types of activities such as brewing, packaging, bottle distribution, retailer sales, spent grain disposal or re-sale and so forth. And finally the physical place where these activities take place in the spatial landscape of the city can be allocated.

Within this description it is necessary that at minimum and at an aggregate level of scope there are estimates of the size of the sector in terms of people participating therein on an employment basis, of the number of people that benefit from services provided by the sector, or from goods produced by the sector, of the estimated economic size of the sector and of the quantity of outputs are that are provided by the sector on ideally a weight or alternatively a number of units basis (see preliminary data requirements listing).

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[10] International Trade Centre (2014). TradeMap: Trade Statistics for International Business Development. [Online]. Available at: http://www.trademap.org/

The **data requirement** is necessary to be able to create a representation with a reasonable level of certainty and robustness. For example, figures such as physical outputs produced by the sector form a key element to understand detailed resource flows within the sector. This is possible by using the 'process block' objects outlined in section 6.1, using energy and material balances, such that when knowing outputs produced by a sector, all the inputs that were necessary can be estimated, as well as other waste outputs which were produced, and required labour inputs. The more additional data points which are available, the better the validity of the sector representation in the model. For this purpose key datasets such as outputs produced should be available with a minimum historic timeline of 5 years.

The **number of activity locations** requirement holds that the majority of a sectors activities in the sector should be occurring in a limited number of point sources, serves to create boundaries on the number of spatial sites that need to be described within the feasibility of the FCA program. A point source is described as a spatial area with a relatively homogenous type of produced output, such as a large agricultural area, a manufacturing site, a water treatment plant, and so forth. To illustrate, if there are 3,000 individual small production sites that need to be spatially delineated and which also vary significantly in terms of outputs produced, the available time to create an accurate representation is too limited. In contrast, if there are 10-50 point source production sites where 90% of activities within the sector takes place, despite another 1000 where the remaining 10% is carried out, that would provide for a sufficient constraint to accurately represent a sector for a demonstration of functionality.

The **resource driven sector** requirement stems from overall limitations on the availability of resource flow data related to service activities. In existing life cycle inventory, material flow databases, and individual peer-review analyses there is a large omission in the description of service sectors and their underlying activities from a resource flow perspective. Moreover, within an African context such data related on service activities is unfortunately even more limited in scope. Whilst a methodology to incorporate all types of service activities on a resource flow basis will be examined within the FCA model prototype development, an accurate representation thereof in this early prototype phase is deemed to be challenging, because of the lack of basic groundwork that has been done in this sphere.

9.1 Sector Selection

The selection is to be made on the basis of a set of criteria as outlined, which relate to the ability to adequately represent the sector application in the model given data availability, and the importance of the sector for the city-region and in terms of resource flows.

A number of key examples following these criteria for a sector applications include:

- **A food and energy sector application,** such as sugar cane production, sugar manufacturing, and molasses and bagasse by-products utilisation as ethanol and for thermal incineration to electricity (example described in section 9.2).
- **A water and sanitation sector application,** as the examination of current and future water needs given city-region development, in relation to existing water supply infrastructure, water use and quality change across key city-region activities, and the construction of new water treatment facilities and networks.
- **An electricity sector application,** as the feasibility to meet energy supply in a low-carbon manner given demand development, natural gas production and fossil fuel imports, renewable source availability incl. hydro-power, wind, solar, and biomass, and electricity grids development.

In section 9.2 the food and energy sector application example is described, including how it relates to the set of 50 process blocks which are defined across the 14 ‘archetype’ model sectors, as outlined in section 8.

9.2 Sector Example

The selection of a sector is illustrated on the basis of an example related to agri-food products and energy production in Ghana, namely the recent development to construct a sugar factory based on sugar cane inputs, as part of the wider sugar industry development in the country. Since the 1980s the country has been a large importer of sugar, because the two Komenda and Asutsuara sugar mills, built respectively in 1959 and 1996, were closed down by 1982 due to a lack of productivity and competition.[11] Nowadays the average cost of the country in the import of refined sugar, primarily from Brazil, is estimated to be approximately 200 million USD per year, for a total of around 300,000 tonnes of refined sugar, equivalent to nearly 14% of all food imports in tonnage (see table 10.3 below).[12] At the same time the country is well suited to produce sugarcane, and its potential remains underexploited, with at present an estimated area of 6000 hectares planted with sugar cane providing a yield of 150,000 tons of sugar cane a year, according to FAOSTAT figures.[13] In contrast, the largest crops in Ghana is Cassava, with an area of 870,000 hectares grown and a production of 14.6 million tonnes, as shown in table 10.1 below.

In response to the import gap deficit, and conjoint to the interest of national and international companies, the government of Ghana has managed to secure a 36 million USD loan from the Indian EXIM bank to build a new sugar factory at Komenda in the centre of the country. The construction of the mill is now under development by the Indian engineering firm SEFTECH with anticipated completion near end of 2016. The mill would serve to process at capacity 450,000 tonnes of sugarcane per year, and produce 45,000 tonnes of refined sugar. It would also provide for 18,000 metric tonnes of molasses per year as a by-product, and provide for 3 MW of power capacity of which 2/3rd are required for factory operation, by burning the bagasse by-product to generate steam which drives a turbine.[14]

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[11] Ellis, K, Singh, R., 2010. Assessing the Economic Impact of Competition. Overseas Development Institute

[12] International Trade Centre, 2014. Trade Map: Trade Statistics for International Business Development. [Online]. Available at: http://www.trademap.org/

[13] FAO, 2014. FAO STAT crop data Ghana Sugarcane 2013. [online]. Available at: http://www.faostat.fao.org.

[14] Mahama, J., 2014. Address by President John Mahama at the groundbreaking ceremony for a new sugar processing plant in komenda, August 19, 2014. [online]. Available at: http://www.presidency.gov.gh/node/647

The long term aim is for the molasses to be converted into ethanol, on the basis of a small bio-ethanol refinery. In complement a 24.5 USD million loan has been granted by the Indian government to cultivate 1500-3000 hectares of irrigated sugarcane plantations. It has been estimated that sugarcane in Ghana needs 3-4mm of water per day for good crop yields.[15]

The current development is the most concrete development for the re-start of a sugar industry in Ghana. In 2011 Cargill announced a plan to develop a 450,000 ton capacity sugar refinery based on processing imported syrup feedstock, to be located in the Tema industrial area within the Greater Accra Metropolitan Area (GAMA). The development never took off, however, and appears to have been abandoned.[16] A more recent development is a series of feasibility studies of the Mauritian company Omnicana which is looking into establishing a sugar factory in the North of the country with a capacity of 100,000 tonnes of sugar per year, at a cost of 250 million USD, on the basis of a granted land concession of 20,000 hectares.[17]

The development of such an agricultural sector case study, based on the GAMA city-region dependence of its hinterland, including energy connections to electricity and bio-ethanol, provides for a comprehensive functionality demonstration. A total of 16.3% of the population lives in the GAMA according to the 2010 Ghana Statistical Service Census, with an estimated 24% share of the countries sugar consumption.[18] Based on these figures a total of approximately 72,000 tonnes of sugar would no longer arrive from shipments at the port of Tema from where it is distributed, but would be supplied by truck from GAMA city-region's hinterland if the domestic sugar industry would developed as anticipated.

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[15] ESPA, 2013. Sugar Rush. [Online]. Available at: goo.gl/Pz4nzk

[16] Chullen, J., 2010. Africa Sugar Digest: Ghana New Sugar Factory Proposed. [online]. Available at: http://goo.gl/oUXn8U

[17] Ackbarally, N., 2014. Mauritius: Sugar cane sweetens trade with Ghana. African Business Magazine. [online]. Available at: http://goo.gl/vZ0t05

[18] Based on an estimated three times higher rate of sugar consumption in urban then rural communities as established from South African studies, and an estimated 52% urban to 48% rural population. Sources: Vorster, H., et al., 2014. Added sugar intake in South Africa: findings from the Adult Prospective Urban and Rural Epidemiology cohort study. American Journal of Clinical Nutrition. 99(6). pp. 1479-1486., Steyn, K., Fourie, J., 2006. Chronic Diseases of lifestyle in South Africa: Medical Research Council.

In taking such a sector example the effects of future developments of the implementation of both sugar factories could be investigated, including its envisioned bio-ethanol conversion, and electricity generation. As an example a series of related city region decisions options could possibly be assessed including in relation to financing investment, land use, sugar market regulation, and value added redistribution decision options. Impacts of the economic development that the growth of sugar cane conjoint with its processing will deliver can be investigated whilst taking land use impacts, GHG emissions, and solid waste flows into account with the context of a demonstration. Moreover, also the example lends itself well to provide for a suitable sector case study in relation to the criteria as outlined in section 9, in relation to demonstration of functionality at this early stage.

In particular the following aspects about the criteria can be outlined:

- The sugar production development is of large **sector importance**, given the impacts on the countries trade-balance, financial situation, and agri-food industrial development.
- The **sector description** is clear in that the outputs are known (sugar, molasses, electricity), the process blocks to be developed are clear (e.g. agricultural fields, sugar mills, electricity infrastructure, and the inputs of these), and the alternative choices for planting other crops are known.
- **Sector data** is available for a significant period with agricultural production data going back several decades, as well as electricity generation data.
- The **number of activity locations** are limited in that it does represent a supply chain with a number of centralised processing points, as opposed to a large decentralised complex supply chain.
- The sector is **resource driven** based on several hundred thousand tons of resource flows, and their related value added.

The particular interrelations in such a sector example that would need to be examined relate directly to five process blocks: sugar cane cultivation, the sugar processing factory, transportation and distribution of sugar cane, refined sugar, and by-products, bio-ethanol conversion of molasses, electricity generation from the surplus generation of the sugar factories, and the impacts of the latter two on the overall energy system.

The five process blocks that these represent are related to a number of underlying process blocks, which need to be worked out to provide for an accurate depiction of the economy on the basis of resource flows and energy, including import/export effects outside of Ghana, and between Accra and its hinterland. For example, to understand how much the GHG balance changes within Ghana versus outside of Ghana by shifting the production of sugar geographically from Brazil. The relationships between the five process blocks and their underlying resource related inputs depicted by other process blocks, such as the construction of machinery for the sugar factories, is defined in table 10.4 from page 64 to 68 below.

Table 10.1 - Top 10 Crops produced in 2012 in million tonnes in Ghana. Source: FAOSTAT Database [online]. Available at: http://www.faostat.fao.org.

Crop	Harvested area (hectares)	Harvest (Million Tonnes)
Cassava	870,000	14.6
Yams	430,000	6.6
Plantains	not available	3.6
Oil, palm fruit	360,000	2.1
Maize	1,023,459	1.9
Taro	200,000	1.3
Cocoa beans	not available	0.9
Oranges	not available	0.6
Rice, paddy	215,905	0.6
Groundnuts	328,940	04

Table 10.2 - Agri & Seafood Products with significant share in Ghana imp./exp.*

Description		**% Contribution to Food Imports****	**% Contribution to Food Exports****
Total Products Contribution		**55.1**	**69.4**
Oilseeds	Seeds	0.04	42.6
Cocoa beans, whole/broken/raw/roasted	Fruits	0.0	21.2
Rice	Grains	23.8	0.01
Wheat and Meslin	Grains	14.7	0.05
Fish, frozen, whole	Seafood	10.9	0.5
Brazil/cashew nuts/coconuts	Nuts	0.03	2.4
Maize (Corn)	Grains	1.5	0.06
Onions/garlic/leaks	Vegetables	1.5	0.12
Malt, fresh/roasted	Grains	1.2	
Tomatoes	Vegetables	0.43	0.04
Dates/figs/pineapples/mangoes/avocadoes/guavas	Fruits	0.01	0.9
Cassava/Arrowroot/Yams	Vegetables	0.0	0.6
Bananas/plantains,	Fruits	0.01	0.5
Apples/pears/quinces, fresh	Fruits	0.3	0.01
Fish, fresh, whole	Seafood	0.24	0.03
Dried Vegetables, shelled	Vegetables	0.4	0.2
Citrus Fruit Fresh or Dried	Fruits	0.0	0.2

*Calculations on the basis of physical flow data average for 2001-2013 in tonnage of total food imports/exports. Percentage estimate includes agri-food sector products. Source: TradeMap Database

**The global import and export values do not match due to incomplete data-flows for individual countries forming a mismatch when aggregating to the global level

Table 10.3 – Agri-food products with significant share in Ghana imp./exp.*

Description		% Contribution to Food Imports*	% Contribution to Food Exports*
Total Products Contribution		**34.9**	**31.0**
Palm oil & its fractions	Lipids	2.6	21.2
Cane sugar/ sucrose	Sugars	13.7	0.0
Fixed vegetable fats/oil	Lipids	1.1	5.7
Poultry meat & edible offal	Meats	4.5	0.0
Non-alcoholic beverages*	Beverages	1.9	0.04
Cocoa butter/oil/paste/powder	Lipids	0.01	1.5
Ethyl Alcohol & other spirits	Beverages	1.4	0.01
Bread/biscuits/pastries/cakes	Grain prod.	1.3	0.2
Fruits & vegetable juices	Beverages	1.1	0.1
Milk and cream	Dairy	1.1	0.09
Wheat or meslin flour	Grain prod.	1.1	0.05
Coconut/palm kernel/babassu oil	Lipids	0.05	1.1
Animal feed preparations	Animal Feed	0.9	0.01
Margarine	Lipids	0.9	0.2
Prepared fish	Fish	0.8	0.3
Sugars lactose/synthetic/conf.	Sugars	0.8	0.03
Wine	Beverages	0.5	0.05
Pasta & couscous	Grain prod.	0.5	0.2
Flour of meat/fish unfit for	Animal Feed	0.46	0.04
Cereal grouts, meal and pellets	Grain Prods.	0.2	0.2

*Calculations on the basis of physical flow data average for 2001-2013 in tonnage of total food imports/exports. Percentage estimate includes agriculture and seafood products. Source: TradeMap Database

**excluding water, fruit or vegetable juices

Table 10.4 – Sector to Sector input-output qualitative interrelationships table

Selected sector	**Entities related to Sugar Cane Production**			
Sectors / Entities	**Sector Entity**	**Infrastructure**	**Machinery**	**Consumables**
Agriculture & Seafood	Cultivation and harvesting of sugar cane			
Chemicals Manufacturing				Manufacturing of NPK fertilizers
Construction		Construction of housing and sheds near farms		
Energy Generation			Electricity for pumping of irrigation water	
Human and Animal Services				Sales of sugarcane
Mechanical Manufacturing			Production of pumping equipment + sugarcane harvester	
Mineral Extraction & Processing			Extraction & processing of equipment metals	Extraction of fertilizer raw material inputs
Recycling, Disposal, Remanufacturing	Disposal of agricultural residues	Disposal of building wastes		
Transportation		Construction material transportation to site	Transportation of equipment to site	
Water Supply	Irrigation of Sugar Cane			Water Consumption of sugar cane cultivation

Table 10.4 – Sector to Sector input-output qualitative interrelationships table (continued)

Selected sector	**Entities related to Sugar Processing Plants**			
Sectors / Entities	**Sector entity**	**Infrastructure**	**Machinery**	**Consumables**
Agri-Food Processing	Operation of sugar processing plant			
Construction		Construction of sugar processing plant		
Energy Generation				Electricity inputs into sugar processing plants
Human and Animal Services				Sales of refined sugar, molasses, electricity
Mechanical Manufacturing			Production of processing sugarcane to sugar processing machinery	
Mineral Extraction & Processing			Extraction & processing of machinery equipment metals	
Recycling, Disposal, Remanufacturing		Disposal of building wastes		
Transportation		Construction material transportation to site		Sugar cane transportation by truck on roads to processing plants
Water Supply				Water Consumption in Sugar Factory Processing

Table 10.4 – Sector to Sector input-output qualitative interrelationships table (continued).

Selected sector	**Entities related to Electricity Generation**			
Sectors / Entities	**Sector Entity**	**Infrastructure**	**Machinery**	**Consumables**
Agri-Food Processing	Production of bagasse by-products			
Construction		Construction of thermal power generation & Electricity Grid Connections		
Energy Generation	Operation of electricity power plants			
Forestry				Growth and harvesting of additional biomass feedstock for incineration
Human and Animal Services				Sales of generated electricity
Mechanical Manufacturing			Manufacturing of electricity generation machinery incl. turbines, incineration chambers.	
Mineral Extraction & Processing			Extraction & processing of machinery equipment metals	
Recycling, Disposal, Remanufacturing				Disposal of ash from thermal power plant incinerator
Transportation	Operation of transportation vehicles			Transportation of bagasse from sugar refinery to electricity generation plant

Water Supply				Water use in thermal power cycle.

Table 10.4 – Sector to Sector input-output qualitative interrelationships table (continued).

Selected sector	**Entities related to Transportation of Sugar Cane and Distribution of Refined Sugar and By-products**			
Sectors / Entities	**Sector Entity**	**Infrastructure**	**Machinery**	**Consumables**
Chemicals manufacturing				Refining of crude oil into diesel fuels for transportation
Construction		Construction and maintenance of road networks		
Energy Generation				Electricity inputs into petrochemical refinery
Human and Animal Services			Maintenance of transportation vehicles	
Mechanical Manufacturing		Construction of transportation vehicles materials		Manufacturing of petroleum refinery machinery and drilling equipment
Mineral Extraction & Processing				Extraction of crude oil by onshore and offshore drilling as used in petroleum refining
Recycling, Disposal, Remanufacturing				Waste disposal of crude oil refining output residues
Transportation	Operation of transportation vehicles		Assembly/construction of transportation vehicles from components	Transportation of refined sugar and by-products to distribution and retail points
Water Supply				Water use in petroleum refining operation.

Table 10.4 – Sector to Sector input-output qualitative interrelationships table (continued).

Selected sector	**Entities related to Bio-Ethanol facility**			
Sectors / Entities	Sector Entity	Infrastructure	Machinery	Consumables
Biological Processing	Operation and maintenance of bio-ethanol facility incl. molasses fermentation by micro-organisms			
Construction		Construction of bio-ethanol production facility		
Energy Generation				Electricity inputs into bio-ethanol facility operation
Human and Animal Services				Sales of bio-ethanol outputs
Mechanical Manufacturing			Manufacturing of fermentation and auxiliary machinery for bio-ethanol plant	
Mineral Extraction & Processing			Extraction & processing of machinery equipment metals	
Recycling, Disposal, Remanufacturing				Disposal of bio-ethanol facility production residues
Transportation	Operation of transportation vehicles			Transportation of molasses to bio-ethanol facility, and bio-ethanol to retailers
Water Supply				Water consumption in bio-ethanol facility processes

10. Data Input Requirements

Below, a first generic city-region data requirements that depict the spatial environment and land use to create the spatial map within the model is outlined. Second, sector specific data to represent details of physical entities. Third, requirements are listed to provide for validation steps of process blocks for the environment, material/energy flows, and infrastructure. Fourth, an overview is provided of data necessary to represent the population and companies as agents in the model.

All datasets are described on the basis of minimum requirements and complete requirements, necessary to define a city-region and the sector. The description provides a minimum to maximum range, whereas in most city-regions a complete dataset lies at the 'idealized' end and only in rare cases are such complete datasets available, at least in this day and age. The minimum outline the requirements that provide for a demonstration of functionality using the prototype with a significant number of assumptions, plus greater uncertainty given the lack of real-life datasets to validate the local sector application with.

The minimum requirements are those needed to be able to adequately describe the local object-property relations of what goes on a process block. For instance, an agricultural field for an agricultural sector application, or a water treatment facility for a water sector application so as to simulate these activities in the model. Knowledge of the local city-region is required to create a 'tailored' version of a generic process block, to adequately allocate it to the spatial landscape, and to validate simulated outputs with real-life data.

The more information provided on the historic actuals of the material, energy inputs and outputs, labour associated within the sector, and thereby goods and/or services produced, the better the quality of a sector simulation will become. At minimum, information is required on the physical outputs of the sector, the number of labourers and labour hours worked, its key production locations across the landscape of the city-region, the access of people to the service provided by the sector and the networks used for transportation (where applicable), and a listing of what technologies to produce the respective sector's good or service (see minimum datasets in table 11.1 to 11.4 below)

All additional information and detail such as historic data on energy inputs, material inputs, and wastes produced for the sector (or ideally individual locations or facilities), as well as in which other sectors the outputs of the particular sector were utilised and what the economic turnover was in the sector, will lead to much greater validity of the simulation as the error range in the simulation will be greatly reduced (see complete datasets for ideal versions in table 11.1 to 11.4 below).

Finally, to outline the datasets, in several cases a separation is made within the city-region between the spatial area of the city metropolitan area (also referred to as the larger urban zone), and the supply hinterland of city. In the majority of cities the border between the metropolitan area and supply hinterland is well defined by politically defined boundaries. If the distinction is not clear it can be based on a cut-off such as the city metropolitan area having a population density above 150 inhabitants/km^2, or a user defined boundary.

The boundary of the supply hinterland is often not adequately defined. It can be based on the relationship of resource flows coming from the hinterland into the city, which is variable over time.

Since each city varies in its make-up, a conscious decision of where to place the supply hinterland needs to be made on a case-by-case basis. The supply hinterland is composed primarily of rural land with small settlements where agricultural, and mineral extractive activities take place alongside forestry and natural unmanaged ecosystems. It could in certain cases for large cities include smaller cities.

10.1 Sector Space and Land Use data

Table 11.1 – Data requirements to describe the spatial environment

Datatype	Minimum dataset	Unit	Complete dataset	Unit
Surface Area	Recent annual data point of surface area for the city metropolitan area and its supply hinterland	km^2 / area name	Datasets for surface area for the city by city sub-districts within the metropolitan area and its supply hinterland.	km^2 / area name
Land use	Recent area division by main land use types in % for the metropolitan area and the supply hinterland based on a significant representative portion.*	% of surface area per land use type	Time series of area division by main land use types per sub-district for the metropolitan area and supply hinterland at the level of individual cells with bounded land use	Cell coordinates within sub-districts and their land use type per year
Spatial outline of sector production sites	Key production sites for output/service and their location coordinates	Site with coordinates	All production sites for output/service and their location coordinates	Site with coordinates
Spatial outline of Sector Network Infrastructure (where applicable depending on sector)	Key/Main network links where applicable such as pipelines or gridlines start and ending coordinates	Links with start + end coordinates	All network links such as pipelines or gridlines and their capacity with start and ending coordinates, and intersections with their coordinates	Links with start + end coordinates, intersections with coordinates

*Main land use types can include arable land, forests, farmland (divided in crop and pasture), semi-natural and natural areas, wetlands, water bodies, mineral extraction sites, landfills, residential, commercial, institutional, road, parking, and industrial areas.

10.2 Sector Entity Objects Data

Table 11.2 – Data requirements to describe sector entity objects

Datatype	Minimum dataset	Unit	Complete dataset	Unit
Production capacity of sector production sites	Production Capacity of key sector sites	Site production capacity (units or tonnes per day)	Production Capacity for all sector sites	Site production capacity (units or tonnes per day)
Capacity of Sector Network Infrastructure (where applicable depending on sector)	Key/Main network links capacity	Units or Tonnage per distance per day	All network links such as pipelines or gridlines and their capacity	Units or Tonnage per distance per day
Sector material inputs	No minimum		Long time series (20+ years) of (physical) sector inputs typically at a weekly or monthly level per production site**	
Sector outputs (expressed in physical units of mass or energy where applicable)	Recent data points of physical (output) or service produced in quantities per year for entire sector (<5 years).	Quantity or no. per unit time	Long time series (20+ years) of (physical) sector outputs per production site typically at a weekly or monthly level.*	Quantity per unit time

Sector output inflows into other sectors as input/consumption (input-output relation)	No minimum	Long time series (20+ years of sector outputs consumption in other sectors (commercial, industrial, residential etc.) typically at a weekly or monthly level.	Quantity or % per other sector per unit time
Sector solid wastes	No minimum	Long time series (20+ years) of sector related solid material waste outputs typically at a weekly or monthly level*	Quantity per unit time
Sector liquid wastes / pollution	No minimum	Long time series (20+ years) of sector related liquid waste/pollution outputs typically at a weekly or monthly level*	Quantity per unit time
Sector gaseous wastes / pollution	No minimum	Long time series (20+ years) of sector related emissions typically at a weekly or monthly level*	Quantity per unit time

10.3 Sector Process Block Object data

Table 11.3 – The data requirements to validate process blocks within a sector

Datatype	Minimum dataset	Unit	Complete dataset	Unit
Sector turnover and revenues	No minimum	Financial quantity per unit time	Long time series (20+ years) of turnover and revenues in sector.	Financial quantity per unit time
Sector electricity inputs	No minimum unless no physical output data for sector is available then time-series of electricity data in quantities per month for entire sector (<5 years).	kWh per unit time	Long time series (20+ years) of (physical) sector inputs per production site typically at a weekly or monthly level **	kWh per unit time
Sector labour inputs	Recent data point of number of jobs in aggregate sector or portion of sector for production site(s)	No. per year	Long time series (20+ years) of number of jobs per production sites in sector	No. per year
Sector work hours	Recent data point of number of average hours worked per job in sector or portion of sector for production site(s)	No. of hours per worker	Long time series (20+ years) of average hours worked per job in sector production sites in sector	No. of hours per worker

Technology Descriptions	A listing of the technologies used at least one production sites based on site surveys (e.g. in case of water the physical, chemical, and biological treatment units on-site)	Listing for one site	A listing of the technologies used at a large number of production sites based on site surveys including photographs (e.g. in case of water the physical, chemical, and biological treatment units on-site)	Listing + Photographs per site

*Output time series variation depends on the time-criticality of sector provision to understand breakdowns. For example, in case of the electricity sector data on a minute by minute level, it is necessary to understand risks of breakdowns, whilst for manufacturing a weekly profile provides for a good quality level for the purpose to understand stock drawdowns and variability.

10.4 Sector Agent Object data

Table 11.4 – The data requirements to describe agent objects

Datatype	Minimum dataset	Unit	Complete dataset	Unit
Population Statistics	Recent annual data point of population number and its age plus gender distribution for the city metropolitan area and its supply hinterland (or urban and rural)	No. / age	Time series of population number and age plus gender distribution (20+ years) split out by city sub-districts within the metropolitan area and its supply hinterland	No. of age per year
Access to sector service (where applicable)	% of population in metropolitan area and supply hinterland with access to sector service	%	Long-term time series (20+ years) of % of population in sub-districts of metropolitan area and supply hinterland with access to sector service	% per area per year
Household Statistics	Recent annual data point of number of households and member composition for a significant part of the city-region (e.g. single, couple, couple with 1,2,3,4,5+ children etc.)	No. of type X,Y,Z	Long time series (20 + years) of no. of households and member composition (single, couple, couple with 1,2,3,4,5+ children etc.) split out by sub-districts / civil administration regions	No. of type X,Y,Z, for spatial sub-districts per year

Employment Statistics	Recent annual data point of workforce, employment, unemployment, for a significant part of the metropolitan area and its supply hinterland.	No. with emply. status	Time series of workforce, employment, unemployment (20+ years) for firm sizes (e.g. 0-9, 10-49, 50-249, 250+ employees) split out by sub-districts /civil administration regions for the metropolitan area and its supply hinterland.	No. with emply. status by firm size categories for spatial zone per year
Population activity information	Description of a list of main activities, varying by social groups and male, female, children (including sleep, work, food consumption, travel, leisure, and other human and household maintenance.)*	Activity listing + description for main social groups	Profile of all activities during 24 hours on a minute by minute basis, for population members varying by relevant societal groups, household type and membership, based on established surveys.	Activity profile + duration at minute level for 24 h
Economic activity aggregate	A recent data point of the Gross Domestic Product (GDP) and/or Gross Value Added (GVA) of the metropolitan area also in Purchasing Power Parity (PPP)	Nominal GDP and/or GVA in local currency value and PPP value	Time series of the Gross Domestic Product (GDP) and Gross value Added (GVA) split out by sub-districts/civil administration regions for the metropolitan area and its supply hinterland	Nominal GDP and GVA in local currency value and PPP value per area per year.

Household income	A recent data point of household income by composition (single couples, couples with 1,2,3,4,5+ children), gender, and no. of households.	Nominal currency value of income per household type	Long time series (20+ years) of household income and disposable household income by household composition (single couples, couples with 1,2,3,4,5+ children), gender, and no. of households.	Nominal currency value of income per household type and year
Job-types	No minimum		Long time series (20+ years) of no of jobs by category.	No. per job type per year
Education level of population	No minimum		Long time series of educational enrolment, dropouts, and diploma's obtained per education level combined with age	No. per age per year
Demographics of life	Short time series of births and deaths (< 5 years) for city region split out between metropolitan area and its supply hinterland by age plus gender.	No.	Long time series of births and death (20+ years) by age plus gender split out by sub-districts /civil administration regions.	No. per spatial sub-district per year
Demographics of migration	No minimum		Long time series of immigration and emigration from the city region by age and gender (20+ years)	No. per spatial sub-district per year

*Variation of social groups relates to employment status, main work plausibly also relevant is participation in formal versus informal economy,

11. Data Treatment Practices

The treatment of data within the FCA prototype model development needs to adhere to standardised protocols and standardised units of measurements, as to ensure data quality and minimize calculation errors. Aspects of data security are dealt with in later development phases once the model will become available to wider stakeholders in phase 2 of the development trajectory.

The data sets in the model need to be harmonised prior to entry in the model to ensure that similar physical units are used across all objects, at all times following the international system of units (SI system) as it is the most widely and coherent system of unit measurement. For example, including energy on the basis of joules, as opposed to British Thermal Units (BTU's), weight in kilograms and metric tons instead of long or short tons. To this end a series of standardised conversion tables need to be built such that in cases that data is reported in other units then following the SI system, appropriate conversions, based on standardised reference works of conversion factors.[19] The tables can be included in the database environment, to provide for appropriate efficient data management practices, in case of importing existing datasets.

The SI standards are not sufficient, however, in dealing with resource related flows, however, since particular values will differ per country due to unique physical circumstances of extracted resources. For example, the gross heat content in a barrel of 159 litres of crude oil extracted from oil fields in Cameroon, is 2% higher than the gross heat content of a similar barrel extracted in Angola, due to variations in the composition of the barrel of crude oil. In such cases of physical variations which can transparently be traced based on existing data efforts, country or city-region specific values are to be incorporated, as oppose to global averages. For this purpose, again particular appropriate tables are to be taken from standardised reference works, such as in this case the Gross Heat Content table of crude oil production per country from the US Energy Information Administration.[20]

A third key aspect of the data treatment practice to be embedded within the FCA prototype development is to ensure that original data is kept cleanly separated from harmonized data, as to provide for a clean tracing of steps that were taken to adjust or

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[19] For example, Thompson, A., Taylor, B., (2008). Guide for the Use of the International System of Units (SI). National Institute of Standards and Technology U.S. Department of Commerce, lists several hundred conversion factors used by the US government.

[20] US EIA (2014). International Energy Statistics: Gross Heat Content of Crude Oil Production (Thousand Btu per Barrel). [online]. Available at: http://goo.gl/bwAKvA

aggregate datasets and prevent any data loss from occurring. As such original data is always to be kept in separate file and database records from treated and harmonized data, so that at any point in time both the original and the harmonized datasets can be inspected for purposes of validation, accuracy, or otherwise. To incorporate this practice a protocol will be provided for within the data collection strategy (milestone 6 of the FCA project), as part of any model instance data building effort.

12. International Classification Standards

The aspect of tailoring the sub-sector divisions in the model to specific city-region or international classification structures, as to enable congruence with locally used sector related data standards, was outlined in section 8.

At present three international classification standards for sectors or industries and their activities are mainly used:

- **UN ISIC v4,** United Nations International Standard Industrial Classification of All Economic Activities, last updated in 2008, which divides the economy into 21 main sectors, 99 groups underlying the sectors, and a large number of classes within groups.
- **NAICS 2012,** the North American Industry Classification System, last updated in 2012, which divides industries into 20 main sectors, each with a large number of subsectors up to a 6 digit level of detail covering 19,256 activities.
- **NACE v2.,** the European Statistical Classification of Economic Activities, last updated in 2008, which divides the economy into 21 main sectors, 88 divisions, 272 groups, and 615 classes. NACE is similar to ISIC at high levels, and more detailed at lower levels.

Within the FCA project correspondence tables are to be created between the 14 sectors as outlined and the three standardisation systems at the higher level of sectors and divisions. In addition for purposes of creating comparisons with existing sectors and industrial classifications, also correspondence between materials names and product classification standards is to be created, for the materials developed within the context of the 50 Process Blocks. The purpose is to allow quick comparisons with production, import, and export data in existence on a financial and physical resource basis, in relation to modelled flow values of materials.

At present three product classification standards are in primary use:

- **Harmonised System**, the World Customs Organisation listing of products within 99 main product categories, including level of detail up to 10 digit level (e.g. whether an imported donkey is of the male or female gender).
- **UN CPC**, the United Nations Central Product Classification, last updated in 2008, which covers 99 main product categories (e.g. stone sand and clay), their

groups (e.g. monumental or building stone), classes (e.g. marble and other calcareous monumental or building stone) and subclasses. Typically classes and subclasses are similar in their datatype.

- **UN SITC,** the United Nations System for International Trade Classification, last updated in 2008, which covers 99 main product categories, their groups, subgroups (e.g. milk (including skimmed milk) and cream, not concentrated or sweetened), and sub-subgroups (e.g. milk of a fat content, by weight, not exceeding 1%).
- **EU CPA,** the statistical classification of Products by Activity of the European Union, last updated in 2008, which is similar to the UN CPC except for more detail at lower levels.

The correspondence tables to be made within the FCA decision-maker prototype model development are to be based on specific materials after their identification for the 50 process blocks whose resource flow relationships are to be built.

Appendix A – First List of Main Entity Variants

Table A.1 - first listing of entity variants.

Entity type	Entity subtype	Pool (yes/no)
Infrastructu	Industrial buildings	No
	Residential buildings	N
	Commercial buildings	N
	Storage buildings	Yes
	Auxiliary infrastructure	N
	Roads	N
	Railways	N
	Bridges	N
	Tunnels	N
	Subways	N
Machinery	Hand Operation	N
	Thermal Operation	N
	Electric Operation	N
	Pneumatic Operation	N
	Hydraulic Operation	N
	Mechanical Operation	N
	Hybrid Operation	N
Materials	Metals and their alloys	N
	Semiconductors	N
	Superconductors	N
	Magnetic materials	N
	Dielectrics and insulators	N
	Electrical materials (other)	N
	Ceramics, refractories, glasses	N

	Polymers and elastomers	N
	Minerals and ores	N
	Rocks	N
	Fertilizers	N
	Timbers and woods	N
	Cement and concrete	N
	Building materials	N
	Fuels, propellants and explosives	N
	Composites	N
	Gases	N
	Liquids	N
Biota	Anseriformes (Ducks, Geese)	No
	Bovini (Cattles, Buffalos)	No
	Canidae (Dogs)	No
	Caprini (Sheep, Goats)	No
	Camelidae (Camels)	No
	Felidae (Cats)	No
	Galliformes (Chickens, Turkeys)	No
	Suidae (pigs, hogs, swines)	No
	Crops	No
	Flowers	No
	Grasses	No
	Groundcovers	No
	Vines	No
	Trees	No
	Shrubs	No
Atmosphere	Surface layer	Yes
	Minimum boundary layer	Yes
	Troposphere	Yes
Lithosphere	Topsoil	Yes
	Sub-soil	Yes
	Bedrock	Yes

Biosphere	Agricultural fields	Yes
	Deserts	Yes
	Dunes	Yes
	Forests	Yes
	Floodplains	Yes
	Grasslands	Yes
	Marshes	Yes
	Peat lands	Yes
	Savannahs	Yes
	Tundra’s	Yes
	Urban systems	Yes
Hydrospher	Lagoons	Yes
	Lakes	Yes
	Ponds and pools	Yes
	Rivers and Streams	Yes
	Swamps	Yes
	Wetlands	Yes

Appendix B – Data Dictionary

Table B.1 – Data Dictionary in table format

Table name	**SRASTER**					
Attribute	CELLNO	XMIN (L1)	XMAX(L2)	YMIN (A1)	YMAX (A2)	ADDATTRIB (z)
Data type	INT	FLOAT	FLOAT	FLOAT	FLOAT	

Table name	**SVECTOR**			
Attribute	VECTORNO	POLYNO (p)	TOTPOLY (n)	ADDATTRIB (z)
Data type	INT	TINYINT	TINYINT	

Table name	**SVECTOR POINTS**							
Attribute	POINTNO	XVAL (L)	YVAL (A)	POINTTYPE (1,2,3)	POINTNO (u)	POLYNO	FIRSTP (f)	*VECTORNO*
Data type	INT	FLOAT	FLOAT	TINYINT	TINYINT	TINYINT	TINYINT	INT

Table name	**EOBJ**								
Attribute	EOBJNO	ETYPE (y)	POOLQ (p)	CREATION (c)	END (e)	LONG (L)	LAT (L)	*ENTITYREL*(ee)*	ADDATTRIB (z)
Data type	INT	TINYINT	STRING (y/n)	INT	INT	FLOAT	FLOAT	INT	

*Recursive relationship with EOBJNO to include entities that relate to entities

Table name	**ELAYERS**							
Attribute	LAYERNO	*EOBJNO*	LAYERTYPE (r)	LAYERNAME (n)	*LREL* (em)	WEIGHT (w)	VOLUME (v)	WEIGHTSHR (h)
Data type	INT	INT	STRING (e/r)	STRING	INT	INT	INT	TINYINT

*Recursive relationship with LAYERNO to include entity to layer relationship at material level

Table name	**EENERGY**				
Attribute	ENERGYNO	ENERGYSTATE (f)	ENERGYFORM (o)	*LAYERNO*	ADDATTRIB (z)
Data type	INT	INT	STRING	INT	

Table name	**EMETA**								
Attribute	METAID	*EOBJNO*	LAYER (LR)	*LAYERNO*	PERSON (MP)	EDATE (MT)	SOURCE (MS)	CDATE(MC)	METHOD (MM)
Data type	INT	INT	STRING (y/n)		STRING	INT	STRING	INT	STRING

Table name	**POBJ**									
Attribute	TABLEID	POBJNO	PTYPE (y)	PNAME (n)	EINP (ei)	EOUT (eo)	EIOFACTOR (ef)	EVAR (ev)	TIME (t)	ADDAT (z)
Data type	INT	INT	STRING	STRING	STRING	STRING	FLOAT	FLOAT	INT	

Table name	**PMAT**							
Attribute	MATNO	*POBJNO*	MINP (mi)	MOUT (mo)	MIOFACTOR (mf)	MVAR (mv)	FLOWTYPE (mf)	TIME (t)
Data type	INT	INT	STRING	STRING	TINYINT	TINYINT	STRING	INT

Table name	**PLABOUR**				
Attribute	LABNO	*POBJNO*	LABOURINP (li)	JOBTYPE (jt)	JOBTYPE (jt)

Data type	INT	INT	SMALLINT	STRING	STRING

Table name	**PSTOCH**				
Attribute	PSID	MOUT (mo)	FREQUENCY (fr)	PERIOD (tp)	ADDATTRIBUTE (z)
Data type	INT	INT	FLOAT	INT	

Table name	**PSEQUENCE**				
Attribute	SEQTABID	PSEQNO	*POBJNO*	*PTYPE (y)*	ADDATTRIB (z)
Data type	INT	TINYINT	INT	STRING	

Table name	**PMETA**							
Attribute	METAID	*POBJNO*	PERSON (MP)	EDATE (MT)	SOURCE (MS)	CDATE(MC)	METHOD (MM)	ADDATTRIB (z)
Data type	INT	INT	STRING	INT	STRING	INT	STRING	

Table name	**PMTECHNOLOGY**						
Attribute	METAID	*POBJNO*	AUTOMATION (pa)	MODERNITY (pm)	PRODTURNOVER (PT)	SPATIALINT (PI)	ADDATTRIB (z)
Data type	INT	INT	STRING	STRING	STRING	STRING	

Table name	**AOBJ**		
Attribute	AOBJNO	ATYPE (y)	TIME (t)
Data type	INT	STRING	INT

Table name	**HOUSEHTYPE**				
Attribute	HOUSEHTYPE	NOHEADS	HEADRELATIONSHIP (y/n)	NOCHILDREN	EMPLOYMENT
Data type	INT	TINYINT	STRING	TINYINT	TYININT

Table name	**ACTPROFILES**						
Attribute	PROFID	PROFID	ACTIVITY	DURATION (t)	SEASON	*SEQUENCEID* ()	*HOUSEHTYPE (t)*
Data type	INT	INT	STRING	INT	STRING	INT	STRING

Table name	**AACTIVITYSTATE**				
Attribute	ACTIVITYID	*AOBJNO*	ACTIVITY	DURATION(t)	*GRIDNO*
Data type	INT	INT	STRING	INT	INT

Appendix C – Preliminary set of Process Blocks

In the FCA prototype development phase a series of 50 process blocks are to be developed to underpin the sector. A preliminary listing can be found in table C1 which is informed by an assessment of the largest resource flows which generically occur across sectors and the economy. The final selection is to be made after sector selection has taken place, since this may shift the emphasis of required resource flows to be modelled. In table C2 below also a preliminary listing of the 70 additional process blocks envisioned for development in phase 1b is included, which result in the sum of 120 process blocks.

Table C.1 – Preliminary overview of 50 Process Blocks for development under phase 1a

No.	Development phase	Sector	Product
1	1a	Agriculture and Seafood	Dry grain cultivation (Wheat, Maize, Barley, Sorghum)
2	1a	Agriculture and Seafood	Wet grain cultivation (Rice)
3	1a	Agriculture and Seafood	Sugar Cane Cultivation
4	1a	Agriculture and Seafood	Animal Husbandry - Chickens
5	1a	Agriculture and Seafood	Animal Husbandry - Cattle
6	1a	Agriculture and Seafood	Animal Husbandry - Goats and Sheep
7	1a	Agriculture and Seafood	Fishing - drag / lift netting
8	1a	Agri-Food Processing	Sugar processing (cane sugars)
9	1a	Agri-Food Processing	Meat slaughterhouse production
10	1a	Agri-Food Processing	Fish parts processing
11	1a	Agri-Food Processing	Flour production (wheat, maize, barley, sorghum, rice)
12	1a	Biological Processing	Ethanol production
13	1a	Chemicals manufacturing	Crude oil refining into base chemicals
14	1a	Chemicals manufacturing	Potassium Fertilizer manufacturing (potassium chloride (MOP), potassium sulfate (SOP))
15	1a	Chemicals manufacturing	Propylene Polymers production from base chemicals
16	1a	Chemicals manufacturing	Soda ash/Sodium carbonate production by the Solvay Process (from salt and limestone)
17	1a	Chemicals manufacturing	Explosives manufacturing (ANFO)
18	1a	Construction	Clinker production from limestone, clay, gypsum

19	1a	Construction	Calcium oxide (quicklime) production
20	1a	Construction	Cement manufacturing from clinker
21	1a	Construction	Brick production from raw mixed materials
22	1a	Construction	Industrial buildings (Factory buildings)
23	1a	Energy generation	Thermal as power generation (simply cycle & combined cycle gas turbines)
24	1a	Energy generation	Thermal coal power generation (pulverized coal)
25	1a	Energy generation	Diesel power generation (thermal generators)
26	1a	Energy generation	Electricity transmission and distribution networks
27	1a	Energy generation	Wood-fuel collection and incineration
28	1a	Energy generation	Solar-PV (mono and polysilicon PV), silicon ingot production, wafering, module production
29	1a	Energy generation	Hydropower electricity (pumped storage, hydro-electric, run-off river)
30	1a	Forestry	Plantation Forest Cultivation
31	1a	Forestry	Logging (sawlogs, veneer logs)
32	1a	Forestry	Sawn wood production
33	1a	Mechanical manufacturing	Flat rolled iron/steel manufacturing
34	1a	Mechanical manufacturing	Rods, angles and plates of iron/steel manufacturing
35	1a	Mechanical manufacturing	Tubes, pipes, profiles of iron/steel manufacturing
36	1a	Mechanical manufacturing	Motor vehicles parts manufacturing
37	1a	Mechanical manufacturing	Float and polished glass sheets manufacturing
38	1a	Mechanical manufacturing	Plastic products (plates, sheets, film, foil, tape, and strips)
39	1a	Mineral extraction & processing	On-shore drilling of conventional crude oil and natural gas
40	1a	Mineral extraction & processing	Open-pit metals extraction (Coal, iron ore, copper, bauxite)
41	1a	Mineral extraction & processing	Quarrying (Dimension Stone, Salt, Limestone, Gravel and Stone, Sulfur, Clays)
42	1a	Mineral extraction & processing	Ore beneficiation (crushing, grinding, flotation)
43	1a	Mineral extraction & processing	Bauxite processing into alumina and aluminium
44	1a	Mineral extraction & processing	Iron ore processing into pig iron and steel
45	1a	Mineral extraction & processing	Coal processing into pulverized powder
46	1a	Transportation	Gravel and asphalted road construction
47	1a	Transportation	Diesel lorries manufacturing and use
48	1a	Water supply	Pipeline water networks
49	1a	Water supply	Source water treatment plant
50	1a	Water supply	Waste water treatment plant

Table C.2 – Preliminary overview of 70 Process Blocks for development under phase 1b

No.	Development phase	Sector	Product
1	1b	Agriculture and Seafood	Bean cultivation (soya beans, coffee pods)
2	1b	Agriculture and Seafood	Vegetable cultivation (onions, garlic, leeks)
3	1b	Agriculture and Seafood	Vegetable cultivation (yams, potatoes)
4	1b	Agriculture and Seafood	Fruit tree cultivation (apples, pears)
5	1b	Agriculture and Seafood	Seafood - inland tank aquaculture
6	1b	Agriculture and Seafood	Fishing - Angling techniques (long-lining, trolling, drop-
7	1b	Agriculture and Seafood	Animal Husbandry - Pigs
8	1b	Agriculture and Seafood	Cotton Cultivation
9	1b	Agri-Food Processing	Pumpkin and hay animal feed processing
10	1b	Agri-Food Processing	Skimmed cow milk powder processing
11	1b	Agri-Food Processing	Starches processing
12	1b	Agri-Food Processing	Bread production
13	1b	Agri-Food Processing	Fruit and vegetable juice manufacturing
14	1b	Agri-Food Processing	Beer production from malt
15	1b	Agri-Food Processing	Sauce and condiment production
16	1b	Biological Processing	Yeast manufacturing
17	1b	Chemicals manufacturing	Phosphoric acid and sulfuric acid manufacturing (inorganic chemicals)
18	1b	Chemicals manufacturing	Phosphorus Fertilizer manufacturing (MAP, DAP, single and triple superphosphate)
19	1b	Chemicals manufacturing	Ethylene Polymers production from base chemicals
20	1b	Chemicals Manufacturing	Vinyl chloride/halogenated olefins polymers production from base chemicals
21	1b	Chemicals manufacturing	Nitrogen Fertilizer manufacturing (ammonium nitrate, potassium nitrate, urea)
22	1b	Chemicals Manufacturing	Mixed fertilizers production (NPK mixtures)
23	1b	Chemicals Manufacturing	Industrial gases production (e.g. Nitrogen Adsorption)
24	1b	Chemicals Manufacturing	Ammonia production (Haber-Bosch)
25	1b	Construction	Industrial buildings (Storage Warehouses)
26	1b	Construction	Low-rise buildings (houses)
27	1b	Construction	High-rise buildings (office buildings)
28	1b	Construction	Tiles and pavings (ceramic, hearth)
29	1b	Construction	Gypsum calcination to plaster

30	1b	Construction	Controlled building demolition
31	1b	Energy generation	On-shore and offshore wind turbine electricity
32	1b	Energy generation	Nuclear fuel elements manufacturing
33	1b	Energy generation	Nuclear fission boiling water reactor
34	1b	Energy generation	Integrated Gasification Combustion Cycle plants (Coal,
35	1b	Energy generation	Upper surface geothermal heat generation
36	1b	Forestry	Corrugated cardboard packaging production
37	1b	Forestry	Pulp wood processing (roundwood, split wood)
38	1b	Forestry	Chemical Wood Pulp production (sulphate pulp, recovered fibre pulp)
39	1b	Forestry	Wood Packaging cases manufacturing
40	1b	Forestry	Uncoated and coated papers production for writing and
41	1b	Forestry	Plywood and particle board production
42	1b	Human and Animal Services	Desk-based services
43	1b	Human and Animal Services	Goods and property exchange services (supermarkets, shops)
44	1b	Human and Animal Services	Communication services (phone networks, internet networks)
45	1b	Mechanical manufacturing	Insulated copper wire and cable manufacturing / iron/steel wire manufacturing
46	1b	Mechanical manufacturing	Bulldozers, backhoes, excavators, and shovels and their parts manufacturing
47	1b	Mechanical manufacturing	Rubber tires manufacturing
48	1b	Mechanical manufacturing	Glass bottles and carboys manufacturing
49	1b	Mechanical manufacturing	Basic furniture (chairs, tables, couches, storage cabinets)
50	1b	Mechanical manufacturing	Materials handling manufacturing (forklifts, cranes, aerial work platforms)
51	1b	Mechanical manufacturing	Conveyor systems manufacturing
52	1b	Mechanical manufacturing	Pumps and compressors manufacturing
53	1b	Mechanical manufacturing	Electric motors and generators manufacturing
54	1b	Mechanical manufacturing	Woven fabrics manufacturing
55	1b	Mechanical manufacturing	Laptop computers manufacturing
56	1b	Mechanical manufacturing	Electronic white goods manufacturing (refrigerators and freezers)
57	1b	Mineral extraction & processing	Strip-mining (Coal, phosphate rock, potash ores)
58	1b	Mineral extraction & processing	Room and pillar underground extraction (Coal, iron ore, copper, salt, phosphate rock)
59	1b	Mineral extraction & processing	Block caving underground extraction (Coal, iron ore, copper, salt, phosphate rock, potash ores)

60	1b	Mineral extraction & processing	Long wall underground extraction (Coal, iron ore, copper, potash ores
61	1b	Mineral extraction & processing	Primary copper processing to copper ingots
62	1b	Recycling, Disposal, and Remanufacturing	Waste landfilling
63	1b	Recycling, Disposal, and Remanufacturing	Mixed urban wastes sorting and recycling (incl. shredding)
64	1b	Transportation	Personal motorized vehicles manufacturing and use (scooters, motors)
65	1b	Transportation	Container ships manufacturing and use
66	1b	Transportation	Pipelines manufacturing and placement
67	1b	Transportation	Cars manufacturing and use
68	1b	Transportation	Railways construction
69	1b	Transportation	Diesel-electrical trains manufacturing and use
70	1b	Water supply	Bottled water manufacturing