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# DATA MODEL FOR MULTI-BIOMASS SUPPLY CHAIN

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## ABSTRACT

Biomass plays an important role as one of the main renewable energy sources. Given the high logistical cost associated with biomass adoption, having an efficient supply chain that provides bio-refineries with adequate quantities of biomass at a reasonable price and in a timely manner is critical. To this end, this paper proposes a flexible data model for a multi-biomass supply chain. The role of this data model is to list, analyze, and structure a large amount of data for a multi-biomass supply chain in a logical way. The result is a set of tables that can be recorded in a database management system. These tables contain input data that can then be loaded into a mathematical programming environment to support biomass supply chain modeling and optimization.

**Keywords:** Conceptual data model, database design, logistics, and multi-biomass supply chain.

## INTRODUCTION

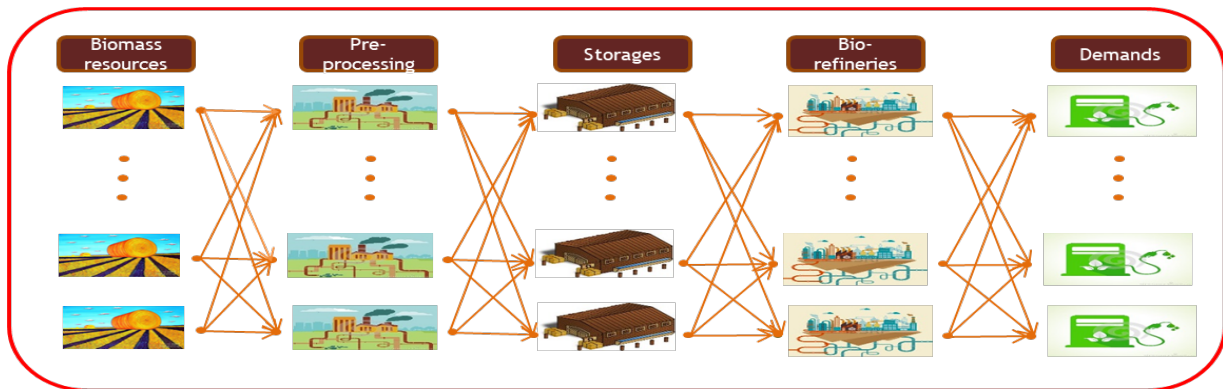
Unavoidable effects of climate change caused by greenhouse gas emissions, together with a growing global concern for energy demand, motivated a recent stream of research for alternatives to fossil fuels (Bauer et al. 2016; Liu et al. 2007). Biofuel obtained from biomass, as a renewable and clean energy source, is one of the few potential replacements for fossil fuels and can play an important role in transitioning from traditional sources of energy (Zandi Atashbar et al. 2018a). Although biomass is cheap relative to other energy sources, the delivery cost at refinery gates varies significantly due to the complicated logistics of biomass. Unlike many other industrial logistics with a constant flow of resources, the biomass supply chain is highly seasonal and dynamic. The raw materials (oilseed and lignocellulosic crops) are produced slowly, seasonally, and with a limited yield over a vast territory. A refinery must use successive crops during the year, e.g., miscanthus in spring, rape in July, cereal straws in August, camelina in October, and short-rotation trees like willows in winter.

From a field to fuel, the biomass supply chain includes various activities such as cultivation, harvesting, handling, storage, transportation, and biofuel conversion. In practice, a biomass supply chain is a complex network of enterprises. The role of biomass supply chain management is to make all the complex decisions involved in designing and operating such chains. To date, most models focus on one or two steps at a time, perhaps because of the system's complicity. However, if we are to design an agile biomass supply chain, it is essential to model and optimize a multi-biomass supply chain as an integrated entity.

A feasible way to design a straightforward descriptive tool can be a layered graph; nodes are associated with entities (e.g., production activities, end-customers, storage facilities, preprocessing plants, transshipment stations, etc.), and arcs are associated with product flows (Gumus & Guneri 2009). Figure 1 shows a sample layered graphical framework for multi-biomass biomass supply chains.

This research stream combines operations research techniques with biomass supply chain data models (Zandi Atashbar et al. 2018a; Sharma et al. 2013; Sun et al. 2020; Nunes et al. 2020), wherein these models reference

a database (Frombo et al. 2009; Freppaz et al. 2004). The model is required to be independent as possible from its data to be able to handle a large amount of data. Any logistic network can be defined by the user



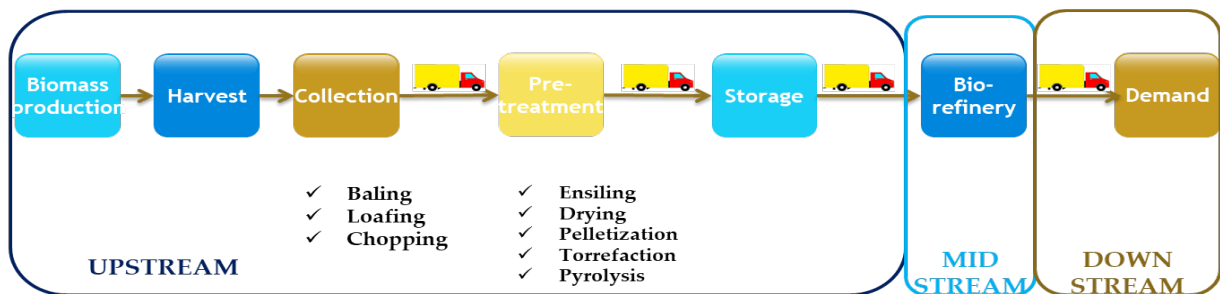
and stored in the database instead of imposing a frozen structure in the mathematical model. The goal is to come to a “data-driven” mathematical model which can be easily modified and extended. Very few studies provide a comprehensive data model to address such issues (De Meyer et al. 2016). Here, we aim to address this gap by developing a simple and unified framework of the biomass supply chain, which deals with complexity and adaptiveness specific to this industry.

**Figure 1. A Biomass Supply Chain Framework**

## METHODOLOGY

### Data Description, Assumptions, and Set-up

The activities in the biomass supply chain are often regrouped into three major segments shown in Figure 2. The **upstream segment** takes place before the refinery. It includes biomass production, harvest, collection, preprocessing, and centralized storage. The **midstream segment** corresponds to the conversion processes at the refinery. Finally, the **downstream segment** covers the output storage of the refinery and the distribution to customers.



**Figure 2. Major segments and activities in biomass supply chain.**

Very few authors like (Eksioglu 2009) have tried to model the three segments together. There are multiple reasons for this void in the literature. First, very different actors and contract types are involved in the upstream and downstream. Secondly, the midstream and downstream are not really unique to the biomass supply chain since they are similar to the production and distribution in the petroleum industry. This explains why most research articles focus on the upstream segment which raises the most interesting problems. Biomass supply chain planners face complex and challenging problems at different decision levels such as biorefineries location, transportation mode selection, preprocessing technology selection, and vehicle fleet size.

This paper focuses on the biomass supply chain over a multi-period planning horizon, with different biomass types called “products”, centralized storage facilities, and several biorefineries of which some are actual locations and others potential locations designated as nodes on the network. The supply chain is analyzed begins with harvested products, which are ready to ship and then to refinery storage. The aim is to prepare a database for this multi-biomass supply chain, at the tactical and strategic decision levels. The planning horizon is divided into discrete time slots (“periods”), currently 52 periods of 7 days. The number and duration of periods are designed in a way that future modifications to the model can be easy and streamlined. The strategic decisions concern involves the identification and location of refineries to minimize logistical costs to and from the refineries. Tactical decisions deal with the amounts collected in the farms, stored and transported, in each period. The area studied corresponds to Picardie and Champagne-Ardenne in France. It is partitioned into discrete territorial units called “zones” (currently 279 cantons). The cantons are those of the 2010 agricultural census, used to prepare biomass production data. Refineries are either already placed or need to be located, and there is at most one refinery per zone. Each refinery defines its needs per product and per period over the planning horizon. Biomass production data is computed by one partner of this project (Agro-Transfert et Territoires – AGT-RT) and include cultivation and harvesting. The density and humidity of a product are the same, whatever the zone is. Moreover, the humidity and density of stable products do not change along the chain, but storage loss is handled. Products are transported by road, but other transport modes can be added. The transportation network is defined by a graph. The database design needs to be flexible despite current choices (e.g., new products, preprocessing sites, new locations for refineries, etc.).

### Data Model Design

In the biomass supply chain, decision support systems are generally described as three modules 1) a database module 2) a query module 3) a decision module shown in Figure 3. The database module stores the input data of the optimization model. These input data include non-georeferenced data such as the different biomass operations and georeferenced data such as the characteristics of different facilities. To organize, visualize and process input data, the database module is linked to a GIS-based query. The decision module includes the tool to optimize the biomass supply chain (De Meyer et al. 2016). This paper focuses on the database module, and it is flexible enough to easily add, delete, or change types, attributes, and attribute types.

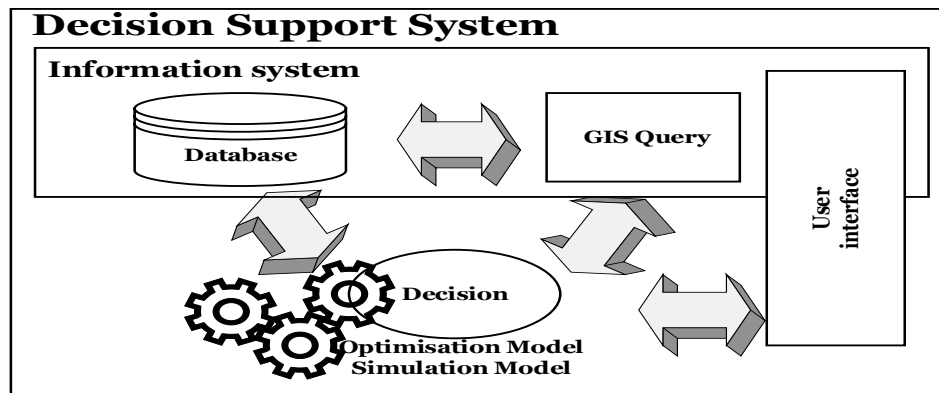


Figure 3. General architecture decision support system for biomass supply chains (De Meyer et al. 2013)

## THEORETICAL UNDERPINNING & CONCEPTUAL MODEL

### Conceptual Data Model (CDM)

A good way to logically structure a big set of data is to design a database, a set of linked files offering better protection against common errors like duplicate or missing records. The structuration of a database, independently of data values, is called a **data model**. Most databases today comply with the **relational data model**, in which data must be decomposed into a set of linked tables. To reduce complexity when designing a relational data model, it is recommended as a first step to prepare a graphical representation called **Conceptual Data Model (CDM)**. Our conceptual data model is based on only two concepts - entities and relationships. Given the interconnectivity of relationships between constituents of a multi-biomass supply chain (amount of produce collected in farms, storage, shipment, and location of refineries to optimize logistics), our conceptual data model is best grounded in the entity-relationship model as prescribed by (Chen 1976). The significance of the entity-relationship model lies in its capability to merge best practices from a family of predecessor models, namely the network model (Bachman 1975), the relational model (Codd 2002), and the entity-set model (Senko et al. 1973). The entity-relationship model, by virtue of its high degree of data independence, adopts a more natural view of the real-world (Chen 1976). An **entity** is a set of persons or things (real or abstract) of the same nature, called members of the entity. The **identifier (ID) or key** of an entity is one attribute to identify unambiguously each member. Entities are linked by **relationships or associations**. These processes and flows are translated into entities and relationships to design an entity-relationship data model (Chen 1976; 1988; Storey 1991). In this way, the supply chain can be modeled by linking the components of the chain (the entities) with each other by user-defined relationships and “if-then-else” rules that determine the dependencies and requirements between the components (Chen 1976; Chen 1988; Storey 1991; Kelly et al. 2013). In addition, these entities are characterized by properties, also called **attributes** (Chen 1976; Chen 1988; Storey 1991). Table 1 lists the relationships and entities of the CDM for this study.

<b>Name</b>	<b>Type</b>	<b>Contents</b>
<b>Parameters</b>	Entity	General parameters: number of periods, period duration, etc.
<b>Zones</b>	Entity	Territorial units considered, currently cantons
<b>Distances</b>	Relationship	Inter-zone distances precomputed using Map Point
<b>Crops</b>	Entity	Crops harvested to get products
<b>Products</b>	Entity	Products: crop of origin, density, humidity, etc.
<b>Local</b>	Relationship	Local product variations: yields, harvesting windows, etc.
<b>Node types</b>	Entity	Node types, currently BP, FS, CS and RL
<b>Nodes</b>	Entity	Nodes (zone + node type + product) with storage capacity, etc.
<b>Arc types</b>	Entity	Allowed arc types, at least (BP,FS), (BP,CS), (FS,CS) and (CS,RL)
<b>Vehicles</b>	Entity	Vehicle types
<b>Refineries</b>	Entity	Refinery types which can be created on RS nodes
<b>Demands</b>	Relationship	Demands per refinery type, product, and period
<b>Flows (X)</b>	Relationship	Flow variables per arc and per period (results)
<b>Stocks (S)</b>	Relationship	Stock per node and per period (results)
<b>Locations (Y)</b>	Relationship	Binary location variable per refinery type and per zone (results)

**Table 1. Entities and relationships of the CDM giving a table in EXCEL**

Figure 4 illustrates the CDM for the biomass supply chain. Our initial idea was to define the vertices of the supply chain graph as territorial units like cantons. The problem is that they contain various sites with different properties, at least fields where crops are harvested, on-farm storage facilities, centralized storage facilities, and refinery storage. Other kinds of nodes such as intermodal transshipment hubs, preprocessing facilities, importations via harbors, and even stocks of by-products from other refineries can be added in the future.

Moreover, we can notice that the activities on each site are separated per product. For instance, as we need to know the amount of each product in centralized storage, this kind of site can be viewed as one stock per

product. In fact, all sites can be viewed as sets of stocks. This is obvious for on-farm and centralized storage units. Concerning cultivated fields, the amount harvestable for each product is also a kind of stock. Finally, as the supply chain does not cover the conversion processes of refineries, a refinery site can also be modeled as a set of input stocks, one for each required product.

The main design choices can be derived from these remarks:

- We call zones the territorial units considered and nodes the different sites they contain. They have gathered respectively in two entities “Zones” and “Nodes”. The zones selected are currently cantons because it is difficult to compute potential productions at lower levels.
- Nodes are partitioned according to their role, called node type. Currently, four node types are defined in an entity “Node types”: BP (biomass production node), FS (farm storage), CS (centralized storage), and RS (refinery storage). Other node types could be added in the future.
- Each node is viewed as a stock, defined by a zone, a node type, and a product. As biomass data from AGT-RT are consolidated by zone (canton), we do the same for all nodes. So, for each zone and each product, there can be at most one node of each type, e.g., the CS node for rape seeds aggregates all centralized stocks of rape seeds in a canton. Note that this also implies at most one refinery per zone. All nodes in a zone are assumed to be in a city chosen as the geographic center for the canton. This location is required to compute distances between any two cantons.
- Some product data like the amount available are associated with the nodes of the zones, but the yield, harvest window, and cost depend on the region, while density and humidity are constant, whatever the zone is. So, these three types of product data are respectively stored in three different tables: “Nodes”, “Local”, and “Products”.
- There are many potential refinery locations but only a few sizes of refineries. We think the demands of a refinery of a certain size will be determined by its conversion processes but not by its exact location. So, to enter fewer data, we separate refinery locations and refinery types (sizes). An attribute in entity “Zones” indicates if a zone has already one refinery, if it can receive one, or if creation is forbidden. The few refinery types and the demands for each type are respectively defined in one entity “Refineries” and one relationship “Demands”. For instance, if we have two small and one large refinery to build among 200 possible zones, we have two records only in “Refineries”, instead of copying the same data into all possible zones.
- We use a classical trick for the general parameters which cannot be considered as attributes of a particular entity. They are stored in a table “Parameters” which contains a single record, with one parameter per column: number of periods, number of days in one period, etc.
- All product flows, storage and vehicle capacities, and refinery needs are expressed in metric tons, i.e., the tons used in Europe and not the US tons. “tRM” means “ton of raw material”.

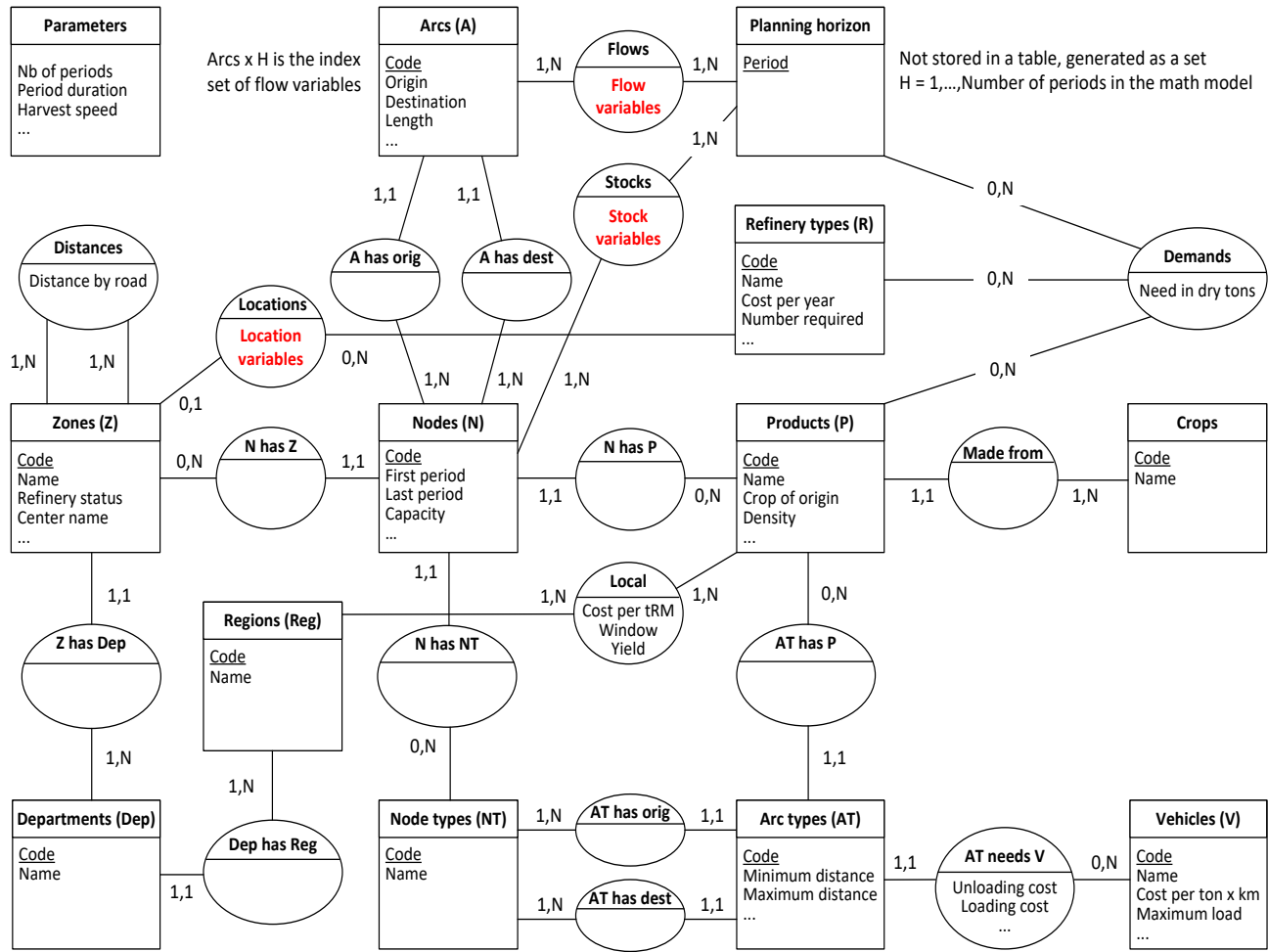
Other design choices aim at limiting model size. The largest number of variables comes from product flows, which are indexed by one arc (pair of nodes) and one period. Each arc can be defined by a zone of origin, its node type, a zone of destination, its node type, and a product. It is quite likely that the model will be too big

if we allow flows between any two nodes, for all products and all periods. So, the number of arcs and flow variables must be as small as possible. This can be done at 5 levels:

- **First level.** To avoid flows  $F(p, i, t, j, t')$  like in Shastri et al. 2013 (amount of product  $p$  shipped from zone  $i$  in period  $t$  and arriving in zone  $j$  in period  $t'$ ), we assume that any product shipped in one period arrives in the same period. This is possible due to the territory considered (two regions) and the rather long period duration (one week). As the product is known for each node and as  $i$  and  $j$  store the same product, we need no product index and use flow variables  $F(i, j, t)$ .
- **Second level.** The allowed arc types can be restricted using one entity “Arc types”. For instance, (BP,FS), (BP,CS), (FS,CS) and (CS,RS) are always allowed. If the user permits direct deliveries from farms to refineries, arc types (BP,RS) and (FS,RS) may be added. One advantage is that each arc can now be defined by one pair of zones, one arc type, and one product. Another advantage is that a vehicle can be specified for each arc type. The set of arcs of the logistic network can be generated automatically, instead of being typed, but only for the arc types allowed in “Arc types”.
- **Third level.** The arcs with a BP or FS origin can be limited to the products harvested in the zone.
- **Fourth level.** For each arc type, we can specify a default distance when nodes  $i$  and  $j$  are in the same zone, and minimum and maximum distances otherwise. For instance, (BP,FS) arcs must not leave a zone, so we can specify an interval  $[0,0]$ . As farmers bring their products to centralized storage facilities at a 10 km maximum, we can specify an interval  $[0,10]$  for (BP,CS) and (FS,CS) arc types linking two distinct zones. Long-range arcs should be exceptional, e.g., between one external port where biomass is imported (Le Havre, Rotterdam...) and cantons where a refinery may be located.
- **Fifth level.** We restrict the periods of flow variables, e.g., (BP,CS) and (BP,FS) flows for a product are limited to the harvest period. Due to insurance problems, on-farm storage is limited to 1 to 2 months after the end of the harvest window, so (FS, CS) flows can be defined only in these time intervals. More generally, a flow from node  $i$  to node  $j$  may exist only when both nodes are open.

Finally, an effort has been made to have logical names for all tables and attributes. A letter used in attribute prefixes or codes like arc types has always the same meaning. Here is the logic:

A = arc	D = distance	N = node	R = refinery type
AT = arc type	Dur = duration	NT = node type	S = storage/stock
B = biomass	F = farm	Num = number	T = type
C = center/centralized	L = local product data	P = product/production	V = vehicle



**Figure 4. CDM for biomass supply chains**

**Conversion of the CDM into a set of tables**

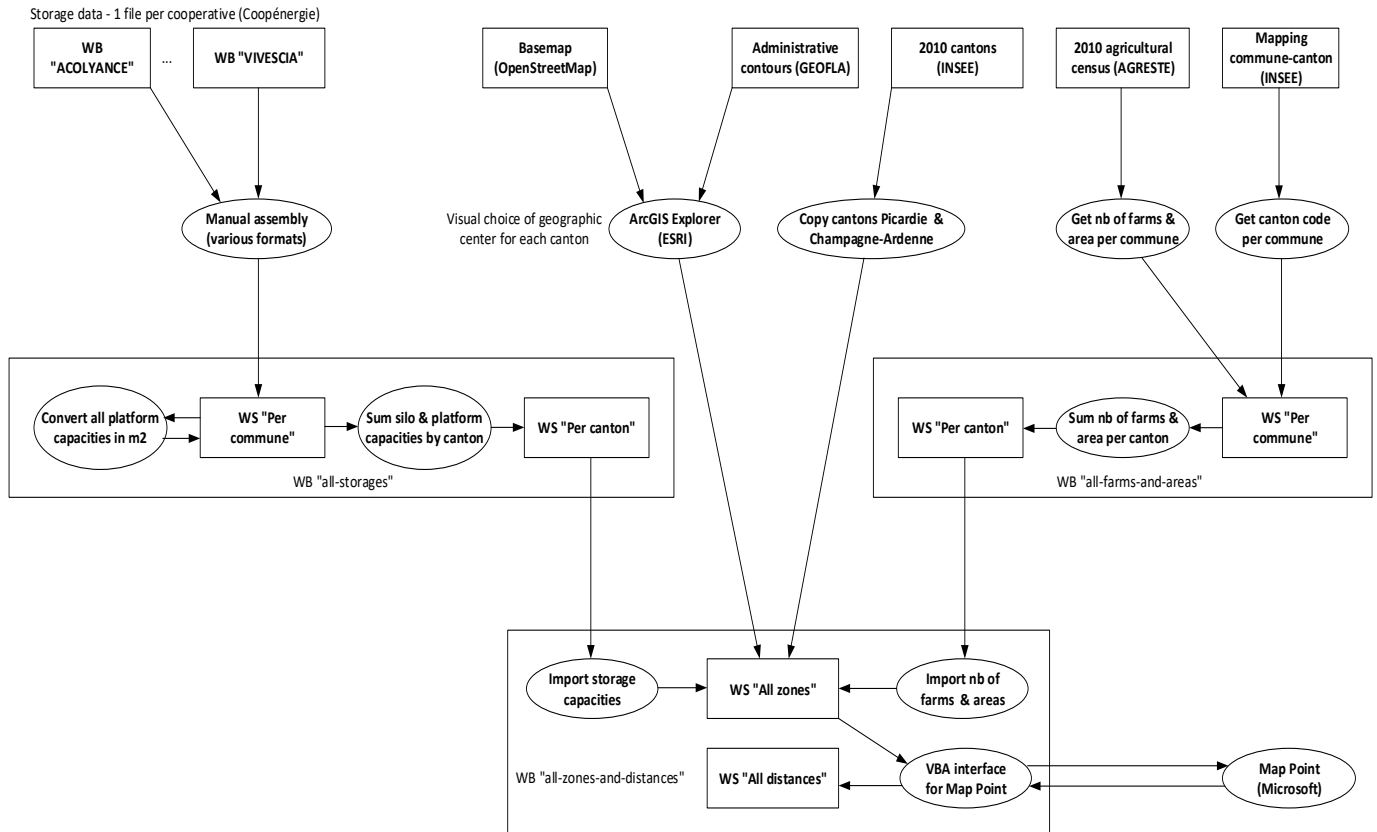
In a second step, this CDM can be converted into a set of tables which are then implemented in EXCEL or a true database management system (DBMS). The CDM must be translated into a set of rectangular tables which specify the set of members of each entity and the values of their attributes. Each table can be implemented as one worksheet in EXCEL. In the first step, each entity of the CDM must be converted into one table. The name of the EXCEL worksheet is often the same as the entity name. Its rows correspond to the members of the entity and its columns to the attributes. At this stage, rows and columns are also called records and fields. The first row (column headers) must give attribute names. Table 1 is the list of entities and relationships that we decided to implement as tables (worksheets) in our EXCEL database.

**APPLICATION OF DATA MODEL**

Before coming to a complete database, a lot of upstream work is required to obtain the set of zones considered (cantons), inter-canton distances by road, centralized storage data, and biomass production data. We have compiled an auxiliary workbook titled “all zones and distances” that contains administrative data for the 279 cantons of Picardie and Champagne-Ardenne: canton code and name, a city chosen as a geographic center to



compute distances, number of farms, area cultivated, the storage capacity of silos, area of platforms and inter-canton distances. The workflow to prepare this workbook is illustrated in Figure 5. The process is rather complex because it has been decomposed in successive steps to be more reliable. Note that rectangles are EXCEL workbooks while ellipses represent procedures. A workbook may contain several worksheets (inner rectangles) and macros written in VBA (Visual Basic for Applications, inner ellipses). Arrows indicate data flows.



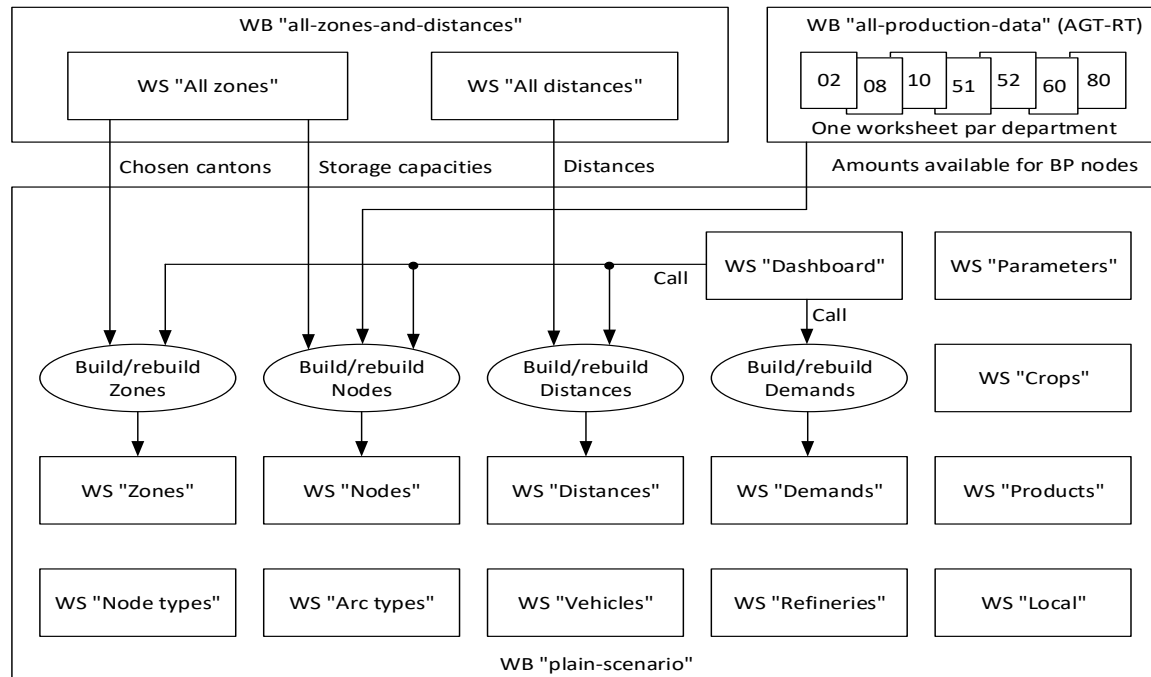
**Figure 5. Workflow to prepare workbook "all-zones-and-distances"**

The other auxiliary workbook “all-production-data” was built by our industry partner AGT-RT. It gathers biomass production data per canton and per product, e.g., current and potential amount available, production cost, loading cost, GHG emission, and fuel/energy consumption. It contains one worksheet per department. Table “all-production-data” contains one row with the following fields for each pair (canton, product harvested in this canton):

- Code and name of the canton
- Product, defined by the crop and the part concerned (seeds, straw, chaff, whole plant)
- The current production, null or very small for camelina, Ethiopian mustard, miscanthus, and willow
- Potential production for camelina, Ethiopian mustard, miscanthus, and willow
- Harvest window (first and last week)
- Percentage of dry matter
- Conditioning at the end of the technical itinerary (bulk or bales)
- Product density

Indicators for biomass production, loading on the tractor, loading on truck, tractor unloading, and truck unloading: cost per tRM, diesel consumption, energy consumption, and GHG emission.

The links between a scenario and the two auxiliary workbooks are shown in Figure 6.



**Figure 6. Scenario file and links with auxiliary workbooks**

### Dashboard for scenario generation

We have now a set of structured tables allowing all data for an optimization scenario to be stored in an EXCEL workbook. The data model is flexible enough to add new node types, new products, etc., and it becomes easier to write the equations of the math model.

To generate easily various test scenarios, we designed a workbook. It contains one worksheet for each table of the data model. All are prefilled except the largest ones which contain column names only: Zones, Distances, Nodes, and Demands. These large tables are going to be filled automatically from a set of directives entered by the user in a new worksheet "Dashboard" in Figure 7, inserted before the real tables of the database.

This control panel allows specifying:

- The departments of Picardie and Champagne-Ardenne are to consider in the scenario (pink cells).
- The number of refineries, existing or to create (cell K3) and their opening periods (cell K4).
- The products asked for by refineries, are among the ones for which we have production data (orange cells).
- For each product, up to two demand intervals (first period, last period, and constant demand per period in dry tons) can be specified in blue rows 11-14. The other blue cells are computed in EXCEL. For each product, we have the storage capacity computed for 4 weeks of demand (row 15), the total need in dry tons for one and all refineries (rows 16-17), and the total need of all refineries in tRM (row 18).

The amount available in table "Nodes" in tRM is also displayed but only if this worksheet has been already built. Finally, the total demand of refineries for all products is computed in dry tons in cell K5.

- The list of cantons where one refinery already exists and the one where a refinery may be created (green cells). Creation in all other zones is forbidden.

Then four buttons call VBA macros to fill automatically the largest tables: Zones, Distances, Nodes, and "Demands". The idea is to generate data only for selected departments and products. This is necessary to reduce as much as possible the volume of data.

AMBRE DASHBOARD											
TERRITORY SELECTION		Region	Picardie			Champagne-Ardenne			Refineries	1	
		Department	02	60	80	08	10	51	52	Working period	1-50
		Select with X			X					Total dry tons	80000,00
BIOMASS SELECTION		Product	P1	P2	P3	P4	P5	P6	P7	P8	P9
		Crop	Colza	Colza	Colza	Céréales	Céréales	Miscanthus	T1CR Saule	Cameline	Moutarde d'E.
		Form	Graines	Pailles	Menues-Pailles	Pailles	Menues-Pailles	Plante entière	Plante entière	Graines	Graines
		Select with X	X	X	X	X		X		X	X
DEMAND OF EACH REFINERY FOR EACH PRODUCT		Interval 1	31-50	1-50	1-50	1-50		1-50		9-15	16-22
		Need/period dry tons	900	100	200	360		240		720	680
		Interval 2	1-8								
		Need/period dry tons	900								
		Stock 4 weeks dry tons	3600	400	800	1440		960		2880	2720
		Need/refinery dry tons	25200,00	5000,00	10000,00	18000,00		12000,00		5040,00	4760,00
		Total in dry tons	25200,00	5000,00	10000,00	18000,00		12000,00		5040,00	4760,00
		Total in tRM	28000,00	5882,35	11363,64	21176,47		15000,00		5478,26	5173,91
		Total in Nodes in tRM	38028,15	9577,46	42253,50	57950,71		111481,12		7875,52	7383,43
REFINERY CANTONS		Existing	8018								
		Allowed	None								
Build table "Zones" If ticked departments have changed			Build table "Distances" If zones (cantons) have changed			Build/rebuild Nodes If zones, products, demands or refinery cantons have changed			Build/rebuild Demands If demand intervals or needs per period have changed		
Dashboard   Parameters   Zones   Distances   Crops   Products   Local   Node types   Nodes   Arc types   Vehicle ...											

Figure 7. Example of a screenshot of worksheet "Dashboard"

## CONCLUSION

This paper proposes a data model which describes and structures the real-world data required for solving the biomass supply chain problem at hand. This data model is meant to serve as a template for the database component of information and decision support systems related to the upstream segment of biomass supply chains. It covers biomass feedstocks, storage facilities (farm storage and centralized storage), biomass production zones, and the demands of bio-refineries. It is flexible enough to add new facilities and new biomass feedstocks. While the dashboard offers a front-end tool for decision-makers, the programming logic needs to be implemented in the back end. The next step in this research is to generate scenarios specific to logistics costs within the multi-biomass supply chain and optimize the scenarios for efficient decision-making. Separating the data model from the mathematical model allows equations to be written more easily and modifications in the data do not necessarily require reciprocating changes in the programming model, therefore rendering a more efficient interface.

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