Saving Cooperative Energy

D3.3 Extended Value Stream maps of NACE 1.6:

Arable crops, drying and storage

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1. Introduction

This document, taking as a first starting point the Current Value Stream Mapping of the sector of ARABLE CROPS, DRYING AND STORAGE, contains the description of each industrial process including the associated equipment. According to this data, the most relevant ones from the energy point of view have been identified in order to serve as basis for the following stages of the project such as the setting up of benchmarking baselines in thermal and electricity consumption.

2. Current Value Stream Mapping

Below are the current value stream mappings of the sectors:

- Crops Drying
- Winter cereals drying
- Rice drying
- Fodder dehydratation

The VSM have been obtained using the LEAN&GREEN symbology.

Besides, the most relevant inputs and outputs regarding energy issues and also greenhouse effect gasses emissions and water consumption, raw materials have been identified in the flow diagram.

2.1.Grain Drying: Corn, Rice and Winter Cereals (Wheat, Barley …)

For corn and winter cereals, the drying and storage processes are similar. In the case of rice, the drying step may require 2 (or more) changeovers as this grain is very sensitive to heat. Thus, the current value stream mapping is showed in the Figure 1, highlighting the special part of the process for the particular case of rice.

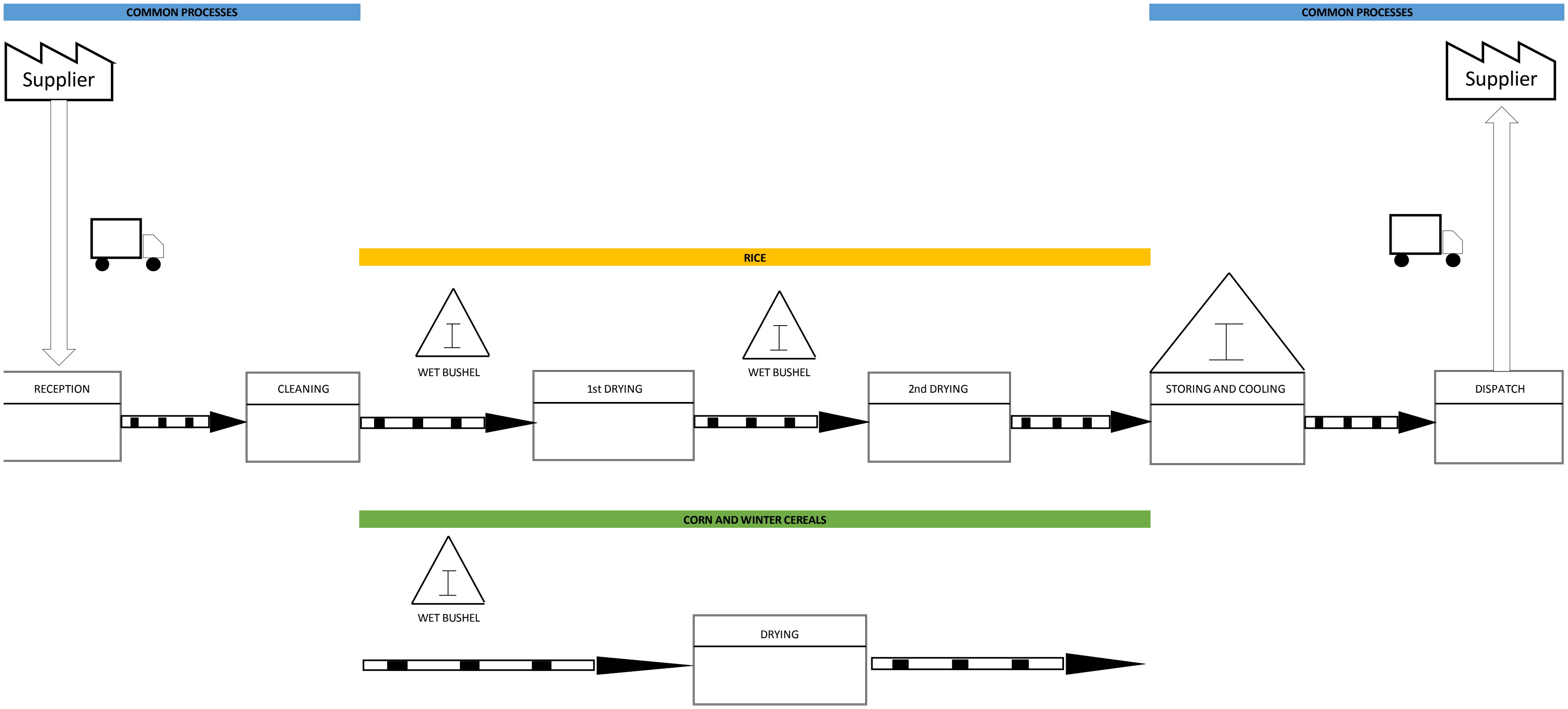


Figure 1: Current value stream mapping for corn, rice and winter cereals drying and storage

2.2.Fodder Dehydration

Concerning fodder dehydration, the processes are different in comparison with the grain drying and storage activity. They usually include grinding and granulation phases in addition to the dehydration (drying). The current value stream mapping for this subsector is showed in the Figure 2.

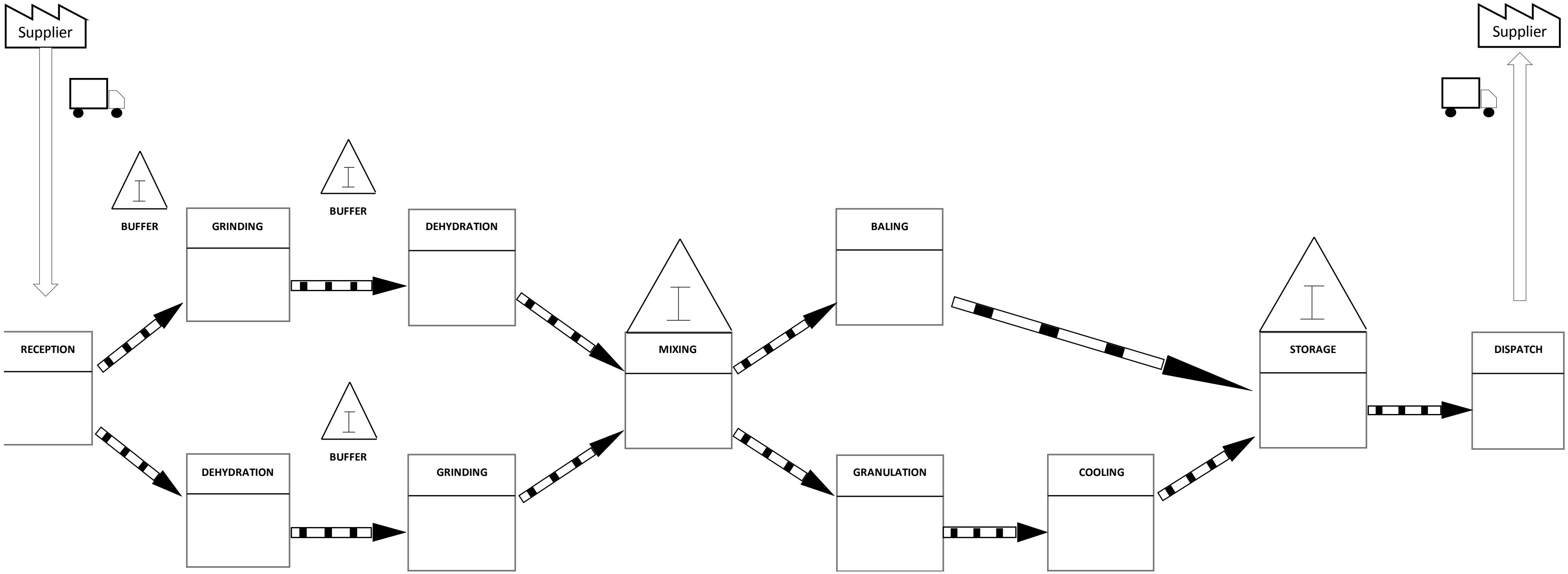


Figure 2: Current value stream mapping for fodder dehydration

3. Processes description and equipment

3.1. Reception and handling

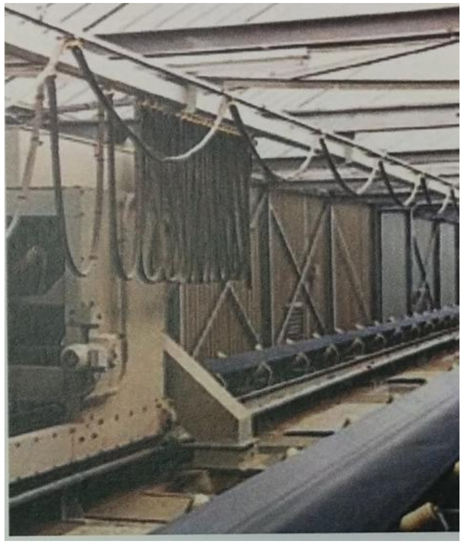
In grain silos, the products are provided by trucks or farm tractors. These products enter the plant via reception pits. The grain is then handled by conveyors and elevators into the treatment equipment.

There are two main types of conveyors used in grain silos:

- Chain conveyors: used for linear and horizontal handling, they are entirely closed (avoiding dust emissions) and compact. However, they require high power demands.
- Belt conveyors: used for long linear and horizontal handling, they consist of a belt, on which the grain is put, moved by a drum in the extremity. They are energy efficient but also dangerous and cumbersome.

The elevators use a succession of buckets to transport the grain to higher levels.
Other types of grain handling equipment exist such as spiral conveyors and air conveyors. However, they are not widespread.

RECEPTION PITS	HANDLING EQUIPEMENT		



Road reception pit	
Average capacity	50 t
Installed power (kW)	5 kW

Chain conveyor	
Average capacity	200 t/h
Installed power (kW)	15 kW

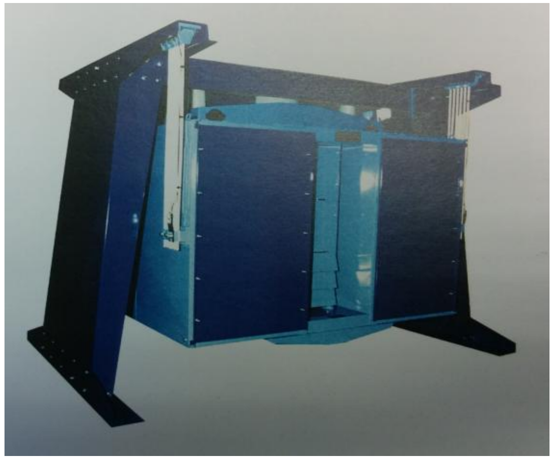
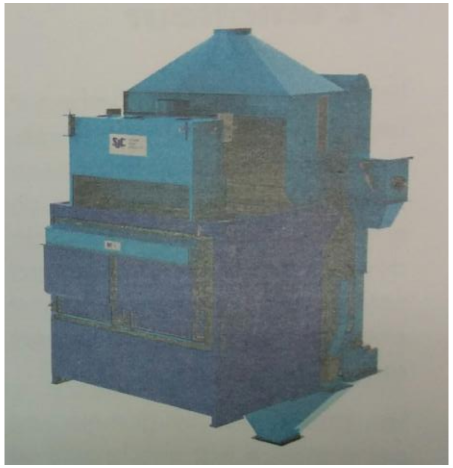
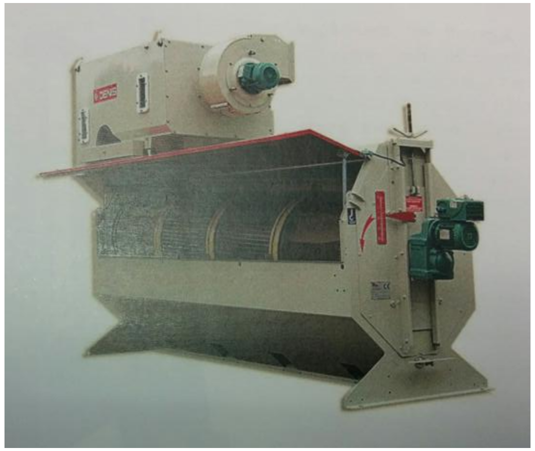
Belt conveyor	
Average capacity	200 t/h
Installed power (kW)	15 kW

Elevator	
Average capacity	200 t/h
Installed power (kW)	22 kW

3.2.Cleaning and calibrating

Several cleaning and calibrating equipment can be found in grain silos:

- Crumblers: they allow to separate the grain from large impurities (flaws, mud, ...). They are usually used just before the drying phase.
- Scrubbers: they separate the grain from large and fine impurities (flaws, mud, dust, …). The separation is partly done by an air flow passing through the grain. They are used either just before the drying step, or afterwards when all the grain has been treated.
- Calibrators: these are used to classify the grains according to their morphology and their weight. They use multiple superposed boxes of sieves.

CALIBRATORS		CLEANERS			
					
Calibrator		**Scrubber**		**Crumbler**	
Average capacity	100 t/h	Average capacity	100 t/h	Average capacity	40 t/h
Installed power (kW)	1,1 kW	Installed power (kW)	1,1 kW	Installed power (kW)	3 kW

3.3.Drying and dehydration

In grain silos, the grain is usually dried by dual-flow column dryers. They comprise a central column containing the grain, permeable to the surrounding air through dihedral channels. The grain flows by gravity in the vertical column and discontinuously, grain injections and extractions being carried out at regular intervals. The column comprises one or more drying stages through which the hot air passes (60 °C to 120 °C depending on the species) and a cooling zone traversed by an air at ambient temperature. The drying air is usually heated using burners operating on natural gas or LP gas.

The dehydration plants often use drum dryers. They operate similarly to column dryers except that the grain box is horizontal and a hot air generator is used instead of burners.

DRYERS			
			
Dual-flow column dryer		**Drum dryer**	
Average capacity	30 t/h	Average capacity	20 t/h
Installed power (kW)	75 kW (electricity) 10 000 kW (gas)	Installed power (kW)	220 kW (electricity) 24 000 kW (gas)

3.4.Cooling

The grain cooling takes place in the storage cells. These cells are ventilated with fresh outside air all along the storage period. Large capacity fans are used to pass through the pile of grain as the pressure required is very high.

Some plants use cold units to cool the air blown into the cells. This method improves the cooling efficiency and duration.

COOLING EQUIPMPENTS			
			
Ventilation fan		**Cold unit**	
Average capacity	-	Average capacity	-
Installed power (kW)	110 kW (fans)	Installed power (kW)	75 kW (fans) 55 kW (compressor)

3.5. Grinding

After the dehydration step, fodder and forage products are usually milled in order to be granulated (or dispatched unchanged). The equipment used are usually hammer mills. In these equipment, products are exposed to the action of hammers tied to a rotating rotor. The resulting flour passes through a grid which opening diameter makes it possible to control the particle size of the finished product.

GRINDERS

Hammer mill

Average capacity	100 t/h
Installed power (kW)	110 kW

3.6.Mixing

This step allows to dose and mix the products to be pelletized or baled according to the quality and specifications required by customers. This process uses a weighing instrument fed stepwise by the various products, which allows to obtain a precise distribution.

MIXERS	
	
Dosing screw	
Average capacity	30 t/h
Installed power (kW)	30 kW

3.7.Granulation – Pelletizing

The granulation (or pelletizing) aims at converting milled feed products (fodder, forage, …) into pellets. This transformation has the benefit of densifying the products which generates an increase in storage capacity and a reduction of transport costs. The use of different types of granulation dies allows to control the size of the pellets.

PELLET MILLS

Pellet mill	
Average capacity	15 t/h
Installed power (kW)	200 kW

3.8.Pellets cooling

The pellets resulting of the granulation phase are very hot. Specific equipment are then installed just after the pellet mills in order to cool the pellets. They function similarly to the dryers: a flow of fresh air is introduced in a tank in which the hot pellets pass. Two main kinds of pellets coolers are used:

- Horizontal coolers: they use a metal belt composed of performed elements allowing to transport the pellet while cooling them with an air flow.
- Vertical cross-flow coolers: the pallets pass through a vertical cell (by gravity) in which the cooling air is blown from below.

In addition, some coolers use specific cold units in order to increase the cooling efficiency.

PELLET COOLERS

Horizontal coolers		Vertical cross-flow coolers	
Average capacity	15 t/h	Average capacity	30 t/h
Installed power (kW)	1,5 kW	Installed power (kW)	5,5 kW

3.9.Fodder baling

At the exit of the drum dryer and the mixing phase, the uncrushed dried fodder are referred for chest presses to be compacted in the form of approximately 370 kg bales.

FODDER BALING

Fodder baler	
Average capacity	10 t/h
Installed power (kW)	80 kW

3.10. Auxiliary and horizontal processes

On each industrial sites we can find some auxiliary processes such as lighting, compressed air production, heating/cooling of offices and central dust aspiration systems.

AUXILIARY PROCESSES

Lighting		Compressor		Heat pump		Central dust aspiration system	
Average capacity	-	Average capacity	-	Average capacity	-	Average capacity	-
Installed power (kW)	20 kW	Installed power (kW)	15 kW	Installed power (kW)	5 kW	Installed power (kW)	37 kW

4. Overview list of the processes and equipment

SUBSECTOR/PRODUCT	PROCESS	EQUIPMENT	ELECTRIC AND/OR THERMAL	SOURCE OF ENERGY
CROPS DRYING	Reception and handling	Road reception pit	Electric	Electricity
		Chain conveyor	Electric	Electricity
		Belt conveyor	Electric	Electricity
		Elevator	Electric	Electricity
	Cleaning and calibrating	Calibrator	Electric	Electricity
		Scrubber	Electric	Electricity
		Crumbler	Electric	Electricity
	Drying and dehydration	Dual-flow column dryer	Electric and thermal	Electricity and gas
	Cooling	Ventilation fan	Electric	Electricity
		Cold unit	Electric	Electricity
	Dispatch	Chain conveyor	Electric	Electricity
		Belt conveyor	Electric	Electricity
		Elevator	Electric	Electricity
	Lighting	Neon	Electric	Electricity
	Compressed air	Compressor	Electric	Electricity
	Heating/Air conditionner	Heat pump	Electric	Electricity
	Central dust aspiration system	Aspiration fan	Electric	Electricity

SUBSECTOR/PRODUCT	PROCESS	EQUIPMENT	ELECTRIC AND/OR THERMAL	SOURCE OF ENERGY
WINTER CEREALS DRYING	Reception and handling	Road reception pit	Electric	Electricity
		Chain conveyor	Electric	Electricity
		Belt conveyor	Electric	Electricity
		Elevator	Electric	Electricity
	Cleaning and calibrating	Calibrator	Electric	Electricity
		Scrubber	Electric	Electricity
		Crumbler	Electric	Electricity
	Drying and dehydration	Dual-flow column dryer	Electric and thermal	Electricity and gas
	Cooling	Ventilation fan	Electric	Electricity
		Cold unit	Electric	Electricity
	Dispatch	Chain conveyor	Electric	Electricity
		Belt conveyor	Electric	Electricity
		Elevator	Electric	Electricity
	Lighting	Neon	Electric	Electricity
	Compressed air	Compressor	Electric	Electricity
	Heating/Air conditionner	Heat pump	Electric	Electricity
	Central dust aspiration system	Aspiration fan	Electric	Electricity

SUBSECTOR/PRODUCT	PROCESS	EQUIPMENT	ELECTRIC AND/OR THERMAL	SOURCE OF ENERGY
RICE DRYING	Reception and handling	Road reception pit	Electric	Electricity
		Chain conveyor	Electric	Electricity
		Belt conveyor	Electric	Electricity
		Elevator	Electric	Electricity
	Cleaning and calibrating	Calibrator	Electric	Electricity
		Scrubber	Electric	Electricity
		Crumbler	Electric	Electricity
	Drying and dehydration	Dual-flow column dryer	Electric and thermal	Electricity and gas
	Cooling	Ventilation fan	Electric	Electricity
		Cold unit	Electric	Electricity
	Dispatch	Chain conveyor	Electric	Electricity
		Belt conveyor	Electric	Electricity
		Elevator	Electric	Electricity
	Lighting	Neon	Electric	Electricity
	Compressed air	Compressor	Electric	Electricity
	Heating/Air conditionner	Heat pump	Electric	Electricity
	Central dust aspiration system	Aspiration fan	Electric	Electricity

SUBSECTOR/PRODUCT	PROCESS	EQUIPMENT	ELECTRIC AND/OR THERMAL	SOURCE OF ENERGY
FODDER DESHYDRATATION	Reception and handling	Reception pit	Electric	Electricity
		Chain conveyor	Electric	Electricity
		Belt conveyor	Electric	Electricity
		Elevator	Electric	Electricity
	Mixing	Dosing screw	Electric	Electricity
	Dehydratation	Drum dryer	Electric and thermal	Electricity and gas
	Grinding	Hammer mill	Electric	Electricity
	Fodder mixing	Mixer	Electric	Electricity
	Granulation - Pelletizing	Pellet mill	Electric	Electricity
	Pellet cooling	Horizontal coolers	Electric	Electricity
		Vertical cross-flow coolers	Electric	Electricity
	Baling	Baling equipment	Electric	Electricity
	Lighting	Neon	electric	Electricity
	Compressed air	Compressor	electric	Electricity
	Heating/Air conditionner	Heat pump	electric	Electricity

5. Sankey diagram

Sankey diagrams are a specific type of flow diagram, in which the width of the arrows is shown proportionally to the flow quantity.

In this case, they will be used to visualize energy consumption in each process, putting a visual emphasis on the major energy flows within the whole process carried out in a grain silo or a fodder dehydration plant. They will be very useful in identifying dominant contributions to the overall energy flow.

In the following points, a Sankey diagram example is shown for each subsector considered (corn drying, rice drying, winter cereals drying, fodder dehydration).

5.1.Corn drying

Hypothesis used for calculation:

Calculations were made on a typical corn drying silo. Below are the technical characteristics used to generate the Sankey diagram.

Cereal dried	Corn
Initial humidity of the product (%)	35%
Final humidity of the product (%)	15%
Quantity of wet product dried (t)	10 000
Dryer power (pts)	6000
Wet grain flow rate (t/h)	30
dried grain flow rate (t/h)	22,9411765
Evaporated water flow rate (TEE/h)	7,05882353
Evaporated water quantity (t)	2352,94118
number of hours running (h)	333,333333

Cereal dried	Corn
Average gaz KPI (kWh PCS/TEE)	1050
Average electricit KPI (kWhé/TEE)	31,5523582
Thermal power of dryer (kW)	7411,76471
Electric power of dryer	193
Turnover rate	2
Average capacity of ventilated cell	2000

Gas	
Global consumption (kWh PCS)	2 470 588,24

Electricity		
Global consumption (kWh)	191 859,82	
Drying	74 240,84	39%
Conveyors	19 803,50	10%
Elevators	8 487,21	4%
ventilation	51 966,35	27%
Aspiration	12 336,72	6%
Lighting	8 341,73	4%
compressor	13 346,77	7%
Cleaner	3 336,69	2%

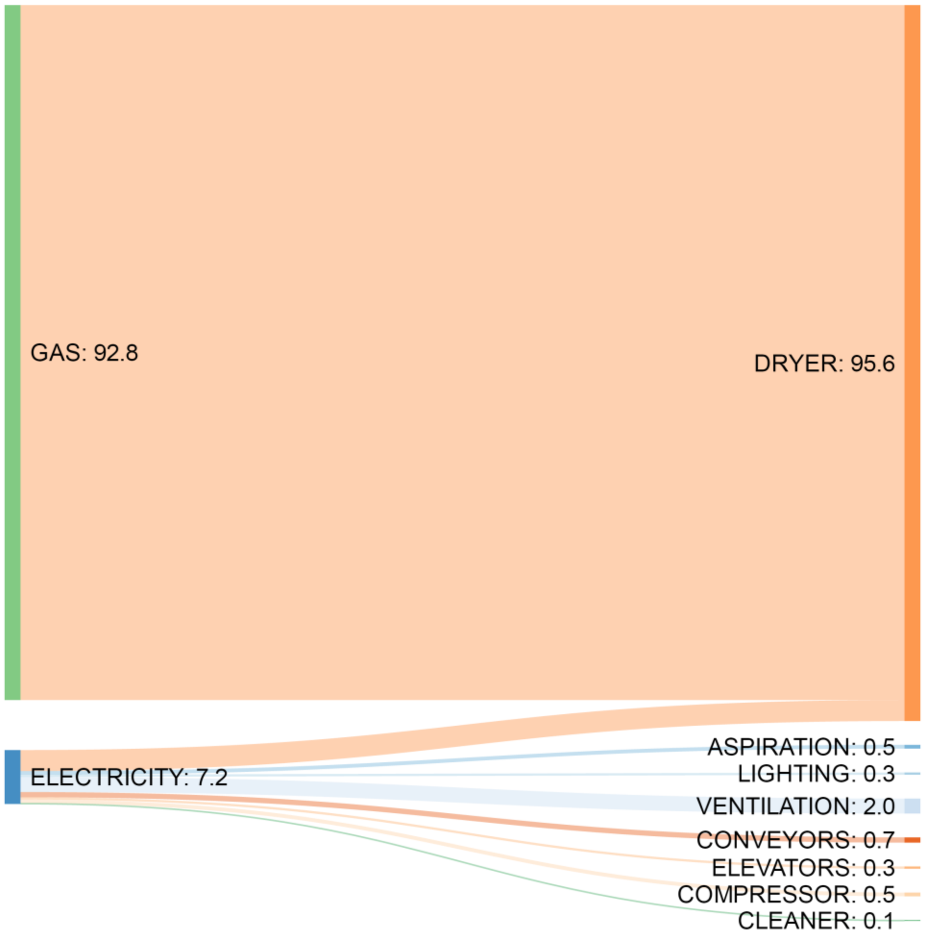


Figure 3: Sankey Diagramm in percentage of Energy consumption – Corn drying

5.2.Rice drying

Hypothesis used for calculation:

Calculations were made on a typical corn drying silo. Below are the technical characteristics used to generate the Sankey diagram.

Cereal dried	Rice
Initial humidity of the product (%)	20%
Final humidity (%)	14%
Quantity of wet product dried (t)	5 000
Dryer power (pts)	3000
Wet grain flow rate (t/h)	50
dried grain flow rate (t/h)	46,5
Evaporated water flow rate (TEE/h)	3,49
Evaporated water quantity (t)	348,8
number of hours running (h)	100,0
Average gaz KPI (kWh PCS/TEE)	1400
Average electricit KPI (kWhé/TEE)	45,1
Thermal power of dryer (kW)	4883,7
Electric power of dryer	96
Turnover rate	2
Average capacity of ventilated cell	2000

Gas	
Global consumption (kWh PCS)	488 372,09

Electricity		
Global consumption (kWh)	84 843,74	
Drying	15 722,30	19%
Conveyors	9 901,75	12%
Elevators	4 243,61	5%
ventilation	31 607,44	37%
Aspiration	7 503,55	9%
Lighting	3 448,93	4%
compressor	5 518,29	7%
Cleaner	6 897,87	8%

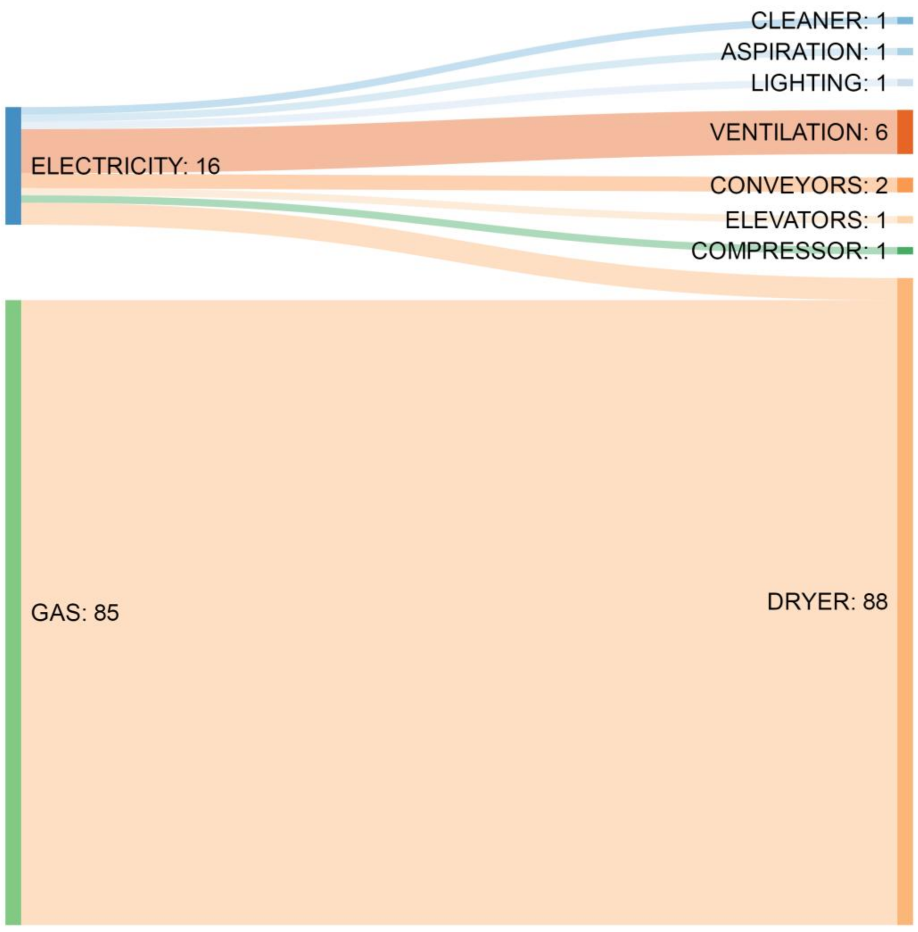


Figure 4: Sankey Diagramm in percentage of Energy consumption – rice drying

5.3. Winter cereals drying

Hypothesis used for calculation:

Calculations were made on a typical corn drying silo. Below are the technical characteristics used to generate the Sankey diagram.

Cereal dried	winter cereals
Initial humidity of the product (%)	20%
Final humidity (%)	14%
Quantity of wet product dried (t)	3 000
Dryer power (pts)	3000
Wet grain flow rate (t/h)	50
dried grain flow rate (t/h)	46,5
Evaporated water flow rate (TEE/h)	3,49
Evaporated water quantity (t)	209,3
number of hours running (h)	60,0
Average gaz KPI (kWh PCS/TEE)	1400
Average electricit KPI (kWhé/TEE)	50,8
Thermal power of dryer (kW)	4883,7
Electric power of dryer	96
Turnover rate	2
Average capacity of ventilated cell	2000

Gas	
Global consumption (kWh PCS)	293 023,26

Electricity		
Global consumption (kWh)	50 239,81	
Drying	10 622,30	21%
Conveyors	5 941,05	12%
Elevators	2 546,16	5%
ventilation	18 964,47	38%
Aspiration	4 502,13	9%
Lighting	2 128,81	4%
compressor	3 406,09	7%
Cleaner	2 128,81	4%

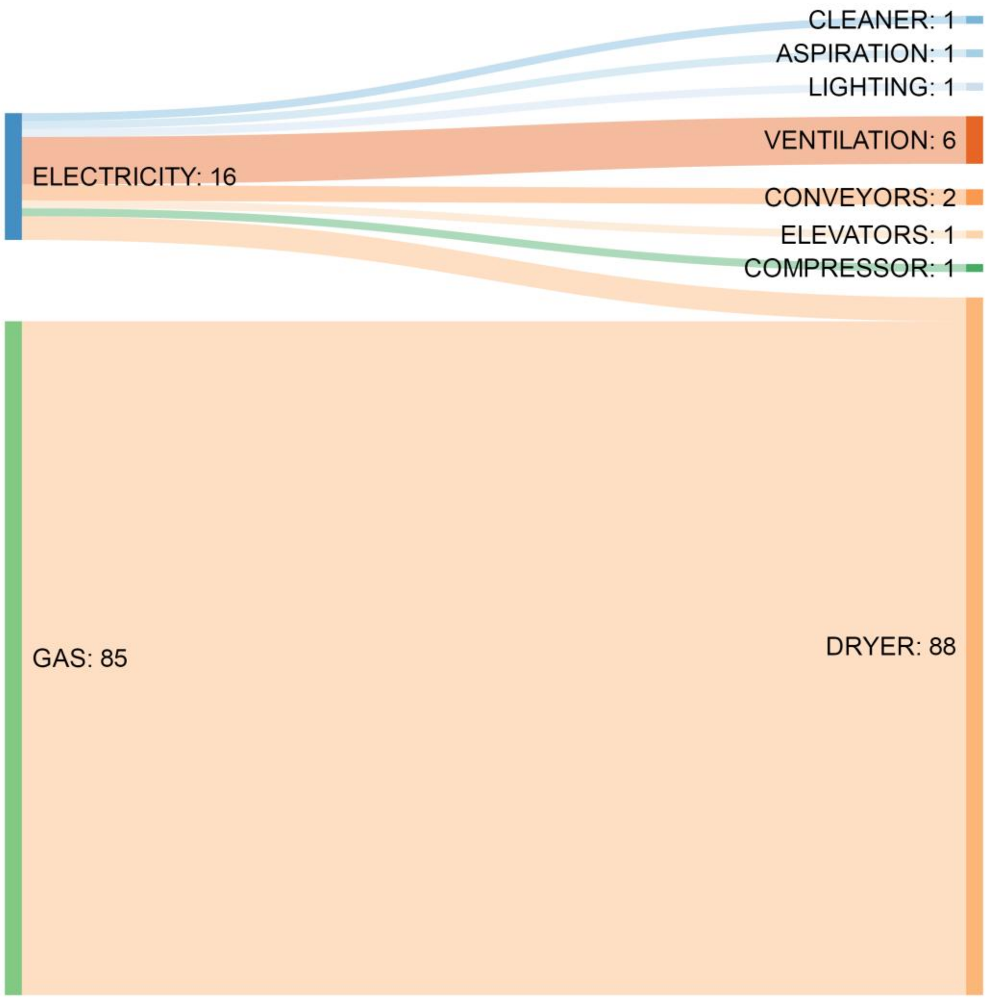


Figure 5 : **Sankey Diagramm in percentage of Energy consumption – Winter cereals drying**

5.4. Fodder dehydration

Hypothesis used for calculation:

Calculations were made on a typical corn drying silo. Below are the technical characteristics used to generate the Sankey diagram.

Fodder dehydratation	
Initial humidity of the product (%)	50%
Final humidity (%)	10%
Quantity of wet product dried (t)	20 000
Dryer power (pts)	20 000
Wet grain flow rate (t/h)	50
dried grain flow rate (t/h)	27,8
Evaporated water flow rate (TEE/h)	22,22
Evaporated water quantity (t)	8888,9
number of hours running (h)	400,0
Quantity of product pelletized (t)	5555,6
Quantity of products baled (t)	5555,6

Fodder dehydratation	
Average gaz KPI (kWh PCS/TEE)	847
Average electricit KPI (kWhé/TEE)	30,2
Thermal power of dryer (kW)	18822,2
Electric power of dryer (kW)	94
Electric KPI for reception and handling (kWh/t)	71
Electric KPI for Griding (kWh/t)	6
Electric KPI for Mixing (kWh/t)	3,5
Electric KPI for granulation (kWh/t)	60
Electric KPI for Cooling (kWh/t)	2,6
Electric KPI for balling (kWh/t)	17

Gas	
Global consumption (kWh PCS)	7 528 888,89

Electricity		
Global consumption (kWh)	1 691 661,05	
Reception and handling	788 888,89	47%
Dehydratation	268 093,72	16%
Grinding	33 333,33	2%
Fodder mixing	19 444,44	1%
Granulation - pelletizing	333 333,33	20%
Pellet cooling	14 444,44	1%
Baling	94 444,44	6%
Lighting	15 519,83	1%
Compressed air	124 158,61	7%

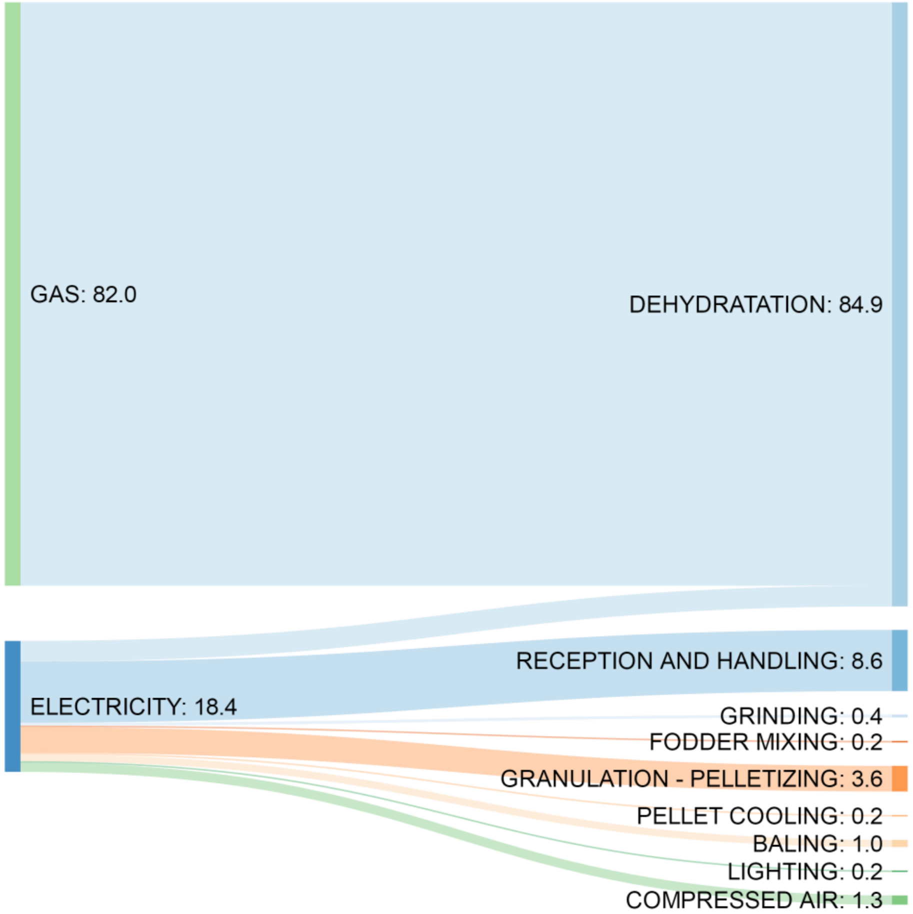


Figure 6: Sankey Diagramm in percentage of Energy consumption – fodder dehydratation

6. Identification of the key points for setting up the baselines in electric and thermal processes

Taking into consideration the identification of the inputs and outputs of the main processes regarding energy issues, the most relevant key points for setting up the Key Performance Indicators are the followings:

- **Electricity consumption:**

  In grain silos (corn, rice and winter cereals), the most important uses of electric energy can be derived from the extended value stream maps or the Sankey diagrams presented in part 4. They include, for instance, ventilation, aspiration, handling (conveyors and elevators) and drying. Considering these uses, KPIs can be defined by taking into account their specific electric consumptions and the activity of the plant they are related to.

  In the case of fodder dehydration, the main uses, from the electric point of view, are grinding, granulation and handling. Again, KPIs can be simply defined according to the activity of the plant and the specific energy consumptions.

  The following table proposes KPI definitions for the uses mentioned above:

Use	Electric KPI definition
Handling	Electricity consumption of the handling equipment divided by the tonnage of grain/fodder received
Ventilation	Electricity consumption of the cooling fans divided by the tonnage of grain/fodder stored
Aspiration	Electricity consumption of the handling equipment divided by the tonnage of grain/fodder received
Drying	Electricity consumption of the dryers divided by the tonnage of evaporated water
Grinding	Electricity consumption of the grinder (hammer mills) divided by the tonnage of grain/fodder grinded
Granulation	Electricity consumption of the pellet mills divided by the tonnage of grain/fodder pelleted

- **Thermal processes:**

In the activities presented in this report, two main processes need thermal capabilities:

- Drying/dehydration: burners (used in dual-flow dryers) and hot air generators (used in horizontal dryers) may use different types of fuels (natural gas, LP gas, coal, …). A simple KPI related to this process could be the amount of fuel consumed by the dryers (in T or kWh) divided by the tonnage of evaporated water
- Pelletizing: A steam flow is often needed in order to make the grain/fodder pelletizing efficient and reliable. This steam is produced by boilers supplied with fuel. Thus, we can derive the following KPI for this process: fuel consumption of boilers (in T or kWh) divided by the tonnage grain/fodder pelleted.

This is only a preliminary approach to the identification of the Key Performance Indicators. The expert team responsible for the tasks related to setting up the Key Performance Indicators in thermal processes and electricity consumption will define the final ones according to their expertise.

7. Possible inefficiencies in the performance of the processes

Among the usual inefficiencies in the NACE 1.6 sector, we can mention:

- **"Bottlenecks":** they refer to an equipment which nominal flowrate is low compared to the flowrates of the other equipment involved in the path of the grain/fodder. Thus, the "bottleneck" equipment imposes its cadence to the whole path making the other equipment operate at low energy yields. Changing the ""bottleneck" equipment by another with a higher nominal flowrate allows to reduce the travel time of the products while making energy savings.
- **Ventilation leaks:** ventilation often results in the appearance of air leaks along the path of the air. When they become too large, these leaks cause a drift in the energy consumption. Making a hunt for air leaks to minimize this phenomenon allows to make important energy gains.
- **Drying overventilation:** dryers tend to operate with important drying air flows usually greater than needed. This has the result of increasing fuel consumption as it is proportional to the quantity of air blown in the dryer. Thus, decreasing drying air flows could lead to substantial fuel savings.

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