COUNCIL FOR DEVELOPMENT AND RECONSTRUCTION

SUSTAINABLE SLUDGE MANAGEMENT IN THE BEKAA REGION

FINAL FEASIBILITY STUDY
DRAFT V.1

Cabinet MERLIN
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LIST OF ABBREVIATIONS

AOX	Adsorbable Organic Halogen
ATEX	equipment intended for use in EXplosive ATmospheres (European directive)
ATP	Adenosine TriPhosphate
BOD_5	Biochemical Oxygen Demand
BWE	Bekaa Water Establishment
°C	Degrees Celsius
C/N	Carbon to Nitrogen ratio
CAPEX	Capital Expenditures
CDR	Council for Development and Reconstruction
Cf.	Confer (refer to)
CH4	Methane
CO	Carbon Monoxide
CO2	Carbon Dioxide
COD	Chemical Oxygen Demand
COx	Carbon Oxides
d	Day
DM	Dry Matter
etc.	et cetera (and so on)
FeCl3	Ferric chloride
FGTR	Flue Gas Treatment Residues (Fly Ash)
g	Grams
H2O	Water
H2S	Hydrogen Sulfide
ha	hectare
IBRD	International Bank for Reconstruction and Development
ICP	Inductively Coupled Plasma (spectrometry)
i.e.	id est (meaning)
kcal	kilocalorie
Kg	Kilograms
l	Liters
LHV	Lower Heating Value

LWA	Litani Water Authority
M	Million
m^3	Cubic meter
MSW	Municipal Solid Waste
NFU	French Standard
NH3	Ammonia
NOx	Nitrogen Oxides
O&M	Operation & Maintenance
OM	Organic Matter
OPEX	Operating Expenses
PCB	PolyChlorinated Biphenyl
PE	Population Equivalent
pers.	Person
RM	Raw Matter
SOx	Sulfur Oxides
t	Metric ton
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
UAA	Usable Agricultural Area
USAID	United States Agency for International Development
UV	UltraViolet
VM	Volatile Matter
WWTP	WasteWater Treatment Plant

EXECUTIVE SUMMARY

The Lebanese Republic has received a loan from the International Bank for Reconstruction and Development (IBRD) towards the cost of the Lake Qaraoun Pollution Prevention Project.

The objectives of the Lake Qaraoun Pollution Prevention Project are to reduce the quantity of untreated municipal sewage discharged into the Upper Basin of the Litani River and to improve pollution management around Lake Qaraoun. Part of this project includes the sustainable management of sewage sludge for the Bekaa valley, subject of the present feasibility study.

The CDR requested a detailed assessment of the treatment, disposal and recovery/reuse processes for all the sludge produced by the wastewater treatment plants in the study area.

The feasibility study for the sustainable sludge management of the Bekaa region took into consideration the sludge generated by the 13 wastewater treatment plants in the Bekaa valley at the 2040 horizon and a total population of 1,678,650 PE. The design bases and the costs for all treatment infrastructures are therefore set for the 2040 horizon.

By 2040, the whole project will output a total sludge production without lime of 32,250 tDM/year and of 112,674 m^3/year.

In order to dispose of the sludge produced in the Bekaa, four feasible scenarios were proposed. For each scenario, the additional sludge treatment units have been designed and priced, along with their related operating costs.

A multi-criteria analysis allowed us to hierarchize these scenarios based on selected technical and financial criteria. The scenario that seems to be the best option for the sustainable management of the sludge generated by the 13 wastewater treatment plants at the 2040 horizon consists of:

- ✓ adding solar dryers at the end of the sludge treatment lines of Zahlé, Marj, Temnine, Iaat and Joub Janine WWTPs,
- ✓ and adding storage areas in Joub Janine, Ablah, Fourzol and Aitanit WWTPs.

In this scenario, 70% of the total sludge output will be evacuated in a dedicated landfill and the rest will be spread in agriculture.

The total investment for this scenario at the 2040 horizon is of 30 M€ (17.9 €/PE or 62 €/TMS) and the yearly operating cost is of 4 M€ (2.38 €/PE or 8.3 €/TMS).

These conclusions were presented to the stakeholders at the Ministry of Energy and Water on July 28, 2021. Following this presentation an additional scenario (i.e. scenario 5) was requested as per the following criteria:

1- Implementation of dry solar beds or drying beds in each WWTP (as per scenario 4)
2- Dispose the sludge in a dedicated landfill for each WWTP. Each WWTP will have its own dedicated landfill, where at a later stage the stakeholders will identify these plots and area.
3- Calculate the area of the plot that will be used as a dedicated landfill for each WWTP.
4- Present a cost estimate for constructing sanitary cells.
5- Provide the operation & maintenance cost of handling/dumping the sludge in these landfills assuming the dedicated landfill is located at a 5km radius from each WWTP.

After comparing the five scenarios, it seems that scenario 5 is the best option. It is however dependent on the availability of lands for sludge disposal within 5km of the wastewater treatment plants. Moreover, it is important to note that the CAPEX of scenario 5 *does not take into consideration land acquisition.*

A. INTRODUCTION

A.1. GENERAL OVERVIEW

The project is located in the Bekaa region. The study area covers the governorate of Baalbek-Hermel and the governorate of the Bekaa excluding the Rashaya district. It stretches from Hermel in the north to the Qaraoun dam in the south.

The project aims to assess and to propose a sustainable management of the sludge produced in all the wastewater treatment plants existing, under construction or under study in the study area.

The project encompasses thirteen wastewater treatment plants by 2040, which corresponds to the project horizon.

The wastewater treatment plants are located in the following cities and villages:

- Existing WWTPs: Yammouneh, Iaat, Ablah, Fourzol, Zahlé, Joub Jannine, Saghbine, and Aitanit (Machghara)
- WWTPs under construction: Temnine El Tahta and Marj
- WWTPs under study: Hermel, El Laboue, and East Zahlé

A.2. EXPECTED RESULTS OF THE MISSION

The project aims to achieve the following objectives:

1- Prepare a feasibility study for sustainable sludge management in the Beqaa Region which falls under the administration of the BWE

2- Present justified and prioritized solutions for sustainable sludge management

B. AVAILABLE STUDIES AND INFORMATION

B.1. DATA COLLECTED FROM CDR

During the data collection, the following studies made available to the Consultant by the CDR were used:

- TECSULT INTERNATIONAL INC. / KREDO s.a.r.l.: *Plan Directeur de Valorisation ou de Disposition des Boues D'épuration, 2003*

- ARCADIS EUROCONSULT & INFORMATION SYSTEMS GROUP s.a.r.l.: *Commercialization of Compost & Non-organic waste in Lebanon, May 2003*

- UNDP-CEDRO Project: *Energy from Wastewater Sewage Sludge in Lebanon, 2013*

- TECSULT INTERNATIONAL INC. / KREDO s.a.r.l.: *Compostage des boues d'épuration avec les déchets solides, March 2004*

- Xanthoulis Dimitri (International Consultant) – UN-FAO report: *Wastewater reuse and Sludge Valorisation reuse, 2010*

- Water supply and wastewater systems master plan for the Bekaa water establishment: *Wastewater assessment report November 2013 (Updated May 2015),* DAI/KREDO

B.2. SITE VISITS AND INTERVIEWS

B.2.1. Site visits

As part of this study, surveys were conducted and site visit reports were generated for each existing wastewater treatment plant.

On February 19th and 20th 2020, the Consultant visited five wastewater treatment plants located in: Aitanit, Saghbine, Joub Jannine, Zahlé, and Iaat (Baalbek). The Yammouneh wastewater treatment plant was not visited because it is currently closed since it is not operational and needs rehabilitation.

On September 14th 2020, two plots were visited with the support and coordination of the Litani Water Authority. These plots belonging to the LWA, are located in Kfar Zabad and in Machghara. They were visited with the objective of scouting a potential location for a centralized sludge treatment unit or final outlet.

B.2.2. Meetings and interviews

During the data collection phase, different stakeholders were met from: the Ministry of Energy and Water, the Ministry of Environment, the CDR, the Litani Water Authority. Insights about feasible outlets and possible sludge treatment processes were shared.

Finally, complementary information about the characteristics of the treatment plants was provided by the operators and the consultants in charge and specifically the following reports:

- CDR Contract N°: 2544 dated 28/11/03, ZAHLE WASTEWATER PROJECT: *Operation and Maintenance Report For the month of December 2019,* SUEZ

- Contractor contract n° 19434-supervision contract n°19435: Operation and maintenance services of the Joub Janine & Saghbine WWTP & pumping stations within West Bekaa:

Progress report from September 01, 2017 till October 30, 2017, Dar Al Handasah Nazih Taleb & Partners

- Conseil du Développement et de la Reconstruction: *Plan directeur de valorisation ou de disposition des boues d'épuration Liban Phase IV – Rapport final (Mai 2003),* Tecsult International / Kredo
- Yammouneh: *Data collected from Dar Al Handassah Taleb*
- Hermel: *design report,* Dar Al Handasah Nazih Taleb & Partners
- Temnine el Tahta: CDR CONTRACT No. 17787*: Draft Environment Impact Assessment Report January 2013,* Dar Al Handasah Nazih Taleb & Partners
- Marj: *design report,* BTD
- Council for Development and Reconstruction*:* Preparation of a feasibility study for East Zahleh region wastewater project: *Final report June 2017,* BTD

C. DESIGN BASES

C.1. INTRODUCTION

In general, sludge treatment units are designed taking into account the maximum output of sludge at the project horizon: year 2040 in this feasibility study. The assumption is that it should be possible to treat and dispose of the total quantity of sludge produced by all the wastewater treatment plants, if they were all at their maximum capacity at any given time.

In order to establish the maximum output of sludge production of each wastewater treatment plant by 2040, the processes used for the effluent and sludge treatment, as well as the effluent characteristics of the treatment plants needed to be defined.

Those design bases are recalled below and are used in the rest of the study. They are the result of the surveys carried out with the support and coordination of the Litani Water Authority, the Bekaa Water Establishment, the municipalities of Ablah and Fourzol and the complements provided by the operators and the consultants of the wastewater treatment plants included in the study area.

C.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment processes adopted in every wastewater treatment plant are detailed in the table below:

Plant	Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Yammouneh	Coarse screening Fine screening Grit and grease removal		Aeration tank Clarification	Chlorination
Iaat (Baalbek)	Screening Grit and grease removal		Aeration tank Clarification	Chlorination
Ablah	Coarse screening Fine screening	Primary settling	Trickling filters Clarification	Chlorination
Fourzol	Coarse screening Fine screening	Primary settling	Trickling filters Clarification	Chlorination
Zahlé	Coarse screening Fine screening Grit and grease removal		Aerobic/anaerobic tanks Clarification	Filtration UV disinfection
Joub Jannine	Coarse screening Fine screening Grit and grease removal		Aerobic/anaerobic/anoxic tanks Clarification	Chlorination (filtration and UV disinfection inactive)

Saghbine	Coarse screening Fine screening Grit and grease removal		Aerobic/anaerobic/anoxic tanks Clarification	Chlorination (filtration and UV disinfection inactive)
Aitanit (Machghara)	Coarse screening Fine screening	Primary settling	Trickling filters Clarification	Chlorination
Marj	Coarse screening Fine screening Grit and grease removal	Settling	Anaerobic tank Anoxic tank Aerobic tank Settling	Chlorination
Temnine el Tahta	Coarse screening Fine screening Grit and grease removal		Pre-anoxia tank Anaerobic tank Anoxic tank Aerobic tank Settling	Filtration UV disinfection *Chlorination in case of emergency*
Hermel	Coarse screening Fine screening Grit and grease removal		Aeration tank Clarification	Chlorination
El Laboue	Coarse screening Fine screening Grit and grease removal		Aeration tank Clarification	Chlorination Optional: disk filters and UV disinfection
East Zahlé	Coarse screening Fine screening Grit and grease removal	Settling	Anaerobic tank Anoxic tank Aerobic tank Settling	Chlorination

Table 1 - Treatment processes for incoming effluents by WWTP

C.3. SLUDGE TREATMENT PROCESSES

The sludge treatment processes adopted in every wastewater treatment plant are detailed in the table below:

Plant	Thickening	Digestion	Dewatering	Liming	Drying
Yammouneh	X		X		
Iaat (Baalbek)	X	Aerobic	Belt filter press	X	
Ablah		Aerobic			Drying beds

Fourzol		Aerobic			Drying beds
Zahlé	X		Belt filter press	X	
Joub Jannine	X	Aerobic	Belt filter press		
Saghbine	X	Aerobic	Belt filter press		
Aitanit (Machghara)		Aerobic			Drying beds
Temnine el Tahta	Gravity	Aerobic	Belt filter press	Optional	Optional solar drying
Marj	X	Aerobic	Belt filter press		Drying beds
Hermel			Centrifugation	X	
El Laboue		Anaerobic (optional)	Belt filter press		
East Zahlé	X	Aerobic	Belt filter press		Drying beds in case of emergency

Table 2 - Treatment processes for sludge produced by WWTP

C.4. EFFLUENT CHARACTERISTICS

C.4.1. ASSUMPTIONS

In cases where information could not be acquired during site visits or were not provided by the operators and consultants in charge of the treatment plants, the flows and loads were calculated on the basis of the capacity of the plant (in PE) and the standard French unit allocations shown in *Table 3* below:

Parameter	Unit	Value
Inflow to the plant	l/pers.day	135
BOD_5	*g/pers.day*	60
COD	*g/pers.day*	120
TSS	*g/pers.day*	70
TKN	*g/pers.day*	12
TP	*g/pers.day*	2

Table 3 - Typical French ratios for calculating effluent characteristics

C.4.2. 2025

The origins, flows and pollutant loads of effluents by 2025 are given in the table below:

Plant	Effluent type	PE	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
Yammouneh	Household	6 000	788	350	438	72	12
Iaat (Baalbek)	Household + various industries	100 000	13 175	7 350	7 000	480	156
Ablah	Household + agri-food industries	14 630	2 000	878	1 024	176	29
Fourzol	Household + agri-food industries	7 400	1 000	444	518	89	15
Zahlé	Household + various industries	205 000	37 300	16 039	15 853	2 611	634
Joub Jannine	Household + agri-food industries	77 000	10 000	3 900	5 200	700	170
Saghbine	Household + agri-food industries	4 000	560	225	299	40	10
Aitanit (Machghara)	Household	35 700	5 000	2 142	2 499	428	71
Hermel	Household	84 000	11 760	4 872	6 126	846	168
Temnine el Tahta	Household + agri-food industries	102 000	14 790	6 049	6 700	1 035	252

Marj	Household + various industries	260 000	31 200	12 480	13 728	1 872	468

Table 4 - Characteristics of the effluents by the year 2025

C.4.3. 2040

The origins, flows and pollutant loads of effluents by 2040 are given in the table below:

Plant	Effluent type	PE	Average flow rate plant inlet (m³/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
Yammouneh	Household	6 000	788	350	438	72	12
Iaat (Baalbek)	Household + various industries	100 000	13 175	7 350	7 000	480	156
Ablah	Household + agri-food industries	14 630	2 000	878	1 024	176	29
Fourzol	Household + agri-food industries	18 520	2 500	1 111	1 296	222	37
Zahlé	Household + various industries	300 000	56 000	24 080	23 800	3 920	952
Joub Jannine	Household + agri-food industries	150 000	20 000	9 000	10 500	1 800	300
Saghbine	Household + agri-food industries	5 800	750	348	406	70	12
Aitanit (Machghara)	Household	35 700	5 000	2 142	2 499	428	71
Hermel	Household	112 000	15 680	6 496	8 168	1 128	224
Temnine el Tahta	Household + agri-food industries	340 000	49 300	20 558	24 404	4 080	680
Marj	Household + various industries	350 000	43 200	17 280	19 008	2 592	648
El Laboue	Household + various industries	79 000	10 635	3 730	7 530	948	158
East Zahlé	Household + agri-food industries	167 000	22 500	9 000	9 900	1 350	338

Table 5 - Characteristics of the effluents by the year 2040

C.5. SLUDGE OUTPUT BY PLANT

C.5.1. ASSUMPTIONS

By applying the typical ratios shown in *Table 6* below to the incoming loads at each plant, the average sludge production was calculated in kg of dry matter:

Parameter	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Organic sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and organic sludge production	*Kg DM/kg BOD_5 treated*	1.1

Table 6 - Typical French ratios for calculating sludge outputs

The dryness values used are taken from the design reports, the operating monthly reports or from data directly provided by the operator which made it possible to calculate the corresponding sludge volumes.

The densities considered for these calculations are given in *Table 7.*

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 and 0,8

Table 7 - Sludge density by dryness

C.5.2. 2025

The values presented in *Table 8* correspond to the production of sludge at the end of the sludge treatment process without lime by 2025.

Plants	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
Yammouneh	103	575	18 %
Iaat	2 173	9 313	21 %
Ablah	317	304	94 %
Fourzol	160	154	94 %
Zahlé	4 742	23 710	20 %
Joub Jannine	1 153	5 765	18 %
Saghbine	67	333	18 %
Aitanit (Machghara)	774	741	94 %
Hermel	1 440	5 762	25 %
Temnine El Tahta	1 788	8 048	20 %
Marj	4 510	22 550	20 %
TOTAL	**17 227**	**77 255**	

Table 8 - Annual sludge production expected by 2025

Total sludge production should therefore reach nearly **17,227 t DM/year** and the volume of sludge to be disposed of should be around **78,000 m³/year** by 2025.

This output should be distributed as shown in *Figure 1* :

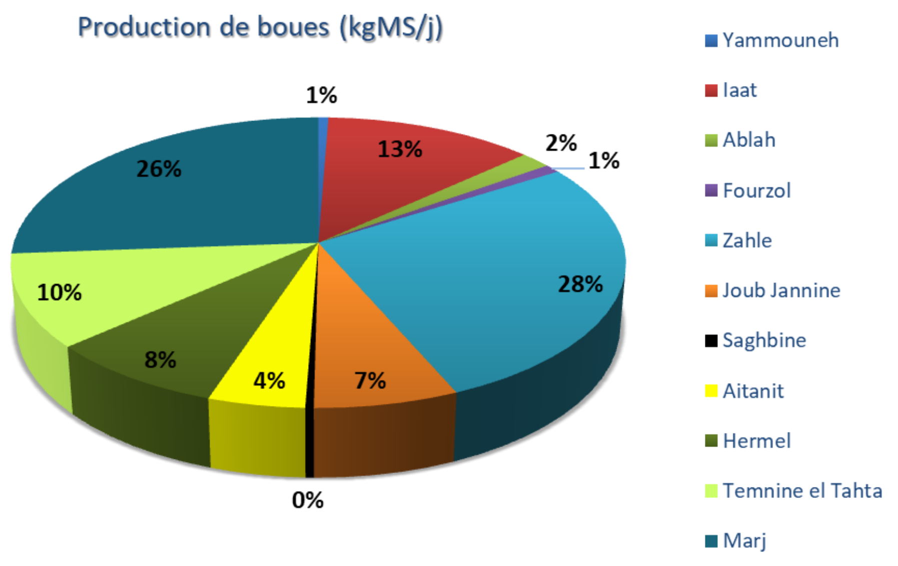


Figure 1. Breakdown of sludge production by plant by 2025

C.5.3. 2040

The values presented in *Table 9* correspond to the production of sludge at the end of the sludge treatment process without lime by 2040.

Plants	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
Yammouneh	103	575	18 %
Iaat	2 173	9 313	21 %
Ablah	317	304	94 %
Fourzol	402	384	94 %
Zahlé	7 119	35 596	20 %
Joub Jannine	2 661	13 304	18 %
Saghbine	103	514	18 %
Aitanit (Machghara)	774	741	94 %
Hermel	1 921	7 682	25 %
Temnine El Tahta	6 078	27 351	20 %
Marj	6 244	31 220	20 %
El Laboue	1 103	5 514	18 %
East Zahlé	3 252	3 903	75 %
TOTAL	**32 250**	**136 401**	

Table 9 - Annual sludge production expected by 2040

The total sludge production should therefore amount to **32,250 t DM/year** and the volume of sludge to be disposed of should be around **137,000 m³/year** by 2040.

This output should be distributed as shown in Figure 2. Breakdown of sludge production by plant by 2040:

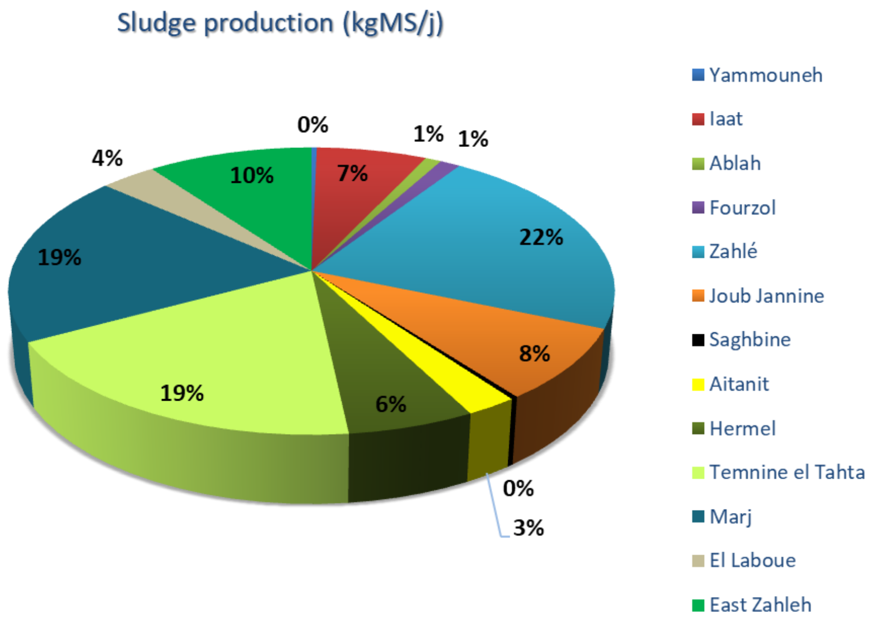


Figure 2. Breakdown of sludge production by plant by 2040

D. OPERATING PRINCIPLES OF SLUDGE TREATMENT UNITS

D.1. DIGESTION

D.1.1. Aerobic digestion

The aerobic digester operates on the same principles as the activated sludge process. Currently, three types of aerobic digestion processes are used in sludge stabilization:

- ✓ conventional aerobic digestion (mesophilic);
- ✓ aerobic digestion with pure oxygen;
- ✓ thermophilic aerobic digestion

D.1.1.1. Conventional aerobic digestion

Conventional aerobic digestion stabilizes the activated excess sludge in unheated open digesters through diffused air or surface mechanical aeration. The digestion occurs at a mesophilic temperature range (between 20 °C and 45 °C). Solids concentrations in the aerobic digesters should not be greater than 3%. Aspects to be considered in the design of aerobic digesters are similar to those for activated sludge systems, such as:

- ✓ hydraulic detention time which, in this case, is equal to the solids retention time, or sludge age
- ✓ organic loading
- ✓ oxygen demand
- ✓ power requirements (enough for supplying the oxygen demand and maintaining the sludge in suspension)

Volatile solids reductions in aerobic digesters of 35–50% can be normally obtained with 10–15 days of detention time. If coliforms removal is a goal, the hydraulic detention time must be greater than 40 days.

D.1.1.2. Aerobic digestion with pure oxygen

Aerobic digestion using pure oxygen is a variant of the conventional aerobic digestion, in which oxygen instead of air is directly supplied to the medium.

This process is suitable for large wastewater treatment plants, where area is a prime factor, and in which pure oxygen is already being used in the biological reactor.

D.1.1.3. Thermophilic aerobic digestion

Thermophilic aerobic digestion (TAD) started in Germany in the early 1970s aiming at the stabilization and disinfection of sewage sludge. The process is able to stabilize about 70% of the biodegradable organic matter in the sludge after a period of only three days. To assure an autothermic reaction process, the sludge fed to the digester must have a minimum concentration of 4%, with solids loading rate of about 50 kg TS/m3 digester and an organic loading rate of 70 kg BOD/m3 digester.

The main advantages of thermophilic aerobic digestion are:

- ✓ reduction of the hydraulic detention time (volume of the digester) for organic matter stabilization;
- ✓ production of a disinfected sludge.

The main disadvantages of the process are:

- high capital cost;
- operational complexity;
- foam build-up on the digester surface. A freeboard of 30% of the digester height is recommended to accommodate the produced foam.

D.1.2. Anaerobic digestion

D.1.2.1. Operating Principle

Anaerobic digestion of sludge is a biological process that allows for significant degradation of organic matter through methane-producing bacterial fermentation in a closed chamber in the absence of air.

The organic matter from thickened sludge is sent for digestion. This organic matter is therefore essentially particulate organic matter.

At first, the particulate matter will be liquefied (solubilized) so that it can be absorbed by the micro-organisms as a substrate: this is the liquefaction step. This transformation leads to the formation of amino acids, sugars, fatty acids. These are therefore nutrients on the one hand for the fermenting microorganisms and on the other hand for the anaerobic oxidizing microorganisms which decompose them to form gases (CO2, CH4) during a gasification phase.

This sequence of biological reactions leads to the formation of biogas (composed mainly of methane CH4 and CO2) and a digestate.

This fermentation takes place in a closed, confined digester, which prevents any contact of the gas produced with the outside air and confines odors resulting from the process itself. The micro-organisms involved in the digestion are bacteria naturally present in the environment.

The anaerobic digestion of sludge forms biogas containing approximately 60% methane and 40% carbon dioxide.

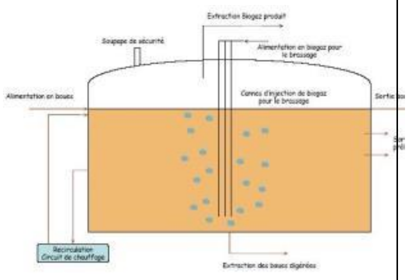
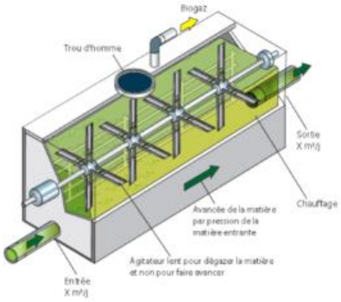
D.1.2.2. Type of anaerobic digestion

Anaerobic digestion can be organized according to three technologies which are distinguished by the consistency of the substrates in the digester:

- **Continuous liquid anaerobic digestion**: this process consists of continuously injecting liquid sludge (maximum 15% dry matter) into the anaerobic digestion unit. The retention time is about 25 days. This process is widely used for the digestion of sludge from wastewater treatment plants;

- **Semi-solid anaerobic digestion**: the substrate is injected into a digester operating in piston flow. This type of anaerobic digestion is mainly used for the treatment of household waste and there is no previous experience with sludge alone;

- **Batched dry anaerobic digestion**: this process consists in placing solid waste in an anaerobic digestion unit. At the end of the retention time required for digestion (about 70 days), the waste is evacuated and replaced by new inputs. This type of anaerobic digestion is widely used for the digestion of agricultural waste.

Liquid	Semi-solid	Dry
Dryness between 8 and 15% Continuous Stirred-Tank Reactor (CSTR)	Dryness between 15 and 40 % Piston Flow Reactor	Dryness between 20 and 50% Discontinuous Flow in Batches
		
Inhibition thresholds [3-6gN/L]. To set up the conditions necessary for the good mixing of the substrates (grinding of the whole waste, hydrolysis of grease, homogenization of the mixture and stirring of the digester ...)	Starting from 20,000 tonnes of raw matter/year Especially suitable for household waste.	Lower CH_4 production Not very compatible with injection (a lot of energy spent on biogas treatment) Delicate percolation management Lower investment cost Easier implementation

D.1.2.3. Temperature configuration

Anaerobic digestion must be done at high temperature. There are two configurations:

- ✓ Mesophilic digestion: 35 to 40 °C;
- ✓ Thermophilic digestion: 55 °C.

Mesophilic digestion

The digester is brought to a temperature of 35 - 40°C. The advantages of this process, in addition to the reduction of energy costs, are as follows:

- ✓ The robustness of the system;
- ✓ The low sensitivity to variations in temperature and composition of the mixture;
- ✓ Low sensitivity to load variation;
- ✓ Simplicity of operation;
- ✓ Limited thermal requirements;
- ✓ The possibility of heating the digesters by recovered energy (heat pump...), rather than with part of the biogas produced.

This solution also has disadvantages:

- ✓ A slow degradation;
- ✓ A long retention time (≈ 25 days);
- ✓ A more important footprint;

- A more expensive investment.

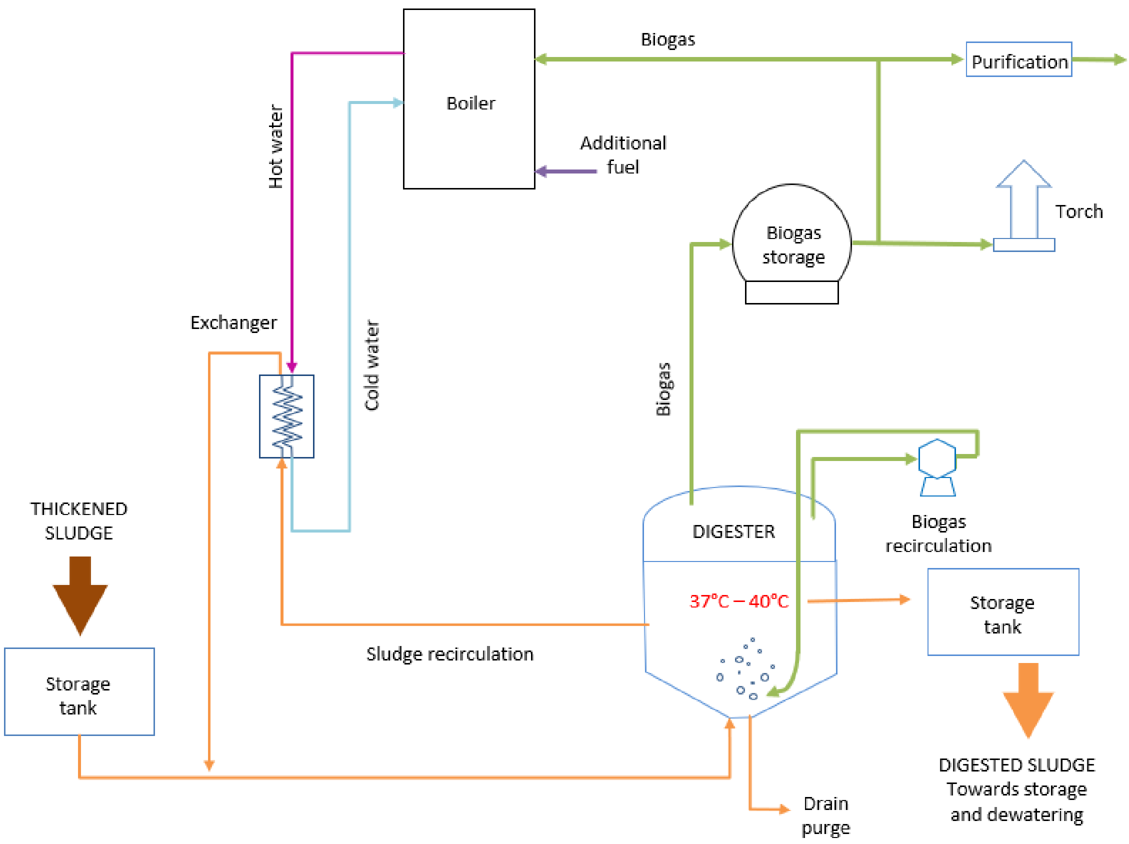


Figure 3. Functional diagram of mesophilic digestion

Thermophilic digestion

The digester is brought to a temperature of 55°C. The advantages of this process are:

- Accelerating reaction kinetics (faster degradation);
- Decreasing the retention time (≤ 15 days), reduction of 40% of the digestion volume compared to a mesophilic digestion;
- Lower investment due to the reduced digestion volume.
- The completion time of these digesters is slightly shorter.

However, this solution has the following disadvantages:

- Lower methane content and higher water and siloxane content (impact on biogas treatment before recovery); the proportion of stripped CO_2 is higher due to the temperature;
- Sensitivity to pollutants and load shocks;
- Complexification of the operation (very fine tuning of the temperature);
- Risk of strong degradation of dryness after dewatering and high consumption of dewatering reagent;
- Very high energy consumption due to the fact that the digesters are always to be kept at the right temperature;
- More risks of odor emissions (NH_3 and H_2S);
- Production of biogas equal to that generated by mesophilic digestion;

- Higher sensitivity to soluble nitrogen due to higher temperatures and pH;
- Higher operating costs compared to the thermophilic process.

D.1.2.4. Technical comparison

The table below compares the operating characteristics as well as the advantages and disadvantages of the two temperature configurations:

MESOPHILIC / THERMOPHILIC COMPARISON		
	MESOPHILIC DIGESTION	**THERMOPHILIC DIGESTION**
TEMPERATURE	**35-40°C**	**55-60°C**
RETENTION TIME	**20 to 30 days**	**12 to 15 days**
VOLUME LOAD	**2 kgVM/m³/D**	**4 kgVM/m³/D**
ADVANTAGES	(+) Robust system (+) Simplicity of operation (+) Possibility of covering thermal needs with a low temperature heat pump	(+) Decrease in the retention time (+) Reduction of digestion volume (+) Limited investment in civil engineering
DISADVANTAGES	(-) Long retention time (-) Significant civil engineering investment	(-) Sensitivity to pollutants, load shocks and temperature variations (-) Complexity of the operation (-) Risk of deterioration in dewatering performance (lower dryness) (-) Increased consumption of dewatering reagent (-) Lower methane content and higher content of water, CO2 and siloxanes (impact on biogas treatment) (-) High energy consumption to maintain sludge temperature (-) Higher risk of odor emissions (NH3 and H2S)

The criteria for choosing the mode of digestion, mesophilic or thermophilic, are:

- The importance of having a robust tool that is easy to use;
- The footprint available on the site;
- Whether or not the project owner wants to optimize the production of biogas to be recovered by injection. Indeed, thermophilic digestion requires a greater quantity of heat.

D.1.2.5. Digester types

Digester construction materials

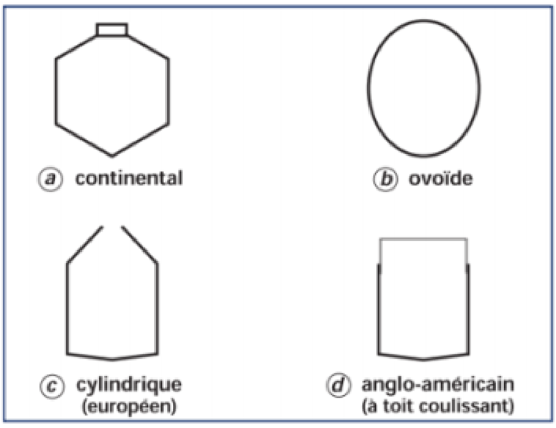
If the tanks are conventionally made of concrete, some manufacturers now offer steel tanks (vitrified or stainless steel). These new types of digesters have many advantages over concrete digesters, despite some disadvantages as well:

ADVANTAGES AND DISADVANTAGES OF STEEL DIGESTERS COMPARED TO CONCRETE		
	ADVANTAGES	**DISADVANTAGES**
STEEL DIGESTER 	(+) Reduction in construction time and logistics costs (+) No need for formwork (+) Gas and water sealing, easy to drill or plug holes (+) Lower resistance to overpressure, which limits the explosion radius (+) When the anaerobic digestion installation is dismantled, the stainless steel can be resold for recycling.	(-) A need for protection against lightning and power surges (additional equipment, cost...) (-) Life span and warranty of the casing

To date, they are little used for sewage sludge digestion, so the number of references is relatively low. Cabinet MERLIN has three experiences with this subject, the anaerobic digestion of the La Crau WWTP (near Toulon) in vitrified steel built nearly 10 years ago, as well as the Mulhouse and Sète (stainless steel) digestions under construction.

Digester shape

In France, facilities are generally equipped with continental or flat-roofed continental type digesters.



This is because they are the only products offered by the two largest French constructors (Suez and Veolia groups). In the rest of Europe (Germany, Switzerland, Austria, etc.), egg-shaped digesters are more commonly found, which reduce the footprint and facilitate stirring by eliminating dead zones.

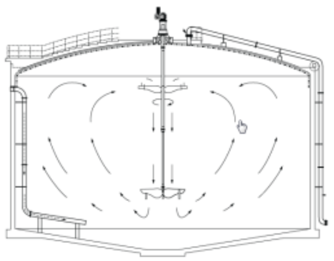
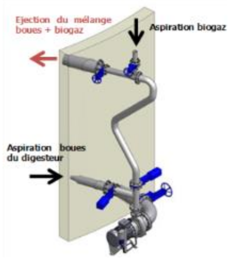
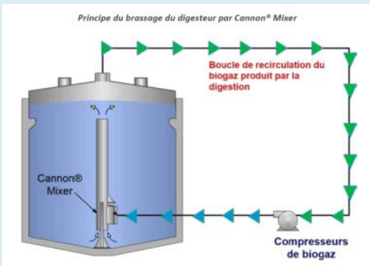
D.1.2.6. Stirring technologies

Stirring ensures contact of all nutrients, temperature homogeneity and minimizes deposit build-up. Two stirring techniques are possible:

- ✓ Biogas stirring: the biogas produced is compressed and reinjected into the digestion volume;
- ✓ Mechanical stirring.

In France, stirring is generally carried out by bubbling biogas in 80% of existing installations. The other installations include mechanical stirring.

As for the digester configuration, the table below summarizes the advantages and disadvantages of each type of digester stirring.

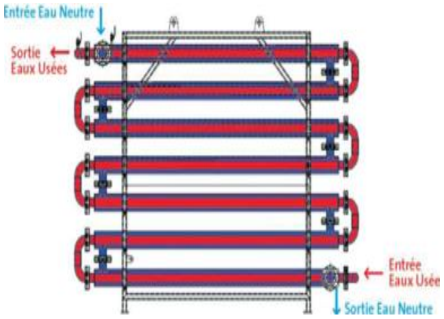
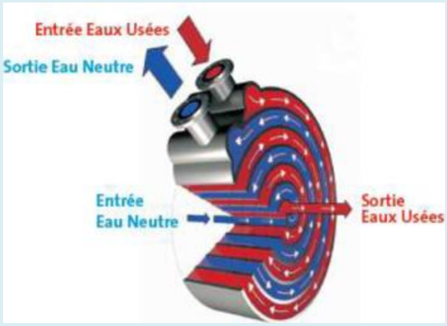
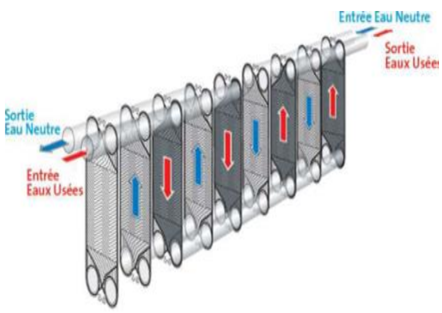
COMPARISON OF STIRRING TECHNOLOGIES		
STIRRING TYPE	**ADVANTAGES**	**DISADVANTAGES**
LOW-SPEED MECHANICAL MIXING 	(+) Energy performance (+) Solution increasingly offered by manufacturers	(-) difficult maintenance (-) no back-up solution possible (-) solution not offered by all constructors (-) risk of the blades falling into the digester with a unique agitation (not to be minimized)
LOW-SPEED LATERAL MIXING 	(+) Usually suitable for agricultural anaerobic digestion installations.	(-) energy performance (at least two stirrers to be provided with a total power equivalent to a tilting device)
HYDRO EJECTOR 	(+) No equipment in digestion - easy maintenance access (+) mechanical stirring and coupled gas stirring in a single unit	(-) ATEX zone but fixed to the digester (-) energy consumption (-) investment costs
CANNON® MIXER 	(+) Robustness of equipment (+) Stirring performance	(-) creation of an additional space in the ATEX zone in the blower room (-) patented solution limited to one manufacturer (-) high energy consumption (-) some feedback on maintenance problems with stirring machines

D.1.2.7. Type of exchangers to heat sludge

During the implementation of anaerobic digestion of sludge, heat exchangers can be localized:

- ✓ Fresh sludge: the exchanger(s) is positioned at the level of the digester feed pipe;
- ✓ Recirculated sludge: the exchanger(s) is positioned at the level of the sludge recirculation loop;
- ✓ Specificity of the sludge/sludge exchanger: a sludge/sludge exchanger can be implemented. The objective of this optimization is to recover energy from the digested sludge leaving the unit (i.e. at 35°C for mesophilic digestion) to heat the incoming fresh sludge. This process allows the recovery of about 15% of energy from a mesophilic digestion.

There are several types of exchangers for sludge heating:

<table>
<tr><th colspan="3">COMPARISON OF EXCHANGER TECHNOLOGIES</th></tr>
<tr><th>TYPE OF EXCHANGERS</th><th>ADVANTAGES</th><th>DISADVANTAGES</th></tr>
<tr><td>Tubular
</td><td>(+) Reliability, as it is the exchanger with the most feedback</td><td>(-) Space requirement</td></tr>
<tr><td>Spiral
</td><td>(+) Ease of operation
(+) Compactness</td><td>(-) Risk of clogging</td></tr>
<tr><td>With plates
</td><td>(+) Heat recovery efficiency</td><td>(-) Significant risk of clogging

→ This type of exchanger is more suitable for heat recovery from treated water</td></tr>
</table>

D.1.2.8. Biogas management: gas holder and gas burner

Integrated or non-integrated gas holders

COMPARISON OF INTEGRATED OR NON-INTEGRATED GAS HOLDERS		
CONFIGURATION	**ADVANTAGES**	**DISADVANTAGES**
❶ Concrete digester with independent gas holder 	(+) In the case of stirring with a central agitator, less stirring power is required.	(-) ATEX zones and overpressure radius (-) required footprint (-) investment cost
❷ Digester with roof-mounted gas holder 	(+) Space saving (+) Investment cost	(-) Sustainability (-) Implementation difficulties (-) the ATEX zone is not to be minimized due to the consideration of a secondary explosion above the digester.
❸ Concrete digester with flexible roof membrane 	(+) For large digester diameters, the economic advantage of a concrete roof is very appealing (+) Space saving (+) minimized dome coating and H_2S resistance problem	(-) Investment cost

Hidden flame gas burner technology

Can be considered for implementation:

- ✓ a single-stage biogas burner;
- ✓ a two-stage biogas burner;
- ✓ Two gas burners: a biogas burner and a biomethane burner.

The advantage of a two-stage gas burner compared to a single-stage gas burner is that it guarantees a wide operating range while maintaining good combustion quality.

Providing 2 gas burners (one gas burner for biogas and another for biomethane) can meet the need for destruction of non-compliant biomethane if the biogas circuit does not include the possibility of re-forming biogas from the non-compliant biomethane (by CO2 injection). In most cases, the dilution of the biomethane in the large volume of biogas stored in the gas holder alleviates this problem.

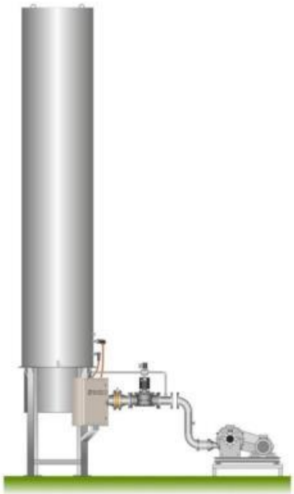


Figure 4.Gas burner example

D.2. DEWATERING

Dewatering processes differ according to the operating principle:

- ✓ Pressure filtration (belt filter presses, plate and frame presses, screw presses).
- ✓ Accelerated settling (centrifuges).
- ✓ Combination of filtration and natural evaporation (drying beds).

The choice between these different techniques will be made on the basis of an assessment of the following main criteria:

- ✓ The subsequent destination of the sludge,
- ✓ The initial characteristics of the sludge to be dewatered,
- ✓ The required pre-conditioning,
- ✓ The technical performance of the process,
- ✓ The integration of the dewatering unit into the plant,
- ✓ Investment and operating costs.

In addition to price, the destination of the sludge should be the determining factor in the choice of dewatering method. For example, agricultural recovery and reuse will be favored by filter dewatering, which makes it possible to obtain a sludge that holds better in heaps than a sludge dewatered by centrifugation.

For other sectors (drying or specific incineration in particular), dryness is the primordial factor, so high-performance centrifuges or even frame presses should be favored.

D.2.1. Centrifuge

D.2.1.1. Operating Principle

Centrifugal dewatering is the most common dewatering technique on large capacity plants. It consists in separating the liquid and solid phases, due to their density, by centrifugal acceleration in a vessel in which a scroll rotates. This scroll scrapes and removes the solid phase. In general, the design of the scroll is adapted to a specific type of sludge.

The compactness of this technology makes it possible to develop mobile dewatering units, which ensures a certain flexibility of the process.

The high operating autonomy inherent in the easily automated nature of the process (low manpower requirements) makes it possible to size centrifugation plants over long operating ranges (24 hours a day), thus reducing the processing capacity of the machines and consequently the investment costs.

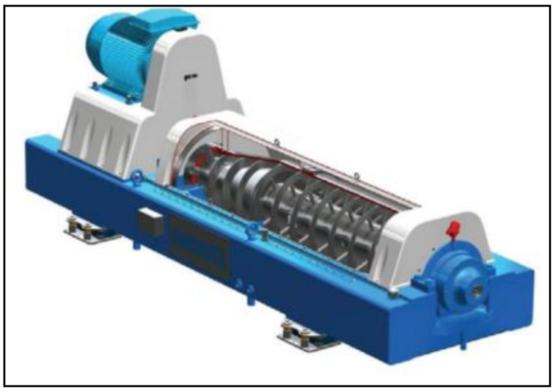


Figure 5. Example of centrifuges

Three types of conditioning can be carried out before dewatering:

- ✓ **Mineral conditioning**, with the use of lime and a coagulant (chlorine or ferric sulphate). It allows a strong increase in dryness and sludge stabilization. This type of conditioning is used especially when the treated sludge is destined for agricultural spreading or for landfilling in non-hazardous waste storage facilities;
- ✓ **Organic polymer conditioning**.

  It can be carried out after the eventual addition of coagulant.
- ✓ **Thermal conditioning**, which makes it possible to exceed 50% dryness. It is used with digested sludge in large installations.

D.2.1.2. Performance

	Primary sludge	**Combined sludge***	**Extended aeration sludge**	**Digested combined sludge**
Centrifugation	29 to 37 %	17 to 22 %	14 to 19 %	
" High performance " version	32 to 40 %	20 to 25 %	17 to 22 %	23 to 25%

** In combined sludge, the dryness depends on the proportion of primary sludge and secondary sludge*

For digested combined sludge, we can consider that the concentration of digested or undigested sludge gives the same dryness. However, depending on the installation, an improvement in the dewatering performance or a degradation of the sludge can be observed after sludge digestion, without any clear rule.

The average dryness observed on known operations gives values between 19 and 28% in mesophilic digestion:

- ✓ An underloaded digester will be able to give a higher dryness thanks to the better stabilization of the sludge (25 to 28%);
- ✓ A straining of the sludge before digestion (filament removal) can cause a loss of several dryness points (19 to 20%);
- ✓ A normal average operation could give sludge between 23 and 25% at the nominal load in mesophilic digestion without upstream thermal conditioning.

The performances obtained on installations in operation in France (Process: Activated sludge with primary clarification and mesophilic digestion) are as follows:

✓ La Feyssine	18 to 21 % (average 20%)
✓ Cherbourg Est	21 to 25 % (average 23%)
✓ Vannes	20 to 23 % (average 22%)
✓ Strasbourg	23 %
✓ Petite Californie (Nantes)	27%

D.2.2. Filter Press

D.2.2.1. Operating Principle

The filter press is a dewatering technique that consists in mechanically exerting a strong pressure on the sludge. The sludge releases the interstitial water through a filter. A more or less dry "cake" is then formed with the retained solids.

Prior to dewatering, coagulation / flocculation reagents are used, their main function being to increase the agglomeration of particles to facilitate filtration. Ferric chloride and lime are the most often chosen conditioning agents, but polymer electrolytes can also be used. The use of specific polymers and screens facilitates the settling of the cake, a crucial stage in the dewatering process.

The screens must then be washed. This washing also generates large quantities of water loaded with suspended solids, which is reintroduced upstream of the water treatment process. The resulting sludge dilution must be taken into account to determine the capacity of the installation. This system generally operates discontinuously in cycles (filling, filtering, frame opening, washing) that can last for a longer or shorter period of time depending on the nature of the sludge suspensions, the efficiency of the feed and the conditioning.

There are several mechanical dewatering techniques of the "filter press" type:

- ✓ Belt filter press;
- ✓ Plate and frame filter press;
- ✓ Screw press.

D.2.2.2. Filter press technologies

Belt filter press

A belt filter press consists of compressing the sludge between two cloth belts until a dryness of between 20 and 25% is achieved. Once the cloth is free of sludge, it must be washed to keep its porosity. This system requires the addition of polymers whose composition and quantity must be constantly adapted to the quality of the sludge. Widely used elsewhere, belt filters are now less common in France, except for small treatment units. This technology, which nevertheless gives good results, is being replaced by more compact technologies giving higher dryness (such as centrifugation). Recently, screw press systems have been coming back, even if they offer lower dryness levels than centrifugation.

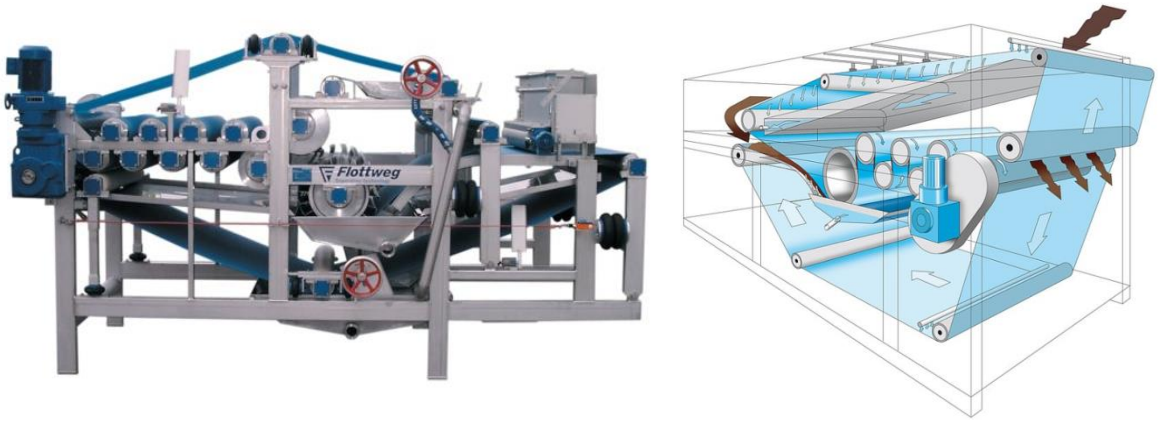


Figure 6. Example of belt press

Plate and frame filter press

A plate filter press is composed of a succession of plates covered with filtering cloths and clamped by means of one or two hydraulic jacks between a fixed and a mobile bed. The sludge is introduced by means of a pump up to the necessary pressure (generally 7 to 15 bars). At this pressure, the water passes through the cloth which retains the solid particles. This filtrate is collected either at each plate or at the end of the filter. The retained particles form a cake of variable dryness depending on the type of sludge and conditioning. Conditioning with lime improves the pressing stage and gives the highest dryness, but only if this mineral is added in proportions of up to 30% and more of the sludge's TSS.

Sludge can be conditioned in several ways upstream of the plate press, either by adding polymer, by adding lime or milk of lime, or ferric chloride.

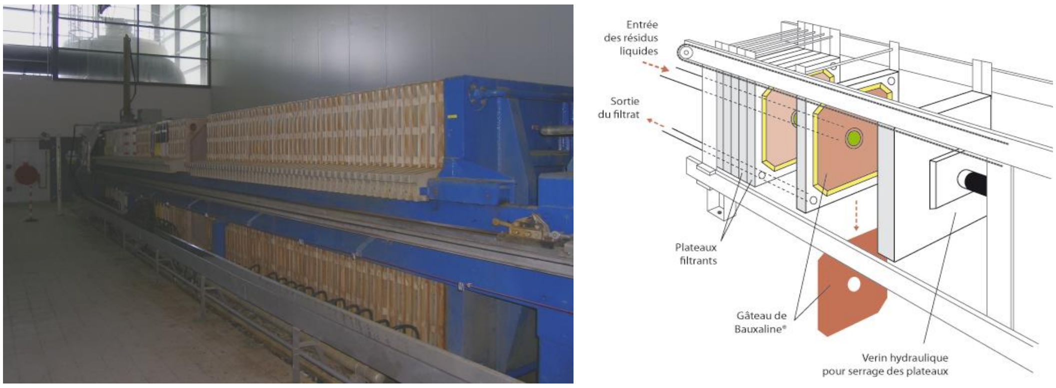


Figure 7. Example of plate filter press

It should be noted that the best performance is obtained with prior conditioning of the sludge with lime and $FeCl_3$. Given the increased risk of stripping of the nitrogen contained in the sludge during liming after digestion (release of ammonia), it is advisable to stop liming the digested sludge in order to avoid generating degraded operating conditions in terms of ambient air in the room housing the filter presses and which may require special provisions such as the wearing of restrictive personal protective equipment (oxygen mask, etc.). Consequently, a preliminary conditioning of the sludge with polymer and FeCl3 becomes preferable, which results in a strong degradation of the dewatering performance; poor feedback is recorded in this case (strong conditioning and low dryness).

Screw press

The flocculated sludge is injected by a pump into a cylindrical screen in which a screw slowly rotates. As the volume reduces between the screen, central core and spirals as the sludge advances, the pressure exerted on the sludge increases. The water contained in the sludge then tends to escape through the slots in the screen. A ring at the tip of the screw continuously scrapes the inside of the screen. A mobile washing ramp periodically cleans the outside of the screen, section by section, without interrupting dewatering. This technology makes it possible to obtain sludge with a lower dryness than centrifugation, but quite acceptable depending on the outlet of the sludge.

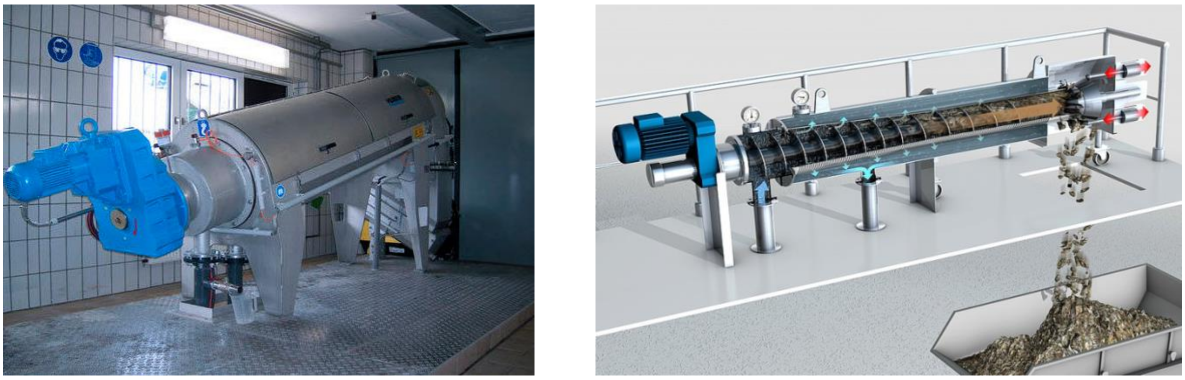


Figure 8. Example of screw press

D.2.2.3. Performance

	Primary sludge	Combined sludge	Extended aeration sludge	Digested combined sludge
Belt filter press	30 to 38 %	18 to 23 %	15 to 20 %	18 to 23 %
Frame filter press with lime + FeCl3	35 to 45 %	30 to 40 %	25 to 35 %	Risky
Frame filter press with FeCl3 + Polymer	-	-	-	*26 % max
Screw press	25 to 30 %	20 to 25 %	16 to 19 %	No feedback

* there are not many feedbacks on this technology applied to digested sludge (Limoges WWTP with significant system operation problems - average dryness of 23%).

D.2.3. Comparison of technologies

COMPARISON OF DEWATERING TECHNOLOGIES		
	ADVANTAGES	DISADVANTAGES
Centrifuge	(+) Continuous operation (+) Compact (+) Full automation	(-) Energy consumption (-) Performance < 25%DM
Belt filter press	(+) Performance on secondary sludge (+) Continuous operation	(-) Space requirement (-) Regular washings (-) Not suitable for fibrous sludge (-) Cost of maintenance and renewal (-) Performance < 18%DM (-) Operation requiring the permanent presence of operating personnel
Frame filter press	(+) Limited maintenance (+) Suitable for all types of sludge (+) Performance > 30%DM but with lime + FeCl3	(-) High investment (-) Space requirement (-) Not suitable for sticky sludge (-) Discontinuous operation (-) Not easily automated (even presses with automatic frame opening require the presence of operating personnel) (-) Ammonia release from digested sludge if lime is used
Screw press	(+) Limited maintenance (+) Suitable for all types of sludge (+) Continuous operation (+) High level of automation	(-) High investment (-) Performance < 20%DM

D.3. SOLAR DRYING

D.3.1. Operating principle

The sludge is placed in drying greenhouses to remove some of the water it contains and to concentrate it and then facilitate its evacuation.

These greenhouses are often automated (sludge inlet, ventilation, stirring ...).

This process has the particularity of using a renewable, inexhaustible and free energy: solar energy. Concerning the efficiency of this process, the dryness reached at the output is about 70% to 80%.

D.3.2. Evaporation process and drying kinetics

- ✓ Fresh sludge introduced into the greenhouse heats up to the ambient temperature of the greenhouse (higher temperature than the outside air due to the greenhouse effect). This warm-up period is generally very short relative to the total time of the drying process.

- ✓ "Superficial" regime

Drying is carried out by evaporation of the water available on the surface. This phase lasts as long as the surface is sufficiently supplied with water from the inside of the sludge.

- ✓ Slow-down phase

This phase begins when the sludge reaches its hygroscopic threshold, i.e. the water remaining in the sludge can no longer rise to the surface. The drying front that was in surface migrates to the interior of the sludge. The further away this drying front is from the external surface of the sludge, the slower the drying speed.

In order to remain in the optimal evaporation phase, the greenhouses are coupled with sludge bed turning systems.

The equipment breaks the sludge crust that forms on the surface when the drying front moves towards the inside of the sludge and renews the sludge surface in contact with the air.

- ✓ Final destination of the sludge

The following outlets are available to the sludge extracted from the solar drying greenhouses:

Final destination of the sludge	Required dryness
Agricultural recovery and reuse	Dried sludge: > 60 %
Composting	18-30 %
Incineration	> 35 %
Co-incineration	> 25 %
Storage facility	30-35 %

D.3.3. Main parameters

The objective of solar drying is to evaporate the water contained in the sludge. The rate of evaporation depends on the amount of water that the air can store, so the drying possibilities decrease as the humidity in the air increases.

The meteorological factors that favor evaporation are mainly the following:

- high temperature: The very structure of the greenhouse allows for heat storage and higher air and sludge temperatures than the ambient temperatures;

- low relative humidity (unsaturated air in the vicinity of the evaporation surface);

- wind speed and movement;

- the air-sludge exchange surface. The larger this surface, the more water evaporates from the sludge. The arrangement of the sludge in the greenhouse (beds, windrows), its height and the structure of the sludge (granulated or not) are the factors influencing the exchange surface. The figure below shows how the distribution of sludge in windrows increases the exchange surface.

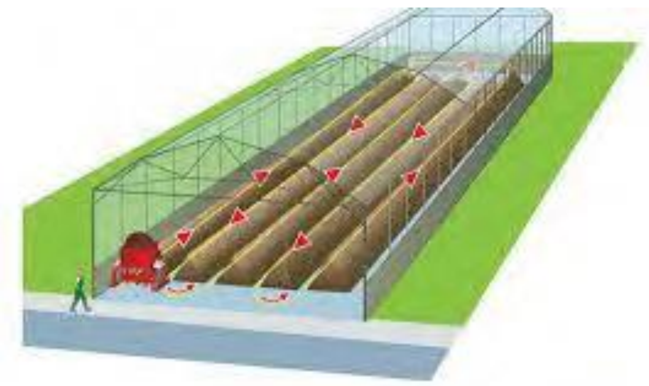


Figure 9. Windrows representation

Note: depending on the season, it may be possible to store the sludge by increasing the Sludge bed height. Some manufacturers offer equipment to perform this drying/storage function. The Sludge bed height can then reach 1.0 m to 1.2 m. In that case, it could be possible to store several weeks of production.

Figure 10. Example of solar dryer

D.3.4. Equipment

D.3.4.1. Roof Ventilation Flaps

Motor driven roof ventilation flaps are installed over the entire length of the drying hall. These are similar to those used in many greenhouses for ventilation.

D.3.4.2. Axial Fans

Fans are placed inside the hall in such a way that air turbulence is created above the entire surface of the drying bed, destroying the moist boundary layer above the sludge surface. This artificial wind is important for the drying process as it avoids any stratification of temperature or humidity.

D.3.4.3. Natural air flow

Air hatches are positioned between the greenhouse and the walls on which the sludge turning tool is moved. Whenever the hatches are opened, a natural air drift occurs and fresh, dry air enters the solar drying beds.

D.3.4.4. Sludge turning system

The establishment of a sludge turning system will allow to:

- spread the dehydrated sludge over the entire width of the solar drying bed
- increase the exchange surface between the sewage sludge and dry air due to scarification (scratching the surface)
- avoid any uncontrolled fermentation phenomenon by constantly maintaining an aerobic environment within the sludge bed (less odor production)
- ensure the homogenization of the final product thanks to constant turning of the sludge.

Some examples of different sludge turning systems currently available are given below:

- HELIANTIS process:

The process proposed by Heliantis is a system with a roller covering the width of the drying bed.

  - rail guidance on the walls of the greenhouse
  - movable back and forth to guarantee scarification (HELIANTIS process)

Figure 11. Heliantis process

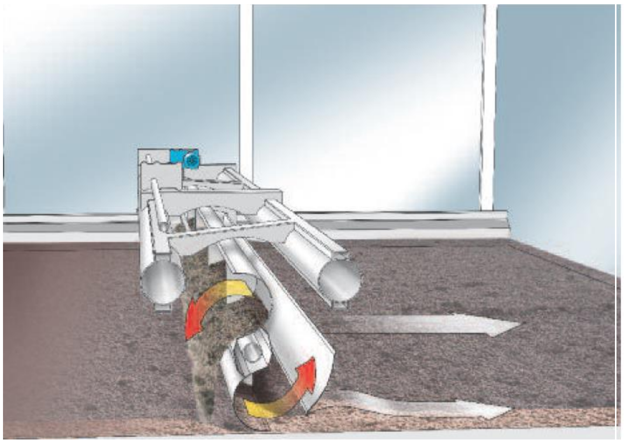
- THERMOSYSTEM process

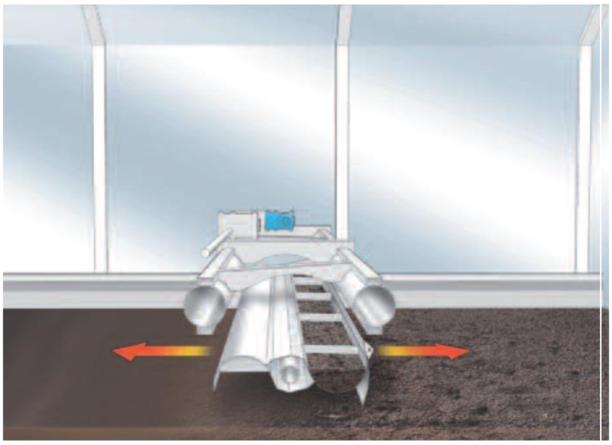
Thermosystem process is a system using a sludge manager that transports the sludge in a targeted manner, transversely or lengthwise. This makes it possible to operate the system continuously, freely defining the unloading and evacuation points.

Figure 12. Thermosystem process

- ✓ HUBER process SRT

The process proposed by Huber is a system with a reversal bridge covering the width of the drying bed.





The turning bridge is equipped with rotating excavators. The excavators turn the whole sludge bed and produce granules by sludge rotation.

Sludge is moved forward during the turning cycle by simultaneous action of the excavators to the movement of the turning bridge.

The systems are designed to receive, store and dry all sludge produced during a year. The dried sludge is discharged either into a trough, or by means of a belt conveyor directly into a container.

D.4. INCINERATOR

D.4.1. Incineration principle

Incineration is a high-temperature oxidation of volatile organic matter into a gaseous mixture (CO_2 + H_2O+AOx + COx + SOx) and water. The mineral matter can be oxidized but remains mineral (ashes).

The incineration capacity of sludge depends on its organic matter content and its dryness, characteristics that determine the Lower Heating Value.

It has the following advantages:

- ✓ Its antiseptic virtues: As bacteria or viruses are destroyed before 200°C, incineration reduces any risk of microbial contamination;
- ✓ The significant reduction in mass of matter: it is the process that leads to the lowest masses of residues;
- ✓ The possibility of energy recovery.

Sewage sludge often has a high water content and therefore usually requires drying, or the addition of additional fuels to ensure stable and efficient combustion.

The combustion of sewage sludge from wastewater treatment plants consists of several joint phases:

- ✓ the evaporation of interstitial water from the sludge,
- ✓ the oxidation of organic matter,
- ✓ the rise in temperature resulting from the oxidation of organic matter, mainly CO, CO_2 and H_2O and to a lesser extent SOx and NOx,
- ✓ the rise in temperature of mineral matter.

D.4.2. Sludge Characteristics

To define and study an incineration facility, it is necessary to characterize the sludge according to the following parameters:

- ✓ **Water content or moisture content (in %):**

  The water content is the weight amount of water contained in a mass of waste in relation to the weight amount of that wet waste.
  In order to ignite the waste, it must be dry, which means that the water contained must be evaporated.
- ✓ **Dry matter, mineral matter, organic matter:**

  Sludge is composed of water and dry matter, which is itself composed of organic and mineral matter.
  The dryness represents the percentage of dry matter contained in a mass of waste.
  Organic matter or Volatile Matter (VM) is the combustible part of sludge. It is composed of living or dead organisms or generated by living organisms. It is made up of organic molecules, i.e. containing carbon.
- ✓ **C.H.O.N.S (Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur):**

  This parameter represents the elemental composition of organic matter in Carbon, Hydrogen, Oxygen, Nitrogen and Sulphur making it possible to define the quantity of oxygen necessary for the oxidation of organic matter and the quantity and quality of the flue gas generated by this oxidation.

- **Lower Heating Value**

The Lower Heating Value represents the amount of energy released by the combustion of one kilogram of waste, assuming that all the water from the fuel or formed during combustion remains in the vapor state in the combustion products.
It therefore represents the energy that is released and can be recovered during the process.
The LHV of volatile matter is estimated to be 5500 kcal/kg.
The LHV of sludge is a function of its volatile matter content and dryness and is given by the following formula:

$$LHV_{sludge} = LHV_{volatile\ matter} \times Dryness_{sludge} \times Rate\ of\ VM_{sludge} - \left(1 - Dryness_{sludge}\right) \times \Delta h_{VAP\ water}$$

Where Δhvap water is the heat of vaporization of water (i.e. 580 kcal/kg)

The amount of heat that can be released depends on the amount of dry matter (vs. moisture) and the amount of organic matter in the sludge.
The graph below shows the evolution of the LHV as a function of these two characteristics:

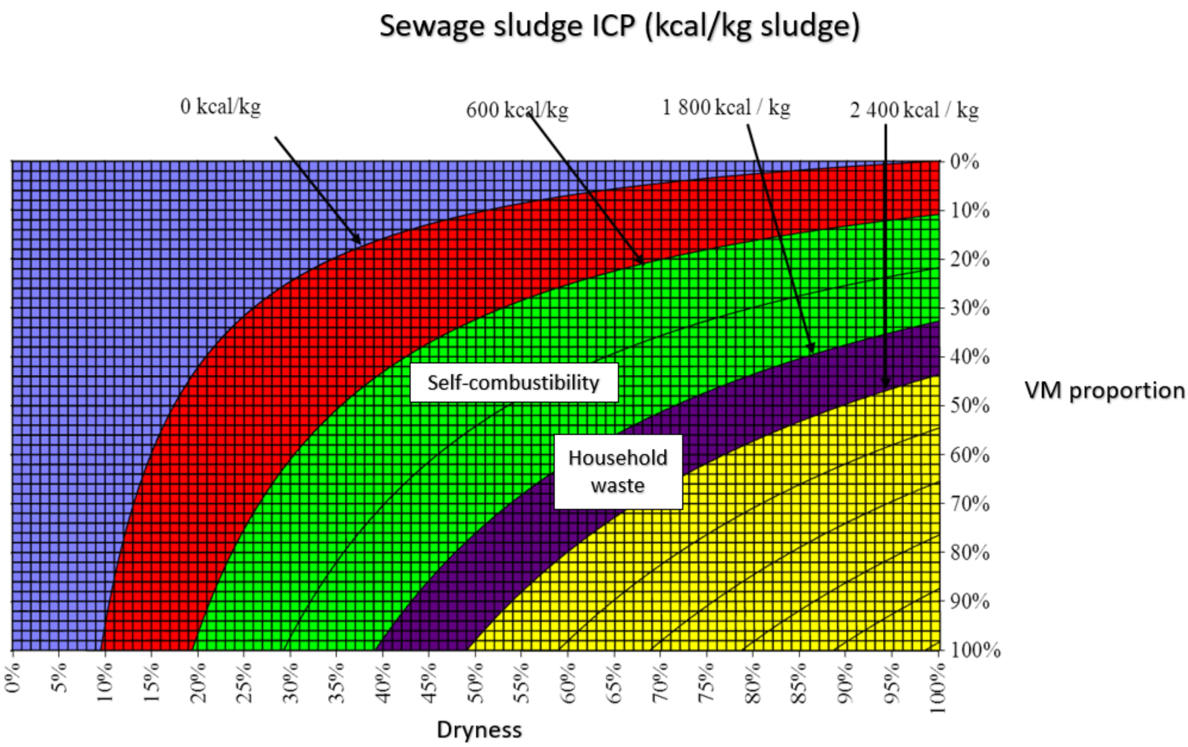


Figure 13. Evolution of the heating value of sludge

- **Heavy metal trace elements:**

These are the heavy metals, i.e. with a high molecular weight (Pb, Cr, Cu, Mn, Ni, As, Cd, Hg, Ti...).
Their knowledge is essential since their content in atmospheric emissions from incinerators is regulated (in countries practicing this type of recovery and reuse), and moreover, they condition the recovery and reuse of clinker.

From the initial heavy metal content of the sludge, it is possible to determine the concentrations of these elements in the mineral matter after sludge incineration, except for mercury, which is partly volatile.

D.4.3. Objective of sludge incineration: self-combustibility

The combustion reaction can be illustrated as follows:

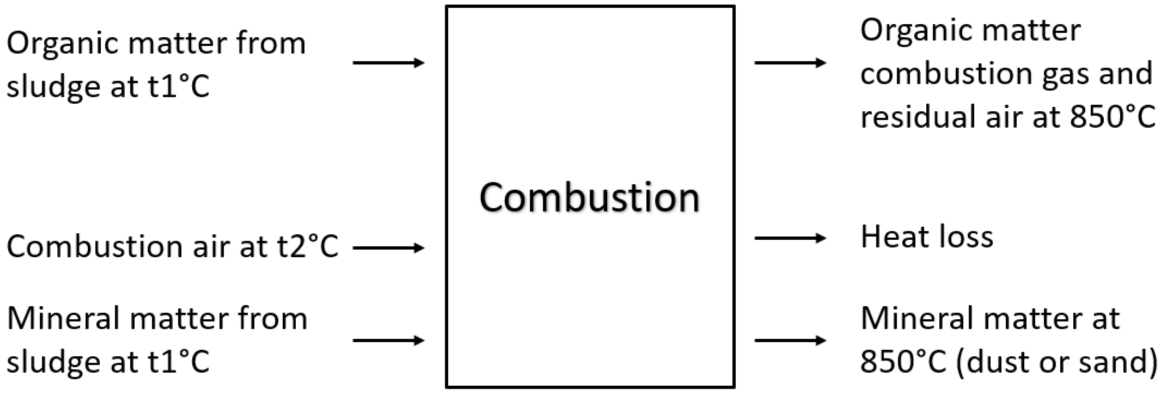


Figure 14. Diagram of the combustion reaction

The constituent elements of the sludge undergo the transformations highlighted below:

1. **The interstitial water in the sludge is transformed into water vapor:**

   This reaction requires energy corresponding to the vaporization of the water and the rise in temperature of the water from 100°C to 850°C.

2. **Mineral matter is transformed into mineral matter in the form of ashes:**

   Mineral matter undergoes a thermal increase in its initial temperature to 850°C, which also requires energy.

3. **The atoms constituting the organic matter are transformed in the presence of air according to:**

   $C \rightarrow CO_2$
   $H \rightarrow H_2O$ (vapor)
   $O \rightarrow O_2$
   $N \rightarrow$ mostly to N_2
   $S \rightarrow SO_2$
   $P \rightarrow P_2O_5$
   $Cl \rightarrow HCl$

   The atomic compounds that make up the organic matter react with the excess combustion air to form gases, the temperature of which has risen to 850°C.

   From the knowledge of the elementary composition of the organic matter, is determined:

   - The amount of air required for the oxidation of organic matter.

     The total air flow rate is calculated according to the contributions necessary for the oxidation reaction and the quantity of excess oxygen that it is necessary to preserve at the end of combustion.

- The gas flow generated by the thermal oxidation of sludge.

Energy is also required by this reaction corresponding to the increase in gas temperature from the initial temperature of the organic matter to 850°C.
On the other hand, energy is released during the clean combustion of the sludge.

4. **Combustion air forms the excess air:**

- ✓ Excess air that is not used for combustion is heated to 850°C, which requires energy.

The heat balance results in:

- energy released from the combustion of organic matter in sludge,
- energy required to raise the temperature of mineral matter, flue gases, water vapor, excess air, vaporization of sludge interstitial water, plus heat losses.

Self-heating of the furnace is achieved when the heat released by the combustion of the organic matter is sufficient to maintain the temperature in the post-combustion chamber at the desired level 850°C - 900°C, i.e. if the energy released by combustion compensates for the energy requirements.

The LHV of the sludge is a function of its dryness and organic content.

Sludge from low load biological systems generally have an organic matter content of 70% and traditional dewatering processes can achieve a dryness of 20%. In this configuration, self-heating is not achieved.
Energy has to be added to the system or the energy requirements reduced by:

- preheating of the combustion air,
- increasing the LHV of the sludge by improving its dryness by partial pre-drying of the sludge or by better dewatering,
- addition of a supplementary fuel.

D.4.4. Residues from incineration

Combustion of waste produces:

- ✓ a gaseous effluent with a more or less acidic character, due to the presence of acid gases (HCl, HF) and gaseous acid anhydrides (SO_2, CO_2),
- ✓ solids composed of inert compounds contained in basic waste, clinker and ash.

Clinker is the slag removed from combustion furnaces in powdered form.

The flue gases carry fine particles with them. Since regulations impose limits on emissions into the atmosphere, a flue gas treatment is always associated with an incineration unit, and consists of neutralizing acid gases with a base and promoting the condensation of heavy metals.

There are two ways of doing this:

- ✓ after filtration, the gases are neutralized in the wet phase,

- ✓ the neutralization of acid gases is carried out in the dry phase, before filtration. Additional filtration upstream of the neutralization may be necessary depending on the dust content of the flue gas leaving the furnace.

Residues collected under the filter are referred to as fly ash prior to any injection of solid or liquid neutralizer into the flue gas.

FGTR (Flue Gas Treatment Residues (Fly Ash)) are the solid residues recovered during the neutralization of acid gases from the flue gases.

Depending on the treatment process, FGTR contains either only neutralization products or a mixture of fly ash and neutralization products.

D.4.5. Main furnace technologies

The incineration techniques that can be used for sewage sludge incineration are: rotary kiln incinerators and fluidized bed incinerators. The latter technique is the most widespread.

D.4.5.1. Rotary Kilns

The rotary kiln consists of a cylinder slightly inclined with respect to the horizontal in order to facilitate the contact between the combustion air and the waste.

The waste is introduced through a hopper and injected into the furnace by a pusher.

The combustion air is injected at the head of the rotating cylinder.

An afterburner chamber ensures complete combustion of the gases.

The clinker is extracted gravitationally under the effect of the slope.

The peripheral speed of the cylinder varies between 0.5 and 3 cm/s.

This type of furnace can be used to incinerate waste with an LHV greater than 750 kcal/kg.

The retention time is essential to ensure complete combustion of the waste and is fixed:

- ✓ For solid waste by the speed of rotation of the furnace and by its inclination;
- ✓ For volatile fuels and liquids by gas velocity.

In the combustion chamber, the equipment undergoes significant thermal shocks, the walls being alternately in contact with layers of waste at 100°C and with the combustion gases at around 800 to 1,000°C, leading to their rapid degradation.

The specific incineration of grease and paste-like sludge is not compatible with this incineration technique. The abundance of paste-like waste makes it impossible to aerate through the layer of burning waste and the risk of clogging the grids and damaging the ventilators is great. Rotary kilns are only suitable for the incineration of solids, possibly with a small proportion of sludge added.

The by-products are mainly slag.

D.4.5.2. Fluidized-bed furnaces

Initially reserved for specific applications in the oil or paper industries for reprocessing effluents, this technology is undergoing further development.

This process has the advantage of being a static furnace with no moving parts, allowing total deodorization of the flue gas.

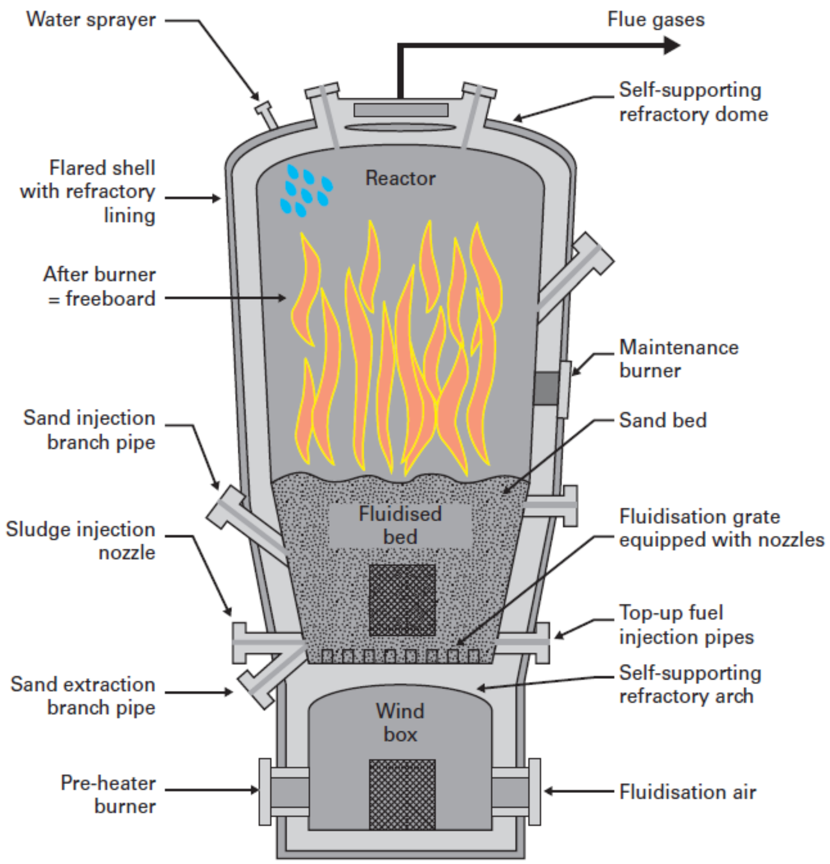


Figure 15. Fluidized bed incinerator diagram (source Thermylis - Degremont process)

Sludge is generally incinerated in fluidized bed furnaces, a closed vertical chamber containing a bed of hot sand (750-850°C) kept in suspension by an ascending air current (1-2 m/s) injected through a distribution grid. The sludge is injected into the bed (screw or feed pump) or introduced at the head. The fly ash production is discharged with the gases and incinerated in post combustion. The self-combustibility of the sludge, even digested sludge, can be reached at 36 to 38% DM. It may require an additional fuel and requires the optimization of all energy recovery sources.

A fluidized bed furnace consists of a refractory-lined steel reactor with 4 parts (from bottom to top):

- ✓ An intake area for fluidization and combustion air, the wind box;
- ✓ An air distribution system by means of nozzles inserted either in a metal plate lined with refractories in the case of a cold wind box, or in a self-supporting arch made of firebricks in the case of a hot wind box;
- ✓ The fluidizing air is admitted into the wind box, either at room temperature (cold wind box) or preheated between 400 and 650°C (hot wind box);
- ✓ A bed of sand, the height of which is of the order of 1 m, in which sludge and auxiliary fuel injectors are regularly placed;
- ✓ A post-combustion chamber in the upper part which, thanks to a retention time of several seconds, ensures the complete combustion of the gases resulting from the ignition of the volatile matter, and separates the dust from the sand particles.

Combustion occurs in the sand bed, which by attrition breaks up the sludge lumps, and below in the middle part of the reactor.

In the upper part of the furnace, water injectors are provided to reduce the temperature. If necessary, the use of the hot wind box is reserved for furnaces with a self-supporting arch not exceeding 8 meters. The cold wind box allows the construction of large diameter furnaces (15 m and more), the metal plate being supported by beams fixed in the cold wind box and therefore protected from thermal stress.

Incineration in fluidized bed furnaces generates a higher rate of fine particle flight than incineration in rotary furnaces. This implies a dust removal from the flue gas prior to flue gas treatment.

As a general rule, ashes contain less than 1% unburnt material.

D.4.6. Technical comparison of specific incineration

SPECIFIC INCINERATION TECHNOLOGY COMPARISON		
	ADVANTAGES	**DISADVANTAGES**
Rotary kilns	(+) One of the main advantages of the rotary kiln is the quality of the stirring provided by the rotation of the kiln, which causes the waste to be turned over periodically. (+) The introduction of air through the waste bed ensures the quality of combustion. (+) The retention time is reduced, as the clinker is evacuated at a temperature between 300 and 500°C, making it easier to handle.	(-) The volumes treated are limited by the method of waste introduction by pusher. (-) The evacuation of the clinker at a temperature of between 300 and 500°C makes it difficult to handle.
Fluidized bed furnaces	(+) The presence of a sand bed, whose properties are similar to those of a fluid, ensures good thermal transmission efficiency and good matter exchange. It generates a more thorough combustion and a better thermal efficiency of the installation. (+) Thanks to the high thermal inertia inherent to the fluidized sand bed (temperature loss of 5°C/h), it is possible to incinerate waste at very variable and low LHVs, without any significant change in operating parameters. (+) Its design and maintenance ease, with no mechanical parts in the hot zones. (+) The bed temperature is relatively homogeneous. (+) Its compactness.	(-) Ash removal. (-) This technology does not allow the incineration of all type of waste. In particular, certain compounds can cause the formation of agglomerates. (-) Does not tolerate too much iron. (-) This type of incinerator must mainly operate continuously. Indeed, refractories do not tolerate thermal shocks well. However, the thermal inertia of the sand bed and the low temperature losses allow short shutdowns.

E. ULTIMATE ORGANIC RECOVERY AND REUSE

In the absence of Lebanese standards, we chose to present the French standards related to the agricultural recovery and reuse by spreading or composting.

E.1. PREAMBLE (FRENCH CONTEXT)

The development of anaerobic digestion projects, and in particular co-digestion, has revived the debate and controversy over the return of sewage sludge to the ground.

Until now, the spreading of sludge was mainly carried out in the following forms:

- ✓ Liquid sludge, for small units;
- ✓ Dewatered sludge (limed or not);
- ✓ Dried sludge;
- ✓ In the form of compost.

Only the implementation of composting in compliance with NFU 44 095 standard allowed up until now to do away with a spreading plan.

However, sludge now tends to find itself in "competition" with deposits of source-separated bio-waste, which must be subject to "matter" recovery and reuse, i.e. returned to the ground (after composting and/or anaerobic digestion).

The very object of the controversy comes from the fact that sludge can contain various trace elements, and in particular:

- ✓ Heavy metals (Cadmium, Chromium, Copper, Mercury, Arsenic...)
- ✓ Organic micropollutants (PAHs, PCBs, pesticides)
- ✓ Drug residues (Antibiotics, hormone treatments, ...)
- ✓ Pathogenic organisms.

The various current regulations, whether for sludge or compost spreading, do not set limit values for most of the micropollutants qualified as emerging (including medicinal residues), especially since the AMPERES (analysis of priority and emerging micropollutants in discharges and surface waters) studies clearly showed that some of these micropollutants removed from the liquid fraction ended up adsorbed in the sludge. It is likely that, in the medium term, regulatory changes will take into account limit values for these emerging micropollutants.

Important things to retain in the case of Lebanon:

This comprehensive approach is based on a detailed legislative and regulatory framework that has been gradually put in place for decades with the support of professional agricultural organizations. The conditions and the legislative environment do not yet exist in Lebanon, but we can retain the general principles of organization which are of common sense, in order to build the necessary communication to develop acceptability by the Lebanese agricultural world.

In this perspective, we can retain the following elements:

- Liquid sludge behaves more like a fertilizer than an organic soil enhancer.
  Generally speaking, urban sewage sludge for small communities generally contains few micropollutants and this is not the limiting factor for spreading. Spreading is done with a slurry spreader.
  These products contain nitrogen, phosphorus and potassium and a few trace elements, which are the mineral elements necessary for plant growth.
  On cereal crops, they are spread before tillage (ploughing) and sowing.
  If we add the nitrogen requirement of the crop in year T1, (nitrogen rapidly available for the crop and consumed within the year), we add twice too much phosphorus which is well stored by most soils. Potassium remains in deficit.
  Under these conditions, in year T1, one must supplement with mineral fertilizers in potash. In the year T2 all the nitrogen must be added as fertilizer, no phosphorus in reserve in the soil, and all the potash.
  These very general considerations are modulated according to sludge analysis, analysis of soils and fertilized crops in years T1 and T2.
  These inputs are very easily washed out and therefore they should not be applied on very filtering or humid soils, so as not to facilitate the transit to the underground water, out of reach of the crop roots.

- Dewatered sludge behaves halfway between a fertilizer and a soil enhancer. The elemental composition, nutritive for the plants.
  The elements are less available for the plants and the fertilizer supply is spread over three successive crops instead of two. The risk of washout is lower. A minority part is incorporated into the organic fraction of the soil and can contribute to improve the structure and aeration of the soil in association with the clay fraction of the soil. These products can be spread with a manure spreader.
  Limed dewatered sludge is inhibited in fermentation by the lime which gives it a retarding effect, since the lime must dissolve in the soil before the nutrients can be made available to the plants in a form they can assimilate.
  In heavy and clayey soils, calcium can have a beneficial effect as well as in acidic soils where it helps to balance the PH. However, in some soils that already contain a lot of available calcium, naturally or not, it may be counter-indicated.

- Dried sludge behaves like an enhancer and is incorporated into the soil's organic matter supply much like a manure or compost. The fertilizing effect is negligible when spread. These products release nutrients very gradually and over the long term. On the other hand, they contribute to the improvement of the health and structure of the soil.

- Composts or sludge co-composts behave like dried sludge. They are of interest only if there is a stock of carbonaceous materials, green waste, branches or other, to be recovered, available in large quantities and free of charge. Their production requires an investment in infrastructure and equipment and therefore have a production cost that must be absorbed by selling.

E.2. AGRICULTURAL SPREADING

E.2.1. French regulations

E.2.1.1. French Water Law - ISTA

The spreading of sludge from urban WWTPs is subject to the ISTA (Installation, Structures, Works, Activities) heading n°2130. For the record, the heading mentioned is recalled below:

N°	DESIGNATION	CONSEQUENCE
2.1.3.0	**Wastewater treatment sludge spreading, the quantity of sludge spread during the year, produced in the treatment unit in question, with the following characteristics:**	
	a) Quantity of dry matter greater than 800 t/year or total nitrogen greater than 40 t/year	Authorization
	b) Quantity of dry matter between 3 and 800 t/year or total nitrogen between 0.15 t/year and 40 t/year	Declaration

For the application of these thresholds, the maximum volumes and quantities of sludge intended for spreading in the treatment units concerned must be taken into account.

Sewerage works subject to declaration or authorization in the context of sludge spreading are also subject to specific articles R.211-46 and R.211-47 of the French Environment Code.

These articles induce additional provisions to be carried out during the environmental impact or incidence study and specific provisions when the spreading of sludge from a treatment unit subject to authorization is carried out in several departments.

NOTE:

A proposed decree modifying the nomenclature of installations, structures, works and activities (ISTA) referred to in Article L.214-1 of the French Environmental Code and certain provisions of the French Environmental Code and the French General Code of Territorial Collectivities, was the subject of a public consultation (from 3 to 26/05/2019).

Article 5 of this proposed decree stipulates that the table annexed to Article R.214-1 of the French Environment Code would thus be amended:

3° Section 2.1.3.0. is replaced by a section 2.1.3.0. which reads as follows:

N°	DESIGNATION	CONSEQUENCE
2.1.3.0	**Spreading, and storage for the purpose of spreading, of sludge produced in one or more wastewater treatment plants falling under heading 2.1.1.0 of this nomenclature, the quantity of sludge spread in the year having the following characteristics:**	
	a) Quantity of dry matter spread greater than 800 t/year or total nitrogen greater than 40 t/year.	Authorization
	b) Quantity spread of dry matter between 3 and 800 t/year or total nitrogen between 0.15 t/year and 40 t/year.	Declaration

For the application of these thresholds, the maximum volumes and quantities of sludge intended for spreading in the treatment units concerned must be taken into account.

4° Section 2.1.4.0. is replaced by a section 2.1.4.0. which reads as follows:

N°	DESIGNATION	CONSEQUENCE
2.1.4.0	**Spreading, and storage for the purpose of spreading, effluents or sludges, excluding livestock effluents and excluding sludges or effluents from activities, installations, structures and works regulated under the other headings of the present nomenclature or subject to authorization or registration under the nomenclature of classified installations annexed to Article R.511-9**	
	The quantity of effluent or sludge spread representing an annual volume greater than 50,000 m^3/year or a flow greater than 1 t/year of total nitrogen or 500 kg/year of BOD5	Declaration

E.2.1.2. French environmental Code - sludge spreading sub-section

The main regulatory texts, other than the nomenclature of the water law, governing the spreading of sludge are as follows:

- ✓ Decree n°97-1133 of 8 December 1997 relating to the spreading of sludge from wastewater treatment. This decree was repealed by decree n°2007-397 of 22 March 2007 and transcribed in the French Environment Code (art. R.211-25 to R.211-47);
- ✓ The Order of 8 January 1998 setting the technical prescriptions applicable to the spreading of sludge on agricultural land, taken in application of decree n°97-1133 and modified by the Order of 3 June 1998;
- ✓ The Circular of 16 March 1999 relating to the regulations on the spreading of sludge from urban wastewater treatment plants, a document explaining the provisions of the previous decree and order;
- ✓ The Order of February 2, 1998 relating to water extraction and consumption as well as emissions of all kinds from listed installations for environmental protection subject to authorization, modified by the Order of May 11, 2015.

These texts apply to matter composed in whole or in part of sewage sludge and which does not have an approval, a provisional authorization for sale or which does not comply with a mandatory standard.

GENERAL PROVISIONS

This regulation implements 4 principles:

- ✓ The **harmlessness** to human and animal health, crops, soil and aquatic environments;
- ✓ The **agronomic value** of sludge;
- ✓ The **rigor** by the carrying out of a preliminary study, a provisional programme, the keeping of a register and the performance of an annual follow-up;
- ✓ The **transparency** since all the data must be transmitted to the Prefecture and the user.

The main provisions for the spreading of sludge, laid down by the French Environmental Code, are as follows:

*« **Sewage** from sewage collection facilities can only be **assimilated to sludge when it has undergone treatment to remove grit and grease**. Otherwise, their spreading is prohibited. **The spreading of grit and grease is forbidden**, whatever the source.*

***Septage** from non-collective wastewater treatment systems is **assimilated to sludge** from wastewater treatment plants.*

*The **mixing of sludge** from separate treatment plants is **prohibited**. However, the Prefect may authorize [...] the mixing of sludge and other waste, provided that the purpose of the operation tends to **improve the agronomic characteristics** of the sludge to be spread.*

*The **operators** of wastewater collection, pre-treatment and treatment units [...] are **sludge producers**. As such, they are responsible for applying the provisions of the French Environment Code and the Order of 8 January 1998. In the case of sewage, this responsibility is assumed by the sewage company. If the mixing of sludge of various origins, or sludge and other waste, is authorized, the prefect designates the person(s) responsible for applying these provisions. »*

NOTE:

A proposed decree modifying the **nomenclature of installations, structures, works and activities (ISTA)** referred to in Article L.214-1 of the French Environmental Code and certain provisions of the French Environmental Code and the French General Code of Territorial Communities, was the subject of a public consultation (from 3 to 26/05/2019). Article 2 of this draft decree stipulates that Article R.211-29 of the French Environment Code would thus be amended:

- ✓ **Initial version (currently in force):**

  « *Sewage from sewage collection works can only be assimilated to sludge when it has undergone treatment to remove grit and grease. Otherwise, their spreading is prohibited. The spreading of grit and grease is forbidden, whatever the source.*

  The mixing of sludge from separate treatment facilities is prohibited. However, the Prefect may authorize the grouping of sludge in common storage or treatment units, when the composition of this waste meets the conditions set out in articles R.211-38 to R.211-45. He may also, under the same conditions, authorize the mixing of sludge and other waste, when the purpose of the operation tends to improve the agronomic characteristics of the sludge to be spread.

  Septage from non-collective wastewater treatment systems is assimilated to sludge from wastewater treatment plants for the application of this sub-section. »

- ✓ **Proposed revisions:**

  « The mixing of sludge in common storage or treatment units, for the purpose of spreading, is authorized, when its composition meets the conditions set out in articles R.211-38 to R.211-45 and complies with the technical prescriptions applicable to the spreading of sludge on agricultural soils taken in application of article R.211-43 of the French Environment Code.

  The mixing of sludge with other waste is prohibited. However, without prejudice to the application of the provisions of Title IV of Book V of this French Code, the prefect may authorize the mixing of sludge with other non-hazardous waste, provided that the waste making up the mixture complies individually with the technical requirements applicable to it for spreading on agricultural land and provided that the purpose of the operation tends to improve the agronomic characteristics of the sludge to be spread.

  Sewage from sewage collection works can only be assimilated to sludge when it has undergone treatment to remove grit and grease. Otherwise, their spreading is prohibited. The spreading of grit and grease is forbidden, whatever the source.

  Septage from non-collective waste water treatment systems is assimilated to sludge from treatment plants for the application of the present sub-section. »

  *« Sludge can only be spread if it is of **interest for the soil** or for the nutrition of crops and plantations.*

*The sludge must have been treated [...] in such a way as to significantly **reduce its fermentability and the health risks** associated with its use.*

***Storage capacity** must be provided to take account of the different **periods when agricultural spreading is either prohibited or not possible**. All measures must be taken to ensure that storage does not cause inconvenience or nuisance to the neighborhood, nor pollution of water or soil by run-off or infiltration.*

***An alternative solution for the disposal or recovery and reuse of sludge must be provided** to offset any temporary impediment to complying with the above provisions.*

***Spreading is prohibited** during periods when the **ground is covered by frost** or heavy snow (except for solid sludge), during **periods of heavy rainfall**, outside regularly worked land and normally exploited meadows, on **steeply sloping land**, under conditions which would cause runoff from the spreading field or **with the help of air dispersion devices** which produce fine fogs.*

***Minimum distances** must also be respected [...] so as to preserve the quality of ground and surface water and [...] so as to protect public health and limit odor nuisances. »*

NOTE:

A proposed Order modifying the Order of 8 January 1998 setting the technical prescriptions applicable to the spreading of sludge on agricultural land, issued in application of Decree n°97-1133 of 8 December 1997 relating to the spreading of sludge from wastewater treatment, was the subject of a public consultation (from 3 to 26/05/2019). Article 5 of this proposed Order stipulates that Article 5 of the Order of 8/01/1998 would thus be modified:

« *Sludge storage facilities are designed and installed in such a way as to protect local residents from neighborhood nuisances (olfactory, noise and visual) and health risks, particularly during the sludge intake and discharge phases. They are designed to retain the leachate generated during the storage period. The discharge of leachate into the natural environment is prohibited.*

The sludge storage structures are designed to cope with periods when spreading is impossible or prohibited in accordance with the spreading schedules defined in the nitrate action programmes. In this respect, the operator of the sludge storage facility must justify a minimum storage capacity of six months of sludge production for spreading. The quantity of sludge taken into account in the design of the facility is that mentioned in the preliminary study provided for in Article R.211-33 of the French Environment Code.

The Prefect may depart from this requirement when:

1° The water or sludge treatment facilities also ensure the storage of sludge;

2° The temporary storage of sludge on spreading plots is possible;

3° Alternative solutions to the agricultural recovery and reuse provided for in articles R.211-25 to R.211-47 of the French Environment Code, for which the operator can prove that they are sustainable, make it possible to manage these substances for periods during which spreading is impossible or prohibited. It is the Client's responsibility to ensure the traceability of sludge batches to their final destination and to ensure compliance with the regulatory requirements relating to the management of these substances, whether the sludge is treated on the site of the waste water treatment plant or outside.

The temporary deposit of sludge, on the spreading plots and without any development work, is only authorized when the following five conditions are simultaneously met:

(a) The sludge is solid and stabilized; otherwise, the maximum duration of the deposit is less than 48 hours;

(b) All precautions have been taken to avoid rapid percolation to surface or ground water or any run-off;

(c) The deposit shall comply with the minimum isolation distances for spreading as defined in Article 13 and a distance of at least 3 meters from roads and ditches;

(d) The deposit shall be permitted only between the beginning and the end of the relevant spreading season. The volume of the deposit shall be adapted to the fertilization of the receiving crop unit;

(e) In vulnerable zones, the duration of the deposit is limited to 30 days.

The storage facilities are also designed to allow the sludge to be divided into one or more clearly identified batches and analyzed according to the methods provided for in Article 14 of this Order, each analysis being attached to a batch.

Only sludge from one or more wastewater treatment plants shall be admitted into the storage facility.

In case of grouping or mixing of sludge coming from different treatment plants on the same storage facility, the operator of the storage facility shall request from each sludge producer, before admitting the sludge and in order to check its admissibility, prior information containing:

- *name and contact details of the producer and the production site of the sludge received,*
- *description of the sludge treatment process,*
- *a characterization of the sludge with regard to the substances whose limit values appear in Tables 1a and 1b of Annex I to this Order, carried out before each transfer for mixing and at least according to the regulatory analysis frequencies defined in Annex IV.*

The sludge to be mixed is stored on the site, or near the emitting plant while awaiting the analysis results. In application of the principle of non-dilution, any batch of sludge that does not comply with at least one of the limit values set out in tables 1a and 1b of Appendix I of this Order is refused by the operator.

The information relating to the sludge is kept for ten years by the operator and made available to the water police department. At any time, the operator of the sludge storage facility that has carried out the mixing must be able to identify on each batch, the origin and characteristics of the sludge composing it. »

The distances and deadlines to be respected are summarized in the Order of 8 January 1998:

Nature of the activities to be protected	Minimum isolation distance	Scope of application
Wells, boreholes, springs, aqueducts carrying water intended for human consumption in free flow, underground or semi-buried installations used for the storage of water, whether it is used for drinking water supply or for watering vegetable crops.	35 m	All types of sludge, slope of the land less than 7%.
	100 m	All types of mud, slope of the land greater than 7%.
Rivers and bodies of water	5 m from the shoreline	Sludge stabilized and buried in the soil immediately after spreading, slope of the land less than 7%.
	35 m from the shoreline	General case
	100 m from the shoreline	Solid, stabilized sludge and slope of the ground greater than 7%.
	200 m from the shoreline	Unstabilized or non-solid sludge and slope of the ground greater than 7%.
Buildings inhabited or habitually occupied by third parties, leisure areas or establishments open to the public	100 m	General case
	Not applicable	Sanitized sludge, stabilized sludge and buried in the ground immediately after spreading
Shellfish growing areas	500 m	All sludges except sanitized sludges and except derogation linked to topography.

Nature of the activities to be protected	Minimum delay	Scope of application
Grassland or fodder crops	Six weeks before grazing animals or harvesting fodder crops	General case
	Three weeks before grazing animals or harvesting fodder crops	Sanitized sludge
Land used for market gardening and fruit growing, with the exception of fruit tree crops	No spreading during the growing season.	All types of sludge
Land intended or assigned to market gardening or fruit growing, in direct contact with the soil, or likely to be eaten raw.	Eighteen months before the harvest, and during the harvest itself	General case
	Ten months before the harvest, and during the harvest itself.	Sanitized sludge

SPREADING PLAN

In addition, according to the French Environmental Code, sludge spreading plans are mandatory. Once drawn up between the plant owner and the farmer, they are subject to prefectural authorization, and their durability is conditioned by sludge traceability and agronomic monitoring. In response to a citizen's request, the prefect must make the results of the spreading public.

The content of the spreading plan (also known as a preliminary study) is specified in the Order of 8 January 1998. It includes in particular:

- ✓ The presentation of the origin, the quantities produced and used and the characteristics of the sludge;

- Identification of the constraints linked to the natural environment or human activities within the study area, including the presence of sensitive uses (housing, catchments, special productions, etc.) and the constraints of plot accessibility;
- Soil characteristics, cropping systems and description of the crops envisaged within the study area;
- A soil analysis carried out at a reference point, identified by its Lambert coordinates, representative of each homogeneous area;
- A description of the technical methods for carrying out the spreading (equipment, location and volume of the temporary storage depots and storage structures, spreading periods, etc.);
- General recommendations for the use of sludge;
- The cartographic representation of the study perimeter and the areas suitable for spreading;
- The cartographic representation of the plots excluded from spreading on the study perimeter and the reasons for exclusion (water sources, slopes, neighborhood...);
- A proof of the agreement of the sludge users to make their plots available and a list of these plots according to their cadastral references.

In addition, the spreading on agricultural land of sludge from treatment plants likely to receive a pollutant flow of more than 120 kgBOD5/d is subject to the sludge producer's approval:

- Of a provisional spreading programme, drawn up jointly or in agreement with the users, defining the plots concerned by the annual campaign, the crops grown and their needs, the recommendations for the use of sludge, in particular the quantities to be spread, the spreading schedule and the receiving plots;
- At the end of each annual campaign, of an agronomic assessment of the campaign, including in particular the manure balance, and the analyses carried out on the soil and sludge.

These documents are sent by the sludge producer to the Prefect.

SLUDGE QUALITY

Finally, the Order of 8 January 1998 defines the limit values that must be respected concerning sludge or soil in order to allow sludge to be spread. Indeed, sludge cannot be spread:

- If the contents of **metallic trace elements** in soils exceed one of the limit values shown in the following table:

Table 1 - Limit values for trace element concentration in soils

Trace elements in soils	Limit value for soil concentration (mg/kg DM)
Cadmium	2
Chrome	150
Copper	100
Mercury	1
Nickel	50
Lead	100
Zinc	300

- As long as one of the **contents of trace elements or compounds** in the sludge exceeds the limit values given in the following tables:

Table 2 - Limit content of trace elements in sludge			
Trace elements	Limit value in sludge (mg/kg DM)	Maximum cumulative flow brought by the sludge in 10 years (g/m^2)	
		General case	Pasture or soil pH<6
Cadmium	10	0,015	0.015
Chrome	1 000	1,5	1.2
Copper	1 000	1,5	1.2
Mercury	10	0,015	0.012
Nickel	200	0,3	0.3
Lead	800	1,5	0.9
Zinc	3 000	4,5	3
Cr + Cu + Ni+ Zn	4 000	6	4
Selenium	-	-	4 (pasture only)

Table 3 - Limit contents of organic trace compounds in sludge				
Organic compounds	Limit value in sludge (mg/kg DM)		Maximum cumulative flow brought by the sludge in 10 years (mg/m2)	
	General case	Spreading on pastures	General case	Spreading on pastures
Total of the 7 main PCBs (*)	0,8	0,8	1,2	1,2
Fluoranthene	5	4	7,5	6
Benzo(b)fluoranthene	2,5	2,5	4	4
Benzo(a)pyrene	2	1,5	3	2

(*) PCB 28, 52, 101, 118, 138, 153, 180

Finally, sludge must not be spread on soils with a pH before spreading of less than 6, except when the following three conditions are simultaneously met:

- ✓ The pH is above 5;
- ✓ The sludge has been treated with lime;
- ✓ The maximum cumulative flow of trace elements brought to the soil by the sludge is lower than the values in Table 2.

E.2.1.3. French Environment Code - sub-section vulnerable zone to nitrate pollution

The regulations governing the protection of waters against nitrate pollution from agricultural sources are as follows:

- ✓ Decree n°93-1038 of 27 August 1993 on the protection of waters against pollution by nitrates of agricultural origin. This decree was repealed by decree n°2007-397 of 22 March 2007 and transcribed in the **French Environment Code (art. R.211-75 to R.211-79)**;
- ✓ The **Order of 22 November 1993** relating to the French code of good agricultural practices, taken in application of decree n°93-1038;
- ✓ Decree n°2001-34 of 30 May 2001 relating to the action programme to be implemented for the protection of waters against pollution by nitrates of agricultural origin. This decree was repealed by decree n°2007-397 of 22 March 2007 and transcribed in the French Environment Code. Following several amending decrees (decree 2011-1257; 2013-786 and 2018-1246) the reference text now corresponds to the **French Environment Code (art. R.211-80 to R.211-82)**;
- ✓ **The Order of 23 October 2013 relating to regional action programmes for the protection of waters against pollution by nitrates of agricultural origin**, taken in application of articles R.211-80 to R.211-82 of the French Environment Code;

The code of good agricultural practice is a collection of provisions **whose application is voluntary**.

Articles R.211-75 to R.211-79 of the French Environment Code give the definition of vulnerable zones that contribute to water pollution through the direct or indirect discharge of nitrates.

They also define the establishment of a Code of Good Agricultural Practices in order to serve as a reference for farmers to protect waters against nitrate pollution, in particular through livestock farming and soil fertilization activities.

The content of the French Code of Good Agricultural Practices is set by the order of 22 November 1993, which also specifies that **the provisions of this code may be supplemented or modified as necessary by a prefectural order**. This code of good agricultural practices constitutes a **set of recommendations for farmers located in non-vulnerable zones and a minimum basis for action programmes in vulnerable zones**.

It defines three types of fertilizers: standardized sludge is included in one of the first two classes, according to its C/N ratio, possibly corrected according to the form of carbon:

- ✓ **Type I:** Fertilizer containing organic nitrogen and high C/N (higher than 8);
- ✓ **Type II:** fertilizer containing organic nitrogen and low C/N (less than or equal to 8);
- ✓ **Type III**: mineral and synthetic urea fertilizers.

Depending on the type of fertilizer, it sets a certain number of recommendations.

With regard to periods during which fertilizer application is inappropriate

	Type I	Type II	Type III
Uncultivated soils	All year round	All year round	All year round
Autumn field crops		from 1st November to 15th January	from 1st September to 15th January
Spring field crops	from 1 July to 31 August	from 1st July to 15th January	from 1 July (*) to 15 February
Grassland more than six months old not grazed		from 15 November to 15 January	from 1 October to 31 January
Special crops	To be specified locally	To be specified locally	To be specified locally

(*) From 15 July to 15 February for irrigated crops, to be specified locally according to heading 10 "irrigation management".

With regard to spreading conditions on soggy, flooded, frozen or snow-covered soils

	Frozen ground on the surface alternating between freezing and thawing in 24 hours.	Soil caught in the frost	Flooded or soggy floor*	Snow-covered ground
Type I	Possible	Possible if necessary (**)	Not recommended	Possible if necessary (**)
Type II	Possible	Not recommended	Not recommended	Not recommended
Type III	Possible	Possible if necessary (**)	Not recommended	Not recommended

(*) Except for crops in aquatic environments (rice paddies, watercress beds)

(**) The choice is specified according to the climate, the frequency and duration of the climatic conditions in question, as well as the nature of the soil and its slope.

With regard to spreading conditions near surface water:

Spread fertilizers at minimum distances from surface water and take into account the weather conditions at the time of spreading, the conditions of spreading (landfill), the nature of the plant cover of the soil. For type I or II fertilizers (excluding livestock effluents), this distance is 2 meters.

Spreading methods:

Balance the foreseeable needs of the crop.

Split the inputs if necessary and revise the doses downwards if the production objective cannot be achieved due to the state of the crop (climatic hazards, diseases, etc.).

Ensure uniformity of spreading of the determined dose.

In order to best control the leakage of nutrients into the water, it is necessary to determine the precise fertilizer requirements and to ensure the regularity of the spreading in order to avoid situations of over-fertilization.

Other recommendations for good land management and irrigation practices are also specified.

ACTION PLANS

These action plans mentioned in Articles R211-80 to R211-82 of the French Environmental Code take into account the local situation and specify the measures necessary for good fertilization control and adapted management of agricultural land in order to limit to an acceptable level the leakage of nitrogen compounds into surface and ground water.

The action plan shall define the requirements **that must be complied with** within the time limits set within the vulnerable zone or part of the vulnerable zone concerned.

E.2.1.4. Sludge from listed installations for the protection of the environment

The regulatory text governing the spreading of sludge from listed installations for the protection of the environment subject to authorization is as follows:

- ✓ **The Order of 2 February 1998** relating to water extraction and consumption as well as emissions of all kinds from listed installations for environmental protection subject to authorization, section 4 spreading.

The Order provides for the regulation of spreading periods as well as the quantities spread in such a way as to ensure the supply of useful elements to the soil and crops without exceeding their needs and to prevent the accumulation in the soil of substances likely in the long term to degrade its structure or to present an eco-toxic risk.

It specifies that any spreading is subject to a preliminary study included in the impact study, showing the harmlessness and the agronomic interest of the effluents or waste, the suitability of the soil to receive them, the spreading perimeter and the methods of its implementation (spreading plan).

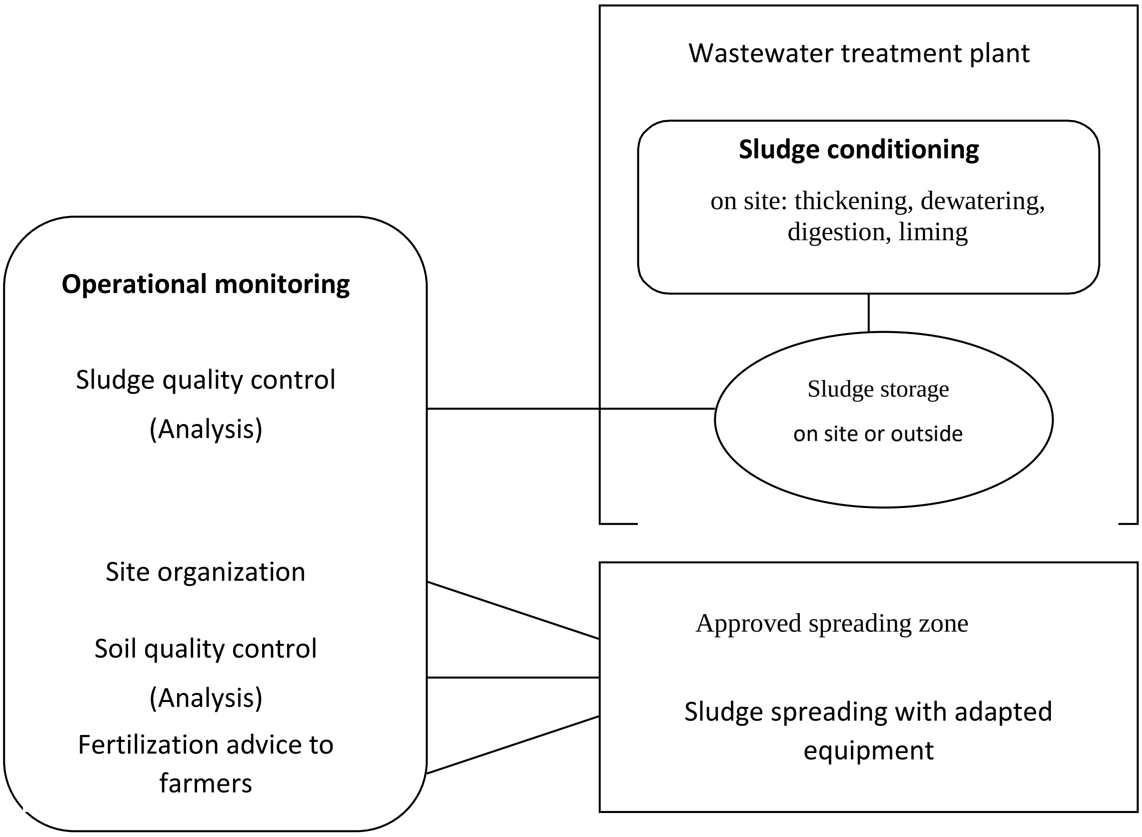
The order also prescribes conditions for sludge storage, specifying in particular that the sludge must be dimensioned to cope with periods when spreading is either impossible or prohibited by the preliminary study (spreading plan). All measures are taken to ensure that the storage arrangements are not a source of inconvenience or nuisance for the neighborhood and do not lead to water or soil pollution by runoff or infiltration. Overflows from storage structures may not be discharged into the natural environment.

E.2.2. Technical aspects

E.2.2.1. Principle

Agricultural spreading of raw, digested or dried sludge is generally carried out in field crops. Sludge can also be spread in forests with good results. This practice is developed abroad, particularly in the United States, but very little in France.

The functioning of the spreading operation is described in the figure below:



E.2.2.2. Implementation of the agricultural spreading process

This process is better suited to small and medium capacity plants than to very large capacity plants for practical reasons of the size of the spreading perimeter. An average input of about 2 tDM/ha/year maximum (limitation of nitrogen input) is required. In practice, sludge is spread every two to three years on agricultural plots.

SLUDGE STORAGE

Given the regulations and crop cycles observed in metropolitan France, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

In general, 6 to 9 months of storage are to be expected (depending on the particularities of the spreading area).

Appropriate works should preferably be carried out on the site of the treatment plant (these works are normally foreseen in the construction phase of the plant's sludge treatment facilities).

In medium and large plants, the spreading perimeter is further away (10 to 30 km), so it is advisable to create decentralized storage facilities close to the spreading areas. In this way, the time between transport and spreading is kept as short as possible during favorable spreading periods.

The storage method varies according to the type of sludge produced:

Type of sludge	Liquid sludge	Pasty sludge	Solid sludge
Type of storage	Synthetic bags (up to 4,000 m3) for temporary storage or cylindrical-conical silo with agitator to homogenize sludge before spreading, located on the wastewater treatment plant.	Semi-buried covered pit or covered area with devices to contain soft matter, located on the treatment plant or on the spreading area.	Covered storage area (simple concrete slab under shed or simple tarp), located on the sewage treatment plant or on the spreading area

In the special case of thermally dried sludge (solid sludge), the same type of handling and storage facilities as for granulated mineral fertilizers is required.

Furthermore, temporary storage of sludge on the ground is not recommended. If the sludge is not stabilized, such storage may not exceed 48 hours. It may be longer if the sludge is solid and stabilized, but any risk of run-off or rapid percolation of juices must be prevented and the limiting distances from houses, watercourses, etc. must be respected.

In addition, storage infrastructure and equipment must be designed to manage sludge in batches. To formalize this batch management of the sludge produced, in the case of non-liquid sludge, separation walls can be installed to isolate each production batch, and for liquid sludge, the ideal is to have two storage units, a main unit for long-term storage and a smaller unit for pre-storage.

Finally, the storage facility should also provide for facilities to facilitate the sampling of the stocks in place, and in complete safety (compliance analyses, agronomic analyses about a month before spreading).

SPREADING EQUIPMENT

The equipment is to be determined according to the nature of the sludge.

A liquid manure tanker is used to spread liquid sludge (dryness up to 8%).

A specific equipment is used to spread sludge from 13 to 25% dryness.

For sludge of higher dryness and solid consistency, a manure spreader (spreading bed or vertical bristles) can be used. However, for the same dryness, the sludge viscosity is variable. As long as the viscosity is not high enough, a sludge spreader (characterized by its sealing) is necessary.

Dried sludge can be spread in granular form with a fertilizer spreader.

AGRONOMIC MONITORING

Sludge spreading operations are most often associated with agronomic monitoring. Plots receiving sludge are subject to soil analysis. The organization in charge of spreading provides advice on additional mineral fertilization with the sludge and soil analyses. In this way, the sludge spreading areas are made aware of the need for rational fertilization management.

E.3. COMPOSTING

Composting is a sludge transformation process, prior to sludge recovery and reuse in agriculture, landscaping or rehabilitation of degraded land.

E.3.1. French regulations

E.3.1.1. Listed installations for the protection of the environment

If the digestate is disposed of by composting, it will be subject to heading 2780 of the listed installations for environmental protection.

Heading 2780 was created by decree no. 2009-1341 of 29 October 2009 and amended by decree no. 2012-384 of 20 March 2012. The title of the heading is as follows:

> *Installations for the composting of non-hazardous waste or vegetable matter, which may have undergone an anaerobic digestion stage.*

N°	DESIGNATION	CONSEQUENCE
2780-1	**Composting of vegetable matter or vegetable waste, livestock effluent, faecal matter:**	
	a) 75 t/d ≤ Quantity of matter treated	Authorization (1km)
	b) 30t/d ≤ Quantity of matter treated < 75 t/d	Registration
	c) 3 t/d ≤ Quantity of matter treated < 30 t/d	Declaration
2780-2	**Composting of the fermentable fraction of waste sorted at source or on site, sludge from urban wastewater treatment plants, paper mills, food processing industries, alone or mixed with waste accepted in an installation falling under heading 2780-1:**	
	a) 75 t/d ≤ Quantity of matter treated	Authorization (3km)
	b) 20t/d ≤ Quantity of matter treated < 75 t/d	Registration
	c) 2 t/d ≤ Quantity of matter treated < 20 t/d	Declaration
2780-3	**Composting of other waste**	
	a) 75 t/d ≤ Quantity of matter treated	Authorization (3km)
	b) Quantity of matter treated < 75 t/d	Registration

The Order of 12 July 2011 relates to the general requirements applicable to listed composting facilities subject to declaration under heading No. 2780.

The Order of 20 April 2012 relates to the general requirements applicable to listed composting facilities subject to registration under heading No. 2780.

The order of 22 April 2008 relates to the general requirements applicable to listed composting facilities subject to authorization under heading 2780.

E.3.1.2. Standard NF U 44-095 - Compost containing matter of agronomic interest resulting from water treatment.

This standard, made compulsory by the Order of 5 September 2003, defines Matter of Agronomic Interest resulting from Water Treatment (M.A.I.W.T.) as matter resulting from a physical, chemical or biological water treatment process and any matter containing it (other than compost, which is the subject of this standard), which, due to its characteristics, is of interest for the fertilization of crops or the maintenance or improvement of agricultural soils.

Within the framework of this standard, **grease, grit, sand, network cleaning products and screening rejects** coming from the collective and non-collective domestic sanitation system **cannot be considered as MAIWTs.**

Annex B of the standard defines the conditions of acceptability of raw materials intended for the manufacture of an organic soil improver containing MAIWT:

The raw materials that can be used are only those that can be used in agriculture under the regulations in force (e.g. rendering sludge is prohibited). The list of MAIWT of authorized industrial sectors is as follows:

- ✓ Sludge from on-site treatment of effluents from industries preparing and processing meat, fish and other foods of animal origin (without prejudice to other European Community legislation, in particular Directive 90/667/EEC on animal waste);
- ✓ Sludge from on-site treatment of effluents from the preparation and processing of fruit, vegetables, cereals, edible oils, cocoa, coffee, tea and tobacco, the production of tobacco preserves, and yeast industries;
- ✓ Sludge from the on-site treatment of effluents from the sugar industry;
- ✓ Sludge from on-site treatment of effluents from the dairy industry;
- ✓ Sludge from on-site treatment of effluents from the bakery and biscuit industry;
- ✓ Sludge from on-site treatment of effluents from alcoholic and non-alcoholic beverage production industries (excluding coffee, tea and cocoa);
- ✓ De-inking sludge from paper recycling;
- ✓ Fiber rejects, fiber, filler and coating sludge from separation;
- ✓ Sludge from on-site effluent treatment other than those mentioned in the previous point;
- ✓ Sludge from the leather industry not containing chromium.

In addition, the contents of MAIWT trace elements and organic trace compounds must comply with the thresholds in Table 1 below. MAIWT must be subject to analytical monitoring of trace elements and organic trace compounds, the frequency of which must comply with the requirements of Tables 2 and 3. It is recommended to reduce the time between the analysis and the use of MAIWT.

Table 1 - Limit values for trace element concentration in MAIWT

TRACE ELEMENTS OR COMPOUNDS	CONTENT LIMIT (mg/kgDM)
Cadmium	10
Chrome	1 000
Copper	1 000
Mercury	10
Nickel	200
Lead	800
Zinc	3 000
Chrome + copper + nickel + zinc	4 000
Total of the 7 main PCBs (28, 52, 101, 118, 138, 153, 180)	0,8
Fluoranthene	5
Benzo(b)fluoranthene	2,5
Benzo(a)pyrene	2

Number of analyses during the first year of MAIWT input to the composting unit:

Table 2 - Number of analyses during the first year of MAIWT input to the composting unit								
tDM excluding lime	<32	32 to 160	161 to 480	481 to 800	801 to 1 600	1 601 to 3 200	3 201 to 4 800	>4 800
As, B	-	-	-	1	1	2	2	3
Trace elements	2	4	8	12	18	24	36	48
Trace compounds	1	2	4	6	9	12	18	24

Number of routine analyses per year:

Table 2 - Number of routine analysis per year								
tDM excluding lime	<32	32 to 160	161 to 480	481 to 800	801 to 1 600	1 601 to 3 200	3 201 to 4 800	>4 800
Trace elements	2	2	4	6	9	12	18	24
Trace compounds	1	2	2	3	4	6	9	12

E.3.1.3. French rural Code - Placing on the market and use of fertilizing materials

Article L.255-12 of the French Rural Code specifies that:

« ***Where a fertilizer or growing medium is derived, in whole or in part, from waste that has been processed*** *in an installation mentioned in article L.214-1 of the French Environment Code subject to authorization or declaration or in an installation mentioned in article L.511-1 of the same code subject to authorization, registration or declaration* ***and which have undergone a recovery operation, in particular recycling or preparation with a view to reuse, the issue of a marketing authorization for this fertilizer or growing medium*** *provided for in Article L.255-2 of this Code, provided that it includes verification of the other conditions laid down in Article L.541-4-3 of the French Environmental Code,* ***causes this fertilizer or growing medium to be exempt from waste status.***

The same applies to a fertilizer or growing medium, ***with the exception of those resulting from the processing of wastewater treatment plant sludge alone or in a mixture with other substances****, due to its conformity to:*

- ✓ *A standard referred to in the 1st paragraph of Article L.255-5 of the present Code for which an assessment by the National Agency for Food, Environmental and Occupational Health Safety shows that it guarantees that all the conditions laid down in Article L.541-4-3 of the French Environmental Code are met;*
- ✓ *A European Union regulation mentioned in the 2nd paragraph of article L.255-5 of this code, provided that it guarantees that all the conditions provided for in article L.541-4-3 of the environment code have been met;*
- ✓ *A set of specifications taken in application of the 3rd paragraph of Article L.255-5 of the present code, provided that it guarantees that all the conditions provided for in Article L.541-4-3 of the French Environmental Code are met. »*

Consequently, compliance with standard NF U 44-095 is no longer sufficient to allow an exemption from waste status for wastewater sludge. Consequently, and by default, the sludge retains its waste status and a plan for spreading the compost must be drawn up.

To date, the regulation does not clearly define the possible alternatives to allow sludge to regain product status. A working group has been set up to defend the "product composting" sector for sludge. Alternatives, such as an additional approval or provisional sales authorization (PSA) could be carried out to obtain a withdrawal of waste status for sludge composted in accordance with standard NF U 44-095. However, recent discussions on this subject have tended towards a total boycott of sludge in sectors that allow it to be returned to the ground.

E.3.2. Technical aspects

E.3.2.1. Principle

Composting processes are conceivable for sludge production of more than 1,000 tonnes RM (Raw Matter) per year (above 10,000 PE) with a minimum dryness of 15 %DM.

Composting is an additional stage that comes after the dewatering of sewage plant sludge, and can be assimilated to biological sludge drying. It is defined as the microbiological degradation of fermentable organic matter under aerobic conditions. It results in an increase in the temperature of the substrate, an increase that can be followed through a characteristic curve corresponding to the development cycles of the different microbial populations.

Sludge composting is based on a very simple principle which consists in aerating a mixture of pasty sludge and structuring carbonaceous co-products, then allowing the whole to evolve for several weeks. It consists of four steps:

- ✓ A stage of mixing the sludge with the co-product and, eventually, recycled compost, in order to obtain optimal dryness and porosity;
- ✓ A fermentation stage which aims to degrade the VM, stabilize, sanitize and dry, in the presence of air;
- ✓ A screening stage, if necessary, to refine the final product and recycle part of it;
- ✓ A maturation and storage stage to complete the degradation of the VM during storage and to give the product its final agronomic quality (this stage requires an adequate storage area corresponding to a storage capacity of 2 to 6 months).

For its proper functioning, composting requires oxygen, water, nitrogen and carbon-rich compounds that are easily mobilized (cellulose, sugars, etc.) and phosphorus necessary for microbial synthesis (proteins, ATP).

Respecting these balances, particularly in oxygen, nitrogen and carbon, requires mixing different products with complementary characteristics in order to obtain a compostable mixture, with sufficient porosity to allow oxygenation of the pile.

Thus, the composting of waste sludge requires the use of coarse co-products, such as bark or green area waste, whose role is to provide a carbon source for the micro-organisms involved in the bioconversion of organic matter and porosity for the diffusion of air through the product. The same is true for the treatment of other liquid effluents (digester/settling tank sludge, septage) which are subject to special technical constraints (prior dewatering, mixing ratio) to guarantee the porosity of the waste heap during the composting phase.

Composting treatment also requires control of the oxygen level in the interstitial air to limit the risks of anaerobic fermentation and the release of nauseating odors.

COMPOSTING PROCESSES

There are many composting technologies available. They differ mainly in the shape of the fermentation reactors, the aeration method, the devices for handling the mass being composted and the degree of automaticity.

Slow technologies:

In this composting technique, the organic waste (in this case, sludge) is disposed of in piles or windrows for several months. Turning is done regularly, using towed or self-propelled machines.

The duration of the composting process depends on the passive diffusion of oxygen, which is conditioned by the turning frequencies of the matter to be transformed.

This technology is rustic and easy to implement, but requires a large surface area. Indeed, the windrows created are of low height, less than two meters, to allow mechanical turning.

It is suitable for composting in rural areas.

- ✓ Turning windrows over in the open: Since storage is carried out in the open air, rainfall is likely to generate a large quantity of leachate and disrupt the smooth running of the composting process. Moreover, mechanical turning is costly in terms of operation and odor control is not possible.
- ✓ Turning windrows under cover: The composting platform is kept out of the water with a cover that addresses some of the above disadvantages. However, the large surface area involved results in prohibitive capital costs.

Accelerated technologies:

The duration of the composting phase, from 2 to 5 weeks, is optimized by forced aeration of the mixtures to be treated with the help of ventilation units.

This technique is quite similar to that used in windrows. Fermentation is carried out in racks, tunnels or cells. The platform is located in a building or is left in the open air.

Forced aeration out in the open:

The open-air installation of the composting platform has the disadvantage of generating leachate and potential odor nuisance.

- ✓ Windrowing: the need to create triangular-shaped windrows limits the storage height and creates a significant footprint.
- ✓ Use of bins: the mixture to be treated is placed in cells or bins; the height of the piles can then be increased to 3 or 4 m, which ensures better management of the surface. In this case, the initial mixture of sludge and co-products must be homogeneous.

Forced aeration under cover:

The covering of the platform solves the problems of leaching and odor diffusion, as the treatment of the air extracted from the buildings is feasible.

- ✓ Forced aerated composting in covered bins, skips or ventilated bags: the correct operation of the installation depends on the quality of the mixture, which must be homogeneous and sufficiently porous; an automated mixing line is therefore imperative. This technique is compatible with the treatment of sludge in wastewater treatment plants, the sludge being managed in batches.

- Tunnel composting under controlled atmosphere: this technique is derived from the production of compost for mushrooms. The mixture placed in a box is permanently over-ventilated. This process makes it possible to control all the fermentation parameters, to accelerate the composting process, the duration of which is then reduced to 1 to 3 weeks, and to confine the treatment to a maximum. The volumes of air to be treated and the footprint are minimized by this process.

Mixed technologies:

- Forced ventilation with turning over: Ventilation is ensured both by a network of drains providing ventilation and by mechanical rollovers. The product is thus more homogeneous. These systems are generally used in the treatment of previously sorted household waste. Costly in investment and operation, they require a large quantity of waste (minimum 50,000 m3/year).
- Composting in closed vertical silos: Fermentation in closed silos consists of composting in air-fed towers. The mixture is introduced from the top and an air ramp blows or sucks in air at the base. The compost is extracted from the bottom. The different layers of product thus follow a piston-like progression from top to bottom. As this process works continuously, it is well suited to the treatment of sludge from sewage treatment plants. However, it is expensive in terms of investment.

Performance

The actual composting process can last between 20 and 60 days depending on the intensity of bacterial activity in the heaps. This activity is directly correlated to the level of oxygenation of the mixture.

When the composting platform is covered, the forced aeration process is very effective in treating the odors that are released during the degradation of the organic matter.

A fast and constant composting with a control of the nuisances (odors, juices...) imperatively requires the installation of an industrial unit.

Composting is accompanied by a reduction in the volume of the mass due to a loss of matter and settling that occurs during mixing and aeration.

The sludge to co-product volume ratio varies from 1 to 3 depending on the composting process.

Regardless of the aeration technique chosen, aerated composting makes it possible to obtain a stabilized product generating little or no odor nuisance, a high level of sanitization destroying in particular pathogens, a semi-dry product texture that facilitates handling, storage and spreading, and a composition that meets the requirements of very diverse soils in terms of fertilization and humic amendment.

The dryness obtained at the end of composting varies according to the technique used:

- Uncovered techniques, slow or accelerated, can achieve a dryness of 35 to 40%,
- Accelerated undercover techniques, a dryness of 40-50%,
- Tunnel composting technology, 50-60% dryness.
- The implementation of a storage phase of the compost after its maturation can ensure a dryness gain of 5 to 10% depending on the season.

F. DISPOSAL PROCESSES

F.1. GREEN PROCESS: AGRICULTURAL RECOVERY AND REUSE

The **green process** corresponds to the solution of agricultural recovery and reuse. Dried or composted sludge is spread and used as agricultural fertilizer for crops.

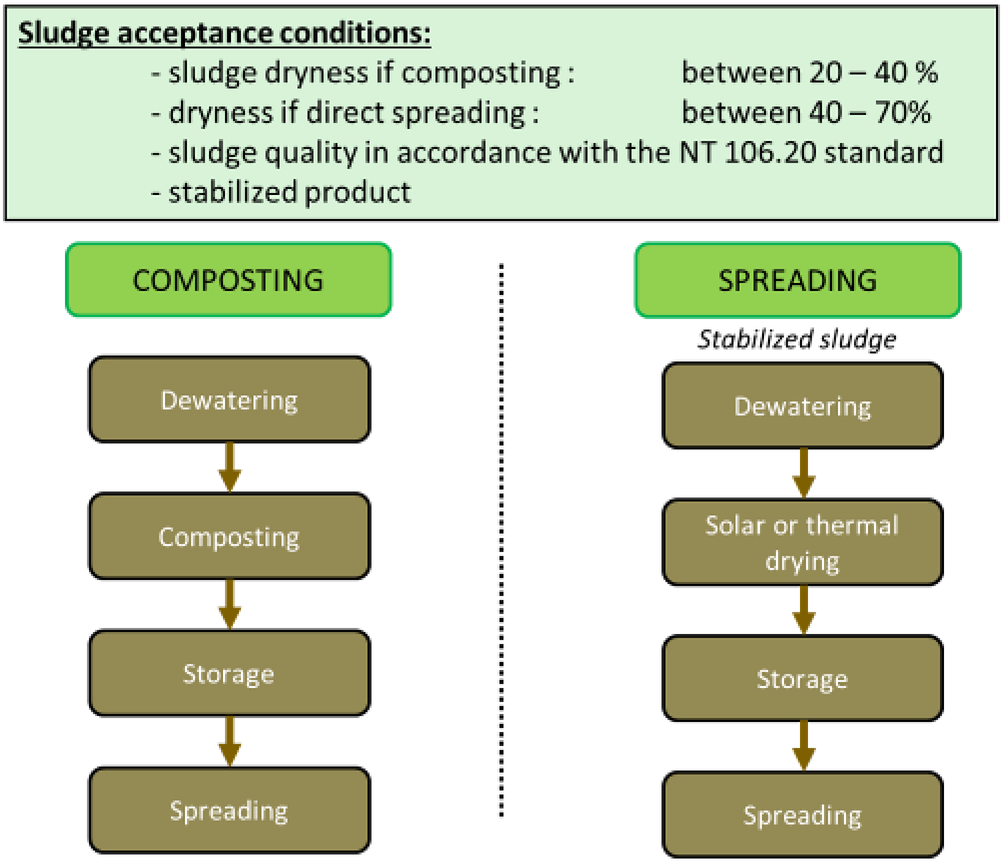


Figure 16. Schematic diagram of the green process

Spreading requires a certain quality of sludge in order to limit soil pollution. Sludge must indeed comply with regulatory parameters (heavy metals, organic compounds, etc.) if it is sent for spreading (cf. section E.2.1 and E.3.1). Sludge from plants connected to non-agri-food industry cannot therefore be destined for the green process. Furthermore, sludge intended for spreading must first be stabilized (in particular with regard to the need for long-term storage of sludge between two spreading cycles), either by liming to reach 30% dryness, or by drying.

The Usable Agricultural Area (UAA) considered in the Bekaa Valley only concerns large cereal crops. Assuming that a maximum of 3 t DM/ha/year can be spread without lime and that the quantity of sludge accepted for spreading represents 20% of the UAA, about 51,000 tons of dry matter could be spread in the Bekaa Valley.

The choice was made not to include sludge composting in our study knowing that the output of structuring co-products is not readily available and that acquiring these co-products will be very expensive. Moreover, composting platforms for green waste and livestock effluents already exist within the area covered by the study; our product would create a competitive situation with existing composting platforms.

F.2. RED PROCESS: THERMAL TREATMENT

The **red process** corresponds to the thermal treatment solution, specifically in this project by specific incineration. The heat produced by the sludge incineration process can potentially be recovered and reused for thermal energy needs on site (in particular for thermal drying or digestion) or nearby.

Conversely, the thermal needs of the incineration process (in case the sludge is not self-heating) can be covered in whole or in part by the production of renewable thermal energy on the site; thus, the implementation of an incineration dedicated to sludge must be accompanied by the implementation of prior anaerobic digestion to produce biogas to be recovered for the thermal supplement of the furnace(s).

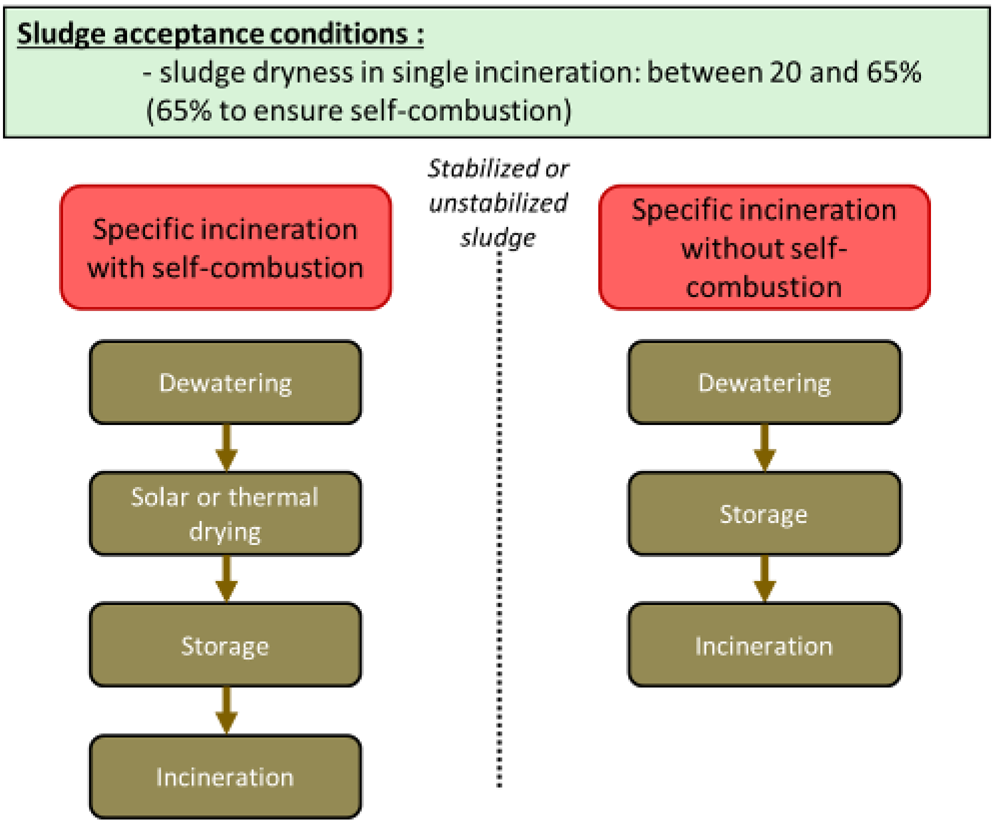


Figure 17. Schematic diagram of the red process

Sludge incineration requires not only a preliminary stage of anaerobic digestion to meet the thermal energy needs of the process, but also an efficient dewatering stage to increase the dryness of the sludge in order to approach self-heating conditions as closely as possible (the LHV of the sludge must be higher than 400 kcal/kg, which corresponds to a dryness of around 25% for an organic matter content of around 60 to 70%VM) and thus limit the thermal needs of the incineration.

It should be noted that the most common specific sludge incineration technology, the fluidized bed incinerator, is not compatible with dried sludge.

A sufficient LHV of the sludge ensures its self-combustion, i.e. no external energy input is required once the furnace is started up: the heat generated by the reaction is used for the combustion process itself. In the case of digestion not followed by drying, the biogas produced during sludge digestion can be used for the thermal needs of incineration. In contrast to limed sludge, which can lead to problems in the operation of the furnace, polluted sludge (from plants connected to industrial facilities) is accepted for incineration.

F.3. BLACK PROCESS: LANDFILL

The **black process** is the landfill solution. The sludge is either buried with Municipal solid waste (MSW) or in dedicated landfills.

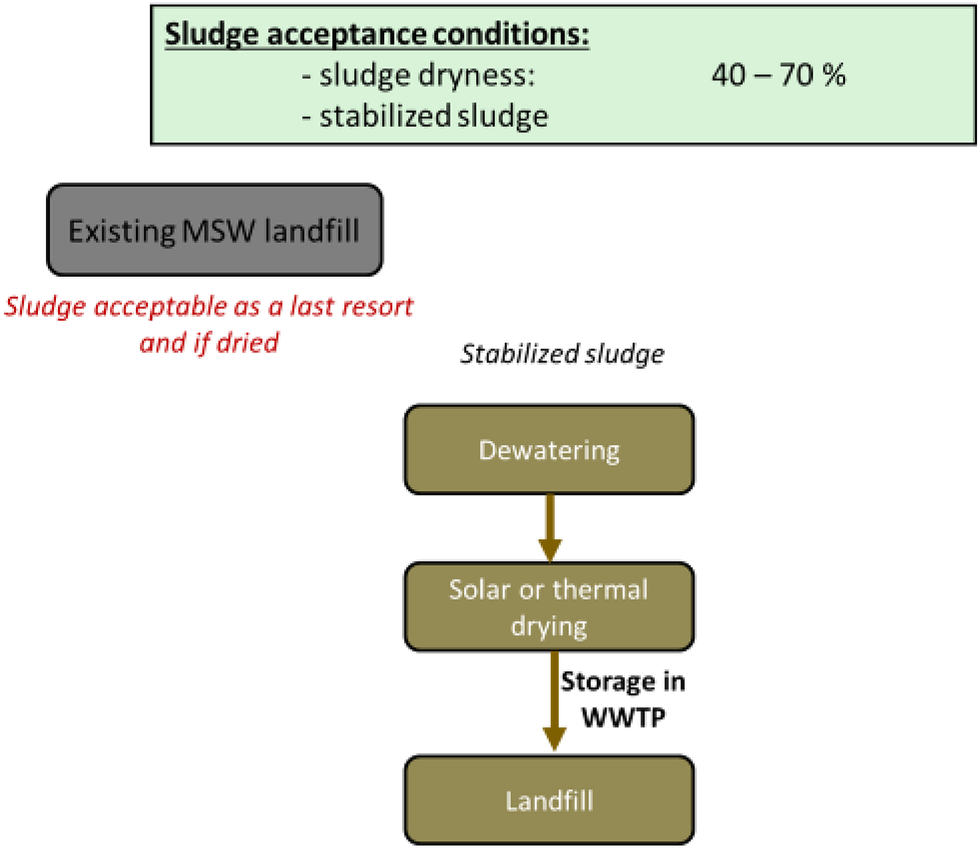


Figure 18. Schematic diagram of the black process

Landfilling the sludge in dedicated cells is the disposal solution currently adopted at the Zahlé wastewater treatment plant. This outlet could be envisaged either in MSW landfill or with the creation of one or more dedicated site(s), provided that the sludge is dried beforehand in both cases. Polluted sludge from plants receiving industrial effluents can be accepted in landfill if the cells are covered with a waterproof lining (to recover leachate and not pollute the soil).

G. OUTLET SCENARIOS

G.1. DEFINITION OF SCENARIOS

In order to define outlet scenarios adapted to the characteristics of the sludge to be disposed of, particularly in terms of the regulatory compliance required, the following principle was applied: potentially polluted sludge (i.e. produced by plants receiving industrial effluents excluding agri-food) is ruled out from the green process.

Consequently, the overall output of wastewater sludge from the Bekaa Valley can be divided into 2 categories:

- Potentially polluted sludge from the WWTPs of Zahlé, Marj, Temnine El Tahta, Iaat and El Laboue.
- Sludge potentially conforming to the requirements of the green process from the WWTPs of Yammouneh, Ablah, Fourzol, Joub Jannine, Saghbine, Aitanit, Hermel and East Zahlé.

NOTE: due to its very low sludge production and its geographical location, the Yammouneh WWTP is attached to the Iaat WWTP and is therefore ruled out with regard to the green process.

NOTE: Existing laboratory analyses did not show any traces of heavy metals in sludge of both categories.

By 2040, the unpolluted sludge from the smallest plants, known as "green process compliant", will represent about 30% of the total output (in tons of dry matter); and the potentially polluted sludge from the largest plants, known as "non-green process compliant", will represent about 70% of the total output (in tons of dry matter).

The green process is the least expensive in terms of implementation and in terms of investments to be planned (especially the long-term storage of sludge). This process is therefore to be favored when it is feasible. Moreover, the ease of implementation of the green process will depend on the acceptability of the agricultural world vis-à-vis the spreading of sludge, a practice which does not exist today in Lebanon, although it is practiced in many countries of Europe in particular. The only investment to be planned is relative to the storage of the sludge once it has stabilized. Thus, the scenarios which resort to spreading assume a drying of the sludge or a liming of the sludge to 30% dryness. Nevertheless, an alternative scenario to the green process must be planned, with a compatible sludge treatment, i.e. one that receives the same sludge at the outlet of the wastewater treatment plant, which is feasible with the black process and not the red process.

The red process results in a very limited quantity of final residue and is suitable for non-compliant sludge. It is therefore to be preferred to the black process.

Furthermore, in the elaboration of the scenarios, it is a matter of proposing multiple outlets so as not to be unprepared with the entire sludge output in case of difficulties on one of the outlets. The 100% red or 100% black processes, although possible, are therefore not sought after.

Moreover, the black process does not allow any material or thermal recovery and reuse of the sludge, so it is a solution of last resort.

G.2. IMPLEMENTATION CONDITIONS

G.2.1. General information

In order to limit the quantities of sludge to be transported, whether for spreading or landfilling as well as for off-site incineration, it is useful at the very least to dewater the sludge before disposal. An efficient dewatering stage (centrifugation) is therefore set up for each process (outlet) on plants that produce large quantities of sludge.

Solar drying is planned for the processes (outlets) which require it, particularly with regard to sludge stabilization; once solar drying is envisaged, liming of the sludge is no longer necessary and should even be avoided.

G.2.2. Red Process

In order to avoid heating too much water in the incinerator, a dewatering stage must be implemented to obtain a dryness level of 25%, at least for the largest plants producing significant quantities of sludge in relation to the size of the incineration stage.

For this process, a digestion stage is included on the Zahlé WWTP, intended to house the incineration plant as it produces the main output of sludge to be incinerated, in order to produce biogas which will be injected into the incinerator to cover its thermal needs in the absence of self-heating of the sludge.

G.2.3. Green Process

In order to avoid transporting too large volumes of sludge over long distances and contaminating soils and crops, it is considered that the implementation of the green process will be accompanied by the elaboration and authorization of a spreading plan for the plants concerned. It will also involve drying the sludge before it is stored and then spread.

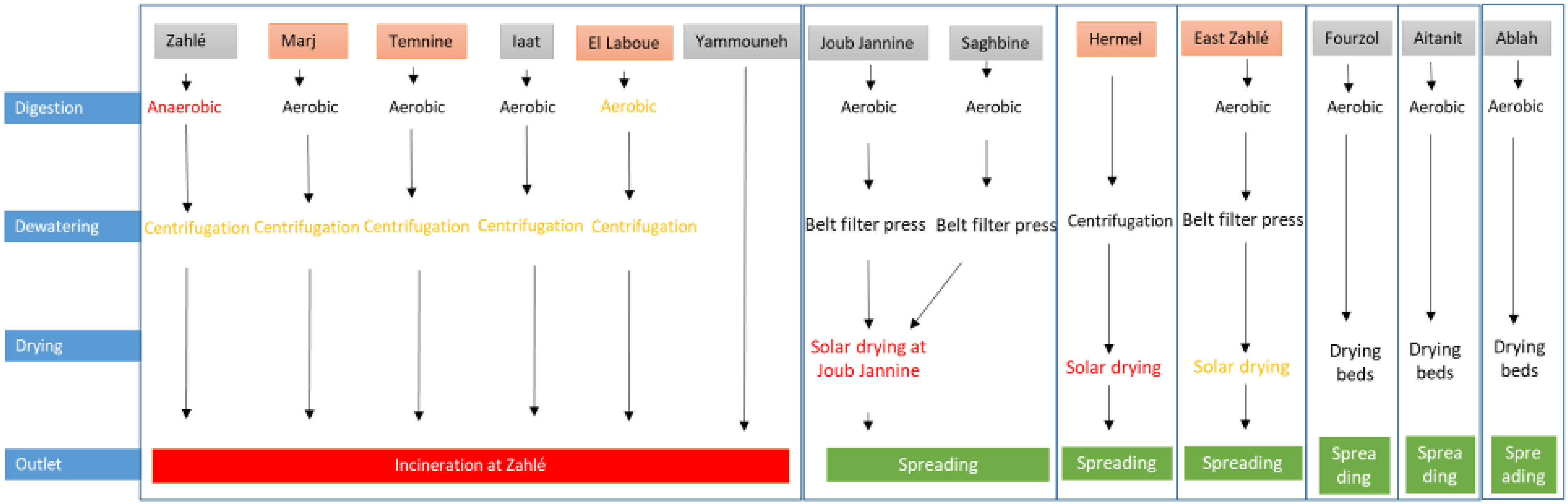
G.2.4. Black Process

Sludge destined for landfill must be dried beforehand in order to stabilize it and to reduce the volume of sludge to be landfilled.

G.3. SLUDGE DISPOSAL SCENARIOS

The different sludge disposal scenarios considered are as follows:

✓ Scenario 1:
- « Compliant sludge »: green process
- « Non-compliant sludge »: red process



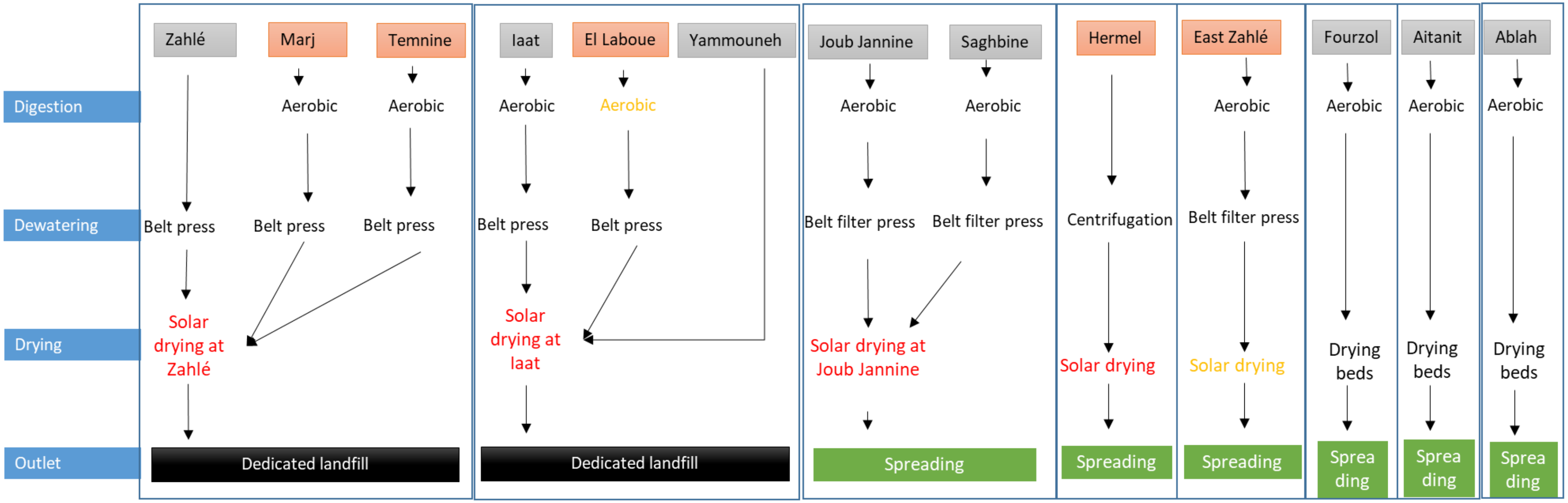
Text caption
Red : to put in place
Orange : instead of existing
Black : exists

WWTP color caption

Grey	existing plant
Pink	planned plant

✓ Scenario 2:

- « Compliant sludge »: green process
- « Non-compliant sludge »: black process

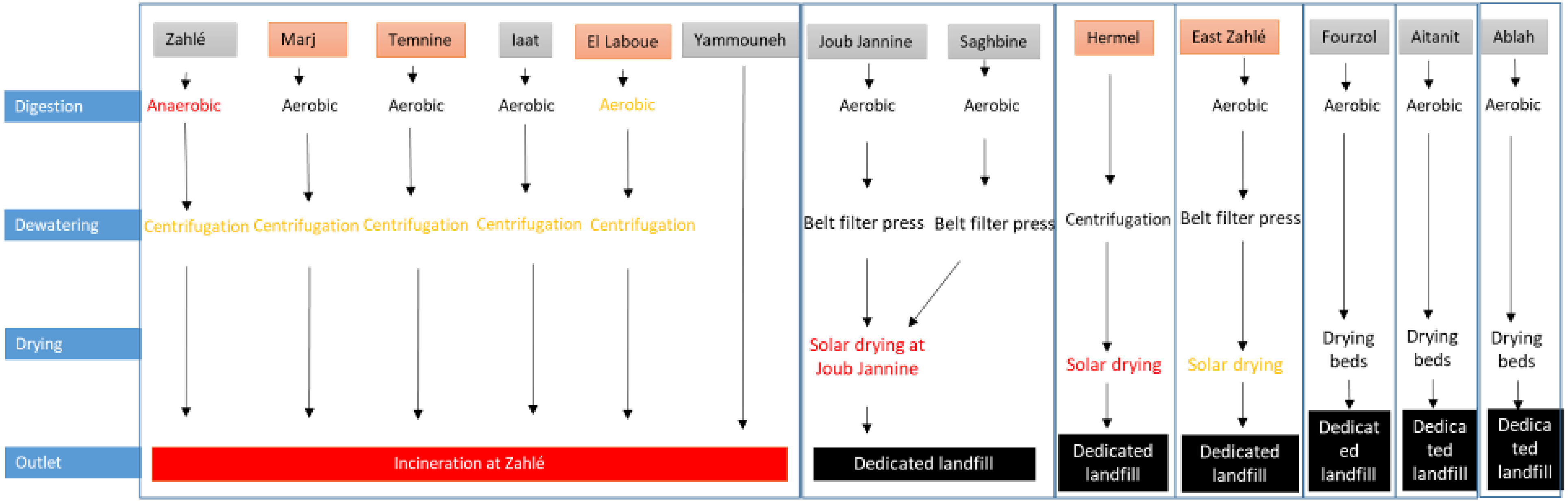


Text caption
Red : to put in place
Orange : instead of existing
Black : exists

WWTP color caption
existing plant
planned plant

✓ Scenario 3:

- « Compliant sludge »: black process
- « Non-compliant sludge »: red process

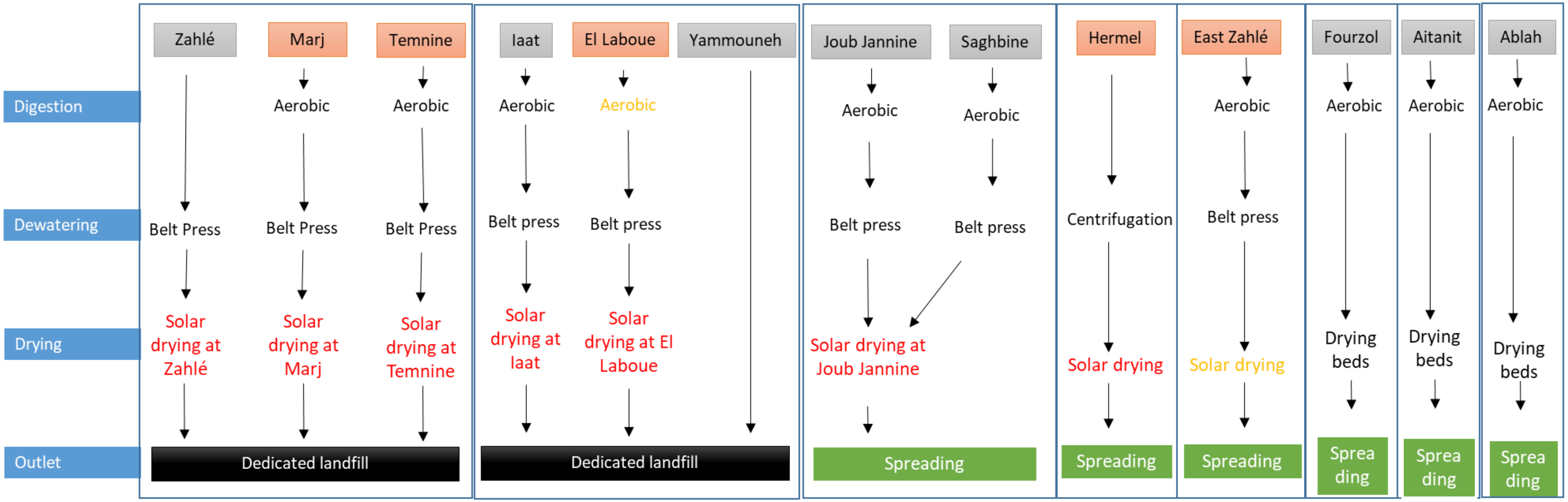


Text caption
Red : to put in place
Orange : instead of existing
Black : exists

WWTP color caption

Grey	existing plant
Pink	planned plant

- Scenario 4:
  - « Compliant sludge »: black process
  - « Non-compliant sludge »: green process



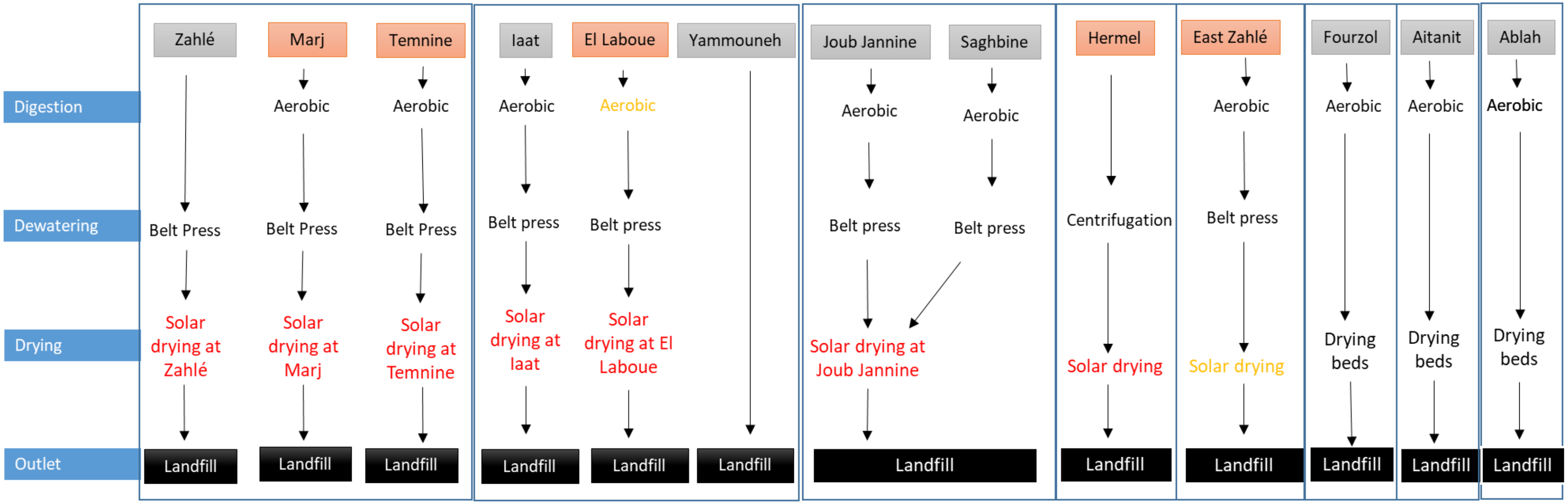
Text caption
Red : to put in place
Orange : instead of existing
Black : exists

WWTP color caption

Grey	existing plant
Pink	planned plant

✓ Scenario 5:

- « Compliant sludge »: black process
- « Non-compliant sludge »: black process



Text caption
Red : to put in place
Orange : instead of existing
Black : exists

WWTP color caption

Grey	existing plant
Pink	planned plant

The design of the additional scenario 5 is detailed in annex N.2. of this report.

G.3.1. STUDY OF SPREADING CAPACITY IN THE BEKAA

The feasibility of spreading potentially compliant sludge depends directly on the available agricultural land. Indeed, if the available land is insufficient, scenarios 1, 2 and 4 are not viable. The subsequent analysis therefore aims at verifying the feasibility of these scenarios in the worst case, i.e. taking into account the largest amount of sludge, i.e. without sludge digestion or drying.

G.3.1.1. Usable agricultural area (UAA)

The UAA considered in the context of the spreading concerns 20% of the major cereal crops. It is assumed that it does not vary between 2020 and 2040, and that the maximum admissible sludge is 3 tDM/ha.year. The corresponding amount of dry matter is given in *Table 10* hereafter:

DISTRICT	UAA cereal (ha)	UAA retained for spreading (ha)	Quantity of DM corresponding to the UAA available (t DM/year)
West Beqaa	13 051	2 610	7 830
Zahlé	13 482	2 696	8 089
Rachaya	6 404	1 281	3 843
Hermel	6 840	1 368	4 104
Baalbek	45 250	9 050	27 150
TOTAL	**85 028**	**17 006**	**51 017**

Table 10 - Useful agricultural area in the Bekaa Valley

Figure 19 hereafter illustrates this table: the size of the circles is proportional to the UAA corresponding to the major cereal crops. The green part of the circles corresponds to the 20% considered usable for sludge spreading.

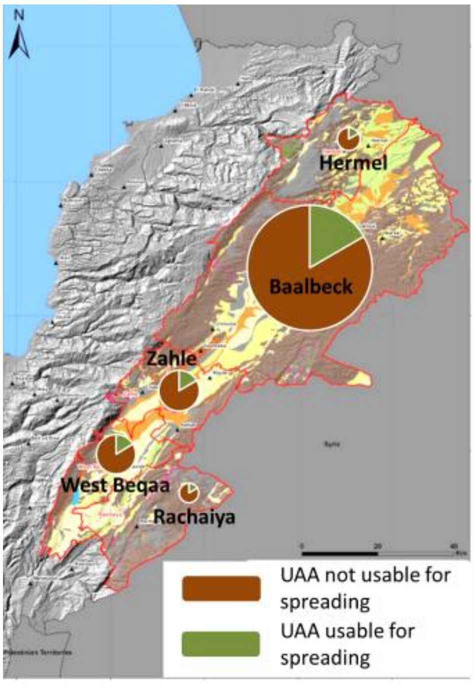


Figure 19. Map of usable UAA for spreading by district

The district of Baalbek, the vastest, has the largest UAA in terms of large cereal crops.

G.3.1.2. Comparison of the UAA and the sludge output to be spread

The production of unpolluted sludge from small plants - corresponding to 30% of the total output - is shown by district by 2040 in *Table 11:*

DISTRICTS	Sludge production (t DM/year) *Excluding lime*
West Beqaa	3 538
Zahlé	3 971
Rachaya	0
Hermel	1 921
Baalbek	103
TOTAL	**9 533**

Table 11 - Annual production of unpolluted sludge from small plants by 2040

The sludge output listed in *Table 11* is much lower, for each district, than the quantities of sludge calculated in *Table 10*: The available UAA can therefore easily "absorb" the sludge output to be spread as defined in scenarios 1, 2 and 4. **The spreading outlet is therefore viable for the sludge output under consideration.**

Figure 20 below illustrates this result:

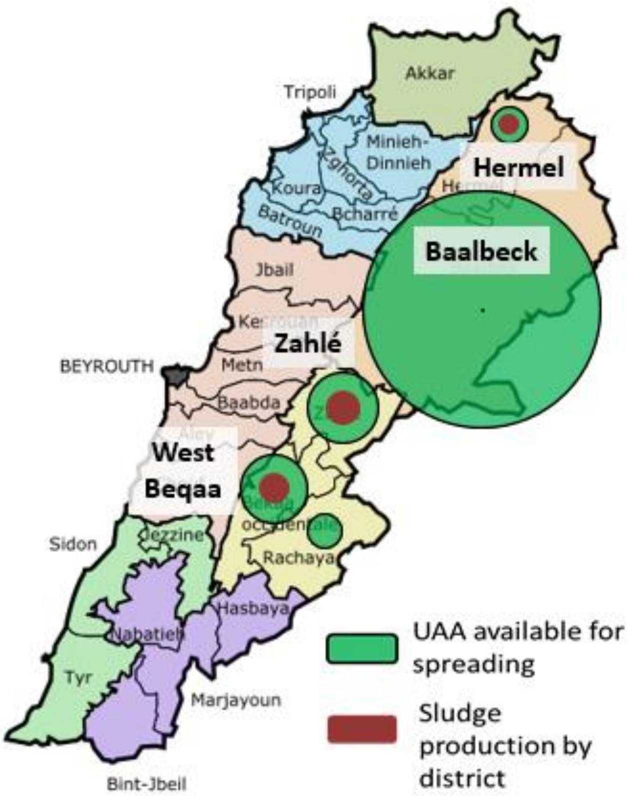


Figure 20. Production of unpolluted sludge from small plants in 2040 and UAA available

H. PROPOSED SOLUTION BY TREATMENT PLANT

The following chapter presents the sludge treatment options selected for each wastewater treatment plant in the Feasibility Study Area, as defined in the scenarios in section G above.

A separate file for each wastewater treatment plant in the study area has been prepared so as to be independent, (especially in view of future calls for tenders). We included in each file:

1. A general overview of the treatment plant presenting the information collected and transmitted by the different parties during the data collection phase, specifically:
    a. The wastewater treatment process of the treatment plant;
    b. The sludge treatment process of the treatment plant;
    c. The hydraulic and organic loads arriving to the treatment plant; and,
    d. The calculation of the quantity of sludge produced by the plant.

    These data were used as a basis for the design of the sludge treatment units and the final outlet.
2. The outlet scenarios selected and the sludge treatment steps to be implemented in order to satisfy the requirements of the final outlet. For each scenario were presented:
    a. The design of the sludge treatments steps;
    b. The general layout of the sludge treatment units to be implemented;
    c. The estimated capital expenditures for each of the treatment steps to be implemented;
    d. The estimated operating expenses resulting from the additional treatment steps to be implemented.

Moreover, we included in this chapter a separate file for the reuse of the Machghara quarry.

H.1. ABLAH

A. GENERAL PRESENTATION

The treatment plant of Ablah is located in the Zahlé district; it has a capacity of 14 630 PE. There is no extension for the treatment plant foreseen at a future horizon.

The treatment plant serves the cities of Ablah and Fourzol.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025	Household + agri-food industries	2 000	878	1 024	176	29
2040	Household + agri-food industries	2 000	878	1 024	176	29

Note: The same values were adopted for the 2025 and the 2040 horizons since no extension is foreseen for the Ablah wastewater treatment plant.

The number of population equivalent (PE) and the flow indicated for the Ablah wastewater treatment plant is extracted from a USAID report (the organization that financed the construction of this WWTP).

The loads at the plant inlet were calculated from the typical French ratios shown in the table below:

	Unit	Value
Inflow to the plant	l/pers.day	135
BOD_5	*g/pers.day*	60
COD	*g/pers.day*	120
TSS	*g/pers.day*	70
TKN	*g/pers.day*	12
TP	*g/pers.day*	2

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening	Primary settling	Trickling filters Clarification	Chlorination

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the produced sewage sludge are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
	Aerobic			Drying beds

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.

Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge is presented in the table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025	317	304	94 %
2040	317	304	94 %

Note: The same values were adopted for the 2025 and the 2040 horizons since no extension is foreseen for the wastewater treatment plant.

The dryness values used were confirmed by the operator of the treatment plant.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of Ablah to be “potentially conforming to the requirements of the green process”.

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site’s dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge, which represents large volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained.
- All the sludge going to the dedicated landfill is previously dried or incinerated.
- The estimated surface area communicated by the Litani river authority is of 40,000 m^2.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Ablah WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, no additional sludge treatment step is required in Ablah WWTP.

B.2.1.1. Design

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 200 m², equivalent to the production of sludge during 6 months is to be constructed on the Ablah WWTP site.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 120 000 €.

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**22,794**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	120,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	600
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**600**
TOTAL	**€/ *year***	**600**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	285
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	303
Distance travelled (Ablah – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	13,098
Processing cost	€/tRM	30
Total processing cost	€/year	9,096
Total annual cost	**€/**year	**22,194**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**22,194**
TOTAL	**€/year**	**22,194**

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Ablah WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, no additional sludge treatment step is required in the Ablah WWTP.

B.2.2.1. Design

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 200 m², equivalent to the production of sludge during 6 months is to be constructed on Ablah WWTP site.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 120 000 €.

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**22,794**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	120,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	600
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**600**
TOTAL	**€/ *year***	**600**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	285
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	303
Distance travelled (Ablah – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	13,098
Processing cost	€/tRM	30
Total processing cost	€/year	9,096
Total annual cost	**€/**year	**22,194**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**22,194**
TOTAL	**€/year**	**22,194**

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Ablah WWTP was considered to be “compliant” and in order to satisfy the requirements of the black process, no additional sludge treatment step is required in the Ablah WWTP.

B.2.3.1. Design

N/A

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**34,624**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	285
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	303
Distance travelled (Ablah – Machghara quarry)	km	55
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	24,013
Processing cost	€/tRM	35
Total processing cost	€/year	10,612
Total annual cost	***€/year***	**34,624**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**34,624**
TOTAL	**€/year**	**34,624**

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Ablah WWTP was considered to be "compliant" and in order to satisfy the requirements of the green process, no additional sludge treatment step is required in the Ablah WWTP.

B.2.4.1. Design

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 200 m², equivalent to the production of sludge during 6 months is to be constructed on the Ablah WWTP site.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 120 000 €.

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**22,794**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	120,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	600
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**600**
TOTAL	**€/ *year***	**600**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	285
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	303
Distance travelled (Ablah – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	13,098
Processing cost	€/tRM	30
Total processing cost	€/year	9,096
Total annual cost	**€/**year	**22,194**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**22,194**
TOTAL	**€/year**	**22,194**

C. ANNEX

C.1. ANNEX 1: GENERAL LAYOUT OF THE STORAGE FOR SCENARIOS 1, 2 AND 4

General Layout of the storage (in blue) for scenarios 1, 2 and 4 at Ablah

H.2. AITANIT

A. GENERAL PRESENTATION

The Aitanit plant is located in the West Bekaa district; it has a capacity of 35 700 PE. There is no extension foreseen for the treatment plant at a future horizon. The Aitanit plant serves the following villages: Baaloul, El Karaoun, Aitanit, Machghara.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025	Household	5 000	2 142	2 499	428	71
2040	Household	5 000	2 142	2 499	428	71

Note: The same values were adopted for the 2025 and the 2040 horizons since no extension is foreseen for the Aitanit wastewater treatment plant.

The number of population equivalent (PE) and the flow indicated for the Aitanit wastewater treatment plant is extracted from a USAID report (the organization that financed the construction of this WWTP). The loads at the plant inlet were calculated from the typical French ratios shown in the table below:

	Unit	Value
Inflow to the plant	l/pers.day	135
BOD_5	*g/pers.day*	60
COD	*g/pers.day*	120
TSS	*g/pers.day*	70
TKN	*g/pers.day*	12
TP	*g/pers.day*	2

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening	Primary settling	Trickling filters Clarification	Chlorination

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the produced sewage sludge are specified in the table below:

Thickening	Digestion	Dewatering	Liming	Drying
	Aerobic			Drying beds

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.

Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge is presented in the table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025	774	741	94 %
2040	774	741	94 %

Note: The same values were adopted for the 2025 and the 2040 horizons since no extension is foreseen for the Aitanit wastewater treatment plant.

The dryness values used were confirmed by the operator of the treatment plant.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of Aitanit to be “potentially conforming to the requirements of the green process”.

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumptions:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site’s dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge, which represents large volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained.
- All the sludge going to the dedicated landfill is previously dried or incinerated.
- The estimated surface area communicated by the Litani river authority is of 40,000 m^2.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Aitanit WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, no additional sludge treatment step is required in the Aitanit WWTP.

B.2.1.1. Design

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 400 m², equivalent to the production of sludge during 6 months is to be constructed on the Aitanit WWTP site.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 240 000 €.

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**55,477**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	240,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	1,200
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**1,200**
TOTAL	**€/ *year***	**1,200**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	697
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	741
Distance travelled (Aitanit – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	32,032
Processing cost	€/tRM	30
Total processing cost	€/year	22,245
Total annual cost	**€/**year	**54,277**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**54,277**
TOTAL	**€/year**	**54,277**

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Aitanit WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, no additional sludge treatment step is required in the Aitanit WWTP.

B.2.2.1. Design

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 400 m², equivalent to the production of sludge during 6 months is to be constructed on Aitanit WWTP site.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 240 000 €.

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**55,477**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	240,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	1,200
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**1,200**
TOTAL	***€/ year***	**1,200**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	697
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	741
Distance travelled (Aitanit – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	32,032
Processing cost	€/tRM	30
Total processing cost	€/year	22,245
Total annual cost	**€/**year	**54,277**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**54,277**
TOTAL	**€/year**	**54,277**

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Aitanit WWTP was considered to be “compliant” and in order to satisfy the requirements of the black process, no additional sludge treatment step is required in the Aitanit WWTP.

B.2.3.1. Design

N/A

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**27,340**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
TOTAL	***€/ year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Tonnage of dry matter to be evacuated	tDM/year	697
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	741
Distance travelled (Aitanit – Machghara quarry)	km	1.3
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	1,388
Processing cost	€/tRM	35
Total processing cost	€/year	25,952
Total annual cost	**€/year**	**27,340**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**27,340**
TOTAL	**€/year**	**27,340**

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Aitanit WWTP was considered to be "compliant" and in order to satisfy the requirements of the green process, no additional sludge treatment step is required in the Aitanit WWTP.

B.2.4.1. Design

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 400 m², equivalent to the production of sludge during 6 months is to be constructed on Aitanit WWTP site.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 240 000 €.

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**55,477**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	240,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	1,200
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**1,200**
TOTAL	***€/ year***	**1,200**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	697
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	741
Distance travelled (Aitanit – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	32,032
Processing cost	€/tRM	30
Total processing cost	€/year	22,245
Total annual cost	**€/**year	**54,277**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**54,277**
TOTAL	**€/year**	**54,277**

C. ANNEX

C.1. ANNEX 1: GENERAL LAYOUT OF THE STORAGE FOR SCENARIOS 1, 2 AND 4

General Layout of the storage (in blue) for scenarios 1, 2 and 4 at Aitanit

H.3. EAST ZAHLE

A. GENERAL PRESENTATION

The East Zahlé treatment plant is under study; its capacity at the 2035 horizon is of 167,000 PE. The plant will serve the following cities and villages: Kfar Zabad, Ain Kfar Zabad, Delhamiye, Terbol, Qoussaya, Deir el Ghazal, Raait, Haouch Hala, Rayaq, Hoshmosh, Tell Aamara, Massa, Nasriye, Haouch el Ghanam, Ali El Nahri, Haret el Fikani, and El Faaour.

An extension of the treatment plant is foreseen at a future horizon, the capacity of the plant will reach 222,000 PE.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025						
2040	Household + agri-food industries	15 680	6 496	8 168	1 128	224

Note: We considered that no sludge will be generated at the 2025 horizon and that the treatment plant will start producing sludge at the 2040 horizon.

The data was transmitted by the Consultant in charge of the feasibility study of the treatment plant.

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening Grit and grease removal	Settling	Anaerobic tank Anoxic tank Aerobic tank Settling	Chlorination

Note: The effluent treatment process is identical for both 2025 and 2040 horizons.

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the sewage sludge produced by the plant are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
X	Aerobic	Belt filter press		*Emergency option: Drying beds in case of filter press shutdown*

Note: The sludge treatment process is identical for both 2025 and 2040 horizons.

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.
Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge by 2040 is presented in *the* table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025			
2040	3 252	3 903	75 %

The dryness values used were taken from the design report submitted by the Consultant in charge of the preparation of the design, construction supervision and O&M supervision.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of East Zahlé to be “potentially conforming to the requirements of the green process”.

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 20%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site’s dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained. The estimated surface area communicated by the Litani river authority is of 40,000 m^2.
- All the sludge going to the dedicated landfill is previously dried or incinerated.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the East Zahlé WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the East Zahlé WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Replacement of planned drying beds with solar drying at East Zahlé	

B.2.1.1. DESIGN

Aerobic digestion

In scenario 1, we propose to keep the aerobic digestion foreseen in the detailed design of the East Zahlé wastewater treatment plant and cancelling the planned liming system.

Belt press filter

In scenario 1, we propose to keep the dewatering process foreseen in the detailed design of the East Zahlé wastewater treatment plant.

Solar Drying

The sludge output of the East Zahlé WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 8.02 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 32 m³/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m².year.
The solar drying area was calculated: 4,050 m².

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 1,900 m², equivalent to the production of sludge during 6 months is to be constructed on the East Zahlé WWTP site.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		**East Zahle**
Coordinates	Included WWTP	33.778932N, 35.960125E
Quantity of sludge to dry	t DM/d	8.02
Dryer surface area	m²	4,050
Civil works	M€	1.4
Equipment	M€	2.3
Total	**M€**	**3.7**

Since the East Zahlé treatment plant is still under study, the cost of the solar dryers can be included in the construction cost of the treatment plant.

Storage

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 1,140,000 €.

Since the East Zahlé treatment plant is still under study, the cost of the storage area can be included in the construction cost of the treatment plant.

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**358,280**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	1,137,500
total investment civil	€	1,513,750
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	24,631
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ year**	**24,631**
TOTAL	**€/ year**	**24,631**
VARIABLE EXPENSES		
Electricity consumption		
Solar drying		
Sludge tonnage	tDM/year	2,927
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	293
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	50,293
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,023**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	2,927
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	4,503
Distance travelled (East Zahlé – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	194,533
Processing cost	€/tRM	30
Total processing cost	€/year	135,092
Total annual cost	**€/year**	**329,625**
TOTAL VARIABLE EXPENSES		
Electricity consumption	**€/year**	**4,023**
Sludge Disposal	**€/year**	**329,625**
TOTAL	**€/year**	**333,649**

Since the East Zahlé treatment plant is still under study, the cost of the additional solar dryers O&M can be included in the O&M cost of the treatment plant.

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the East Zahlé WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the East Zahlé WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Cancellation of planned belt filter press and replacement by centrifugation		Replacement of planned drying beds with solar drying at East Zahlé	

B.2.2.1. DESIGN

Aerobic digestion

In scenario 2, we propose to keep the aerobic digestion foreseen in the detailed design of the East Zahlé wastewater treatment plant and cancelling the planned liming system.

Centrifuges

In order to reduce the area of the solar dryer, we propose to replace the filter press by centrifuges in the WWTP. The objective is to produce sludge with a minimum dryness of 25%.

The design of a centrifuge depends on 2 factors: the feed rate in m^3/h and the mass flow rate in kg of DM/h.

Taking into consideration a 10% reduction in the OM content of digested sludge and a dryness of 2.5% at the outlet of the digester, we suggest the installation of **2 centrifuges of 370 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

INVESTMENT 2040		East Zahlé
Digestion		Aerobic
Sludge to be dewatered	t DM/d	11.26
Dryness	%	2.5
Volume	m^3/d	450
Operation time	h/d	16
Hourly volume	m^3/h	28
Hourly mass	kg DM/h	704
Type of centrifuge		D 4 L C 30 B HP
Number	u	2
Unit capacity	kg DM/h	370

For information on operating principle and performance cf. Section D.2.1 above.

Solar Drying

The sludge output of the East Zahlé WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 8.02 TDM/d with an average dryness of 25%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 32 m³/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m².year.
The solar drying area was calculated: 2,500 m².

Note: the calculation note for the design of the solar dryers is in annex 2.

For information on operating principle and performance cf. Section D.3 above.

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 1,900 m², equivalent to the production of sludge during 6 months is to be constructed on the East Zahlé WWTP site.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		East Zahlé
Type of centrifuge		D 4 L C 30 B HP
Number	u	2
Unit capacity	kg DM/h	370
		€
Civil works (2 stories bldg)	1,500 €/m²	180,000
Equipment (with add %)	30%	337,870
Installation (% of EQ price)	20%	67,574
Electricity (% of EQ price)	15%	50,681
Total (in EURO)		**637,000**

Unit cost	€ HT
D 4 L C 30 B HP	100000
Peripheral equiment (per machine)	14000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	1000
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

Since the East Zahlé treatment plant is still under study, the cost of the centrifuges can be included in the construction cost of the treatment plant.

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		East Zahle
Coordinates		33.778932N, 35.960125E
Quantity of sludge to dry	t DM/d	8.02
Dryer surface area	m²	2,500
Civil works	M€	0.8
Equipment	M€	1.4
Total	**M€**	**2.3**

Since the East Zahlé treatment plant is still under study, the cost of the solar dryers can be included in the construction cost of the treatment plant.

Storage

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 1,140,000 €.

Since the East Zahlé treatment plant is still under study, the cost of the storage area can be included in the construction cost of the treatment plant.

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**358,280**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	1,137,500
total investment civil	€	1,513,750
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	24,631
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**38,932**
TOTAL	***€/ year***	**38,932**

VARIABLE EXPENSES		
Reagents consumption		
Polymer		
Sludge tonnage	tDM/year	2,927
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	35
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/year**	**87,810**
Electricity consumption		
Dewatering		
Sludge tonnage	tDM/year	2,927
Consumption ratio	kWh_e/tDM	100
Electricity consumption	kWh_e/year	292,700
Solar drying		
Sludge tonnage	tDM/year	2,927
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	293
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	342,993
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**27,439**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	2,927
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	4,503
Distance travelled (East Zahlé – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	194,533
Processing cost	€/tRM	30
Total processing cost	€/year	135,092
Total annual cost	**€/year**	**329,625**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**87,810**
Electricity consumption	**€/year**	**27,439**
Sludge Disposal	**€/year**	**329,625**
TOTAL	**€/year**	**444,875**

Since the East Zahlé treatment plant is still under study, the cost of the additional centrifuges and solar dryers O&M can be included in the O&M cost of the treatment plant.

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the East Zahlé WWTP was considered to be “compliant” and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the East Zahlé WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Replacement of planned drying beds with solar drying at East Zahlé	

B.2.3.1. DESIGN

Aerobic digestion

In scenario 3, we propose to keep the aerobic digestion foreseen in the detailed design of the East Zahlé wastewater treatment plant and cancelling the planned liming system.

Belt press filter

In scenario 3, we propose to keep the dewatering process foreseen in the detailed design of the East Zahlé wastewater treatment plant.

Solar Drying

The sludge output of the East Zahlé WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 8.02 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 32 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated: 4,050 m^2.

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		East Zahle
Coordinates	Included WWTP	33.778932N, 35.960125E
Quantity of sludge to dry	t DM/d	8.02
Dryer surface area	m²	4,050
Civil works	M€	1.4
Equipment	M€	2.3
Total	**M€**	**3.7**

Since the East Zahlé treatment plant is still under study, the cost of the solar dryers can be included in the construction cost of the treatment plant.

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**358,280**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	1,137,500
total investment civil	€	1,513,750
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	24,631
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**24,631**
TOTAL	**€/ *year***	**24,631**
VARIABLE EXPENSES		
Electricity consumption		
Solar drying		
Sludge tonnage	tDM/year	2,927
Consumption ratio	kWhe/tDM	0.1
Electricity consumption	kWhe/year	293
Miscellaneous		
Electricity consumption	kWhe/year	50,000
Total electrical consumption		
Total consumption	kWhe/year	50,293
Unit cost	€/kWhe	0.08
Total annual cost	**€/year**	**4,023**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	2,927
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	4,503
Distance travelled (East Zahlé – spreading area)	km	42
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	272,346
Processing cost	€/tRM	35
Total processing cost	€/year	157,608
Total annual cost	**€/year**	**429,954**
TOTAL VARIABLE EXPENSES		
Electricity consumption	**€/year**	**4,023**
Sludge Disposal	**€/year**	**429,954**
TOTAL	**€/year**	**433,977**

Since the East Zahlé treatment plant is still under study, the cost of the additional solar dryers O&M can be included in the O&M cost of the treatment plant.

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the East Zahlé WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the East Zahlé WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Cancellation of planned belt filter press and replacement by centrifugation		Replacement of planned drying beds with solar drying at East Zahlé	

B.2.4.1. DESIGN

Aerobic digestion

In scenario 2, we propose to keep the aerobic digestion foreseen in the detailed design of the East Zahlé wastewater treatment plant and cancelling the planned liming system.

Centrifuges

In order to reduce the area of the solar dryer, we propose to replace the filter press by centrifuges in the WWTP. The objective is to produce sludge with a minimum dryness of 25%.

The design of a centrifuge depends on 2 factors: the feed rate in m^3/h and the mass flow rate in kg of DM/h.
Taking into consideration a 10% reduction in the OM content of digested sludge and a dryness of 2.5% at the outlet of the digester, we suggest the installation of **2 centrifuges of 370 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

INVESTMENT 2040		East Zahlé
Digestion		Aerobic
Sludge to be dewatered	t DM/d	11.26
Dryness	%	2.5
Volume	m^3/d	450
Operation time	h/d	16
Hourly volume	m^3/h	28
Hourly mass	kg DM/h	704
Type of centrifuge		D 4 L C 30 B HP
Number	u	2
Unit capacity	kg DM/h	370

For information on operating principle and performance cf. Section D.2.1 above.

Solar Drying

The sludge output of the East Zahlé WWTP will be dried in solar dryers constructed on the site of the treatment plant.

The total quantity of sludge produced by this plant is equal to 8.02 TDM/d with an average dryness of 25%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.

By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 32 m^3/d.

The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.

The solar drying area was calculated: 2,500 m^2.

Note: the calculation note for the design of the solar dryers is in annex 2.

For information on operating principle and performance cf. Section D.3 above.

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 1,900 m^2, equivalent to the production of sludge during 6 months is to be constructed on the East Zahlé WWTP site.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		East Zahlé
Type of centrifuge		D 4 L C 30 B HP
Number	u	2
Unit capacity	kg DM/h	370
		€
Civil works (2 stories bldg)	1,500 €/m²	180,000
Equipment (with add %)	30%	337,870
Installation (% of EQ price)	20%	67,574
Electricity (% of EQ price)	15%	50,681
Total (in EURO)		637,000

Unit cost	€ HT
D 4 L C 30 B HP	100000
Peripheral equiment (per machine)	14000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	1000
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

Since the East Zahlé treatment plant is still under study, the cost of the centrifuges can be included in the construction cost of the treatment plant.

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		East Zahle
Coordinates		33.778932N, 35.960125E
Quantity of sludge to dry	t DM/d	8.02
Dryer surface area	m²	2,500
Civil works	M€	0.8
Equipment	M€	1.4
Total	**M€**	**2.3**

Since the East Zahlé treatment plant is still under study, the cost of the solar dryers can be included in the construction cost of the treatment plant.

Storage

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 1,140,000 €.

Since the East Zahlé treatment plant is still under study, the cost of the storage area can be included in the construction cost of the treatment plant.

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**358,280**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	1,137,500
total investment civil	€	1,513,750
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	24,631
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**24,631**
TOTAL	***€/ year***	**24,631**

VARIABLE EXPENSES		
Reagents consumption		
Polymer		
Sludge tonnage	tDM/year	2,927
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	35
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/year**	**87,810**
Electricity consumption		
Dewatering		
Sludge tonnage	tDM/year	2,927
Consumption ratio	kWh_e/tDM	100
Electricity consumption	kWh_e/year	292,700
Solar drying		
Sludge tonnage	tDM/year	2,927
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	293
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	342,993
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**27,439**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	2,927
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	4,503
Distance travelled (East Zahlé – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	194,533
Processing cost	€/tRM	30
Total processing cost	€/year	135,092
Total annual cost	**€/year**	**329,625**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**87,810**
Electricity consumption	**€/year**	**27,439**
Sludge Disposal	**€/year**	**329,625**
TOTAL	**€/year**	**444,875**

Since the East Zahlé treatment plant is still under study, the cost of the additional centrifuges and solar dryers O&M can be included in the O&M cost of the treatment plant.

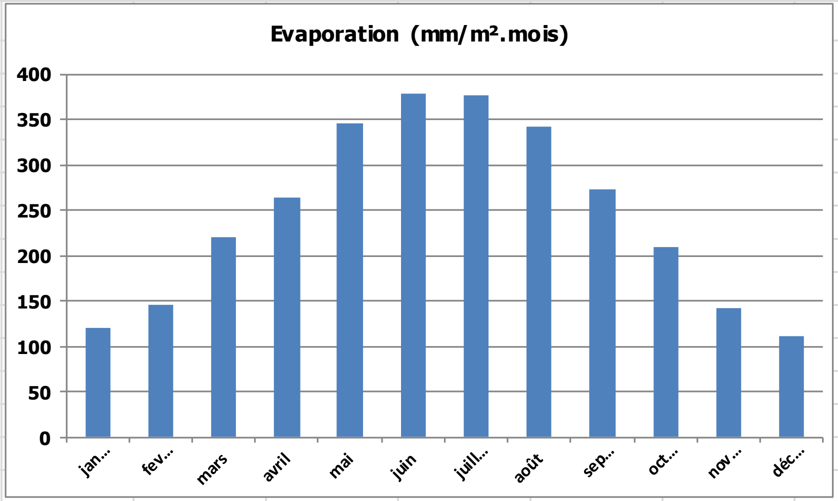
C. ANNEXES

C.1. ANNEX 1: CALCULATION NOTE SOLAR DRYER SCENARIOS 1 & 3

Évaporation	janvier	fevrier	mars	avril	mai	juin	juillet	août	septembre	octobre	novembre	décembre
mm/mois.m²	121	146	221	264	346	379	377	341	273	209	142	111
m³/j	15.80	21.07	28.82	35.63	45.24	51.12	49.27	44.61	36.87	27.27	19.20	14.56

EAST ZAHLE

	Irradiation		Eau évaporée			
	Wh/m².j	**kCal/m².j**	**kH_2O/m².j**	**t H_2O/an**	**kg/mois.m²**	
janvier	2,449	2106.2948	3.90	16	121	
fevrier	3,267	2809	5.20	21	146	
mars	4,467	3842	7.11	29	221	
avril	5,524	4751	8.80	36	264	
mai	7,014	6032	11.17	45	346	
juin	7,926	6816	12.62	51	379	
juillet	7,639	6570	12.17	49	377	
août	6,917	5948	11.02	45	341	
septembre	5,716	4915	9.10	37	273	
octobre	4,228	3636	6.73	27	209	
novembre	2,977	2561	4.74	19	142	
décembre	2,257	1941	3.60	15	111	
total	**5,043**	**51928**	**96.16**	**389**	**2930.19**	kg/m².an



Wh > kCal	0.86
evaporation	540 kCal /kg H_20
Surface serres	4,050 m²
evaporation	
Kg H20	1
kWh	0.628
kJ	2260.87
kCal	540

Séchage solaire des Boues d'épuration

Données entrée — **East Zahle 2040**

QB/MS	8.02 t MS/j
Siccité	18 %
Masse Volumique des boues	1.0 t/m3
Qbe (boues humides)	44.6 t/j
QH2Oe (eau des boues)	36.5 t/j

Objectif Sortie

Siccité moyenn	65%
inter. Variat	± 5%
QBs	12 t/j
QH2Os	4 t/j

Quantité d'eau à éliminer

Qevap	32 m3/j
R évaporation	100 %

Evaporation

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
nbr jours / mois	31	28	31	30	31	30	31	31	30	31	30	31
mm/mois/m²	121	146	221	264	346	379	377	341	273	209	142	111
m3/j/Ha	16	21	29	36	45	51	49	45	37	27	19	15

Surface unitaire d'une serre	**450**	**m2**
Nombre de serres nécessaires	**9**	
Surface utile nécessaire	**0.405**	**ha**

coefficient évap
2930 kg ee/m².an

Evaluation de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Flux de boues (T MS/j)	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**
Siccité initiale	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**
Objectif de siccité	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**
Quantité d'eau à évaporer (m3/j)	32	32	32	32	32	32	32	32	32	32	32	32
QH2O évap (m3/j)	16	21	29	36	45	51	49	45	37	27	19	15
Qbe traitable à (tMS/j)	4	5	7	9	11	13	12	11	9	7	5	4
Si fonctionnement à 8 t MS/j toute l'année												
Qbe non traitée(tMS/j)	4	3	1	0	0	0	0	0	0	1	3	4
Qbe non traitée(tMS/j) cumulable	4	3	1	-1	-3	-5	-4	-3	-1	1	3	4
Stock Boues non traitées (tMS/j)	4	7	8	7	4	0	0	0	0	1	4	9

Evaluation mensuelle de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Qbe du mois traitable à 65% (tMS)	122	147	222	266	349	382	380	344	275	210	143	112
Qbe non traitée du mois(tMS)	127	78	26	0	0	0	0	0	0	38	97	136
Qbe cumulable non traitée du mois(tMS)	127	78	26	-25	-100	-141	-132	-96	-35	38	97	136
Stock cummulé (tMS)	127	204	231	205	105	0	0	0	0	38	135	272

Volume annuel des boues à traiter à 18%	16,263	m3
Hauteur de la production annuelle stockée	4.0	m/an
Hauteur des boues dans la serre	0.30	m
Période de rotation moyenne	27	Jours
Quantité maximale stockée des boues brutesà 18%	2,790	m3
Période maximale de Stockage de la production	62.6	Jours

Production journalière	45 m3
Hauteur journalière du lit de boues	10 cm
Remplissage de la première serre	3.0 j
Rotation de remplissage des serres	27 j

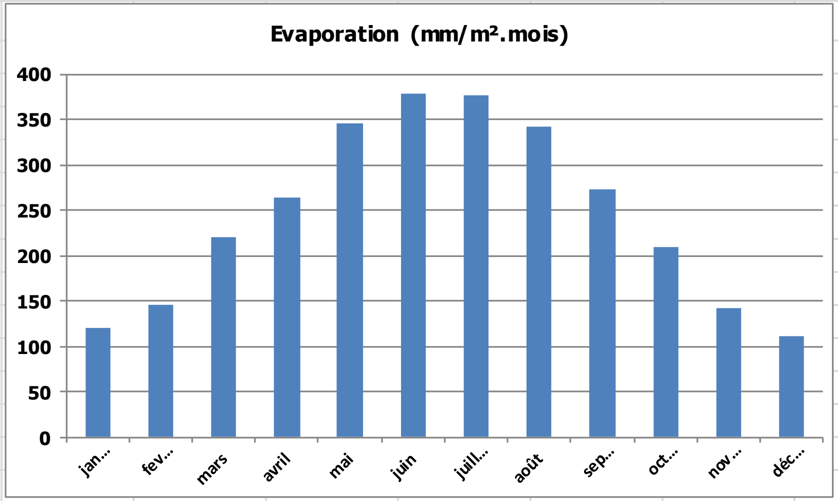
11,759 m3/an à évaporer
11,867 m3/an évaporable

C.2. ANNEX 2: CALCULATION NOTE SOLAR DRYER SCENARIOS 2 & 4

Évaporation	janvier	fevrier	mars	avril	mai	juin	juillet	août	septembre	octobre	novembre	décembre
mm/mois.m²	121	146	221	264	346	379	377	341	273	209	142	111
m³/j	9.75	13.01	17.79	21.99	27.93	31.56	30.42	27.54	22.76	16.84	11.85	8.99

EAST ZAHLE

	Irradiation		Eau évaporée			
	Wh/m².j	**kCal/m².j**	**kH_2O/m².j**	**t H_2O/j**	**kg/mois.m²**	
janvier	2,449	2106.2948	3.90	10	121	
fevrier	3,267	2809	5.20	13	146	
mars	4,467	3842	7.11	18	221	
avril	5,524	4751	8.80	22	264	
mai	7,014	6032	11.17	28	346	
juin	7,926	6816	12.62	32	379	
juillet	7,639	6570	12.17	30	377	
août	6,917	5948	11.02	28	341	
septembre	5,716	4915	9.10	23	273	
octobre	4,228	3636	6.73	17	209	
novembre	2,977	2561	4.74	12	142	
décembre	2,257	1941	3.60	9	111	
total	**5,043**	**51928**	**96.16**	**240**	**2930.19**	kg/m².an



Wh > kCal	0.86
evaporation	540 kCal /kg H_20
Surface serres	2,500 m²
evaporation	
Kg H20	1
kWh	0.628
kJ	2260.87
kCal > kg H2O	540

Séchage solaire des Boues d'épuration

Données entrée — **East Zahle 2040**

QB/MS	8.02 t MS/j
Siccité	25 %
Masse Volumique des boues	1.0 t/m3
Qbe (boues humides)	32.1 t/j
QH2Oe (eau des boues)	24.1 t/j

Objectif Sortie

Siccité moyenn	65%
inter. Variat	± 5%
QBs	12 t/j
QH2Os	4 t/j

Quantité d'eau à éliminer

Qevap	20 m3/j
R évaporation	100 %

Evaporation

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
nbr jours / mois	31	28	31	30	31	30	31	31	30	31	30	31
mm/mois/m²	121	146	221	264	346	379	377	341	273	209	142	111
m3/j	10	13	18	22	28	32	30	28	23	17	12	9

Surface unitaire d'une serre	**500**	**m2**
Nombre de serres nécessaires	**5**	
Surface utile nécessaire	**0.250**	**ha**

coefficient évap
2930 kg ee/m².an

Evaluation de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Flux de boues (T MS/j)	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**	**8.0**
Siccité initiale	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**
Objectif de siccité	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**
Quantité d'eau à évaporer (m3/j)	20	20	20	20	20	20	20	20	20	20	20	20
QH2O évap (m3/j)	10	13	18	22	28	32	30	28	23	17	12	9
Qbe traitable à (tMS/j)	4	5	7	9	11	13	12	11	9	7	5	4
Si fonctionnement à 8 t MS/j toute l'année												
Qbe non traitée(tMS/j)	4	3	1	0	0	0	0	0	0	1	3	4
Qbe non traitée(tMS/j) cumulable	4	3	1	-1	-3	-5	-4	-3	-1	1	3	4
Stock Boues non traitées (tMS/j)	4	7	8	7	3	0	0	0	0	1	4	9

Evaluation mensuelle de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Qbe du mois traitable à 65% (tMS)	123	148	224	268	352	385	383	347	277	212	144	113
Qbe non traitée du mois(tMS)	126	77	25	0	0	0	0	0	0	37	96	135
Qbe cumulable non traitée du mois(tMS)	126	77	25	-27	-103	-144	-134	-98	-37	37	96	135
Stock cummulé (tMS)	126	202	227	200	97	0	0	0	0	37	133	268

Volume annuel des boues à traiter à 25%	11,709	m3
Hauteur de la production annuelle stockée	4.7	m/an
Hauteur des boues dans la serre	0.30	m
Période de rotation moyenne	23	Jours
Quantité maximale stockée des boues brutes à 25%	1,981	m3
Période maximale de Stockage de la production	61.7	Jours

Production journalière	32 m3
Hauteur journalière du lit de boues	6 cm
Remplissage de la première serre	4.7 j
Rotation de remplissage des serres	23 j

7,206 m3/an à évaporer
7,325 m3/an évaporable

H.4. EL LABOUE

A. GENERAL PRESENTATION

The El Laboue wastewater treatment plant is under study. It will be located in the Baalbek district; its capacity at the 2035 horizon will be of 72,000 PE.

An extension of the treatment plant is foreseen for the 2045 horizon, the capacity of the plant will reach 79,000 PE.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025						
2040	Household + various industries	10 635	3 730	7 530	948	158

Note: We considered that no sludge will be generated at the 2025 horizon and that the treatment plant will start producing sludge at the 2040 horizon.

The data were transmitted by the Consultant in charge of the preliminary design of the treatment plant.

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening Grit and grease removal		Aeration tank Clarification	Chlorination *Optional: disk filters and UV disinfection*

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the sewage sludge produced by the plant are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
	Anaerobic (optional)	Belt filter press		

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.
Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge by 2040 horizon is presented in the table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025			
2040	1 103	5 514	18 %

Note: We considered that no sludge will be generated at the 2025 horizon and that the treatment plant will start producing sludge at the 2040 horizon.

The dryness values used were taken from the design report submitted by the Consultant in charge of the preparation of the tender documents.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of El Laboue to be "Potentially polluted sludge" because of the connected industries.

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site's dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara site and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained. The estimated surface area communicated by the Litani river authority is of 40,000 m^2.
- All the sludge going to the dedicated landfill is previously dried or incinerated.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the El Laboue WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the red process, it is necessary to implement the following sludge treatment steps for the El Laboue WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Cancellation of planned anaerobic and replacement by aerobic	Cancellation of planned belt filter press and replacement by centrifugation			Incineration in the Zahlé WWTP

B.2.1.1. DESIGN

Aerobic Digestion

We propose to replace the planned anaerobic digestion foreseen in the design of the El Laboue wastewater treatment plant with an aerobic digestion.

The minimum volume of the digester is calculated from the volume of the excess sludge of the clarifier per year and by considering a hydraulic retention time of 15 days in the digester. The volume of the El Laboue aerobic digester is of 650 m^3.

For information on operating principle and performance cf. Section D.1.1 above.

Centrifuges

In order to increase the LHV of the sludge to be incinerated and to reach an energy balance between digestion and incineration, it is necessary to replace the filter press by centrifuges in the El Laboue WWTP before incineration. The objective is to produce sludge with a minimum dryness of 25%.

The design of a centrifuge depends on two factors: the feed rate in m^3/h and the mass flow rate in kg of DM/h. Taking into consideration a 10% reduction in the OM content of digested sludge and a dryness of 2.5% at the outlet of the digester, we propose to install **2 centrifuges of 180 kgDM/h,** with the following operating conditions: 5 days/week and 16 h/day.

The calculation note for the design of the centrifuges is summarized in the table below:

		El Laboue
Digestion		Aerobic
Sludge to be dewatered	t DM/d	3.82
Dryness	%	2.5
Volume	m^3/d	153
Operation time	h/d	16
Hourly volume	m^3/h	10
Hourly mass	kg DM/h	239
Type of centrifuge		D 3 L C 30 B HP
Number	u	2
Unit capacity	kg DM/h	180

For information on operating principle and performance cf. Section D.2.1 above.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		El Laboue
Type of centrifuge		D 3 L C 30 B HP
Number	u	2
Unit capacity	kg DM/h	180
		€
Civil works (2 stories bldg)	1,500 €/m²	180,000
Equipment (with add %)	30%	262,210
Installation (% of EQ price)	20%	52,442
Electricity (% of EQ price)	15%	39,332
Total (in EURO)		**534,000**

Unit cost

	€ HT
D 3 L C 30 B HP	75000
Peripheral equiment (per machine)	10000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	800
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

Since the El Laboue treatment plant is still under study, the cost of the centrifuges can be included in the construction cost of the treatment plant.

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**436,452**
FIXED EXPENSES		
Major maintenance and renewal		
Total investment equipment	€	353,984
total investment civil	€	180,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	6,210
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**6,210**
TOTAL	***€/ year***	**6,210**

VARIABLE EXPENSES		
Regeants consumption		
Polymer		
Sludge tonnage	tDM/year	992
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	12
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/year**	**29,760**
Electrical consumption		
Dewatering		
Sludge tonnage	tDM/year	992
Consumption ratio	kWh_e/tDM	100
Electricity consumption	kWh_e/year	99,200
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	149,200
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**11,936**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	992
Dryness	%DM	25%
Tonnage of raw matter to be evacuated	tRM/year	3,968
Distance travelled (El Laboue – Zahlé)	km	68
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	388,547
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**388,547**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**29,760**
Electrical consumption	**€/year**	**11,936**
Sludge disposal	**€/year**	**388,547**
TOTAL	**€/year**	**430,243**

Since the El Laboue treatment plant is still under study, the cost of the additional centrifuges O&M can be included in the O&M cost of the treatment plant.

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the El Laboue WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the El Laboue WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Cancellation of planned anaerobic and replacement by aerobic	Belt filter press		Solar drying at Iaat	

B.2.2.1. DESIGN

Aerobic Digestion

We propose to replace the anaerobic digestion foreseen in the design of the El Laboue wastewater treatment plant with an aerobic digestion. The minimum volume of the digester is calculated from the volume of the excess sludge of the clarifier per year and by considering a hydraulic retention time of 15 days in the digester. The volume of the El Laboue aerobic digester is of 650 m^3.

For information on operating principle and performance cf. Section D.1.1 above.

Belt press filter

We propose to keep the dewatering process foreseen in the detailed design of the El Laboue wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the El Laboue WWTP will be dried in solar dryers constructed on the site of the Iaat wastewater treatment plant.

For information on operating principle and performance cf. Section D.3 above.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**261,188**
FIXED EXPENSES		
Major maintenance and renewal		
Total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**0**
TOTAL	***€/ year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	992
Dryness	%DM	18%
Tonnage of raw matter to be evacuated	tRM/year	5,511
Distance travelled (El Laboue – Iaat)	km	33
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	261,888
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**261,888**
TOTAL VARIABLE EXPENSES		
Sludge disposal	**€/year**	**261,188**
TOTAL	**€/year**	**261,188**

Since the El Laboue treatment plant is still under study, the cost of the additional solar dryers O&M can be included in the O&M cost of the treatment plant.

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the El Laboue WWTP was considered to be "non-compliant" and in order to satisfy the requirements of the red process, it is necessary to implement the following sludge treatment steps for the El Laboue WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Cancellation of planned anaerobic and replacement by aerobic	Cancellation of planned belt filter press and replacement by centrifugation			Incineration in the Zahlé WWTP

B.2.3.1. DESIGN

Aerobic Digestion

We propose to replace the planned anaerobic digestion foreseen in the design of the El Laboue wastewater treatment plant with an aerobic digestion.

The minimum volume of the digester is calculated from the volume of the excess sludge of the clarifier per year and by considering a hydraulic retention time of 15 days in the digester. The volume of the El Laboue aerobic digester is of 650 m³.

For information on operating principle and performance cf. Section D.1.1 above.

Centrifuges

In order to increase the LHV of the sludge to be incinerated and to reach an energy balance between digestion and incineration, it is necessary to replace the filter press by centrifuges in the El Laboue WWTP before incineration. The objective is to produce sludge with a minimum dryness of 25%.

The design of a centrifuge depends on 2 factors: the feed rate in m³/h and the mass flow rate in kg of DM/h. Taking into consideration a 10% reduction in the OM content of digested sludge and a dryness of 2.5% at the outlet of the digester, we suggest the installation of **2 centrifuges of 180 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

The calculation note for the design of the centrifuges is summarized in the table below:

		El Laboue
Digestion		Aerobic
Sludge to be dewatered	t DM/d	3.82
Dryness	%	2.5
Volume	m³/d	153
Operation time	h/d	16
Hourly volume	m³/h	10
Hourly mass	kg DM/h	239
Type of centrifuge		D 3 L C 30 B HP
Number	u	2
Unit capacity	kg DM/h	180

For information on operating principle and performance cf. Section D.2.1 above.

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		El Laboue
Type of centrifuge		D 3 L C 30 B HP
Number	u	2
Unit capacity	kg DM/h	180
		€
Civil works (2 stories bldg)	1,500 €/m²	180,000
Equipment (with add %)	30%	262,210
Installation (% of EQ price)	20%	52,442
Electricity (% of EQ price)	15%	39,332
Total (in EURO)		**534,000**

Unit cost

	€ HT
D 3 L C 30 B HP	75000
Peripheral equiment (per machine)	10000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	800
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

Since the El Laboue treatment plant is still under study, the cost of the centrifuges can be included in the construction cost of the treatment plant.

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total			**436,452**
FIXED EXPENSES			
Major maintenance and renewal			
	Total investment equipment	€	353,984
	total investment civil	€	180,000
	ratio equipment	%	1.50%
	ratio civil	%	0.50%
	Total annual cost	***€/year***	6,210
TOTAL FIXED EXPENSES			
	Major maintenance and renewal	***€/ year***	**6,210**
	TOTAL	***€/ year***	**6,210**

VARIABLE EXPENSES		
Regeants consumption		
Polymer		
Sludge tonnage	tDM/year	992
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	12
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/year**	**29,760**
Electrical consumption		
Dewatering		
Sludge tonnage	tDM/year	992
Consumption ratio	kWh_e/tDM	100
Electricity consumption	kWh_e/year	99,200
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	149,200
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**11,936**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	992
Dryness	%DM	25%
Tonnage of raw matter to be evacuated	tRM/year	3,968
Distance travelled (El Laboue – Zahlé)	km	68
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	388,547
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**388,547**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**29,760**
Electrical consumption	**€/year**	**11,936**
Sludge disposal	**€/year**	**388,547**
TOTAL	**€/year**	**430,243**

Since the El Laboue treatment plant is still under study, the cost of the additional centrifuges O&M can be included in the O&M cost of the treatment plant.

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the El Laboue WWTP was considered to be "non-compliant" and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the El Laboue WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Cancellation of planned anaerobic and replacement by aerobic	Cancellation of planned belt filter press and replacement by centrifugation		Solar drying at the El Laboue WWTP	

B.2.4.1. DESIGN

Aerobic Digestion

We propose to replace the planned anaerobic digestion foreseen in the design of the El Laboue wastewater treatment plant with an aerobic digestion.

The minimum volume of the digester is calculated from the volume of the excess sludge of the clarifier per year and by considering a hydraulic retention time of 15 days in the digester. The volume of the El Laboue aerobic digester is of 650 m^3.

For information on operating principle and performance cf. Section D.1.1 above.

Centrifuges

In order to reduce the area of the solar dryer, we propose to replace the filter press by centrifuges in the El Laboue WWTP. The objective is to produce sludge with a minimum dryness of 25%.

The design of a centrifuge depends on 2 factors: the feed rate in m^3/h and the mass flow rate in kg of DM/h. Taking into consideration a 10% reduction in the OM content of digested sludge and a dryness of 2.5% at the outlet of the digester, we suggest the installation of **2 centrifuges of 180 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

The calculation note for the design of the centrifuges is summarized in the table below:

		El Laboue
Digestion		Aerobic
Sludge to be dewatered	t DM/d	3.82
Dryness	%	2.5
Volume	m^3/d	153
Operation time	h/d	16
Hourly volume	m^3/h	10
Hourly mass	kg DM/h	239
Type of centrifuge		D 3 L C 30 B HP
Number	u	2
Unit capacity	kg DM/h	180

For information on operating principle and performance cf. Section D.2.1 above.

Solar Drying

The sludge output of the El Laboue WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 2.72 TDM/d with an average dryness of 25%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 7 m³/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m².year.
The solar drying area was calculated: 1,610 m².

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		El Laboue
Type of centrifuge		D 3 L C 30 B HP
Number	u	2
Unit capacity	kg DM/h	180
		€
Civil works (2 stories bldg)	1,500 €/m²	180,000
Equipment (with add %)	30%	262,210
Installation (% of EQ price)	20%	52,442
Electricity (% of EQ price)	15%	39,332
Total (in EURO)		**534,000**

Unit cost

	€ HT
D 3 L C 30 B HP	75000
Peripheral equipment (per machine)	10000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	800
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

Since the El Laboue treatment plant is still under study, the cost of the centrifuges can be included in the construction cost of the treatment plant.

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		Laboue
Coordinates		*34°12'6.78"N, 36°20'29.98"E*
Quantity of sludge to dry	t DM/d	2.72
Dryer surface area	m²	850
Civil works	M€	0.3
Equipment	M€	0.5
Total	**M€**	**0.8**

Since the El Laboue treatment plant is still under study, the cost of the solar dryers can be included in the construction cost of the treatment plant.

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**340,750**
FIXED EXPENSES		
Major maintenance and renewal		
Total investment equipment	€	837,317
total investment civil	€	463,333
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	14,876
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**14,876**
TOTAL	***€/ year***	**14,876**
VARIABLE EXPENSES		
Reagent consumption		
Polymer		
Sludge tonnage	tDM/year	992
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	12
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/ year**	**29,760**
Electrical consumption		
Dewatering		
Sludge tonnage	tDM/year	992
Consumption ratio	kWh_e/tDM	100
Electricity consumption	kWh_e/year	99,200
Solar drying		
Sludge tonnage	tDM/year	992
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	99
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	149,299
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**11,944**
Sludge Disposal		
Sludge		

Tonnage of dry matter to be evacuated	tDM/year	992
Dryness	%DM	25%
Tonnage of raw matter to be evacuated	tRM/year	3,968
Distance travelled (El Laboue – Machghara quarry)	km	105
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	230,754
Processing cost	€/tRM	35
Total processing cost	€/year	53,415
Total annual cost	**€/year**	**284,170**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**29,760**
Electrical consumption	**€/year**	**11,944**
Sludge disposal	**€/year**	**284,170**
TOTAL	**€/year**	**325,874**

Since the El Laboue treatment plant is still under study, the cost of the additional centrifuges and solar dryers O&M can be included in the O&M cost of the treatment plant.

H.5. FOURZOL

A. GENERAL PRESENTATION

The wastewater treatment plant of Fourzol is located in the Zahlé district; it has a capacity of 7 400 PE. The following cities and villages are connected to the treatment plant: Fourzol, Ablah, Nabi Ayla.

An extension of the treatment plant is foreseen at a future horizon, the capacity of the plant will reach 18,500 PE.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025	Household + agri-food industries	1 000	444	518	89	15
2040	Household + agri-food industries	2 500	1 111	1 296	222	37

The number of population equivalent (PE) and the flow indicated for the Fourzol wastewater treatment plant is extracted from a USAID report (the organization that financed the construction of this WWTP). The loads at the plant inlet were calculated from the typical French ratios shown in the table below:

	Unit	Value
Inflow to the plant	l/pers.day	135
BOD_5	*g/pers.day*	60
COD	*g/pers.day*	120
TSS	*g/pers.day*	70
TKN	*g/pers.day*	12
TP	*g/pers.day*	2

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening	Primary settling	Trickling filters Clarification	Chlorination

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the produced sewage sludge are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
	Aerobic			Drying beds

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.

Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge is presented in *the* table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025	160	154	94 %
2040	402	384	94 %

The dryness values used were confirmed by the operator of the treatment plant.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of Fourzol to be "potentially conforming to the requirements of the green process".

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site's dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge, which represents large volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained.
- All the sludge going to the dedicated landfill is previously dried or incinerated.
- The estimated surface area communicated by the Litani river authority is of 40,000 m^2.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Fourzol WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, no additional sludge treatment step is required in the Fourzol WWTP.

B.2.1.1. Design

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 200 m², equivalent to the production of sludge during 6 months is to be constructed on the Fourzol WWTP site.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 120 000 €.

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**28,712**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	120,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	600
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**600**
TOTAL	**€/ *year***	**600**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	361
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	384
Distance travelled (Fourzol – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	16591
Processing cost	€/tRM	30
Total processing cost	€/year	11521
Total annual cost	**€/**year	**28112**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**28,112**
TOTAL	**€/year**	**28,112**

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Fourzol WWTP was considered to be "compliant" and in order to satisfy the requirements of the green process, no additional sludge treatment step is required in the Fourzol WWTP.

B.2.2.1. Design

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 200 m², equivalent to the production of sludge during 6 months is to be constructed on the Fourzol WWTP site.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 120 000 €.

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**28,712**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	120,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	600
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**600**
TOTAL	**€/ *year***	**600**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	361
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	384
Distance travelled (Fourzol – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	16591
Processing cost	€/tRM	30
Total processing cost	€/year	11521
Total annual cost	**€/**year	**28112**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**28,112**
TOTAL	**€/year**	**28,112**

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Fourzol WWTP was considered to be “compliant” and in order to satisfy the requirements of the black process, no additional sludge treatment step is required in the Fourzol WWTP.

B.2.3.1. Design

N/A

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**42,199**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**0**
TOTAL	**€/ *year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	361
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	384
Distance travelled (Fourzol – Machghara quarry)	km	52
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	28,757
Processing cost	€/tRM	35
Total processing cost	€/year	13,441
Total annual cost	**€/**year	**42,199**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**42,199**
TOTAL	**€/year**	**42,199**

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Fourzol WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, no additional sludge treatment step is required in the Fourzol WWTP.

B.2.4.1. Design

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 200 m², equivalent to the production of sludge during 6 months is to be constructed on the Fourzol WWTP site.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 120 000 €.

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**28,712**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	120,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	600
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**600**
TOTAL	**€/ *year***	**600**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	361
Dryness	%DM	94%
Tonnage of raw matter to be evacuated	tRM/year	384
Distance travelled (Fourzol – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	16591
Processing cost	€/tRM	30
Total processing cost	€/year	11521
Total annual cost	**€/**year	**28112**
TOTAL VARIABLE EXPENSES		
Sludge Disposal	**€/year**	**28,112**
TOTAL	**€/year**	**28,112**

C. ANNEX

C.1. ANNEX 1: GENERAL LAYOUT OF THE STORAGE FOR SCENARIOS 1, 2 AND 4

General Layout of the storage (in blue) for scenarios 1, 2 and 4 at Fourzol

H.6. HERMEL

A. GENERAL PRESENTATION

The Hermel treatment plant is under study; its capacity is of 84,000 PE. It will be located in the Hermel district in the northern Bekaa Valley. The plant will serve the following cities and villages: Bweida, Beit Hera, Mansoura, Nasiriyah and Hermel.

An extension of the treatment plant is foreseen at a future horizon, the capacity of the plant will reach 112,000 PE.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025	Household	11 760	4 872	6 126	846	168
2040	Household	15 680	6 496	8 168	1 128	224

The flow rate and loads at the plant inlet were provided by the consultant in charge of the detailed design of the treatment plant. Only the phosphorus loads were calculated from the typical French ratios shown in the table below:

	Unit	Value
Inflow to the plant	l/pers.day	135
BOD_5	*g/pers.day*	60
COD	*g/pers.day*	120
TSS	*g/pers.day*	70
TKN	*g/pers.day*	12
TP	*g/pers.day*	2

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening Grit and grease removal		Aeration tank Clarification	Chlorination

Note: The effluent treatment process is identical for both 2025 and 2040 horizons.

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the sewage sludge produced by the plant are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
		Centrifugation	X	

Note: The sludge treatment process is identical for both 2025 and 2040 horizons.

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.
Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge by 2025 and by 2040 are presented in table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025	1 440	5 762	25 %
2040	1 921	7 682	25 %

The dryness values used were taken from the design report submitted by the Consultant in charge of the preparation of the design, construction supervision and O&M supervision.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of Hermel to be "potentially conforming to the requirements of the green process".

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site's dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained. The estimated surface area communicated by the Litani river authority is of 40,000 m^2.
- All the sludge going to the dedicated landfill is previously dried or incinerated.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Hermel WWTP was considered to be "compliant" and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the Hermel WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
	Centrifugation	Cancellation of planned liming	Solar drying at the Hermel WWTP to be added	

B.2.1.1. DESIGN

Centrifugation

In scenario 1, we propose to keep the dewatering process foreseen in the detailed design of the Hermel wastewater treatment plant and cancelling the planned liming system.

For information on operating principle and performance cf. Section D.2.1 above.

Solar Drying

The sludge output of the Hermel WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 5.26 TDM/d with an average dryness of 25%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 13 m³/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m².year.
The solar drying area was calculated: 1,640 m².

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 1,300 m², equivalent to the production of sludge during 6 months is to be constructed on the Hermel WWTP site.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		Hermel
Coordinates	Included WWTP	*34°23'40.62"N, 36°24'47.84"E*
Quantity of sludge to dry	t DM/d	5.262
Dryer surface area	m²	1,640
Civil works	M€	0.5
Equipment	M€	0.9
Total	**M€**	**1.5**

Since the Hermel treatment plant is still under study, the cost of the solar dryers can be included in the construction cost of the treatment plant.

Storage

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 780,000 €.

Since the Hermel treatment plant is still under study, the cost of the storage area can be included in the construction cost of the treatment plant.

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**236,668**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	746,200
total investment civil	€	1,025,180
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	16,319
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ year**	**16,319**
TOTAL	**€/ year**	**16,319**
VARIABLE EXPENSES		
Electricity consumption		
Solar drying		
Sludge tonnage	tDM/year	1,921
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	192
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	51,921
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,015**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	1,921
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	2,955
Distance travelled (Hermel – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	127,673
Processing cost	€/tRM	30
Total processing cost	€/year	88,662
Total annual cost	**€/year**	**216,334**
TOTAL VARIABLE EXPENSES		
Electricity consumption	**€/year**	**4,015**
Sludge Disposal	**€/year**	**216,334**
TOTAL	**€/year**	**220,350**

Since the Hermel treatment plant is still under study, the cost of the additional solar dryers O&M can be included in the O&M cost of the treatment plant.

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Hermel WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the Hermel WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
	Centrifugation	Cancellation of planned liming	Solar drying at the Hermel WWTP to be added	

B.2.2.1. DESIGN

Centrifuges

In scenario 2, we propose to keep the dewatering process foreseen in the detailed design of the Hermel wastewater treatment plant and cancelling the planned liming system.

For information on operating principle and performance cf. Section D.2.1 above.

Solar Drying

The sludge output of the Hermel WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 5.26 TDM/d with an average dryness of 25%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 13 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated: 1,640 m^2.

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 1,300 m^2, equivalent to the production of sludge during 6 months is to be constructed on the Hermel WWTP site.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		**Hermel**
Coordinates	Included WWTP	*34°23'40.62"N, 36°24'47.84"E*
Quantity of sludge to dry	t DM/d	5.262
Dryer surface area	m²	1,640
Civil works	M€	0.5
Equipment	M€	0.9
Total	**M€**	**1.5**

Since the Hermel treatment plant is still under study, the cost of the solar dryers can be included in the construction cost of the treatment plant.

Storage

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 780,000 €.

Since the Hermel treatment plant is still under study, the cost of the storage area can be included in the construction cost of the treatment plant.

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**236,668**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	746,200
total investment civil	€	1,025,180
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	16,319
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**16,319**
TOTAL	***€/ year***	**16,319**
VARIABLE EXPENSES		
Electricity consumption		
Solar drying		
Sludge tonnage	tDM/year	1,921
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	192
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	51,921
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,015**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	1,921
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	2,955
Distance travelled (Hermel – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	127,673
Processing cost	€/tRM	30
Total processing cost	€/year	88,662
Total annual cost	**€/year**	**216,334**
TOTAL VARIABLE EXPENSES		
Electricity consumption	**€/year**	**4,015**
Sludge Disposal	**€/year**	**216,334**
TOTAL	**€/year**	**220,350**

Since the Hermel treatment plant is still under study, the cost of the additional solar dryers O&M can be included in the O&M cost of the treatment plant.

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Hermel WWTP was considered to be “compliant” and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the Hermel WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
	Centrifugation	Cancellation of planned liming	Solar drying at the Hermel WWTP to be added	

B.2.3.1. DESIGN

Centrifuges

In scenario 3, we propose to keep the dewatering process foreseen in the detailed design of the Hermel wastewater treatment plant and cancelling the planned liming system.

For information on operating principle and performance cf. Section D.2.1 above.

Solar Drying

The sludge output of the Hermel WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 5.26 TDM/d with an average dryness of 25%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 13 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated: 1,640 m^2.

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		**Hermel**
Coordinates	Included WWTP	*34°23'40.62"N, 36°24'47.84"E*
Quantity of sludge to dry	t DM/d	5.262
Dryer surface area	m²	1,640
Civil works	M€	0.5
Equipment	M€	0.9
Total	**M€**	**1.5**

Since the Hermel treatment plant is still under study, the cost of the solar dryers can be included in the construction cost of the treatment plant.

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**681,632**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	746,200
total investment civil	€	245,180
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	12,419
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**12,419**
TOTAL	**€/ *year***	**12,419**
VARIABLE EXPENSES		
Electricity consumption		
Solar drying		
Sludge tonnage	tDM/year	1,921
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	192
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	51,921
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,015**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	1,921
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	2,955
Distance travelled (Hermel – spreading area)	km	132
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	561,760
Processing cost	€/tRM	35
Total processing cost	€/year	103,438
Total annual cost	**€/year**	**665,198**
TOTAL VARIABLE EXPENSES		
Electricity consumption	**€/year**	**4,015**
Sludge Disposal	**€/year**	**665,198**
TOTAL	**€/year**	**669,213**

Since the Hermel treatment plant is still under study, the cost of the additional solar dryers O&M can be included in the O&M cost of the treatment plant.

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Hermel WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the Hermel WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
	Centrifugation	Cancellation of planned liming	Solar drying at the Hermel WWTP to be added	

B.2.4.1. DESIGN

Centrifuges

In scenario 2, we propose to keep the dewatering process foreseen in the detailed design of the Hermel wastewater treatment plant and cancelling the planned liming system.

For information on operating principle and performance of centrifuges cf. Section D.2.1 above.

Solar Drying

The sludge output of the Hermel WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 5.26 TDM/d with an average dryness of 25%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 13 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated 1,640 m^2.

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance of solar dryers cf. Section D.3 above.

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 1,300 m^2, equivalent to the production of sludge during 6 months is to be constructed on the Hermel WWTP site.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040 Coordinates	Included WWTP	**Hermel** *34°23'40.62"N, 36°24'47.84"E*
Quantity of sludge to dry	t DM/d	5.262
Dryer surface area	m²	1,640
Civil works	M€	0.5
Equipment	M€	0.9
Total	**M€**	**1.5**

Since the Hermel treatment plant is still under study, the cost of the solar dryers can be included in the construction cost of the treatment plant.

Storage

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 780,000 €.

Since the Hermel treatment plant is still under study, the cost of the storage area can be included in the construction cost of the treatment plant.

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**236,668**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	746,200
total investment civil	€	1,025,180
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	16,319
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**16,319**
TOTAL	***€/ year***	**16,319**
VARIABLE EXPENSES		
Electricity consumption		
Solar drying		
Sludge tonnage	tDM/year	1,921
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	192
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	51,921
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,015**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	1,921
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	2,955
Distance travelled (Hermel – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	127,673
Processing cost	€/tRM	30
Total processing cost	€/year	88,662
Total annual cost	**€/year**	**216,334**
TOTAL VARIABLE EXPENSES		
Electricity consumption	**€/year**	**4,015**
Sludge Disposal	**€/year**	**216,334**
TOTAL	**€/year**	**220,350**

Since the Hermel treatment plant is still under study, the cost of the additional solar dryers O&M can be included in the O&M cost of the treatment plant.

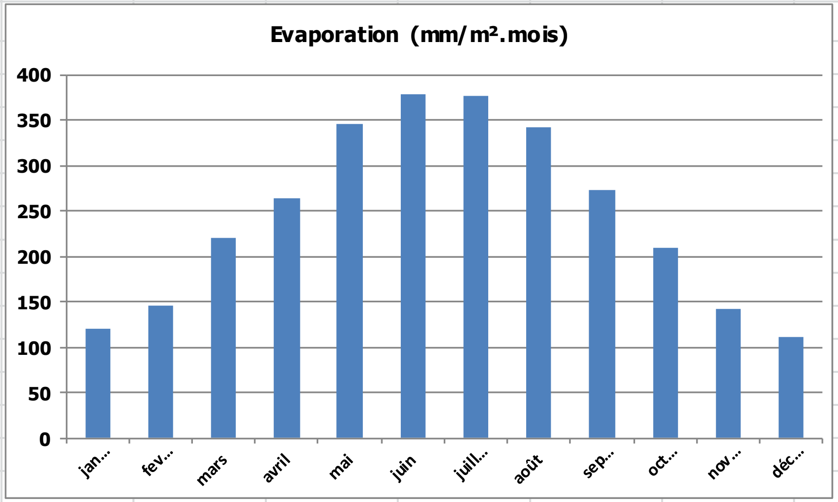
C. ANNEX

C.1. ANNEX 1: CALCULATION NOTE SOLAR DRYER

Évaporation	janvier	fevrier	mars	avril	mai	juin	juillet	août	septembre	octobre	novembre	décembre
mm/mois.m²	121	146	221	264	346	379	377	341	273	209	142	111
m³/j	6.40	8.53	11.67	14.43	18.32	20.70	19.95	18.07	14.93	11.04	7.78	5.90

HERMEL

	Irradiation		Eau évaporée			
	Wh/m².j	**kCal/m².j**	**kH_2O/m².j**	**t H_2O/an**	**kg/mois.m²**	
janvier	2,449	2106.2948	3.90	6	121	
fevrier	3,267	2809	5.20	9	146	
mars	4,467	3842	7.11	12	221	
avril	5,524	4751	8.80	14	264	
mai	7,014	6032	11.17	18	346	
juin	7,926	6816	12.62	21	379	
juillet	7,639	6570	12.17	20	377	
août	6,917	5948	11.02	18	341	
septembre	5,716	4915	9.10	15	273	
octobre	4,228	3636	6.73	11	209	
novembre	2,977	2561	4.74	8	142	
décembre	2,257	1941	3.60	6	111	
total	**5,043**	**51928**	**96.16**	**158**	**2930.19**	kg/m².an



Wh > kCal	0.86
evaporation	540 kCal /kg H_20
Surface serres	1,640 m²
evaporation	
Kg H20	1
kWh	0.628
kJ	2260.87
kCal	540

Séchage solaire des Boues d'épuration

Données entrée — **Hermel 2040**

QB/MS	5.262 t MS/j
Siccité	25 %
Masse Volumique des boues	1.0 t/m3
Qbe (boues humides)	21.0 t/j
QH2Oe (eau des boues)	15.8 t/j

Objectif Sortie

Siccité moyenn	65%
inter. Variat	± 5%
QBs	8 t/j
QH2Os	3 t/j

Quantité d'eau à éliminer

Qevap	13 m3/j
R évaporation	100 %

Evaporation

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
nbr jours / mois	31	28	31	30	31	30	31	31	30	31	30	31
mm/mois/m²	121	146	221	264	346	379	377	341	273	209	142	111
m3/j/Ha	6	9	12	14	18	21	20	18	15	11	8	6

Surface unitaire d'une serre	**410**	**m2**
Nombre de serres nécessaires	**4**	
Surface utile nécessaire	**0.16**	**ha**

coefficient évap
2930 kg ee/m².an

Evaluation de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Flux de boues (T MS/j)	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**	**5.3**
Siccité initiale	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**	**25%**
Objectif de siccité	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**
Quantité d'eau à évaporer (m3/j)	13	13	13	13	13	13	13	13	13	13	13	13
QH2O évap (m3/j)	6	9	12	14	18	21	20	18	15	11	8	6
Qbe traitable à (tMS/j)	3	3	5	6	7	8	8	7	6	4	3	2
Si fonctionnement à 6 t MS/j toute l'année												
Qbe non traitée(tMS/j)	3	2	1	0	0	0	0	0	0	1	2	3
Qbe non traitée(tMS/j) cumulable	3	2	1	-1	-2	-3	-3	-2	-1	1	2	3
Stock Boues non traitées (tMS/j)	3	4	5	4	2	0	0	0	0	1	3	6

Evaluation mensuelle de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Qbe du mois traitable à 65% (tMS)	81	97	147	176	231	252	251	228	182	139	95	74
Qbe non traitée du mois(tMS)	83	50	16	0	0	0	0	0	0	24	63	89
Qbe cumulable non traitée du mois(tMS)	83	50	16	-18	-68	-94	-88	-64	-24	24	63	89
Stock cummulé (tMS)	83	133	149	131	63	0	0	0	0	24	87	176

Volume annuel des boues à traiter à 25%	7,683	m3
Hauteur de la production annuelle stockée	4.7	m/an
Hauteur des boues dans la serre	0.30	m
Période de rotation moyenne	23	Jours
Quantité maximale stockée des boues brutesà 25%	1,300	m3
Période maximale de Stockage de la production	61.8	Jours

Production journalière	21 m3
Hauteur journalière du lit de boues	5 cm
Remplissage de la première serre	5.8 j
Rotation de remplissage des serres	23 j

4,728 m3/an à évaporer
4,806 m3/an évaporable

H.7. IAAT

A. GENERAL PRESENTATION

The Iaat plant is the second largest plant in the Bekaa Valley. It is located in the Baalbek district; its current capacity is of 100,000 PE. The plant currently serves the following cities and villages: Dours, Brital, El Ansar, Ain Bourday, Baalbek, Haouch Tall Safiyeh, Iaat, El Jmayle. There is no extension of the treatment plant foreseen for a future horizon.

The construction and commissioning of the treatment plant were done by Subal Group and supervised by Dar Al Handassah Taleb. The plant is operational since 2009.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant at by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025	Household + various industries	13 175	7 350	7 000	480	156
2040	Household + various industries	13 175	7 350	7 000	480	156

Note: The same values were adopted for the 2025 and the 2040 horizons since no extension is foreseen for the Iaat wastewater treatment plant.

The flow rate and loads at the plant inlet were provided by the operator, only the TSS load was calculated on the basis of the number of PE and the French theoretical ratios shown in the table below:

	Unit	Value
Inflow to the plant	l/pers.day	135
BOD_5	*g/pers.day*	60
COD	*g/pers.day*	120
TSS	*g/pers.day*	70
TKN	*g/pers.day*	12
TP	*g/pers.day*	2

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Screening Grit and grease removal		Aeration tank Clarification	Chlorination

Note: The effluent treatment process is identical for both 2025 and 2040 horizons.

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the sewage sludge produced by the plant are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
X	Aerobic	Belt filter press	X	

Note: The sludge treatment process is identical for both 2025 and 2040 horizons.

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.
Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge by 2025 and by 2040 are presented in *the* table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025	2 173	9 313	21 %
2040	2 173	9 313	21 %

Note: The same values were adopted for the 2025 and the 2040 horizons since no extension is foreseen for the Iaat wastewater treatment plant.

The dryness values used were taken from the design report submitted by the Consultant in charge of the preparation of the tender documents.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of Iaat to be "Potentially polluted sludge" because of the connected industries.

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site's dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained. The estimated surface area communicated by the Litani river authority is of 40,000 m^2.
- All the sludge going to the dedicated landfill is previously dried or incinerated.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Iaat WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the red process, it is necessary to implement the following sludge treatment steps for the Iaat WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Cancellation of planned belt filter press and replacement by centrifugation	Discontinuation of liming		Incineration in the Zahlé WWTP

B.2.1.1. DESIGN

Aerobic Digestion

In scenario 1, we propose to keep the aerobic digestion foreseen in the design of the Iaat wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Centrifuges

In order to increase the LHV of the sludge to be incinerated and to reach an energy balance between digestion and incineration, it is necessary to replace the filter press by centrifuges in the Zahlé WWTP before incineration. The objective is to produce sludge with a minimum dryness of 25%.

The design of a centrifuge depends on 2 factors: the feed rate in m^3/h and the mass flow rate in kg of DM/h. Taking into consideration a 10% reduction in the OM content of digested sludge and a dryness of 2.5% at the outlet of the digester, we suggest the installation of **2 centrifuges of 260 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

The calculation note for the design of the centrifuges is summarized in the table below:

		Iaat
Digestion		Aerobic
Sludge to be dewatered	t DM/d	7.52
Dryness	%	2.5
Volume	m^3/d	301
Operation time	h/d	16
Hourly volume	m^3/h	19
Hourly mass	kg DM/h	470
Type of centrifuge		D 3 LL C 30 B HP
Number	u	2
Unit capacity	kg DM/h	260

For information on operating principle and performance cf. Section D.2.1 above.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		Iaat
Type of centrifuge		D 3 LL C 30 B HP
Number	u	2
Unit capacity	kg DM/h	260
		€
Civil works (2 stories bldg)	1,500 €/m²	180,000
Equipment (with add %)	30%	298,870
Installation (% of EQ price)	20%	59,774
Electricity (% of EQ price)	15%	44,831
Total (in EURO)		**584,000**

Unit cost

	€ HT
D 3 LL C 30 B HP	85000
Peripheral equiment (per machine)	14000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	1000
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total			**581,009**
FIXED EXPENSES			
Major maintenance and renewal			
	Total investment equipment	€	403,475
	total investment civil	€	180,000
	ratio equipment	%	1.50%
	ratio civil	%	0.50%
	Total annual cost	***€/year***	6,952
TOTAL FIXED EXPENSES			
	Major maintenance and renewal	***€/ year***	**6,952**
	TOTAL	***€/ year***	**6,952**
VARIABLE EXPENSES			
Reagents consumption			
Polymer			
	Sludge tonnage	tDM/year	1,956
	Polymer rate	kg/tDM	12
	Total polymer consumption	t/year	23
	Unit cost of pure polymer	€/t	2,500
	Total annual cost	**€/year**	**58,680**
Electrical consumption			
Dewatering			
	Sludge tonnage	tDM/year	1,956
	Consumption ratio	kWh_e/tDM	100
	Electricity consumption	kWh_e/year	195,600
Miscellaneous			
	Electricity consumption	kWh_e/year	50,000
Total electrical consumption			
	Total consumption	kWh_e/year	245,600
	Unit cost	€/kWh_e	0.08
	Total annual cost	**€/year**	**19,648**
Sludge Disposal			
Sludge			
	Tonnage of dry matter to be evacuated	tDM/year	1,956
	Dryness	%DM	25%
	Tonnage of raw matter to be evacuated	tRM/year	7,824
	Distance travelled (Iaat – Zahlé)	km	44
	Unit cost of transport	€/ tRM/km	1.44
	Total cost of transport	€/year	495,729
	Processing cost	€/tRM	0
	Total processing cost	€/year	0
	Total annual cost	**€/year**	**495,729**
TOTAL VARIABLE EXPENSES			
	Reagents consumption	**€/year**	**58,680**
	Electrical consumption	**€/year**	**19,648**
	Sludge disposal	**€/year**	**495,729**
	TOTAL	**€/year**	**574,057**

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Iaat WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the Iaat WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press	Discontinuation of liming	Solar drying at Iaat	

B.2.2.1. DESIGN

Aerobic Digestion

In scenario 2, we propose to keep the aerobic digestion foreseen in the design of the Iaat wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt press filter

In scenario 2, we propose to keep the dewatering process foreseen in the design of the Iaat wastewater treatment plant and cancelling the planned liming system.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the Iaat, El Laboue and Yammouneh wastewater treatment plants will be dried in solar dryers constructed on the site of the Iaat treatment plant.
The total quantity of sludge produced by this plant is equal to 8.33 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 33 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated: 4,200 m^2.

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

Solar drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		**Iaat**
Coordinates		34° 2'55.36"N, 36° 8'44.01"E
	Included WWTP	Yammouneh - El Laboue
Quantity of sludge to dry	t DM/d	8.33
Dryer surface area	m²	4,200
Civil works	M€	1.4
Equipment	M€	2.4
Total	**M€**	**3.8**

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**792,418**
FIXED EXPENSES		
Major maintenance and renewal		
Total investment equipment	€	2,388,235
total investment civil	€	1,400,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	42,824
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**42,824**
TOTAL	***€/ year***	**42,824**
VARIABLE EXPENSES		
Electrical consumption		
Solar drying		
Sludge tonnage	tDM/year	3,051
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	305
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	50,305
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,024**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	3,051
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	4,694
Distance travelled (Iaat – Machghara quarry)	km	86
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	581,286
Processing cost	€/tRM	35
Total processing cost	€/year	164,285
Total annual cost	**€/year**	**745,571**
TOTAL VARIABLE EXPENSES		
Electrical consumption	**€/year**	**4,024**
Sludge disposal	**€/year**	**745,571**
TOTAL	**€/year**	**749,595**

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Iaat WWTP was considered to be "non-compliant" and in order to satisfy the requirements of the red process, it is necessary to implement the following sludge treatment steps for the Iaat WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Cancellation of planned belt filter press and replacement by centrifugation	Discontinuation of liming		Incineration in the Zahlé WWTP

B.2.3.1. DESIGN

Aerobic Digestion

In scenario 3, we propose to keep the aerobic digestion foreseen in the design of the Iaat wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Centrifuges

In order to increase the LHV of the sludge to be incinerated and to reach an energy balance between digestion and incineration, it is necessary to replace the filter press by centrifuges in the Zahlé WWTP before incineration. The objective is to produce sludge with a minimum dryness of 25%.

The design of a centrifuge depends on 2 factors: the feed rate in m^3/h and the mass flow rate in kg of DM/h. Taking into consideration a 10% reduction in the OM content of digested sludge and a dryness of 2.5% at the outlet of the digester, we suggest the installation of **2 centrifuges of 260 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

The calculation note for the design of the centrifuges is summarized in the table below:

		Iaat
Digestion		Aerobic
Sludge to be dewatered	t DM/d	7.52
Dryness	%	2.5
Volume	m^3/d	301
Operation time	h/d	16
Hourly volume	m^3/h	19
Hourly mass	kg DM/h	470
Type of centrifuge		D 3 LL C 30 B HP
Number	u	2
Unit capacity	kg DM/h	260

For information on operating principle and performance cf. Section D.2.1 above.

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		Iaat
Type of centrifuge		D 3 LL C 30 B HP
Number	u	2
Unit capacity	kg DM/h	260
		€
Civil works (2 stories bldg)	1,500 €/m²	180,000
Equipment (with add %)	30%	298,870
Installation (% of EQ price)	20%	59,774
Electricity (% of EQ price)	15%	44,831
Total (in EURO)		**584,000**

Unit cost

	€ HT
D 3 LL C 30 B HP	85000
Peripheral equiment (per machine)	14000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	1000
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**581,009**
FIXED EXPENSES		
Major maintenance and renewal		
Total investment equipment	€	403,475
total investment civil	€	180,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	6,952
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**6,952**
TOTAL	***€/ year***	**6,952**
VARIABLE EXPENSES		
Reagents consumption		
Polymer		
Sludge tonnage	tDM/year	1,956
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	23
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/year**	**58,680**
Electrical consumption		
Dewatering		
Sludge tonnage	tDM/year	1,956
Consumption ratio	kWh_e/tDM	100
Electricity consumption	kWh_e/year	195,600
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	245,600
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**19,648**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	1,956
Dryness	%DM	25%
Tonnage of raw matter to be evacuated	tRM/year	7,824
Distance travelled (Iaat – Zahlé)	km	44
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	495,729
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**495,729**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**58,680**
Electrical consumption	**€/year**	**19,648**
Sludge disposal	**€/year**	**495,729**
TOTAL	**€/year**	**574,057**

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Iaat WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the Iaat WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press	Discontinuation of liming	Solar drying at Iaat	

B.2.4.1. DESIGN

Aerobic Digestion

In scenario 4, we propose to keep the aerobic digestion foreseen in the design of the Iaat wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt press filter

In scenario 4, we propose to keep the dewatering process foreseen in the detailed design of the Iaat wastewater treatment plant and cancelling the planned liming system.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the Iaat WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 5.36 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 22 m³/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m².year.
The solar drying area was calculated: 2,700 m².

Note: the calculation note for the design of the solar dryers is in annex 3.

For information on operating principle and performance cf. Section D.3 above.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

Solar drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		**Iaat**
Coordinates		34° 2'55.36"N, 36° 8'44.01"E
Quantity of sludge to dry	t DM/d	5.36
Dryer surface area	m²	2,700
Civil works	M€	0.9
Equipment	M€	1.5
Total	**M€**	**2.4**

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**502,448**
FIXED EXPENSES		
Major maintenance and renewal		
Total investment equipment	€	1,228,500
total investment civil	€	403,650
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	20,446
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**20,446**
TOTAL	***€/ year***	**20,446**
VARIABLE EXPENSES		
Electrical consumption		
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	50,196
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,016**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	1,956
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	3,009
Distance travelled (Iaat – Machghara quarry)	km	86
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	372,663
Processing cost	€/tRM	35
Total processing cost	€/year	105,323
Total annual cost	**€/year**	**477,986**
TOTAL VARIABLE EXPENSES		
Electrical consumption	**€/year**	**4,016**
Sludge disposal	**€/year**	**477,986**
TOTAL	**€/year**	**482,002**

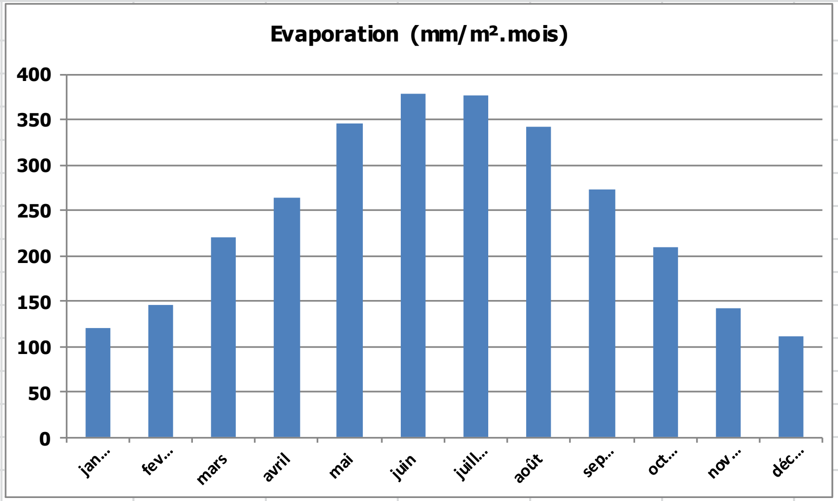
C. ANNEXES

C.1. ANNEX 1: CALCULATION NOTE SOLAR DRYER SCENARIO 2

Évaporation	janvier	fevrier	mars	avril	mai	juin	juillet	août	septembre	octobre	novembre	décembre
mm/mois.m²	121	146	221	264	346	379	377	341	273	209	142	111
m³/j	16.38	21.85	29.88	36.95	46.92	53.01	51.10	46.26	38.23	28.28	19.92	15.10

IAAT + YAMMOUNEH + EL LABOUE

	Irradiation		Eau évaporée			
	Wh/m².j	kCal/m².j	kH_2O/m².j	t H_2O/an	kg/mois.m²	
janvier	2,449	2106.2948	3.90	16	121	
fevrier	3,267	2809	5.20	22	146	
mars	4,467	3842	7.11	30	221	
avril	5,524	4751	8.80	37	264	
mai	7,014	6032	11.17	47	346	
juin	7,926	6816	12.62	53	379	
juillet	7,639	6570	12.17	51	377	
août	6,917	5948	11.02	46	341	
septembre	5,716	4915	9.10	38	273	
octobre	4,228	3636	6.73	28	209	
novembre	2,977	2561	4.74	20	142	
décembre	2,257	1941	3.60	15	111	
total	**5,043**	**51928**	**96.16**	**404**	**2930.19**	kg/m².an



Wh > kCal	0.86
evaporation	540 kCal /kg H_2O
Surface serres	4,200 m²
evaporation	
Kg H20	1
kWh	0.628
kJ	2260.87
kCal	540

Séchage solaire des Boues d'épuration

Données entrée — **Iaat 2040**

QB/MS	8.33	t MS/j
Siccité	18	%
Masse Volumique des boues	1.0	t/m3
Qbe (boues humides)	46.3	t/j
QH2Oe (eau des boues)	37.9	t/j

Objectif Sortie

Siccité moyenn	65%	
inter. Variat	± 5%	
QBs	13	t/j
QH2Os	4	t/j

Quantité d'eau à éliminer

Qevap	33	m3/j
R évaporation	100	%

Evaporation

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
nbr jours / mois	31	28	31	30	31	30	31	31	30	31	30	31
mm/mois/m²	121	146	221	264	346	379	377	341	273	209	142	111
m3/j/Ha	16	22	30	37	47	53	51	46	38	28	20	15

Surface unitaire d'une serre	**350**	**m2**
Nombre de serres nécessaires	**12**	
Surface utile nécessaire	**0.42**	**ha**

coefficient évap

2930 kg ee/m².an

Evaluation de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Flux de boues (T MS/j)	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**	**8.3**
Siccité initiale	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**
Objectif de siccité	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**
Quantité d'eau à évaporer (m3/j)	33	33	33	33	33	33	33	33	33	33	33	33
QH2O évap (m3/j)	16	22	30	37	47	53	51	46	38	28	20	15
Qbe traitable à (tMS/j)	4	5	7	9	12	13	13	12	10	7	5	4
Si fonctionnement à 8 t MS/j toute l'année												
Qbe non traitée(tMS/j)	4	3	1	0	0	0	0	0	0	1	3	5
Qbe non traitée(tMS/j) cumulable	4	3	1	-1	-3	-5	-4	-3	-1	1	3	5
Stock Boues non traitées (tMS/j)	4	7	8	7	4	0	0	0	0	1	5	9

Evaluation mensuelle de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Qbe du mois traitable à 65% (tMS)	126	152	231	276	362	396	394	357	286	218	149	117
Qbe non traitée du mois(tMS)	132	81	28	0	0	0	0	0	0	40	101	142
Qbe cumulable non traitée du mois(tMS)	132	81	28	-26	-104	-146	-136	-99	-36	40	101	142
Stock cummulé (tMS)	132	213	240	214	111	0	0	0	0	40	141	283

Volume annuel des boues à traiter à 18%	16,891	m3
Hauteur de la production annuelle stockée	4.0	m/an
Hauteur des boues dans la serre	0.30	m
Période de rotation moyenne	27	Jours
Quantité maximale stockée des boues brutesà 18%	2,907	m3
Période maximale de Stockage de la production	62.8	Jours

Production journalière	46 m3
Hauteur journalière du lit de boues	13 cm
Remplissage de la première serre	2.3 j
Rotation de remplissage des serres	27 j

12,214 m3/an à évaporer
12,307 m3/an évaporable

C.2. ANNEX 2: GENERAL LAYOUT OF SOLAR DRYING FOR SCENARIO 2

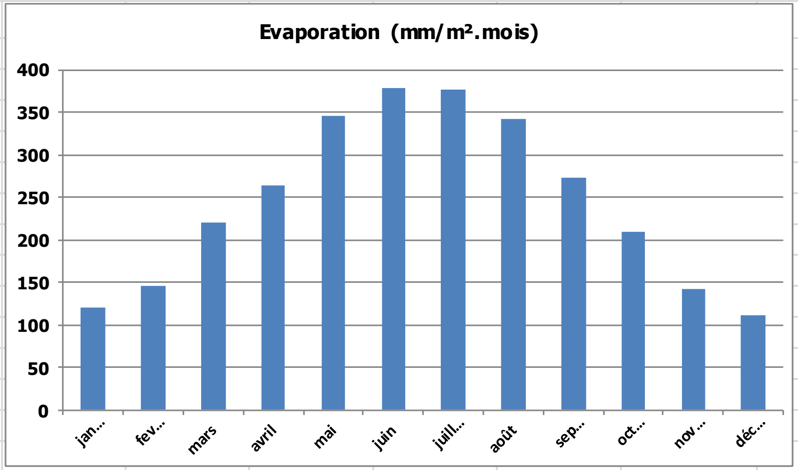
General Layout of solar drying for scenario 2 at Iaat

C.3. ANNEX 3: CALCULATION NOTE SOLAR DRYER SCENARIO 4

Évaporation	janvier	fevrier	mars	avril	mai	juin	juillet	août	septembre	octobre	novembre	décembre
mm/mois.m²	121	146	221	264	346	379	377	341	273	209	142	111
m³/j	10.53	14.05	19.21	23.75	30.16	34.08	32.85	29.74	24.58	18.18	12.80	9.71

IAAT

	Irradiation		Eau évaporée				
	Wh/m².j	kCal/m².j	$kH_2O/m^2.j$	t H_2O/j	m³/ha.j	kg/mois.m²	
janvier	2,449	2106.2948	3.90	11	447.84	121	
fevrier	3,267	2809	5.20	14	539.49	146	
mars	4,467	3842	7.11	19	816.89	221	
avril	5,524	4751	8.80	24	977.47	264	
mai	7,014	6032	11.17	30	1282.52	346	
juin	7,926	6816	12.62	34	1402.50	379	
juillet	7,639	6570	12.17	33	1396.90	377	
août	6,917	5948	11.02	30	1264.73	341	
septembre	5,716	4915	9.10	25	1011.42	273	
octobre	4,228	3636	6.73	18	773.17	209	
novembre	2,977	2561	4.74	13	526.86	142	
décembre	2,257	1941	3.60	10	412.77	111	
total	**5,043**	**51928**	**96.16**	**260**	**10852.56**	**2930.19**	kg/m².an



Wh > kCal	0.86
evaporation	540 kCal /kg H_20
Surface serres	2,700 m²
evaporation	
Kg H20	1
kWh	0.628
kJ	2260.87
kCal	540

Séchage solaire des Boues d'épuration

Données entrée — **Iaat 2040**

QB/MS	5.36	t MS/j
Siccité	18	%
Masse Volumique des boues	1.0	t/m3
Qbe (boues humides)	29.8	t/j
QH2Oe (eau des boues)	24.4	t/j

Objectif Sortie

Siccité moyenn	65%	
inter. Variat	± 5%	
QBs	8	t/j
QH2Os	3	t/j

Quantité d'eau à éliminer

Qevap	22	m3/j
R évaporation	100	%

Evaporation

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
nbr jours / mois	31	28	31	30	31	30	31	31	30	31	30	31
mm/mois/m²	121	146	221	264	346	379	377	341	273	209	142	111
m3/j	11	14	19	24	30	34	33	30	25	18	13	10

Surface unitaire d'une serre	**450**	**m2**
Nombre de serres nécessaires	**6**	
Surface utile nécessaire	**0.27**	**ha**

coefficient évap
2930 kg ee/m².an

Evaluation de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Flux de boues (T MS/j)	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**	**5.4**
Siccité initiale	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**
Objectif de siccité	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**
Quantité d'eau à évaporer (m3/j)	22	22	22	22	22	22	22	22	22	22	22	22
QH2O évap (m3/j)	11	14	19	24	30	34	33	30	25	18	13	10
Qbe traitable à (tMS/j)	3	3	5	6	8	8	8	7	6	5	3	2
Si fonctionnement à 5.4 t MS/j toute l'année												
Qbe non traitée(tMS/j)	3	2	1	0	0	0	0	0	0	1	2	3
Qbe non traitée(tMS/j) cumulable	3	2	1	-1	-2	-3	-3	-2	-1	1	2	3
Stock Boues non traitées (tMS/j)	3	5	5	5	2	0	0	0	0	1	3	6

Evaluation mensuelle de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Qbe du mois traitable à 65% (tMS)	81	98	148	177	233	255	254	230	184	140	96	75
Qbe non traitée du mois(tMS)	85	52	18	0	0	0	0	0	0	26	65	91
Qbe cumulable non traitée du mois(tMS)	85	52	18	-17	-67	-94	-87	-63	-23	26	65	91
Stock cummulé (tMS)	85	137	155	138	72	0	0	0	0	26	91	182

Volume annuel des boues à traiter à 18%	10,869	m3
Hauteur de la production annuelle stockée	4.0	m/an
Hauteur des boues dans la serre	0.30	m
Période de rotation moyenne	27	Jours
Quantité maximale stockée des boues brutesà 18%	1,874	m3
Période maximale de Stockage de la production	62.9	Jours

Production journalière	30 m3
Hauteur journalière du lit de boues	7 cm
Remplissage de la première serre	4.5 j
Rotation de remplissage des serres	27 j

7,859 m3/an à évaporer
7,912 m3/an évaporable

C.4. ANNEX 4: GENERAL LAYOUT OF SOLAR DRYING FOR SCENARIO 4

General Layout of solar drying for scenario 4 at Iaat

H.8. JOUB JANNINE

A. GENERAL PRESENTATION

The Joub Jannine treatment plant is located in West Bekaa; its current capacity is of 77,000 PE. The plant currently serves the following cities and villages: Haouch El Harime, Ghazze, Kefraya, Khorbet Anafar, El Khiyara, Joub Janine, Ana, Deit Tahnich, Aamiq, Tal Dnoub, Lala, Kamed El Lawz, El Sultan Yaacoub El Fawqa, El Sultan Yaacoub El Tahta, part of Ain Zebde.

The construction and commissioning of the treatment plant were done by Subal Engineering and supervised by Dar Al Handassah Taleb. The plant is operational since July 2014.

An extension of the treatment plant is foreseen at a future horizon, the capacity of the plant will reach 150,000 PE.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025	Household + agri-food industries	10 000	3 900	5 200	700	170
2040	Household + agri-food industries	20 000	9 000	10 500	1 800	300

The flow rate and loads at the plant inlet at the 2025 horizon were provided by the consultant that was in charge of the design, construction supervision and supervision of the operation and maintenance of the treatment plant until 2017.

As for the flow rate and loads at the plant inlet at the 2040 horizon, they were calculated from the typical French ratios shown in the table below:

	Unit	Value
Inflow to the plant	l/pers.day	135
BOD_5	*g/pers.day*	60
COD	*g/pers.day*	120
TSS	*g/pers.day*	70
TKN	*g/pers.day*	12
TP	*g/pers.day*	2

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening Grit and grease removal		Aerobic/yearaerobic/yearoxic tanks Clarification	Chlorination (filtration and UV disinfection inactive)

Note: The effluent treatment process is identical for both 2025 and 2040 horizons.

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the sewage sludge produced by the plant are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
X	Aerobic	Belt filter press		

Note: The sludge treatment process is identical for both 2025 and 2040 horizons.

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.
Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge by 2025 and by 2040 are presented in the table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025	1 153	5 765	18 %
2040	2 661	13 304	18 %

The dryness values used were taken from the design report submitted by the Consultant in charge of the preparation of the design, construction supervision and O&M supervision.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of Joub Jannine to be “potentially conforming to the requirements of the green process”.

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site’s dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained. The estimated surface area communicated by the Litani river authority is of 40,000 m^2.
- All the sludge going to the dedicated landfill is previously dried or incinerated.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Joub Jannine WWTP was considered to be "compliant" and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the Joub Jannine WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Solar drying at Joub Jannine	

B.2.1.1. DESIGN

Aerobic Digestion

In scenario 1, we propose to keep the aerobic digestion in place at the Joub Jannine wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt filter press

In scenario 1, we propose to keep the dewatering process foreseen in the design of the Joub Jannine wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the Saghbine and Joub Jannine wastewater treatment plants will be dried in solar dryers constructed on the site of the Joub Jannine treatment plant.
The total quantity of sludge produced by this plant is equal to 6.81 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 27 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated: 3,500 m^2.

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 1,600 m^2, equivalent to the production of sludge during 6 months is to be constructed on the Joub Jannine WWTP site.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		**Joub Jannine**
Coordinates		33°38'17.45"N, 35°46'33.33"E
	Included WWTP	Saghbine
Quantity of sludge to dry	t DM/d	6.81
Dryer surface area	m²	3,500
Civil works	M€	1.2
Equipment	M€	2.0
Total	**M€**	**3.2**

Storage

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 960 000 €.

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**315,466**
FIXED EXPENSES		
Major maintenance and renewal		
Total investment equipment	€	1,592,500
total investment civil	€	1,483,250
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	31,304
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**31,304**
TOTAL	**€/ *year***	**31,304**
VARIABLE EXPENSES		
Electrical consumption		
Solar drying		
Sludge tonnage	tDM/year	2,488
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	249
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	50,249
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,020**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	2,488
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	3,827
Distance travelled (Joub Jannine – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	165,330
Processing cost	€/tRM	30
Total processing cost	€/year	114,812
Total annual cost	**€/year**	**280,142**
TOTAL VARIABLE EXPENSES		
Electrical consumption	**€/year**	**4,020**
Sludge disposal	**€/year**	**280,142**
TOTAL	**€/year**	**284,162**

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Joub Jannine WWTP was considered to be "compliant" and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the Joub Jannine WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Solar drying at Joub Jannine	

B.2.2.1. DESIGN

Aerobic Digestion

In scenario 2, we propose to keep the aerobic digestion in place at the Joub Jannine wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt filter press

In scenario 2, we propose to keep the dewatering process foreseen in the design of the Joub Jannine wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the Saghbine and Joub Jannine wastewater treatment plants will be dried in solar dryers constructed on the site of the Joub Jannine treatment plant.
The total quantity of sludge produced by this plant is equal to 6.81 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 27 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated: 3,500 m^2.

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 1,600 m^2, equivalent to the production of sludge during 6 months is to be constructed on the Joub Jannine WWTP site.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		**Joub Jannine**
Coordinates		33°38'17.45"N, 35°46'33.33"E
	Included WWTP	Saghbine
Quantity of sludge to dry	t DM/d	6.81
Dryer surface area	m²	3,500
Civil works	M€	1.2
Equipment	M€	2.0
Total	**M€**	**3.2**

Storage

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 960 000 €.

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**315,466**
FIXED EXPENSES		
Major maintenance and renewal		
Total investment equipment	€	1,592,500
total investment civil	€	1,483,250
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	31,304
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**31,304**
TOTAL	***€/ year***	**31,304**
VARIABLE EXPENSES		
Electrical consumption		
Solar drying		
Sludge tonnage	tDM/year	2,488
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	249
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	50,249
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,020**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	2,488
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	3,827
Distance travelled (Joub Jannine – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	165,330
Processing cost	€/tRM	30
Total processing cost	€/year	114,812
Total annual cost	**€/year**	**280,142**
TOTAL VARIABLE EXPENSES		
Electrical consumption	**€/year**	**4,020**
Sludge disposal	**€/year**	**280,142**
TOTAL	**€/year**	**284,162**

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Joub Jannine WWTP was considered to be "compliant" and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the Joub Jannine WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Solar drying at Joub Jannine	

B.2.3.1. DESIGN

Aerobic Digestion

In scenario 3, we propose to keep the aerobic digestion in place at the Joub Jannine wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt filter press

In scenario 3, we propose to keep the dewatering process foreseen in the design of the Joub Jannine wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the Saghbine and Joub Jannine wastewater treatment plants will be dried in solar dryers constructed on the site of Joub Jannine treatment plant.
The total quantity of sludge produced by this plant is equal to 6.81 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 27 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated: 3,500 m^2.

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		**Joub Jannine**
Coordinates		33°38'17.45"N, 35°46'33.33"E
	Included WWTP	Saghbine
Quantity of sludge to dry	t DM/d	6.81
Dryer surface area	m²	3,500
Civil works	M€	1.2
Equipment	M€	2.0
Total	**M€**	**3.2**

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**263,669**
FIXED EXPENSES		
Major maintenance and renewal		
Total investment equipment	€	1,592,500
total investment civil	€	523,250
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	26,504
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**26,504**
TOTAL	***€/ year***	**26,504**
VARIABLE EXPENSES		
Electrical consumption		
Solar drying		
Sludge tonnage	tDM/year	2,488
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	249
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	50,249
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,020**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	2,488
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	3,827
Distance travelled (Joub Jannine – Machghara quarry)	km	18
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	99,198
Processing cost	€/tRM	35
Total processing cost	€/year	133,948
Total annual cost	**€/year**	**233,146**
TOTAL VARIABLE EXPENSES		
Electrical consumption	**€/year**	**4,020**
Sludge disposal	**€/year**	**233,146**
TOTAL	**€/year**	**237,165**

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Joub Jannine WWTP was considered to be "compliant" and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the Joub Jannine WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Solar drying at Joub Jannine	

B.2.4.1. DESIGN

Aerobic Digestion

In scenario 4, we propose to keep the aerobic digestion in place at the Joub Jannine wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt filter press

In scenario 4, we propose to keep the dewatering process foreseen in the design of the Joub Jannine wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the Saghbine and Joub Jannine wastewater treatment plants will be dried in solar dryers constructed on the site of the Joub Jannine treatment plant.
The total quantity of sludge produced by this plant is equal to 6.81 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 27 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated: 3,500 m^2.

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

Storage

Given the regulations and crop cycles observed in the Bekaa region, there are two main spreading periods: spring (March-April) and late summer-early autumn (August-September-October). Outside these periods, sludge continues to be produced and should therefore be stored.

A storage area of 1,600 m^2, equivalent to the production of sludge during 6 months is to be constructed on the Joub Jannine WWTP site.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

Solar Drying

The cost of the construction of the solar dryer is shown in the table below:

INVESTMENT 2040		Joub Jannine
Coordinates		33°38'17.45"N, 35°46'33.33"E
	Included WWTP	Saghbine
Quantity of sludge to dry	t DM/d	6.81
Dryer surface area	m²	3,500
Civil works	M€	1.2
Equipment	M€	2.0
Total	**M€**	**3.2**

Storage

The investment relative to the construction of the storage area was calculated using the typical ratio of 600 €/m², giving a total investment cost of 960 000 €.

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total		**315,466**
FIXED EXPENSES		
Major maintenance and renewal		
Total investment equipment	€	1,592,500
total investment civil	€	1,483,250
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	31,304
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**31,304**
TOTAL	***€/ year***	**31,304**
VARIABLE EXPENSES		
Electrical consumption		
Solar drying		
Sludge tonnage	tDM/year	2,488
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	249
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	50,249
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,020**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	2,488
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	3,827
Distance travelled (Joub Jannine – spreading area)	km	30
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	165,330
Processing cost	€/tRM	30
Total processing cost	€/year	114,812
Total annual cost	**€/year**	**280,142**
TOTAL VARIABLE EXPENSES		
Electrical consumption	**€/year**	**4,020**
Sludge disposal	**€/year**	**280,142**
TOTAL	**€/year**	**284,162**

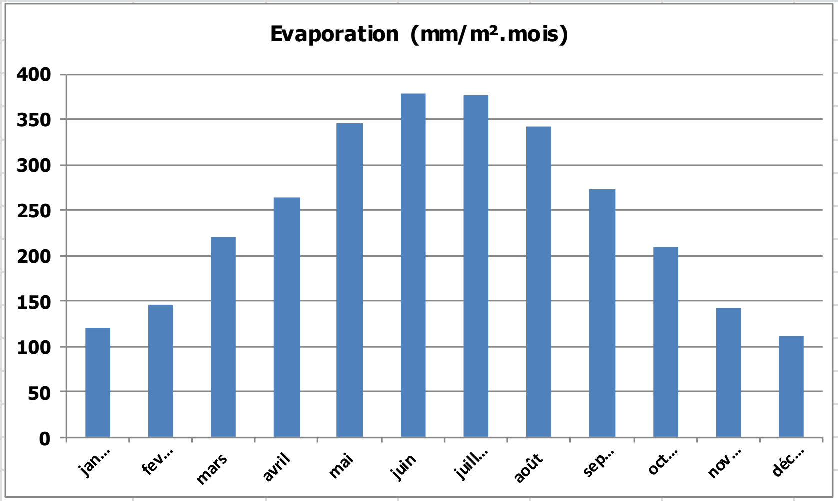
C. ANNEXES

C.1. ANNEX 1: CALCULATION NOTE SOLAR DRYER

Évaporation	janvier	fevrier	mars	avril	mai	juin	juillet	août	septembre	octobre	novembre	décembre
$mm/mois.m^2$	121	146	221	264	346	379	377	341	273	209	142	111
m^3/j	13.65	18.21	24.90	30.79	39.10	44.18	42.58	38.55	31.86	23.57	16.60	12.58

JOUB JANNINE + SAGHBINE

	Irradiation		Eau évaporée			
	$Wh/m^2.j$	**$kCal/m^2.j$**	**$kH_2O/m^2.j$**	**$t\ H_2O/j$**	**$kg/mois.m^2$**	
janvier	2,449	2106.2948	3.90	14	121	
fevrier	3,267	2809	5.20	18	146	
mars	4,467	3842	7.11	25	221	
avril	5,524	4751	8.80	31	264	
mai	7,014	6032	11.17	39	346	
juin	7,926	6816	12.62	44	379	
juillet	7,639	6570	12.17	43	377	
août	6,917	5948	11.02	39	341	
septembre	5,716	4915	9.10	32	273	
octobre	4,228	3636	6.73	24	209	
novembre	2,977	2561	4.74	17	142	
décembre	2,257	1941	3.60	13	111	
total	**5,043**	**51928**	**96.16**	**337**	**2930.19**	$kg/m^2.an$



Wh > kCal	0.86
evaporation	540 kCal /kg H_20
Surface serres	3,500 m^2
evaporation	
Kg H20	1
kWh	0.628
kJ	2260.87
kCal	540

Séchage solaire des Boues d'épuration

Données entrée	Joub 2040
QB/MS	6.81 t MS/j
Siccité	18 %
Masse Volumique des boues	1.0 t/m3
Qbe (boues humides)	37.8 t/j
QH2Oe (eau des boues)	31.0 t/j

Objectif Sortie

Siccité moyenn	65%
inter. Variat	± 5%
QBs	10 t/j
QH2Os	4 t/j

Quantité d'eau à éliminer

Qevap	27 m3/j
R évaporation	100 %

Evaporation

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
nbr jours / mois	31	28	31	30	31	30	31	31	30	31	30	31
mm/mois/m²	121	146	221	264	346	379	377	341	273	209	142	111
m3/j	14	18	25	31	39	44	43	39	32	24	17	13

Surface unitaire d'une serre	500	m2
Nombre de serres nécessaires	7	
Surface utile nécessaire	0.35	ha

coefficient évap

2930 kg ee/m².an

Evaluation de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Flux de boues (T MS/j)	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**	**6.8**
Siccité initiale	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**
Objectif de siccité	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**
Quantité d'eau à évaporer (m3/j)	27	27	27	27	27	27	27	27	27	27	27	27
QH2O évap (m3/j)	14	18	25	31	39	44	43	39	32	24	17	13
Qbe traitable à (tMS/j)	3	5	6	8	10	11	11	10	8	6	4	3
Si fonctionnement à 6.8 t MS/j toute l'année												
Qbe non traitée(tMS/j)	3	2	1	0	0	0	0	0	0	1	3	4
Qbe non traitée(tMS/j) cumulable	3	2	1	-1	-3	-4	-4	-3	-1	1	3	4
Stock Boues non traitées (tMS/j)	3	6	6	5	3	0	0	0	0	1	4	7

Evaluation mensuelle de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Qbe du mois traitable à 65% (tMS)	105	127	192	230	302	330	329	298	238	182	124	97
Qbe non traitée du mois(tMS)	106	64	19	0	0	0	0	0	0	29	80	114
Qbe cumulable non traitée du mois(tMS)	106	64	19	-26	-91	-126	-118	-86	-34	29	80	114
Stock cummulé (tMS)	106	170	188	163	72	0	0	0	0	29	110	224

Volume annuel des boues à traiter à 18%	13,809	m3
Hauteur de la production annuelle stockée	3.9	m/an
Hauteur des boues dans la serre	0.30	m
Période de rotation moyenne	28	Jours
Quantité maximale stockée des boues brutesà 18%	2,289	m3
Période maximale de Stockage de la production	60.5	Jours

Production journalière	38 m3
Hauteur journalière du lit de boues	8 cm
Remplissage de la première serre	4.0 j
Rotation de remplissage des serres	28 j

9,985 m3/an à évaporer
10,256 m3/an évaporable

C.2. ANNEX 2: GENERAL LAYOUT OF THE SOLAR DRYING AND STORAGE FOR SCENARIOS 1, 2 AND 4

General Layout of the solar drying and storage for scenarios 1, 2 and 4 at Joub Jannine

Legend:

- *In red: the solar greenhouse*
- *In blue: storage*

C.3. ANNEX 3: GENERAL LAYOUT OF THE SOLAR DRYING FOR SCENARIO 3

General Layout of the solar drying for scenario 3 at Joub Jannine

H.9. MARJ

A. GENERAL PRESENTATION

The Marj wastewater treatment plant is in the last stage of the tendering procedure. It will be located on the border between the West Bekaa district and Zahlé, on the West Bekaa side; its capacity at the 2025 horizon will be of 260,000 PE.

The plant will serve the following cities and villages: Barr Elias, El Marj, El Raouda, Aanjar, Majdel Aanjar, Saouiri, Taanayel, Taalabaya, Jalala, Chtaura, Jdita, Bouarej, Zebdol, Makse, El Mraijat, Ouadi El Delem, Qabb Elias.

An extension of the treatment plant is foreseen for a future horizon, the capacity of the plant will reach 350,000 PE.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025	Household + various industries	31 200	12 480	13 728	1 872	468
2040	Household + various industries	43 200	17 280	19 008	2 592	648

The data were transmitted by the Consultant in charge of the preliminary design of the treatment plant.

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening Grit and grease removal	Settling	Anaerobic tank Anoxic tank Aerobic tank Settling	Chlorination

Note: The effluent treatment process is identical for both 2025 and 2040 horizons.

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the sewage sludge produced by the plant are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
Gravity	Aerobic	Belt filter press		Emergency Drying beds

Note: The sludge treatment process is identical for both 2025 and 2040 horizons.

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.
Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge by 2025 and by 2040 are presented in the table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025	4 510	5 411	20 %
2040	6 244	7 493	20 %

The dryness values used were taken from the design report submitted by the Consultant in charge of the preparation of the tender documents.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of Marj to be "Potentially polluted sludge" because of the connected industries.

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site's dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained. The estimated surface area communicated by the Litani river authority is of 40,000 m^2.
- All the sludge going to the dedicated landfill is previously dried or incinerated.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Marj WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the red process, it is necessary to implement the following sludge treatment steps for the Marj WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Cancellation of planned belt filter press and replacement by centrifugation			Incineration in the Zahlé WWTP

B.2.1.1. DESIGN

Aerobic Digestion

In scenario 1, we propose to keep the aerobic digestion foreseen in the design of the Marj wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Centrifuges

In order to increase the LHV of the sludge to be incinerated and to reach an energy balance between digestion and incineration, it is necessary to replace the filter press by centrifuges in the Marj WWTP before incineration. The objective is to produce sludge with a minimum dryness of 25%.

The design of a centrifuge depends on 2 factors: the feed rate in m^3/h and the mass flow rate in kg of DM/h. Taking into consideration a 10% reduction in the OM content of digested sludge and a dryness of 2.5% at the outlet of the digester, we suggest the installation of **3 centrifuges of 480 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

The calculation note for the design of the centrifuges is shown in the table below:

		Marj
Digestion		Aerobic
Sludge to be dewatered	t DM/d	21.61
Dryness	%	2.5
Volume	m^3/d	865
Operation time	h/d	16
Hourly volume	m^3/h	54
Hourly mass	kg DM/h	1351
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480

For information on operating principle and performance cf. Section D.2.1 above.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		Marj
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480
		€
Civil works (2 stories bldg)	1,500 €/m²	228,000
Equipment (with add %)	30%	531,180
Installation (% of EQ price)	20%	106,236
Electricity (% of EQ price)	15%	79,677
Total (in EURO)		**946,000**

Unit cost

	€ HT
D 4 LL C 30 B HP	115000
Peripheral equiment (per machine)	8000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	1000
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**1,006,355**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	717,093
total investment civil	€	228,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	11,896
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**11,896**
TOTAL	***€/ year***	**11,896**
VARIABLE EXPENSES		
Reagents consumption		
Polymer		
Sludge tonnage	tDM/year	5,620
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	67
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/year**	**168,589**
Electrical consumption		
Dewatering		
Sludge tonnage	tDM/year	5,620
Consumption ratio	kWh_e/tDM	100
Electricity consumption	kWh_e/year	562,000
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	612,000
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**48,960**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	5,620
Dryness	%DM	25%
Tonnage of raw matter to be evacuated	tRM/year	22,480
Distance travelled (Marj – Zahlé)	km	24
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	776,909
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**776,909**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**168,589**
Electrical consumption	**€/year**	**48,960**
Sludge disposal	**€/year**	**776,909**
TOTAL	**€/year**	**994,458**

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Marj WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the Marj WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Cancellation of optional drying bed in favor of solar drying in the Zahlé WWTP	

B.2.2.1. DESIGN

Aerobic Digestion

In scenario 2, we propose to keep the aerobic digestion foreseen in the design of the Marj wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt filter press

In scenario 2, we propose to keep the belt press filter foreseen in the design of the Marj wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the Marj WWTP will be dried in solar dryers constructed on the site of Zahlé treatment plant.

For information on operating principle and performance cf. Section D.3 above.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**1,079,040**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**0**
TOTAL	**€/ *year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	5,620
Dryness	%DM	18%
Tonnage of raw matter to be evacuated	tRM/year	31,222
Distance travelled (Marj – Zahlé)	km	24
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	1,079,040
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**1,079,040**
TOTAL VARIABLE EXPENSES		
Sludge disposal	**€/year**	**1,079,040**
TOTAL	**€/year**	**1,079,040**

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Marj WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the red process, it is necessary to implement the following sludge treatment steps for the Marj WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Cancellation of planned belt filter press and replacement by centrifugation			Incineration in the Zahlé WWTP

B.2.3.1. DESIGN

Aerobic Digestion

In scenario 3, we propose to keep the aerobic digestion foreseen in the design of the Marj wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Centrifuges

In order to increase the LHV of the sludge to be incinerated and to reach an energy balance between digestion and incineration, it is necessary to replace the filter press by centrifuges in the Marj WWTP before incineration. The objective is to produce sludge with a minimum dryness of 25%.

The design of a centrifuge depends on 2 factors: the feed rate in m^3/h and the mass flow rate in kg of DM/h. Taking into consideration a 10% reduction in the OM content of digested sludge and a dryness of 2.5% at the outlet of the digester, we suggest the installation of **3 centrifuges of 480 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

The calculation note for the design of the centrifuges is shown in the table below:

		Marj
Digestion		Aerobic
Sludge to be dewatered	t DM/d	21.61
Dryness	%	2.5
Volume	m^3/d	865
Operation time	h/d	16
Hourly volume	m^3/h	54
Hourly mass	kg DM/h	1351
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480

For information on operating principle and performance cf. Section D.2.1 above.

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		Marj
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480
		€
Civil works (2 stories bldg)	1,500 €/m²	228,000
Equipment (with add %)	30%	531,180
Installation (% of EQ price)	20%	106,236
Electricity (% of EQ price)	15%	79,677
Total (in EURO)		**946,000**

Unit cost

	€ HT
D 4 LL C 30 B HP	115000
Peripheral equiment (per machine)	8000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	1000
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**1,006,355**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	717,093
total investment civil	€	228,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	11,896
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**11,896**
TOTAL	***€/ year***	**11,896**
VARIABLE EXPENSES		
Reagents consumption		
Polymer		
Sludge tonnage	tDM/year	5,620
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	67
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/year**	**168,589**
Electrical consumption		
Dewatering		
Sludge tonnage	tDM/year	5,620
Consumption ratio	kWh_e/tDM	100
Electricity consumption	kWh_e/year	562,000
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	612,000
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**48,960**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	5,620
Dryness	%DM	25%
Tonnage of raw matter to be evacuated	tRM/year	22,480
Distance travelled (Marj – Zahlé)	km	24
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	776,909
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**776,909**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**168,589**
Electrical consumption	**€/year**	**48,960**
Sludge disposal	**€/year**	**776,909**
TOTAL	**€/year**	**994,458**

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Marj WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the Marj WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Cancellation of optional drying bed in favor of solar drying in Marj	

B.2.4.1. DESIGN

Aerobic Digestion

In scenario 4, we propose to keep the aerobic digestion foreseen in the design of the Marj wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt filter press

In scenario 4, we propose to keep the belt press filter foreseen in the design of the Marj wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the Marj WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 15.4 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 62 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated: 8,000 m^2.

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

The investment cost of the solar dryer is detailed in the table below:

INVESTMENT 2040		**Marj**
Coordinates		33.743799, 35.846684
Quantity of sludge to dry	t DM/d	15.4
Dryer surface area	m²	8,000
Civil works	M€	2.7
Equipment	M€	4.5
Total	**M€**	**7.2**

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**827,907**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	3,640,000
total investment civil	€	1,196,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	60,580
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**60,580**
TOTAL	**€/ *year***	**60,580**
VARIABLE EXPENSES		
Electrical consumption		
Sludge drying		
Sludge tonnage	tDM/year	5,620
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	562
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	50,562
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,045**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	5,620
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	8,646
Distance travelled (Marj – Machghara quarry)	km	37
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	460,667
Processing cost	€/tRM	35
Total processing cost	€/year	302,615
Total annual cost	**€/year**	**763,282**
TOTAL VARIABLE EXPENSES		
Electrical consumption	**€/year**	**4,045**
Sludge disposal	**€/year**	**763,282**
TOTAL	**€/year**	**767,327**

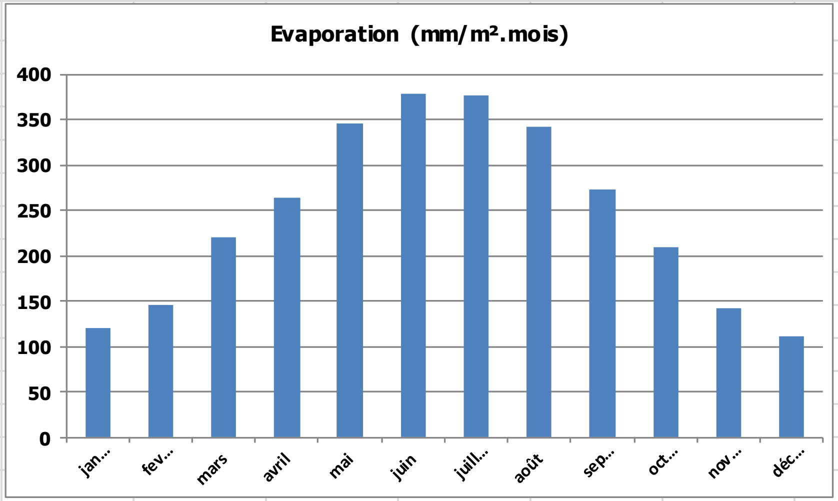
C. ANNEXES

C.1. ANNEX 1: CALCULATION NOTE SOLAR DRYER

Évaporation	janvier	fevrier	mars	avril	mai	juin	juillet	août	septembre	octobre	novembre	décembre
mm/mois.m²	121	146	221	264	346	379	377	341	273	209	142	111
m³/j	31.20	41.62	56.92	70.38	89.36	100.98	97.33	88.12	72.82	53.87	37.93	28.76

MARJ

	Irradiation		Eau évaporée			
	Wh/m².j	kCal/m².j	$kH_2O/m^2.j$	$t\ H_2O/j$	kg/mois.m²	
janvier	2,449	2106.2948	3.90	31	121	
fevrier	3,267	2809	5.20	42	146	
mars	4,467	3842	7.11	57	221	
avril	5,524	4751	8.80	70	264	
mai	7,014	6032	11.17	89	346	
juin	7,926	6816	12.62	101	379	
juillet	7,639	6570	12.17	97	377	
août	6,917	5948	11.02	88	341	
septembre	5,716	4915	9.10	73	273	
octobre	4,228	3636	6.73	54	209	
novembre	2,977	2561	4.74	38	142	
décembre	2,257	1941	3.60	29	111	
total	**5,043**	**51928**	**96.16**	**769**	**2930.19**	kg/m².an



Wh -> kCal	0.86
evaporation	540 kCal /kg H_2O
Surface serres	8,000 m²
evaporation	
Kg H20	1
kWh	0.628
kJ	2260.87
kCal	540

Séchage solaire des Boues d'épuration

Données entrée — **Marj 2040**

QB/MS	15.4 t MS/j
Siccité	18 %
Masse Volumique des boues	1.0 t/m3
Qbe (boues humides)	85.6 t/j
QH2Oe (eau des boues)	70.2 t/j

Objectif Sortie

Siccité moyenn	65%
inter. Variat	± 5%
QBs	24 t/j
QH2Os	8 t/j

Quantité d'eau à éliminer

Qevap	62 m3/j
R évaporation	100 %

Evaporation

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
nbr jours / mois	31	28	31	30	31	30	31	31	30	31	30	31
mm/mois/m²	121	146	221	264	346	379	377	341	273	209	142	111
m3/j	31	42	57	70	89	101	97	88	73	54	38	29

Surface unitaire d'une serre	**500**	**m2**
Nombre de serres nécessaires	**16**	
Surface utile nécessaire	**0.80**	**ha**

coefficient évap
2930 kg ee/m².an

Evaluation de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Flux de boues (T MS/j)	**15.4**	**15.4**	**15.4**	**15.4**	**15.4**	**15.4**	**15.4**	**15.4**	**15.4**	**15.4**	**15.4**	**15.4**
Siccité initiale	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**
Objectif de siccité	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**
Quantité d'eau à évaporer (m3/j)	62	62	62	62	62	62	62	62	62	62	62	62
QH2O évap (m3/j)	31	42	57	70	89	101	97	88	73	54	38	29
Qbe traitable à (tMS/j)	8	10	14	18	22	25	24	22	18	13	9	7
Si fonctionnement à 15.4 t MS/j toute l'année												
Qbe non traitée(tMS/j)	8	5	1	0	0	0	0	0	0	2	6	8
Qbe non traitée(tMS/j) cumulable	8	5	1	-2	-7	-10	-9	-7	-3	2	6	8
Stock Boues non traitées (tMS/j)	8	13	14	12	5	0	0	0	0	2	8	16

Evaluation mensuelle de la production des boues (tMS)

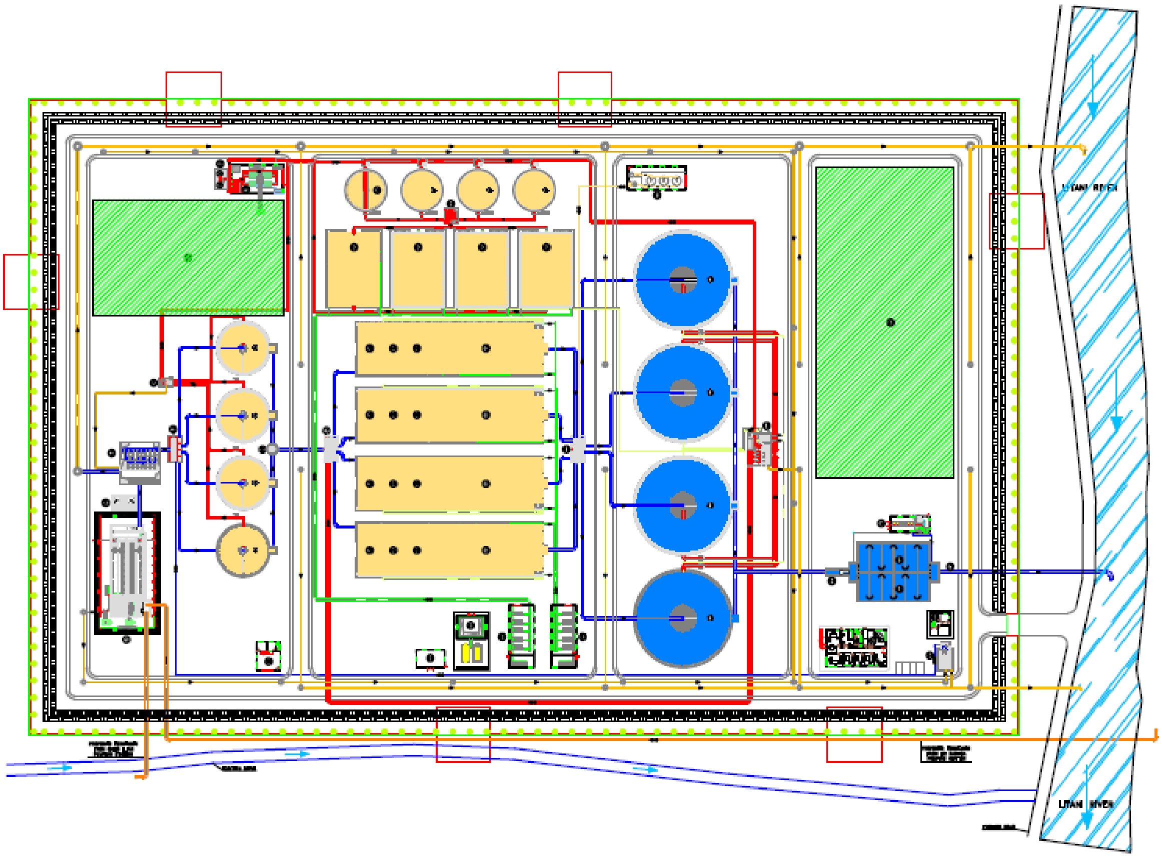
	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Qbe du mois traitable à 65% (tMS)	241	290	439	526	690	754	751	680	544	416	283	222
Qbe non traitée du mois(tMS)	237	141	38	0	0	0	0	0	0	62	179	255
Qbe cumulable non traitée du mois(tMS)	237	141	38	-64	-212	-292	-274	-203	-82	62	179	255
Stock cummulé (tMS)	237	378	416	352	140	0	0	0	0	62	240	496

Volume annuel des boues à traiter à 18%	31,228	m3
Hauteur de la production annuelle stockée	3.9	m/an
Hauteur des boues dans la serre	0.30	m
Période de rotation moyenne	28	Jours
Quantité maximale stockée des boues brutesà 18%	5,065	m3
Période maximale de Stockage de la production	59.2	Jours

Production journalière	86 m3
Hauteur journalière du lit de boues	17 cm
Remplissage de la première serre	1.8 j
Rotation de remplissage des serres	28 j

22,580 m3/an à évaporer
23,442 m3/an évaporable

C.2. ANNEX 2: GENERAL LAYOUT OF THE SOLAR DRYING FOR SCENARIO 4



General Layout of the solar drying (in green) for scenario 4 at Marj

H.10. SAGHBINE

A. GENERAL PRESENTATION

The Saghbine treatment plant is located in West Bekaa; its current capacity is of 4,000 PE. The plant currently serves the following cities and villages: Part of Ain Zebde, Saghbine, Mazraat Bab Maraa.

The construction and commissioning of the treatment plant were done by Subal Engineering and supervised by Dar Al Handassah Taleb. The plant is operational since July 2014.

An extension of the treatment plant is foreseen at a future horizon, the capacity of the plant will reach 5,800 PE.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025	Household + agri-food industries	560	225	299	40	10
2040	Household + agri-food industries	750	348	406	70	12

The flow rate and loads at the plant inlet were provided by the consultant that was in charge of the design, construction supervision and supervision of the operation and maintenance of the treatment plant until 2017.

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening Grit and grease removal		Aerobic/Anaerobic/Anoxic tanks Clarification	Chlorination (filtration and UV disinfection inactive)

Note: The effluent treatment process is identical for both 2025 and 2040 horizons.

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the sewage sludge produced by the plant are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
X	Aerobic	Belt filter press		

Note: The sludge treatment process is identical for both 2025 and 2040 horizons.

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.
Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge by 2025 and by 2040 are presented in the table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025	67	333	18 %
2040	103	514	18 %

The dryness values used were taken from the design report submitted by the Consultant in charge of the preparation of the design, construction supervision and O&M supervision.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of Saghbine to be "potentially conforming to the requirements of the green process".

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site's dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained. The estimated surface area communicated by the Litani river authority is of 40,000 m^2.
- All the sludge going to the dedicated landfill is previously dried or incinerated.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Saghbine WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the Saghbine WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Solar drying at Joub Jannine	

B.2.1.1. DESIGN

Aerobic Digestion

In scenario 1, we propose to keep the aerobic digestion in place at the Saghbine wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt filter press

In scenario 1, we propose to keep in place the belt filter press in the Saghbine wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the wastewater treatment plants of Joub Jannine and Saghbine will be dried in solar dryers constructed in the Joub Jannine WWTP.

The design of the Joub Jannine Solar dryers is included in the Joub Jannine wastewater treatment plant data sheet.

For information on operating principle and performance cf. Section D.3 above.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**12,648**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**0**
TOTAL	**€/ *year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	93
Dryness	%DM	18%
Tonnage of raw matter to be evacuated	tRM/year	517
Distance travelled (Saghbine – Joub Jannine)	km	17
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	12648
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**12,648**
TOTAL VARIABLE EXPENSES		
Sludge disposal	**€/year**	**12,648**
TOTAL	**€/year**	**12,648**

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Saghbine WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the Saghbine WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Solar drying at Joub Jannine	

B.2.2.1. DESIGN

Aerobic Digestion

In scenario 2, we propose to keep the aerobic digestion in place at the Saghbine wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt filter press

In scenario 2, we propose to keep in place the belt filter press in the Saghbine wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the wastewater treatment plants of Joub Jannine and Saghbine will be dried in solar dryers constructed in the Joub Jannine WWTP.

The design of the Joub Jannine Solar dryers is included in the Joub Jannine wastewater treatment plant data sheet.

For information on operating principle and performance cf. Section D.3 above.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**12,648**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**0**
TOTAL	**€/ *year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	93
Dryness	%DM	18%
Tonnage of raw matter to be evacuated	tRM/year	517
Distance travelled (Saghbine – Joub Jannine)	km	17
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	12648
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**12,648**
TOTAL VARIABLE EXPENSES		
Sludge disposal	**€/year**	**12,648**
TOTAL	**€/year**	**12,648**

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Saghbine WWTP was considered to be “compliant” and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the Saghbine WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Solar drying at Joub Jannine	

B.2.3.1. DESIGN

Aerobic Digestion

In scenario 3, we propose to keep the aerobic digestion in place at the Saghbine wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt filter press

In scenario 3, we propose to keep in place the belt filter press in the Saghbine wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the wastewater treatment plants of Joub Jannine and Saghbine will be dried in solar dryers constructed in the Joub Jannine WWTP.

The design of the Joub Jannine Solar dryers is included in the Joub Jannine wastewater treatment plant data sheet.

For information on operating principle and performance cf. Section D.3 above.

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**12,648**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**0**
TOTAL	**€/ *year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	93
Dryness	%DM	18%
Tonnage of raw matter to be evacuated	tRM/year	517
Distance travelled (Saghbine – Joub Jannine)	km	17
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	12648
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**12,648**
TOTAL VARIABLE EXPENSES		
Sludge disposal	**€/year**	**12,648**
TOTAL	**€/year**	**12,648**

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Saghbine WWTP was considered to be “compliant” and in order to satisfy the requirements of the green process, it is necessary to implement the following sludge treatment steps for the Saghbine WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Solar drying at Joub Jannine	

B.2.4.1. DESIGN

Aerobic Digestion

In scenario 2, we propose to keep the aerobic digestion in place at the Saghbine wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt filter press

In scenario 2, we propose to keep in place the belt filter press in the Saghbine wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the wastewater treatment plants of Joub Jannine and Saghbine will be dried in solar dryers constructed in the Joub Jannine WWTP.

The design of the Joub Jannine Solar dryers is included in the Joub Jannine wastewater treatment plant data sheet.

For information on operating principle and performance cf. Section D.3 above.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**12,648**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**0**
TOTAL	**€/ *year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	93
Dryness	%DM	18%
Tonnage of raw matter to be evacuated	tRM/year	517
Distance travelled (Saghbine – Joub Jannine)	km	17
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	12648
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**12,648**
TOTAL VARIABLE EXPENSES		
Sludge disposal	**€/year**	**12,648**
TOTAL	**€/year**	**12,648**

H.11. TEMNINE

A. GENERAL PRESENTATION

To the north-east of Zahlé, the Temnine el Tahta wastewater treatment plant is currently under construction; its current capacity is of 102,000 PE.

The plant currently serves the following cities and villages: Bednayel, Beit Shama, Tleela, Temnine el Tahta, Temnine el Fawqa, Jbaa, al-Hadath, Hosh al-Rifqa, El Ramasa, Zaribet al-Sabha, Shmestar, Taraya, Al-Okaydiyyah (Mazraat Beit Taksh), Qsarnaba, Qalb es Sabaa, Kfar Dan, Kfar Dabach, Mrah el Ahmar, Mrah Haissoun, Mrah Al-Sirgan, Mazraat Beit Suwaidan, Mazraat Beit Salibi, Mazraat al Tout, Masnaa Al-Zahra, Nabi Rashada, Wadi Al-Aswad, Wadi Al-Owaini, Brital, Hizzine, Al-Helaniyah, Haour Taala, Haouch Barada and Ras Al-Nabeh, Haouch Al-Nabi, Khraibeh, Al-Khodor, Saraain al-Fawqa, Saraain al-Tahta, al-Safri, Talya, al-Taybeh, Majdaloun, al-Nabi Sheet and Tobshar, Mazraat Beit Mshik and Freij and Haouch Snaid.

An extension of the treatment plant is foreseen for a future horizon, the capacity of the plant will reach 340,000 PE.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025	Household + agri-food industries	14 790	6 049	6 700	1 035	252
2040	Household + agri-food industries	49 300	20 558	24 404	4 080	680

These data were transmitted by the Consultant in charge of the preliminary design of the treatment plant.

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening Grit and grease removal	N/A	Pre-anoxia tank Anaerobic tank Anoxic tank Aerobic tank Settling	Filtration UV disinfection *Chlorination in case of emergency*

Note: The effluent treatment process is identical for both 2025 and 2040 horizons.

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the sewage sludge produced by the plant are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
Belt Thickener	Aerobic	Belt Press	*Optional*	*Optional solar drying*

Note: The sludge treatment process is identical for both 2025 and 2040 horizons.

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.
Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge at by 2025 and by 2040 are presented in the table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025	1 788	8 048	20 %
2040	6 078	27 351	20 %

The dryness values used were taken from the operating monthly reports and confirmed by the operators or supervisors of the treatment plants, or from data directly provided by the operator or the supervisor.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m³)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of Temnine El Tahta to be “Potentially polluted sludge” because of the connected industries.

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site’s dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained. The estimated surface area communicated by the Litani river authority is of 40,000 m^2.
- All the sludge going to the dedicated landfill is previously dried or incinerated.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Temnine El Tahta WWTP was considered to be "non-compliant" and in order to satisfy the requirements of the red process, it is necessary to implement the following sludge treatment steps for the Temnine El Tahta WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Cancellation of planned belt filter press and replacement by centrifugation			Incineration in the Zahlé WWTP

B.2.1.1. DESIGN

Aerobic Digestion

In scenario 1, we propose to keep the aerobic digestion foreseen in the design of the Temnine El Tahta wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Centrifuges

In order to increase the LHV of the sludge to be incinerated and to reach an energy balance between digestion and incineration, it is necessary to replace the filter press by centrifuges in the Temnine El Tahta WWTP before incineration in Zahlé. The objective is to produce sludge with a minimum dryness of 25%.

The design of a centrifuge depends on 2 factors: the feed rate in m^3/h and the mass flow rate in kg of DM/h. Taking into consideration a 10% reduction in the OM content of digested sludge and a dryness of 2.5% at the outlet of the digester, we suggest the installation of **3 centrifuges of 480 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

The calculation note for the design of the centrifuges is shown in the table below:

		Temnine
Digestion		Aerobic
Sludge to be dewatered	t DM/d	21.04
Dryness	%	2.5
Volume	m^3/d	842
Operation time	h/d	16
Hourly volume	m^3/h	53
Hourly mass	kg DM/h	1315
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480

For information on operating principle and performance cf. Section D.2.1 above.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		Temnine
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480
		€
Civil works (2 stories bldg)	1,500 €/m²	228,000
Equipment (with add %)	30%	531,180
Installation (% of EQ price)	20%	106,236
Electricity (% of EQ price)	15%	79,677
Total (in EURO)		**946,000**

Unit cost

	€ HT
D 4 LL C 30 B HP	115000
Peripheral equiment (per machine)	8000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	1000
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**822,393**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	717,093
total investment civil	€	228,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	11,896
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**11,896**
TOTAL	***€/ year***	**11,896**

VARIABLE EXPENSES		
Reagents consumption		
Polymer		
Sludge tonnage	tDM/year	5,470
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	66
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/year**	**164,100**
Electrical consumption		
Dewatering		
Sludge tonnage	tDM/year	5,470
Consumption ratio	kWh_e/tDM	100
Electricity consumption	kWh_e/year	547,000
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	597,000
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**47,760**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	5,470
Dryness	%DM	25%
Tonnage of raw matter to be evacuated	tRM/year	21,880
Distance travelled (Temnine – Zahlé)	km	19
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	598,637
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**598,637**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**164,100**
Electrical consumption	**€/year**	**47,760**
Sludge disposal	**€/year**	**598,637**
TOTAL	**€/year**	**810,497**

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Temnine El Tahta WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the Temnine El Tahta WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Cancellation of optional solar drying in favor of solar drying in the Zahlé WWTP	

B.2.2.1. DESIGN

Aerobic Digestion

In scenario 2, we propose to keep the aerobic digestion foreseen in the design of the Temnine El Tahta wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt press filter

In scenario 2, we propose to keep the belt press filter foreseen in the detailed design of the Temnine El Tahta wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the Marj WWTP will be dried in solar dryers constructed on the site of the Zahlé treatment plant.
For information on operating principle and performance cf. Section D.3 above.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

N/A.

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**831,440**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**0**
TOTAL	***€/ year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	5,470
Dryness	%DM	18%
Tonnage of raw matter to be evacuated	tRM/year	30,389
Distance travelled (Temnine – Zahlé)	km	19
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	831,440
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**831,440**
TOTAL VARIABLE EXPENSES		
Sludge disposal	**€/year**	**831,440**
TOTAL	**€/year**	**831,440**

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Temnine El Tahta WWTP was considered to be "non-compliant" and in order to satisfy the requirements of the red process, it is necessary to implement the following sludge treatment steps for the Temnine El Tahta WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Cancellation of planned belt filter press and replacement by centrifugation			Incineration in the Zahlé WWTP

B.2.3.1. DESIGN

Aerobic Digestion

In scenario 3, we propose to keep the aerobic digestion foreseen in the design of the Temnine El Tahta wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Centrifuges

In order to increase the LHV of the sludge to be incinerated and to reach an energy balance between digestion and incineration, it is necessary to replace the filter press by centrifuges in the Temnine El Tahta WWTP before incineration in Zahlé. The objective is to produce sludge with a minimum dryness of 25%.
The design of a centrifuge depends on 2 factors: the feed rate in m^3/h and the mass flow rate in kg of DM/h. Taking into consideration a 10% reduction in the OM content of digested sludge and a dryness of 2.5% at the outlet of the digester, we suggest the installation of **3 centrifuges of 480 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

The calculation note for the design of the centrifuges is shown in the table below:

		Temnine
Digestion		Aerobic
Sludge to be dewatered	t DM/d	21.04
Dryness	%	2.5
Volume	m^3/d	842
Operation time	h/d	16
Hourly volume	m^3/h	53
Hourly mass	kg DM/h	1315
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480

For information on operating principle and performance cf. Section D.2.2 above.

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		Temnine
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480
		€
Civil works (2 stories bldg)	1,500 €/m²	228,000
Equipment (with add %)	30%	531,180
Installation (% of EQ price)	20%	106,236
Electricity (% of EQ price)	15%	79,677
Total (in EURO)		**946,000**

Unit cost	
	€ HT
D 4 LL C 30 B HP	115000
Peripheral equiment (per machine)	8000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	1000
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**822,393**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	717,093
total investment civil	€	228,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	11,896
TOTAL FIXED EXPENSES		
Major maintenance and renewal	***€/ year***	**11,896**
TOTAL	***€/ year***	**11,896**

VARIABLE EXPENSES		
Reagents consumption		
Polymer		
Sludge tonnage	tDM/year	5,470
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	66
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/year**	**164,100**
Electrical consumption		
Dewatering		
Sludge tonnage	tDM/year	5,470
Consumption ratio	kWh_e/tDM	100
Electricity consumption	kWh_e/year	547,000
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	597,000
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**47,760**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	5,470
Dryness	%DM	25%
Tonnage of raw matter to be evacuated	tRM/year	21,880
Distance travelled (Temnine – Zahlé)	km	19
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	598,637
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**598,637**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**164,100**
Electrical consumption	**€/year**	**47,760**
Sludge disposal	**€/year**	**598,637**
TOTAL	**€/year**	**810,497**

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Temnine El Tahta WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the Temnine El Tahta WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Aerobic	Belt filter press		Cancellation of optional solar drying in favor of solar drying in the Temnine WWTP	

B.2.4.1. DESIGN

Aerobic Digestion

In scenario 4, we propose to keep the aerobic digestion foreseen in the design of the Temnine El Tahta wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.1 above.

Belt press filter

In scenario 4, we propose to keep the belt press filter foreseen in the detailed design of the Temnine El Tahta wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar Drying

The sludge output of the Temnine El Tahta WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 15 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 60 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated: 7,500 m^2.

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

The investment cost of the solar dryer is detailed in the table below:

INVESTMENT 2040		Temnine
Coordinates		33.866895, 35.995118
Quantity of sludge to dry	t DM/d	14.99
Dryer surface area	m²	7,500
Civil works	M€	2.5
Equipment	M€	4.3
Total	**M€**	**6.8**

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**1,009,756**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	3,412,500
total investment civil	€	1,121,250
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	56,794
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**56,794**
TOTAL	**€/ *year***	**56,794**
VARIABLE EXPENSES		
Electrical consumption		
Solar drying		
Sludge tonnage	tDM/year	5,470
Consumption ratio	kWhe/tDM	0.1
Electricity consumption	kWhe/year	547
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	50,547
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,044**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	5,470
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	8,415
Distance travelled (Temnine – Machghara quarry)	km	54
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	654,380
Processing cost	€/tRM	35
Total processing cost	€/year	294,538
Total annual cost	**€/year**	**948,919**
TOTAL VARIABLE EXPENSES		
Electrical consumption	**€/year**	**4,044**
Sludge disposal	**€/year**	**948,919**
TOTAL	**€/year**	**952,963**

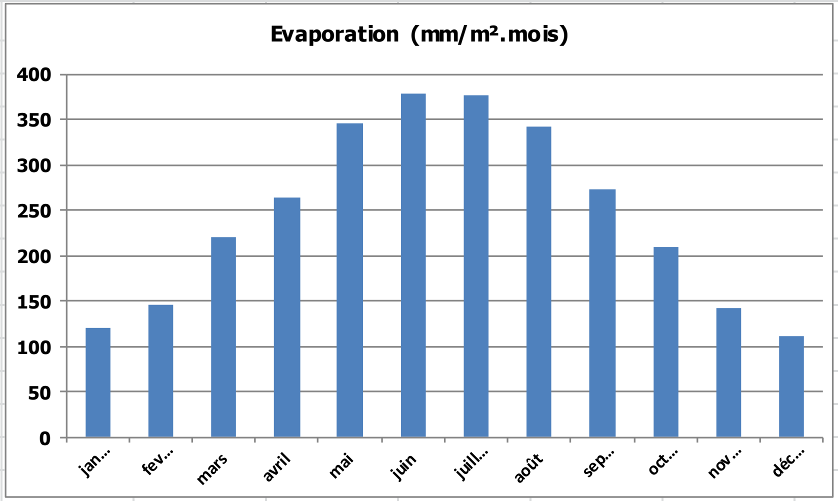
C. ANNEXES

C.1. ANNEX 1: CALCULATION NOTE SOLAR DRYER

Évaporation	janvier	fevrier	mars	avril	mai	juin	juillet	août	septembre	octobre	novembre	décembre
mm/mois.m²	121	146	221	264	346	379	377	341	273	209	142	111
m³/j	29.25	39.02	53.36	65.98	83.78	94.67	91.25	82.62	68.27	50.51	35.56	26.96

TEMNINE

	Irradiation		Eau évaporée			
	Wh/m².j	kCal/m².j	$kH_2O/m^2.j$	$t\ H_2O/j$	kg/mois.m²	
janvier	2,449	2106.2948	3.90	29	121	
fevrier	3,267	2809	5.20	39	146	
mars	4,467	3842	7.11	53	221	
avril	5,524	4751	8.80	66	264	
mai	7,014	6032	11.17	84	346	
juin	7,926	6816	12.62	95	379	
juillet	7,639	6570	12.17	91	377	
août	6,917	5948	11.02	83	341	
septembre	5,716	4915	9.10	68	273	
octobre	4,228	3636	6.73	51	209	
novembre	2,977	2561	4.74	36	142	
décembre	2,257	1941	3.60	27	111	
total	**5,043**	**51928**	**96.16**	**721**	**2930.19**	kg/m².an



Wh -> kCal	0.86
evaporation	540 kCal /kg H_20
Surface serres	7,500 m²
evaporation	
Kg H20	1
kWh	0.628
kJ	2260.87
kCal	540

Séchage solaire des Boues d'épuration

Données entrée	Temnine 2040
QB/MS	14.99 t MS/j
Siccité	18 %
Masse Volumique des boues	1.0 t/m3
Qbe (boues humides)	83.3 t/j
QH2Oe (eau des boues)	68.3 t/j

Objectif Sortie

Siccité moyenn	65%
inter. Variat	± 5%
QBs	23 t/j
QH2Os	8 t/j

Quantité d'eau à éliminer

Qevap	60 m3/j
R évaporation	100 %

Evaporation

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
nbr jours / mois	31	28	31	30	31	30	31	31	30	31	30	31
mm/mois/m²	121	146	221	264	346	379	377	341	273	209	142	111
m3/j	29	39	53	66	84	95	91	83	68	51	36	27

Surface unitaire d'une serre	**500**	**m2**
Nombre de serres nécessaires	**15**	
Surface utile nécessaire	**0.75**	**ha**

coefficient évap
2930 kg ee/m².an

Evaluation de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Flux de boues (T MS/j)	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**
Siccité initiale	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**
Objectif de siccité	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**
Quantité d'eau à évaporer (m3/j)	60	60	60	60	60	60	60	60	60	60	60	60
QH2O évap (m3/j)	29	39	53	66	84	95	91	83	68	51	36	27
Qbe traitable à (tMS/j)	7	10	13	16	21	24	23	21	17	13	9	7
Si fonctionnement à 15 t MS/j toute l'année												
Qbe non traitée(tMS/j)	8	5	2	0	0	0	0	0	0	2	6	8
Qbe non traitée(tMS/j) cumulable	8	5	2	-1	-6	-9	-8	-6	-2	2	6	8
Stock Boues non traitées (tMS/j)	8	13	15	13	7	0	0	0	0	2	9	17

Evaluation mensuelle de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Qbe du mois traitable à 65% (tMS)	226	272	412	493	647	707	704	638	510	390	266	208
Qbe non traitée du mois(tMS)	239	148	53	0	0	0	0	0	0	75	184	257
Qbe cumulable non traitée du mois(tMS)	239	148	53	-43	-182	-257	-239	-173	-60	75	184	257
Stock cummulé (tMS)	239	387	440	397	215	0	0	0	0	75	259	516

Volume annuel des boues à traiter à 18%	30,396	m3
Hauteur de la production annuelle stockée	4.1	m/an
Hauteur des boues dans la serre	0.30	m
Période de rotation moyenne	27	Jours
Quantité maximale stockée des boues brutesà 18%	5,307	m3
Période maximale de Stockage de la production	63.7	Jours

Production journalière	83 m3
Hauteur journalière du lit de boues	17 cm
Remplissage de la première serre	1.8 j
Rotation de remplissage des serres	27 j

21,979 m3/an à évaporer
21,976 m3/an évaporable

H.12. YAMMOUNEH

A. GENERAL PRESENTATION

The Yammouneh plant is currently the smallest wastewater treatment plant in the Bekaa valley. It is located in the Bekaa district and serves the city of Yammouneh. It has a nominal capacity of 5 836 PE. There is no extension of the treatment plant foreseen for a future horizon.

The construction and commissioning of the treatment plant were done by Subal Group and supervised by Dar Al Handassah Taleb as part of the Yammouneh infrastructure project (sewers and WWTP).

The Yammouneh wastewater treatment plant is no longer in operation today and needs to be rehabilitated.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025	Household	788	350	438	72	12
2040	Household	788	350	438	72	12

Note: The same values were adopted for the 2025 and the 2040 horizons since no extension is foreseen for the Yammouneh wastewater treatment plant.

All the information was transmitted by the Engineer in charge of the supervision. Only the nitrogen and phosphorus loads at the Yammouneh WWTP were calculated from the typical French ratios shown in the table below:

	Unit	Value
Inflow to the plant	l/pers.day	135
BOD_5	*g/pers.day*	60
COD	*g/pers.day*	120
TSS	*g/pers.day*	70
TKN	*g/pers.day*	12
TP	*g/pers.day*	2

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening Grit and grease removal	N/A	Aeration tank Clarification	Chlorination

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the produced sewage sludge are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
X		X		

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.

Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge is presented in *the* table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025	103	575	18 %
2040	103	575	18 %

Note: The same values were adopted for the 2025 and the 2040 horizons since no extension is foreseen for the Yammouneh wastewater treatment plant.

The dryness values used were taken from the operating monthly reports and confirmed by the operators or supervisors of the treatment plants, or from data directly provided by the operator or the supervisor.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m^3)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- Although producing compliant sludge, the Yammouneh plant was attached to the Iaat plant producing "Potentially polluted sludge". This is due to its very low sludge production and its geographical location (Iaat WWTP being the closest plant)

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site's dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 m^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge, which represents large volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained.
- All the sludge going to the dedicated landfill is previously dried or incinerated.

- The estimated surface area communicated by the Litani river authority is of 40,000 m².

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Yammouneh WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the red process, no additional sludge treatment step is required in the Yammouneh WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
				Incineration in the Zahlé WWTP

B.2.1.1. Design

Incineration

The sludge generated from Zahlé, Marj, Temnine, Iaat, El Laboue and Yammouneh will be incinerated in the Zahlé WWTP.

The design of the Zahlé incinerator is included in the Zahlé wastewater treatment plant data sheet.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**49,440**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**0**
TOTAL	**€/ *year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	103
Dryness	%DM	18%
Tonnage of raw matter to be evacuated	tRM/year	572
Distance travelled (Yammouneh – Zahlé)	km	60
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	49,440
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**49,440**
TOTAL VARIABLE EXPENSES		
Sludge disposal	**€/year**	**49,440**
TOTAL	**€/year**	**49,440**

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Yammouneh WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the black process, no additional sludge treatment step is required in the Yammouneh WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
			Solar drying in the Iaat WWTP	

B.2.2.1. Design

Solar Drying

The sludge output of the wastewater treatment plants of Iaat, El Laboue and Yammouneh will be dried in solar dryers constructed in the Iaat WWTP.

The design of the Iaat Solar dryers is included in the Iaat wastewater treatment plant data sheet.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**15,656**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**0**
TOTAL	**€/ *year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	103
Dryness	%DM	18%
Tonnage of raw matter to be evacuated	tRM/year	572
Distance travelled (Yammouneh – Iaat)	km	19
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	15,656
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**15,656**
TOTAL VARIABLE EXPENSES		
Sludge disposal	**€/year**	**15,656**
TOTAL	**€/year**	**15,656**

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Yammouneh WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the red process, it is necessary to implement the following sludge treatment steps for the Yammouneh WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
				Incineration in the Zahlé WWTP

B.2.3.1. Design

Incineration

The sludge generated from Zahlé, Marj, Temnine, Iaat, El Laboue and Yammouneh will be incinerated in the Zahlé WWTP. The design of the Zahlé incinerator is included in the Zahlé wastewater treatment plant data sheet.

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**49,440**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**0**
TOTAL	**€/ *year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	103
Dryness	%DM	18%
Tonnage of raw matter to be evacuated	tRM/year	572
Distance travelled (Yammouneh – Zahlé)	km	60
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	49,440
Processing cost	€/tRM	0
Total processing cost	€/year	0
Total annual cost	**€/year**	**49,440**
TOTAL VARIABLE EXPENSES		
Sludge disposal	**€/year**	**49,440**
TOTAL	**€/year**	**49,440**

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Yammouneh WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the black process, no additional sludge treatment step is required in the Yammouneh WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
			Solar drying in the Iaat WWTP	

B.2.4.1. Design

Solar Drying

The sludge output of the wastewater treatment plants of Iaat, El Laboue and Yammouneh will be dried in solar dryers constructed in the Iaat WWTP.

The design of the Iaat Solar dryers is included in the Iaat wastewater treatment plant data sheet.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

N/A

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**104,076**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	0
total investment civil	€	0
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	0
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**0**
TOTAL	**€/ *year***	**0**
VARIABLE EXPENSES		
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	103
Dryness	%DM	18%
Tonnage of raw matter to be evacuated	tRM/year	572
Distance travelled (Yammouneh – Iaat)	km	102
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	84,048
Processing cost	€/tRM	35
Total processing cost	€/year	20,028
Total annual cost	**€/year**	**104,076**
TOTAL VARIABLE EXPENSES		
Sludge disposal	**€/year**	**104,076**
TOTAL	**€/year**	**104,076**

H.13. ZAHLE

A. GENERAL PRESENTATION

Zahlé wastewater treatment plant is the largest plant currently in operation in the Bekaa Valley; its current capacity is of 205,000 PE. The plant currently serves the following cities and villages: Zahlé, Qaa El Rim, Hazerta, El Kirk, Saadnayel, part of Taalbaya, part of Fourzol.

An extension of the treatment plant is foreseen for the 2030 horizon, the capacity of the plant will reach 300,000 PE.

The construction of the treatment plant was done by Suez Trattamento Acque S.P.A. and supervised by Rafik El Khoury & Partners. The treatment plant was commissioned in October 2017. SUEZ has been operating the Zahlé Wastewater Treatment plant since this date.

A.1. EFFLUENT CHARACTERISTICS

The origins, flow rates and pollutant loads of effluents entering the plant by 2025 and by 2040 are given in the table below:

Horizon	Effluent type	Average flow rate plant inlet (m^3/d)	BOD_5 average load (kg_{BOD5}/d)	TSS average load (kg_{TSS}/d)	TKN average load (kg/d)	TP average load (kg/d)
2025	Household + various industries	37 300	16 039	15 853	2 611	634
2040	Household + various industries	56 000	24 080	23 800	3 920	952

These data are extracted from the December 2019 monthly report transmitted by SUEZ and confirmed by their operation and maintenance team.

A.1.1. Origin of effluents

Many industries are connected to the Zahlé plant and notably:

- ✓ Gardenia Grain D'or (agri-food)
- ✓ Somoplast (plastics)
- ✓ Mimosa (paper mill)
- ✓ Samih Hassan El-Yaman & Sons Factories (agri-food)
- ✓ Utrix (Fertilizers)
- ✓ Ethel (chocolate maker)
- ✓ Nicolas Srouji Est. For Contracting (concrete)
- ✓ Chateau Ksara (vineyard)
- ✓ Mediane (diaper factory)
- ✓ Agrifresh (Vegetable and fruit packaging)
- ✓ Domaine Wardy (vineyard)
- ✓ La douceur (chocolate maker)
- ✓ Saba Plast (plastics)
- ✓ Junet (fruit juice factory)

- ✓ Prestige Bekaa (Karouni Group) (printing)
- ✓ ALUTEX 2000 SAL (aluminum plant)
- ✓ Société Walid Abboud (concrete)
- ✓ Kanara (coal)

A.2. EFFLUENT TREATMENT PROCESSES

The effluent treatment process is shown below:

Pre-treatments	Primary treatment	Secondary treatment	Tertiary treatment
Coarse screening Fine screening Grit and grease removal	N/A	Aerobic/ anaerobic tanks Clarification	Filtration UV disinfection

Note: The effluent treatment process is identical for both 2025 and 2040 horizons.

A.3. SLUDGE TREATMENT PROCESSES

The stages of treatment of the sewage sludge produced by the plant are specified below:

Thickening	Digestion	Dewatering	Liming	Drying
GDD screens		Belt filter press	X	

The sludge treatment equipment that is installed in the Zahlé wastewater treatment plant is constituted of two elements:

- GDD screens (direct thickening) for pre-thickening of biological sludge (composed of a flocculation step with addition of polymer and a thickening step)
- Super press belt filters for dewatering

Sludge stabilization is achieved by lime treatment downstream from the dewatering unit.

Note: The sludge treatment process is identical for both 2025 and 2040 horizons.

A.4. SLUDGE OUTPUT BY PLANT

The average sludge production indicated in kg of dry matter was calculated by applying the typical ratios, shown in the table below, to the incoming loads at each plant.
Note: We chose to calculate the sludge production rather than using the values transmitted by the operators because the values transmitted were often unreliable since the sludge produced by the treatment plants is often not weighed before its evacuation to its final destination.

	Unit	Value
BOD_5 treatment efficiency	*%*	90%
Secondary sludge production	*Kg DM/kg BOD_5 treated*	0.9
Primary and Secondary sludge production	*Kg DM/kg BOD_5 treated*	1.1

The average annual production of sludge by 2025 and by 2040 are presented in the table below:

Horizon	Raw sludge production (t DM/year) Without lime	Volume of sludge to be discharged (m^3/year) Without lime	Dryness (%)
2025	4 742	23 710	20 %
2040	7 119	35 596	20 %

The dryness values used were taken from the operating monthly reports and confirmed by the operators or supervisors of the treatment plants, or from data directly provided by the operator or the supervisor.

The available information made it possible to calculate the corresponding sludge volumes using the densities in the table below:

	Density (t/m³)
Thickened sludge (5%)	1
Sludge dewatered by belt press or centrifuge (18-21%)	1
Sludge dried at 65%	0,9
Sludge dried at 90%	Between 0,6 & 0,8

B. OUTLET SCENARIOS

B.1. ASSUMPTIONS

The following assumptions have been made for the design of the facilities in the various scenarios.

Type of sludge:

- We considered the sludge output of the wastewater treatment plant of Zahlé to be "Potentially polluted sludge" because of the connected industries.

Sludge dryness assumptions:

- Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Organic matter assumption:

- The average value for organic matter is taken as 70% of the dry matter.

Storage assumptions:

- Sludge is stored in the location where it was dried.
- Sludge is stored after drying and before spreading. Spreading is only possible for 3 months a year. A downstream storage of 8 to 9 months is necessary before recovery and reuse in agriculture.

Spreading assumption:

- Sludge is spread 30 km away from the place where it was stored.

Incineration assumptions:

- Incinerated sludge is not dried.
- The ashes produced during sludge incineration and the FGTR (flue gas treatment residues) are sent to the Machghara site's dedicated landfill.
- The incinerator incorporates a flue gas treatment system.

Digestion assumptions:

- The anaerobic digestion stage producing more than 3000 Nm^3/d of biogas entirely covers the thermal needs of the incinerator (if this were not the case, the incineration solution would not have been chosen).
- Anaerobic digestion reduces the amount of dry matter (DM) by 30%.
- Aerobic digestion reduces the amount of dry matter (DM) by 10%.
- The digester is on the same site as the WWTP producing the sludge to be digested, in order to avoid transporting the liquid sludge volumes.

Sludge quantity assumption:

- In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

Dedicated landfill assumptions:

- The dedicated landfill is located on the Machghara quarry and will serve as an outlet for all the WWTPs, if the agricultural spreading option is not retained. The estimated surface area communicated by the Litani river authority is of 40,000 m^2.
- All the sludge going to the dedicated landfill is previously dried or incinerated.

B.2. SLUDGE TREATMENT STEPS BY SCENARIO

B.2.1. SCENARIO 1

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Zahlé WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the red process, it is necessary to implement the following sludge treatment steps for the Zahlé WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Creation of an anaerobic digester	Cancellation of planned belt filter press and replacement by centrifugation	Discontinuation of liming		Creation of an incineration unit

B.2.1.1. DESIGN

Anaerobic Digestion

We propose to create an anaerobic digester at the Zahlé WWTP and all related equipment (gas holder, boiler room, waste gas burner...)
The minimum volume of the digester is calculated from the volume of the excess sludge of the clarifier per year (dryness 7%) and by considering a **hydraulic retention time of 25 days in the digester. The volume of the Zahlé anaerobic digester is of 6 900 m³.**
This digester will eventually produce more than 3,000 Nm³/d of biogas.

For information on operating principle and performance cf. Section D.1.2 above.

Centrifuges

In order to increase the LHV of the sludge to be incinerated and to reach an energy balance between digestion and incineration, it is necessary to replace the filter press by centrifuges in the Zahlé WWTP before incineration. The objective is to produce sludge with a minimum dryness of 25%.
The design of a centrifuge depends on 2 factors: the feed rate in m³/h and the mass flow rate in kg of DM/h. Taking into consideration a 30% reduction in the OM content of mixed sludge, we considered the installation of **3 centrifuges of 480 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

The calculation note for the design of the centrifuges is shown in the table below:

		Zahle
Digestion		Anaerobic
Sludge to be dewatered	t DM/d	19.17
Dryness	%	3.5
Volume	m³/d	548
Operation time	h/d	16
Hourly volume	m³/h	34
Hourly mass	kg DM/h	1198
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480

For information on operating principle and performance cf. Section D.2.1 above.

Incinerator

Taking into account the volume of sludge generated from Zahlé, Marj, Temnine, Iaat, El Laboue and Yammouneh to be incinerated by 2040 of 20,864 TDM/year, 2 incineration furnaces with a capacity of 1 tDM/h and a grate diameter of about 3 m are needed.
This furnace has been designed for a 50-week 7-day 24-hour operation, i.e. taking into account 2 weeks of maintenance. In order for the whole unit to be self-heating, the furnaces must eventually be fed with 3,000 Nm^3/d of biogas, which is consistent with the digestion planned upstream.

For information on operating principle and performance cf. Section D.4 above.

B.2.1.2. ESTIMATED CAPITAL EXPENDITURES

Anaerobic Digester

The investment cost of the digester and all its related structures is detailed in the table below:

Structures		Equipment	Civil Works	TOTAL
Upstream and downstream tanks	***ratio***	***170 € HT/m3***	***300 € HT/m3***	
	800 m3 / 800 m3	272,000 €	480,000 €	**752,000 €**
Digester	***ratio***	***110 € HT/m3***	***280 € HT/m3***	
	6900 m3	759,000 €	1,932,000 €	**2,691,000 €**
Boiler room	***ratio***	***400 € HT/kW***	***LS***	
	650 kWth inst.	260,000 €	250,000 €	**510,000 €**
Gasometer	***ratio***	***180 € HT/m3***	***LS***	
	1600 m3	288,000 €	100,000 €	**388,000 €**
Flare	***ratio***	***280 € HT/Nm3.h***		
	150 Nm3/h	42,000 €		**42,000 €**
Biogas pretreatment	***ratio***	***LS***		
		200,000 €		**200,000 €**
Roads and utilities	***ratio***		***5% civil works***	
			140,000 €	**140,000 €**

The total construction cost of the anaerobic digester to be implemented in the Zahlé WWTP is detailed in the table below:

Items		Estimated Amounts Equipment	Civil works	TOTAL		% of EQ	% of CW
Digester		1,821,000 €	2,762,000 €	4,583,000 €			
Electricity and control command		364,000 €		364,000 €		*20.00%*	
Hydraulic connections		109,000 €	221,000 €	330,000 €		*6.00%*	*8.00%*
Road and utilities			140,000 €	140,000 €			
Site installations and site preparation		23,000 €	141,000 €	164,000 €		*1.00%*	*4.50%*
Design and drawings		229,000 €	250,000 €	479,000 €		*10.00%*	*8.00%*
Supervision and coordination of the works		69,000 €	- €	69,000 €		*3.00%*	
Commissioning		57,000 €	25,000 €	82,000 €		*2.50%*	*0.80%*
Insurances		41,000 €	31,000 €	72,000 €		*1.80%*	*1.00%*
TOTAL		**2,713,000 €**	**3,570,000 €**	**6,283,000 €**			

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		**Zahle**
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480
		€
Civil works (2 stories bldg)	1,500 €/m²	228,000
Equipment (with add %)	30%	531,180
Installation (% of EQ price)	20%	106,236
Electricity (% of EQ price)	15%	79,677
Total (in EURO)		**946,000**

Unit cost

	€ HT
D 4 LL C 30 B HP	115000
Peripheral equiment (per machine)	8000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	1000
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

Incinerator

The investment cost of the incinerator to be implemented in the Zahlé WWTP is detailed in the table below:

Structures		**Equipment**	**Civil Works**	**TOTAL**
Incineration	***ratios***	***23 M€ for 1 t/h***	***4.3 M€ for 1 t/h***	***all inclusive***
	2 t/h	46,000,000 €	8,600,000 €	54,600,000 €

This cost includes all the peripheral equipment, the control command system, the design and the supervision of works.

B.2.1.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**2,677,745**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	49,430,093
total investment civil	€	12,398,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	803,441
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**803,441**
TOTAL	**€/ *year***	**803,441**
VARIABLE EXPENSES		
Reagents consumption		
Polymer		
Sludge tonnage	tDM/year	4,983
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	60
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/year**	**149,504**
Antifoam consumption (digestion)		
Total annual cost *(lumpsum)*	**€/year**	**2,000**
Consumption of anti-struvite (digestion)		
Total annual cost *(lumpsum)*	**€/year**	**2,000**
Consumption of activated carbon (biogas pre-treatment)		
Biogas volume	Nm3/year	1,255,792
Processing rate	kg/Nm3	0.0019
Total consumption	t/year	2.386
Unit cost	€/t	1,200
Total annual cost	***€/year***	**2,863**
Ammonia consumption (specific incineration)		
Tonnage of sludge (incinerator inlet)	tDM/year	19,124
Reagent consumption ratio	kg/tDM	4
Total consumption	t/year	76.5
Unit cost	€/t	180
Total annual cost	***€/year***	**13,769**
Consumption of activated carbon (biogas pre-treatment)		
Tonnage of sludge (incinerator inlet)	tDM/year	19,124
Reagent consumption ratio	kg/tDM	79
Total consumption	t/year	1511
Unit cost	€/t	235
Total annual cost	***€/year***	**355,037**

Consumption of activated carbon (specific incineration)		
Tonnage of sludge (incinerator inlet)	tDM/year	19,124
Reagent consumption ratio	kg/tDM	3.5
Total consumption	t/year	66.934
Unit cost	€/t	1,200
Total annual cost	***€/year***	**80,321**
Consumption of sand (specific incineration)		
Tonnage of sludge (incinerator inlet)	tDM/year	19,124
Reagent consumption ratio	kg/tDM	0.6
Total consumption	t/year	11.4744
Unit cost	€/t	50
Total annual cost	***€/year***	**574**
Electrical consumption		
Reception unit		
Electrical consumption	kWh_e/year	150,000
Digestion		
Sludge tonnage	tDM/year	7,119
Consumption ratio	kWh_e/tDM	150
Electrical consumption	kWh_e/year	1,067,850
Biogas treatment		
Biogas volume	Nm^3/year	1,255,792
Consumption ratio	kWh_e/Nm^3	0.35
Electrical consumption	kWh_e/year	439,527
Dewatering		
Sludge tonnage	tDM/year	4,983
Consumption ratio	kWh_e/tDM	100
Electrical consumption	kWh_e/year	498,348
Specific incineration		
Sludge tonnage	tDM/year	19,124
Consumption ratio	kWh_e/tDM	320
Electrical consumption	kWh_e/year	6,119,680
Air treatment - ventilation		
Treated volume	Nm3/h	20,000
Consumption ratio	kWh_e/Nm3.h	18
Electrical consumption	kWh_e/year	360,000
Miscellaneous		
Electrical consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	8,685,405
Unit rate	€/kWh_e	0.08
Total annual cost	**€/year**	**694,832**
Thermal consumption - natural gas		
Specific incineration	kWh_{th}/year	840,000
Unit cost	€/kWh_{th}	0.06
Total annual cost	**€/year**	**50,400**

Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	5,737
Dryness	%DM	100%
Tonnage of raw matter to be evacuated	tRM/year	5,737
Distance travelled (Zahlé – Machghara quarry)	km	39
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	322,201
Processing cost	€/tRM	35
Total processing cost	€/year	200,802
Total annual cost	**€/year**	**523,003**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**606,068**
Electrical consumption	**€/year**	**694,832**
Thermal consumption - natural gas	**€/year**	**50,400**
Sludge disposal	**€/year**	**523,003**
TOTAL	**€/year**	**1,874,304**

B.2.2. SCENARIO 2

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Zahlé WWTP was considered to be "non-compliant" and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the Zahlé WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
	Belt filter press	Discontinuation of liming	Solar drying at Zahlé	

B.2.2.1. DESIGN

Belt filter press

In scenario 2, we propose to keep the belt press filter foreseen in the design of the Zahlé wastewater treatment plant.

For information on operating principle and performance cf. Section D.2.2 above.

Solar drying

The sludge output of the Zahlé, Marj and Temnine wastewater treatment plants will be dried in solar dryers constructed on the site of the Zahlé treatment plant.
The total quantity of sludge produced by this plant is equal to 50 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 200 m³/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m².year.
The solar drying area was calculated: 25,000 m².

Note: the calculation note for the design of the solar dryers is in annex 1.

For information on operating principle and performance cf. Section D.3 above.

B.2.2.2. ESTIMATED CAPITAL EXPENDITURES

Solar Dryer

The investment cost of the solar dryer to be implemented in the Zahlé WWTP is detailed in the table below:

INVESTMENT 2040		Zahle
Coordinates		33°47'40.45"N, 35°54'45.69"E
	Included WWTP	Temnine - Marj
Quantity of sludge to dry	t DM/d	49.84
Dryer surface area	m²	25,000
Civil works	M€	8.3
Equipment	M€	14.2
Total	**M€**	**22.5**

B.2.2.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**2,812,762**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	14,215,686
total investment civil	€	8,333,333
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	254,902
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**254,902**
TOTAL	**€/ *year***	**254,902**
VARIABLE EXPENSES		
Electrical consumption		
Solar drying		
Sludge tonnage	tDM/year	18,209
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	1,821
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	51,821
Unit cost	€/kWh_e	0.08
Total annual cost	**€/year**	**4,146**
Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	18,209
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	28,014
Distance travelled (Zahlé – Machghara Quarry)	km	39
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	1,573,240
Processing cost	€/tRM	35
Total processing cost	€/year	980,474
Total annual cost	**€/year**	**2,553,714**
TOTAL VARIABLE EXPENSES		
Electrical consumption	**€/year**	**4,146**
Sludge disposal	**€/year**	**2,553,714**
TOTAL	**€/year**	**2,557,860**

B.2.3. SCENARIO 3

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Since the sludge output of the Zahlé WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the red process, it is necessary to implement the following sludge treatment steps for the Zahlé WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
Creation of an anaerobic digester	Cancellation of planned belt filter press and replacement by centrifugation	Discontinuation of liming		Creation of an incineration unit

B.2.3.1. DESIGN

Anaerobic Digestion

We propose to create an anaerobic digester at the Zahlé WWTP and all related equipment (gas holder, boiler room, waste gas burner...)
The minimum volume of the digester is calculated from the volume of the excess sludge of the clarifier per year (dryness 7%) and by considering a **hydraulic retention time of 25 days in the digester. The volume of the Zahlé anaerobic digester is of 6 900 m³.**
This digester will eventually produce more than 3,000 Nm³/d of biogas.

For information on operating principle and performance cf. Section D.1.2 above.

Centrifuges

In order to increase the LHV of the sludge to be incinerated and to reach an energy balance between digestion and incineration, it is necessary to replace the filter press by centrifuges in the Zahlé WWTP before incineration. The objective is to produce sludge with a minimum dryness of 25%.
The design of a centrifuge depends on 2 factors: the feed rate in m3/h and the mass flow rate in kg of DM/h. Taking into consideration a 30% reduction in the OM content of mixed sludge, we considered the installation of **3 centrifuges of 480 kgDM/h, with the following operating conditions: 5 days/week and 16 h/day.**

The calculation note for the design of the centrifuges is shown in the table below:

		Zahle
Digestion		Anaerobic
Sludge to be dewatered	t DM/d	19.17
Dryness	%	3.5
Volume	m³/d	548
Operation time	h/d	16
Hourly volume	m³/h	34
Hourly mass	kg DM/h	1198
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480

For information on operating principle and performance cf. Section D.2.1 above.

Incinerator

Taking into account the volume of sludge generated from Zahlé, Marj, Temnine, Iaat, El Laboue and Yammouneh to be incinerated by 2040, 2 incineration furnaces with a capacity of 1 tDM/h and a grate diameter of about 3 m are needed.
This furnace has been designed for a 50-week 7-day 24-hour operation, i.e. taking into account 2 weeks of maintenance. In order for the whole unit to be self-heating, the furnaces must eventually be fed with 3,000 Nm^3/d of biogas, which is consistent with the digestion planned upstream.

For information on operating principle and performance cf. Section D.4 above.

B.2.3.2. ESTIMATED CAPITAL EXPENDITURES

Anaerobic Digester

The investment cost of the digester and all its related structures is detailed in the table below:

Structures		Equipment	Civil Works	TOTAL
Upstream and downstream tanks	***ratio***	***170 € HT/m3***	***300 € HT/m3***	
	800 m3 / 800 m3	272,000 €	480,000 €	**752,000 €**
Digester	***ratio***	***110 € HT/m3***	***280 € HT/m3***	
	6900 m3	759,000 €	1,932,000 €	**2,691,000 €**
Boiler room	***ratio***	***400 € HT/kW***	***LS***	
	650 kWth inst.	260,000 €	250,000 €	**510,000 €**
Gasometer	***ratio***	***180 € HT/m3***	***LS***	
	1600 m3	288,000 €	100,000 €	**388,000 €**
Flare	***ratio***	***280 € HT/Nm3.h***		
	150 Nm3/h	42,000 €		**42,000 €**
Biogas pretreatment	***ratio***	***LS***		
		200,000 €		**200,000 €**
Roads and utilities	***ratio***		***5% civil works***	
			140,000 €	**140,000 €**

The total construction cost of the anaerobic digester to be implemented in the Zahlé WWTP is detailed in the table below:

Items		Estimated Amounts Equipment	Civil works	TOTAL		% of EQ	% of CW
Digester		1,821,000 €	2,762,000 €	4,583,000 €			
Electricity and control command		364,000 €		364,000 €		*20.00%*	
Hydraulic connections		109,000 €	221,000 €	330,000 €		*6.00%*	*8.00%*
Road and utilities			140,000 €	140,000 €			
Site installations and site preparation		23,000 €	141,000 €	164,000 €		*1.00%*	*4.50%*
Design and drawings		229,000 €	250,000 €	479,000 €		*10.00%*	*8.00%*
Supervision and coordination of the works		69,000 €	- €	69,000 €		*3.00%*	
Commissioning		57,000 €	25,000 €	82,000 €		*2.50%*	*0.80%*
Insurances		41,000 €	31,000 €	72,000 €		*1.80%*	*1.00%*
TOTAL		**2,713,000 €**	**3,570,000 €**	**6,283,000 €**			

Centrifuges

The investment cost of the centrifuges is detailed in the table below:

INVESTMENT 2040		Zahle
Type of centrifuge		D 4 LL C 30 B HP
Number	u	3
Unit capacity	kg DM/h	480
		€
Civil works (2 stories bldg)	1,500 €/m²	228,000
Equipment (with add %)	30%	531,180
Installation (% of EQ price)	20%	106,236
Electricity (% of EQ price)	15%	79,677
Total (in EURO)		**946,000**

Unit cost

	€ HT
D 4 LL C 30 B HP	115000
Peripheral equiment (per machine)	8000
Sea-worthy packing and transport (per machine)	1200
Commissioning (par machine)	3000
Set of recommended spare parts	1000
Sludge pump 0-15 m³/h	3500
Polymer preparation unit + dosing pumps	12000

Incinerator

The investment cost of the incinerator to be implemented in the Zahlé WWTP is detailed in the table below:

Structures		Equipment	Civil Works	TOTAL
Incineration	***ratios***	***23 M€ for 1 t/h***	***4.3 M€ for 1 t/h***	***all inclusive***
	2 t/h	46,000,000 €	8,600,000 €	54,600,000 €

This cost includes all the peripheral equipment, the control command system, the design and the supervision of works.

B.2.3.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**2,677,745**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	49,430,093
total investment civil	€	12,398,000
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	803,441
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**803,441**
TOTAL	**€/ *year***	**803,441**
VARIABLE EXPENSES		
Reagents consumption		
Polymer		
Sludge tonnage	tDM/year	4,983
Polymer rate	kg/tDM	12
Total polymer consumption	t/year	60
Unit cost of pure polymer	€/t	2,500
Total annual cost	**€/year**	**149,504**
Antifoam consumption (digestion)		
Total annual cost *(lumpsum)*	**€/year**	**2,000**
Consumption of anti-struvite (digestion)		
Total annual cost *(lumpsum)*	**€/year**	**2,000**
Consumption of activated carbon (biogas pre-treatment)		
Biogas volume	Nm3/year	1,255,792
Processing rate	kg/Nm3	0.0019
Total consumption	t/year	2.386
Unit cost	€/t	1,200
Total annual cost	***€/year***	**2,863**
Ammonia consumption (specific incineration)		
Tonnage of sludge (incinerator inlet)	tDM/year	19124
Reagent consumption ratio	kg/tDM	4
Total consumption	t/year	76.5
Unit cost	€/t	180
Total annual cost	***€/year***	**13,769**
Consumption of activated carbon (biogas pre-treatment)		
Tonnage of sludge (incinerator inlet)	tDM/year	19124
Reagent consumption ratio	kg/tDM	79
Total consumption	t/year	1510.796
Unit cost	€/t	235
Total annual cost	***€/year***	**355,037**

Consumption of activated carbon (specific incineration)		
Tonnage of sludge (incinerator inlet)	tDM/year	19,124
Reagent consumption ratio	kg/tDM	3.5
Total consumption	t/year	66.934
Unit cost	€/t	1,200
Total annual cost	***€/year***	**80,321**
Consumption of sand (specific incineration)		
Tonnage of sludge (incinerator inlet)	tDM/year	19,124
Reagent consumption ratio	kg/tDM	0.6
Total consumption	t/year	11.4744
Unit cost	€/t	50
Total annual cost	***€/year***	**574**
Electrical consumption		
Reception unit		
Electrical consumption	kWh_e/year	150,000
Digestion		
Sludge tonnage	tDM/year	7,119
Consumption ratio	kWh_e/tDM	150
Electrical consumption	kWh_e/year	1,067,850
Biogas treatment		
Biogas volume	Nm^3/year	1,255,792
Consumption ratio	kWh_e/Nm^3	0.35
Electrical consumption	kWh_e/year	439,527
Dewatering		
Sludge tonnage	tDM/year	4,983
Consumption ratio	kWh_e/tDM	100
Electrical consumption	kWh_e/year	498,348
Specific incineration		
Sludge tonnage	tDM/year	19,124
Consumption ratio	kWh_e/tDM	320
Electrical consumption	kWh_e/year	6,119,680
Air treatment - ventilation		
Treated volume	Nm3/h	20,000
Consumption ratio	kWh_e/Nm3.h	18
Electrical consumption	kWh_e/year	360,000
Miscellaneous		
Electrical consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	8,685,405
Unit rate	€/kWh_e	0.08
Total annual cost	**€/year**	**694,832**
Thermal consumption - natural gas		
Specific incineration	kWh_{th}/year	840,000
Unit cost	€/kWh_{th}	0.06
Total annual cost	**€/year**	**50,400**

Sludge Disposal		
Sludge		
Tonnage of dry matter to be evacuated	tDM/year	5,737
Dryness	%DM	100%
Tonnage of raw matter to be evacuated	tRM/year	5,737
Distance travelled (Zahlé – Machghara quarry)	km	39
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	322,201
Processing cost	€/tRM	35
Total processing cost	€/year	200,802
Total annual cost	**€/year**	**523,003**
TOTAL VARIABLE EXPENSES		
Reagents consumption	**€/year**	**606,068**
Electrical consumption	**€/year**	**694,832**
Thermal consumption - natural gas	**€/year**	**50,400**
Sludge disposal	**€/year**	**523,003**
TOTAL	**€/year**	**1,874,304**

B.2.4. SCENARIO 4

In this scenario, the sludge considered "compliant" and the sludge considered "non-compliant" goes through the black process.

Since the sludge output of the Zahlé WWTP was considered to be “non-compliant” and in order to satisfy the requirements of the black process, it is necessary to implement the following sludge treatment steps for the Zahlé WWTP.

Digestion	Dewatering	Liming	Drying	Incineration
	Belt filter press	Discontinuation of liming	Solar drying at Zahlé	

B.2.4.1. DESIGN

Belt filter press

In scenario 4, we propose to keep the belt press filter foreseen in the design of the Zahlé wastewater treatment plant.

For information on operating principle and performance cf. Section D.1.2 above.

Solar drying

The sludge output of the Zahlé WWTP will be dried in solar dryers constructed on the site of the treatment plant.
The total quantity of sludge produced by this plant is equal to 19.5 TDM/d with an average dryness of 18%. At the outlet of the solar dryers, the objective is to produce sludge with a dryness of 65% ± 5%.
By taking into consideration those parameters, the quantity of water to be evaporated was calculated to be of 78 m^3/d.
The local weather conditions were taken into account when designing the solar dryers. The ratio for the annual water evaporation rate was calculated and is equal to 2930 kg ew/m^2.year.
The solar drying area was calculated: 9,800 m^2.

Note: the calculation note for the design of the solar dryers is in annex 3.

For information on operating principle and performance cf. Section D.3 above.

B.2.4.2. ESTIMATED CAPITAL EXPENDITURES

Solar Dryer

The investment cost of the solar dryer to be implemented in the Zahlé WWTP is detailed in the table below:

INVESTMENT 2040		Zahle
Coordinates		33°47'40.45"N, 35°54'45.69"E
Quantity of sludge to dry	t DM/d	19.5
Dryer surface area	m²	9,800
Civil works	M€	3.3
Equipment	M€	5.6
Total	**M€**	**8.8**

B.2.4.3. ESTIMATED OPERATING EXPENSES

ASSUMPTIONS

The cost of the implementation of the spreading was set at 30 €/tRM (turnkey).

The cost of landfilling has been set at 35 €/tRM.

The cost of transport was set at 1.75 $/tRM, i.e. 1.44 €/tRM.

FIXED AND VARIABLE EXPENSES

The table below shows the O&M expenses for the evacuation of the sludge until its final destination:

Total	€	**1,076,680**
FIXED EXPENSES		
Major maintenance and renewal		
total investment equipment	€	4,459,000
total investment civil	€	1,465,100
ratio equipment	%	1.50%
ratio civil	%	0.50%
Total annual cost	***€/year***	74211
TOTAL FIXED EXPENSES		
Major maintenance and renewal	**€/ *year***	**74,211**
TOTAL	**€/ *year***	**74,211**
VARIABLE EXPENSES		
Electrical consumption		
Solar drying		
Sludge tonnage	tDM/year	7,119
Consumption ratio	kWh_e/tDM	0.1
Electricity consumption	kWh_e/year	712
Miscellaneous		
Electricity consumption	kWh_e/year	50,000
Total electrical consumption		
Total consumption	kWh_e/year	50,712
Unit cost	€/kWh_e	0.08
Total annual cost	***€/year***	**4,057**
Sludge Disposal		

Sludge		
Tonnage of dry matter to be evacuated	tDM/year	7,119
Dryness	%DM	65%
Tonnage of raw matter to be evacuated	tRM/year	10,952
Distance travelled (Zahlé – Machghara quarry)	km	39
Unit cost of transport	€/ tRM/km	1.44
Total cost of transport	€/year	615,082
Processing cost	€/tRM	35
Total processing cost	€/year	383,331
Total annual cost	**€/year**	**998,412**
TOTAL VARIABLE EXPENSES		
Electrical consumption	**€/year**	**4,057**
Sludge disposal	**€/year**	**998,412**
TOTAL	**€/year**	**1,002,469**

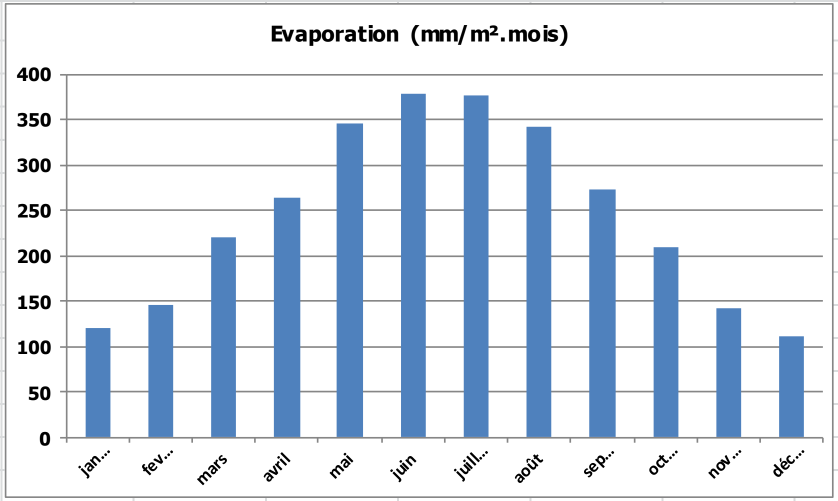
C. ANNEXES

C.1. ANNEX 1: CALCULATION NOTE SOLAR DRYER SCENARIO 2

Évaporation	janvier	fevrier	mars	avril	mai	juin	juillet	août	septembre	octobre	novembre	décembre
mm/mois.m²	121	146	221	264	346	379	377	341	273	209	142	111
m³/j	97.51	130.06	177.87	219.93	279.26	315.56	304.16	275.38	227.57	168.35	118.54	89.88

ZAHLE + TEMNINE + MARJ

	Irradiation		Eau évaporée			
	Wh/m².j	**kCal/m².j**	**$kH_2O/m^2.j$**	**$t H_2O/an$**	**kg/mois.m²**	
janvier	2,449	2106.2948	3.90	98	121	
fevrier	3,267	2809	5.20	130	146	
mars	4,467	3842	7.11	178	221	
avril	5,524	4751	8.80	220	264	
mai	7,014	6032	11.17	279	346	
juin	7,926	6816	12.62	316	379	
juillet	7,639	6570	12.17	304	377	
août	6,917	5948	11.02	275	341	
septembre	5,716	4915	9.10	228	273	
octobre	4,228	3636	6.73	168	209	
novembre	2,977	2561	4.74	119	142	
décembre	2,257	1941	3.60	90	111	
total	**5,043**	**51928**	**96.16**	**2,404**	**2930.19**	kg/m².an



Wh > kCal	0.86
evaporation	540 kCal /kg H_20
Surface serres	25,000 m²
evaporation	
Kg H20	1
kWh	0.628
kJ	2260.87
kCal	540

Séchage solaire des Boues d'épuration

Données entrée — **Zahle + Temnine + Marj 2040**

QB/MS	49.84 t MS/j
Siccité	18 %
Masse Volumique des boues	1.0 t/m3
Qbe (boues humides)	276.9 t/j
QH2Oe (eau des boues)	227.0 t/j

Objectif Sortie

Siccité moyenn	65%
inter. Variat	± 5%
QBs	77 t/j
QH2Os	27 t/j

Quantité d'eau à éliminer

Qevap	200 m3/j
R évaporation	100 %

Evaporation

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
nbr jours / mois	31	28	31	30	31	30	31	31	30	31	30	31
mm/mois/m²	121	146	221	264	346	379	377	341	273	209	142	111
m3/j/Ha	98	130	178	220	279	316	304	275	228	168	119	90

Surface unitaire d'une serre	**1000**	**m2**
Nombre de serres nécessaires	**25**	
Surface utile nécessaire	**2.50**	**ha**

coefficient évap
2930 kg ee/m².an

Evaluation de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Flux de boues (T MS/j)	**49.8**	**49.8**	**49.8**	**49.8**	**49.8**	**49.8**	**49.8**	**49.8**	**49.8**	**49.8**	**49.8**	**49.8**
Siccité initiale	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**
Objectif de siccité	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**
Quantité d'eau à évaporer (m3/j)	200	200	200	200	200	200	200	200	200	200	200	200
QH2O évap (m3/j)	98	130	178	220	279	316	304	275	228	168	119	90
Qbe traitable à (tMS/j)	24	32	44	55	70	79	76	69	57	42	30	22
Si fonctionnement à 53.3 t MS/j toute l'année												
Qbe non traitée(tMS/j)	26	17	6	0	0	0	0	0	0	8	20	27
Qbe non traitée(tMS/j) cumulable	26	17	6	-5	-20	-29	-26	-19	-7	8	20	27
Stock Boues non traitées (tMS/j)	26	43	49	44	24	0	0	0	0	8	28	56

Evaluation mensuelle de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Qbe du mois traitable à 65% (tMS)	753	907	1373	1642	2155	2357	2347	2125	1700	1299	885	694
Qbe non traitée du mois(tMS)	793	489	172	0	0	0	0	0	0	246	610	851
Qbe cumulable non traitée du mois(tMS)	793	489	172	-147	-610	-861	-802	-580	-204	246	610	851
Stock cummulé (tMS)	793	1282	1454	1307	697	0	0	0	0	246	856	1707

Volume annuel des boues à traiter à 18%	101,064	m3
Hauteur de la production annuelle stockée	4.0	m/an
Hauteur des boues dans la serre	0.30	m
Période de rotation moyenne	27	Jours
Quantité maximale stockée des boues brutes à 18%	17,562	m3
Période maximale de Stockage de la production	63.4	Jours

Production journalière	277 m3
Hauteur journalière du lit de boues	28 cm
Remplissage de la première serre	1.1 j
Rotation de remplissage des serres	27 j

73,077 m3/an à évaporer
73,255 m3/an évaporable

C.2. ANNEX 2: GENERAL LAYOUT OF SOLAR DRYING FOR SCENARIO 2

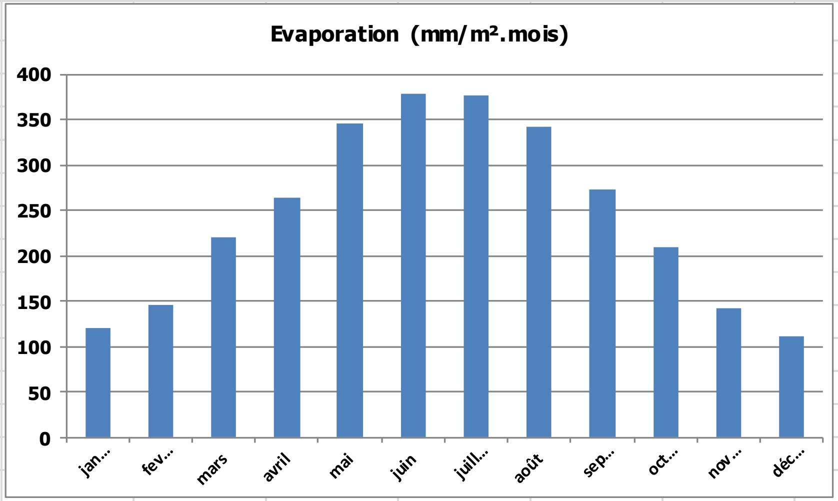
General Layout of the solar dryers in Zahlé at the 2040 horizon (scenario 2)

C.3. ANNEX 3: CALCULATION NOTE SOLAR DRYER SCENARIO 4

Évaporation	janvier	fevrier	mars	avril	mai	juin	juillet	août	septembre	octobre	novembre	décembre
mm/mois.m²	121	146	221	264	346	379	377	341	273	209	142	111
m³/j	38.23	50.98	69.73	86.21	109.47	123.70	119.23	107.95	89.21	65.99	46.47	35.23

ZAHLE

	Irradiation		Eau évaporée			
	Wh/m².j	kCal/m².j	kH$_2$O/m².j	t H$_2$O/j	kg/mois.m²	
janvier	2,449	2106.2948	3.90	38	121	
fevrier	3,267	2809	5.20	51	146	
mars	4,467	3842	7.11	70	221	
avril	5,524	4751	8.80	86	264	
mai	7,014	6032	11.17	109	346	
juin	7,926	6816	12.62	124	379	
juillet	7,639	6570	12.17	119	377	
août	6,917	5948	11.02	108	341	
septembre	5,716	4915	9.10	89	273	
octobre	4,228	3636	6.73	66	209	
novembre	2,977	2561	4.74	46	142	
décembre	2,257	1941	3.60	35	111	
total	**5,043**	**51928**	**96.16**	**942**	**2930.19**	kg/m².an



Wh -> kCal	0.86
evaporation	540 kCal /kg H$_2$0
Surface serres	9,800 m²
evaporation	
Kg H20	1
kWh	0.628
kJ	2260.87
kCal	540

Séchage solaire des Boues d'épuration

Données entrée — **Zahle 2040**

QB/MS	19.5	t MS/j
Siccité	18	%
Masse Volumique des boues	1.0	t/m3
Qbe (boues humides)	108.3	t/j
QH2Oe (eau des boues)	88.8	t/j

Objectif Sortie

Siccité moyenn	65%
inter. Variat	± 5%
QBs	30 t/j
QH2Os	11 t/j

Quantité d'eau à éliminer

Qevap	78	m3/j
R évaporation	100	%

Evaporation

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
nbr jours / mois	31	28	31	30	31	30	31	31	30	31	30	31
mm/mois/m²	121	146	221	264	346	379	377	341	273	209	142	111
m3/j	38	51	70	86	109	124	119	108	89	66	46	35

Surface unitaire d'une serre	**490**	**m2**
Nombre de serres nécessaires	**20**	
Surface utile nécessaire	**0.98**	**ha**

coefficient évap
2930 kg ee/m².an

Evaluation de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Flux de boues (T MS/j)	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**	**19.5**
Siccité initiale	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**	**18%**
Objectif de siccité	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**	**65%**
Quantité d'eau à évaporer (m3/j)	78	78	78	78	78	78	78	78	78	78	78	78
QH2O évap (m3/j)	38	51	70	86	109	124	119	108	89	66	46	35
Qbe traitable à (tMS/j)	10	13	17	21	27	31	30	27	22	16	12	9
Si fonctionnement à 19.5 t MS/j toute l'année												
Qbe non traitée(tMS/j)	10	7	2	0	0	0	0	0	0	3	8	11
Qbe non traitée(tMS/j) cumulable	10	7	2	-2	-8	-11	-10	-7	-3	3	8	11
Stock Boues non traitées (tMS/j)	10	17	19	17	9	0	0	0	0	3	11	22

Evaluation mensuelle de la production des boues (tMS)

	Janvier	Février	Mars	Avril	Mai	Juin	Juillet	Août	Septembre	Octobre	Novembre	Décembre
Qbe du mois traitable à 65% (tMS)	295	355	538	644	845	924	920	833	666	509	347	272
Qbe non traitée du mois(tMS)	310	191	66	0	0	0	0	0	0	95	238	333
Qbe cumulable non traitée du mois(tMS)	310	191	66	-59	-240	-339	-316	-229	-81	95	238	333
Stock cummulé (tMS)	310	500	567	508	267	0	0	0	0	95	333	666

Volume annuel des boues à traiter à 18%	39,542	m3
Hauteur de la production annuelle stockée	4.0	m/an
Hauteur des boues dans la serre	0.30	m
Période de rotation moyenne	27	Jours
Quantité maximale stockée des boues brutesà 18%	6,847	m3
Période maximale de Stockage de la production	63.2	Jours

Production journalière	108 m3
Hauteur journalière du lit de boues	22 cm
Remplissage de la première serre	1.4 j
Rotation de remplissage des serres	27 j

28,592 m3/an à évaporer
28,716 m3/an évaporable

C.4. ANNEX 4: GENERAL LAYOUT OF SOLAR DRYING FOR SCENARIO 4

General Layout of the solar dryers in Zahlé at the 2040 horizon (scenario 4)

H.14. MACHGHARA QUARRY

A. GENERAL PRESENTATION

The Machghara quarry was created in order to build the dam of Qaraoun. It is located south of the Qaraoun dam within the limits of the municipality of Machghara.

A visit of the quarry was carried out on September 14th, 2020 with a representative of the Litani river authority. The estimated surface area communicated by the Litani river authority is of 40,000 m². However, from the satellite view, we estimate the minimum surface area of this quarry to be of 120,000 m² (annex 1).

A.1. DISTANCES FROM THE WWTPS

The first parameter to define is the distances of the quarry from the wastewater treatment plants generating sludge to be evacuated at the Machghara site:

WWTP	Coordinates	Distance in km
Ablah	33°51'20.0"N 35°58'38.4"E	55
Aitanit	33°32'43.8"N 35°41'27.1"E	1.3
East Zahlé	33°46'44.2"N 35°57'36.5"E	42
El Laboue	34°12'6.78"N 36°20'29.98"E	105
Fourzol	33°51'02.7"N 35°57'26.9"E	52
Hermel	34°23'40.62"N 36°24'47.84"E	132
Iaat	34° 2'55.36"N 36° 8'44.01"E	86
Joub Jannine	33°38'17.45"N 35°46'33.33"E	18
Marj	33°44'37.7"N 35°50'48.1"E	37
Temnine	33°52'00.8"N 35°59'42.4"E	54
Yammouneh	34°07'08.0"N 36°01'53.3"E	102
Zahlé	33°47'40.45"N 35°54'45.69"E	39

Note that the other treatment plants which are part of our study do not have as a final outlet the Machghara site.

B. QUANTITIES OF SLUDGE TO BE EVACUATED

Transportation of large amounts of sludge from wastewater treatment facilities to their final destination can be expensive. Our study aimed at reducing the quantity of sludge to be eliminated in order to reduce operation costs to a minimum as well as the surface needed as a final outlet.

B.1. SCENARIO 1

B.1.1. DESIGN

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the red process. Therefore, the by-products that will need a final outlet are the bottom ashes and the fly ashes produced in the foreseen Zahlé incinerator.

The following table shows the tonnage of sludge to be evacuated to the Machghara quarry:

	Horizon 2025 Sludge to be disposed of			Horizon 2040 Sludge to be disposed of		
Evacuated from	**tDM/year**	**t_{ashes}/year**	**m^3/year**	**tDM/year**	**t_{ashes}/year**	**m^3/year**
Zahlé incinerator	3 314	994	1 988	5 737	1 721	3 442
Total	**3 314**	**994**	**1 988**	**5 737**	**1 721**	**3 442**

The surface area needed is calculated as follows:

$$S\ (m^2) = \frac{\sum_{(2025-2040)} ashes + FGTR}{4\ m}$$

That is: $S = 11{,}000\ m^2$

For the calculation details cf. annex 2.

B.1.2. ESTIMATED CAPITAL EXPENDITURES

The cost to rehabilitate the quarry, in order for it to receive the sludge as described above, is included in the operation cost of the treatment plants. We considered a unit price of 35 €/tRM.

Thus, the total cost for the rehabilitation of the quarry is equal to 200,795 € at the 2040 horizon, considering that only 11,000 m² will be rehabilitated.

B.2. SCENARIO 2

B.2.1. DESIGN

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process. Therefore, the sludge that will need a final outlet is the dried sludge produced in the solar dryers of Zahlé and Iaat.

The following table shows the tonnage of sludge to be evacuated to the Machghara quarry:

	Horizon 2025 Sludge to be disposed of		Horizon 2040 Sludge to be disposed of	
Evacuated from	**tRM/year**	**m^3/year**	**tRM/year**	**m^3/year**
Solar dryer Zahlé	16 016	17 796	28 013	31 126
Solar dryer Iaat	3 167	3 519	4 694	5 216
Total	**19 183**	**21 315**	**32 707**	**36 342**

The surface area needed is calculated as follows:

$$S(m^2) = \frac{\sum_{(2025-2040)} "non-compliant"\ dried\ sludge}{4(\mathrm{m})}$$

That is: $S = 115\ 000\ \mathrm{m}^2$

For the calculation details cf. annex 3.

B.2.2. ESTIMATED CAPITAL EXPENDITURES

The cost to rehabilitate the quarry, in order for it to receive the sludge as described above, is included in the operation cost of the treatment plants. We considered a unit price of 35 €/tRM.

Thus, the total cost for the rehabilitation of the quarry is equal to 1,144,745 € at the 2040 horizon.

B.3. SCENARIO 3

B.3.1. DESIGN

In this scenario, the sludge considered "compliant" goes through the black process and the sludge considered "non-compliant" goes through the red process.

Therefore, the sludge or by-products that will need a final outlet are:

- The ashes produced in the foreseen Zahlé incinerator
- The dried sludge produced in the solar dryers of Joub Jannine, Hermel and East Zahlé
- The dried sludge produced in the dry beds of Ablah, Fourzol and Aitanit

The following table shows the tonnage of sludge to be evacuated to the Machghara quarry from the Zahlé incinerator:

	Horizon 2025 Sludge to be disposed of			Horizon 2040 Sludge to be disposed of		
Evacuated from	**tDM/year**	**t_{ashes}/year**	**m³/year**	**tDM/year**	**t_{ashes}/year**	**m³/year**
Zahlé incinerator	3 314	994	1 988	5 737	1 721	3 442
Total	**3 314**	**994**	**1 988**	**5 737**	**1 721**	**3 442**

The following table shows the tonnage of sludge to be evacuated to the Machghara quarry from the solar dryers:

	Horizon 2025 Sludge to be disposed of		Horizon 2040 Sludge to be disposed of	
Evacuated from	**tRM/year**	**m³/year**	**tRM/year**	**m³/year**
Solar dryer Joub Jannine	1 596	1 733	3 828	4 253
Solar dryer Hermel	2 215	2 461	2 955	3 283
Solar dryer East Zahlé	0	0	4 503	5 003
Dry beds Fourzol	153	170	385	428
Dry beds Aitanit	741	823	741	823
Dry beds Ablah	304	338	304	338
Total	**5 009**	**5 525**	**12 716**	**14 128**

The surface area needed is calculated as follows:

$$S = \left(\frac{\sum_{(2025-2040)} ashes + FGTR}{4(\mathrm{m})} + \frac{\sum_{(2025-2040)} dried\ sludge\ considered\ "compliant"}{4(\mathrm{m})} \right)$$

That is: $S = 45\ 000\ \mathrm{m}^2$

For the calculation details cf. annex 4.

B.3.2. ESTIMATED CAPITAL EXPENDITURES

The cost to rehabilitate the quarry, in order for it to receive the sludge as described above, is included in the operation cost of the treatment plants. We considered a unit price of 35 €/tRM.

Thus, the total cost for the rehabilitation of the quarry is equal to 653,905 € at the 2040 horizon, considering that only 45,000 m² will be rehabilitated.

B.4. SCENARIO 4

B.4.1. DESIGN

In this scenario, the sludge considered "compliant" goes through the green process and the sludge considered "non-compliant" goes through the black process.

Therefore, the sludge or by-products that will need a final outlet are:

- The dried sludge produced in the solar dryers of Zahlé, Marj, Temnine, Iaat, Laboue
- The sludge produced in Yammouneh

The following table shows the tonnage of sludge to be evacuated to the Machghara quarry:

	Horizon 2025 Sludge to be disposed of		Horizon 2040 Sludge to be disposed of	
Evacuated from	**tRM/year**	**m³/year**	**tRM/year**	**m³/year**
Solar dryer Zahlé	7,295	8,106	10,952	12,169
Solar dryer Marj	6,245	6,939	8,646	9,607
Solar dryer Temnine	2,476	2,751	8,416	9,351
Solar dryer Iaat	3,009	3,343	3,009	3,343
Solar dryer El Laboue	0	0	1,527	1,697
Yammouneh	572	636	572	636
Total	**19,597**	**21,775**	**33,122**	**36,803**

The surface area needed is calculated as follows:

$$S(m^2) = \frac{\sum_{(2025-2040)} "not - compliant"\ dried\ sludge}{4(\mathrm{m})}$$

That is: $S = 117\ 000\ \mathrm{m}^2$

For the calculation details cf. annex 5.

B.4.2. ESTIMATED CAPITAL EXPENDITURES

The cost to store sludge in the quarry or rehabilitate it, in order for it to receive the sludge as described above, is included in the operation cost of the treatment plants. We considered a unit price of 35 €/tRM.

Thus, the total cost for the storage of sludge in the quarry or its rehabilitation is equal to 1,159,270 € at the 2040 horizon.

C. ANNEXES

C.1. ANNEX 1: AERIAL VIEW OF THE QUARRY

General Layout (in white) of the Machghara quarry

C.2. ANNEX 2: SURFACE CALCULATION DETAILS SCENARIO 1

Scenario 1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15						
Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	verification	Leading coefficient	Intercept	Sum over 15 years	surface of the landfill	
	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	verif	tRM/year	a	b	tRM over 15 years		
Zahlé	994	1042.64	1091.11	1139.57	1188.04	1236.51	1284.98	1333.45	1381.92	1430.39	1478.86	1527.33	1575.80	1624.27	1672.74	1721.21	1,721	48.47	994.167	21,723	$S(m^2)$	10,861
Total	994	1,043	1,091	1,140	1,188	1,237	1,285	1,333	1,382	1,430	1,479	1,527	1,576	1,624	1,673	1,721	1,721			21,723		

C.3. ANNEX 3: SURFACE CALCULATION DETAILS SCENARIO 2

Scenario 2	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15						
years	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	verification	Leading coefficient	Intercept	Sum over 15 years	surface of the landfill	
	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	tRM/year	verif	tRM/year	a	b	tRM over 15 years		
Zahlé	16,016	16816	17615	18415	19215	20015	20815	21615	22415	23214	24014	24814	25614	26414	27214	28014	28,014	800	16016	352,234	$S(m^2)$	115,313
Iaat	3,167	3269	3371	3473	3574	3676	3778	3880	3982	4084	4185	4287	4389	4491	4593	4694	4,694	102	3167	62,894		
Total	19,183	20,085	20,986	21,888	22,790	23,691	24,593	25,495	26,396	27,298	28,200	29,101	30,003	30,905	31,806	32,708	32,708			415,127		

C.4. ANNEX 4: SURFACE CALCULATION DETAILS SCENARIO 3

Scenario 3	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15						
Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	verification	Leading coefficient	Intercept	Sum over 15 years	surface of the landfill	
	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	verif	tMB/an	a	b	tRM over 15 years		
Ablah	304	304	304	304	304	304	304	304	304	304	304	304	304	304	304	304	304	0	304	4,856	$S(m^2)$	45,704
Fourzol	153	169	184	200	215	230	246	261	277	292	308	323	339	354	369	385	385	15	153	4,305		
Joub Jannine	1,689	1689	1689	1689	1689	1689	1689	1689	1689	1689	1689	1689	1689	1689	1689	1689	1689	0	1689	27,028		
Aitanit	741	741	741	741	741	741	741	741	741	741	741	741	741	741	741	741	741	0	741	11,857		
Hermel	2,215	2265	2314	2363	2413	2462	2511	2561	2610	2659	2709	2758	2807	2857	2906	2955	2955	49	2215	41,366		
East Zahleh	0	300	600	901	1201	1501	1801	2101	2401	2702	3002	3302	3602	3902	4203	4503	4503	300	0	36,022		
Zahlé	994	1043	1091	1140	1188	1237	1285	1333	1382	1430	1479	1527	1576	1624	1673	1721	1721	48	994	21,723		
Total	6,097	6,510	6,923	7,337	7,750	8,164	8,577	8,991	9,404	9,817	10,231	10,644	11,058	11,471	11,885	12,298	12,298			147,157		

C.5. ANNEX 5: SURFACE CALCULATION DETAILS SCENARIO 4

Scenario 4	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15						
Year	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	verification	Leading coefficient	Intercept	Sum over 15 years	surface of the landfill	
	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	tMB/an	verif	tMB/an	a	b	tRM over 15 years		
Zahlé	7,295	7539	7783	8027	8271	8514	8758	9002	9246	9490	9733	9977	10221	10465	10709	10952	10952	244	7295	145,982	$S(m^2)$	117,152
Marj	6,245	6405	6565	6725	6885	7045	7205	7365	7525	7685	7845	8005	8165	8325	8485	8646	8646	160	6245	119,121		
Temnine	2,476	2872	3268	3664	4060	4456	4852	5248	5644	6040	6436	6832	7228	7624	8020	8416	8416	396	2476	87,131		
Iaat	3,009	3009	3009	3009	3009	3009	3009	3009	3009	3009	3009	3009	3009	3009	3009	3009	3009	0	3009	48,140		
Laboue	0	102	204	305	407	509	611	713	815	916	1018	1120	1222	1324	1425	1527	1527	102	0	12,218		
Yammouneh	572	572	572	572	572	572	572	572	572	572	572	572	572	572	572	572	572	0	572	9,156		
Total	19,597	20,498	21,400	22,302	23,203	24,105	25,007	25,908	26,810	27,712	28,613	29,515	30,417	31,318	32,220	33,122	33,122			421,748		

I. INVESTMENT SUMMARY

The following tables group and summarize all the estimates made for each of the facilities per scenario. The production of sludge by all the treatment units will correspond to a population of approximately 1,680,000 PE at the 2040 horizon. The following points should be kept in mind:

I.1. SCENARIO 1

In scenario 1, 70% of the total sludge output is incinerated and the rest is spread in agriculture. The treatment units consist of 1 anaerobic digester in Zahlé, centrifuges in 4 WWTPs: Zahlé, Marj, Temnine and Iaat, solar dryers in Joub Janine, storage areas in 4 WWTPs: Joub Janine, Ablah, Fourzol and Aitanit, and 1 incinerator in Zahlé.

The investment for all these units at the project end point is € 67.9 million, or 40 € per PE.

WWTP/Post	Equipment	Civil Engineering	Total € excl. tax
Zahlé	**49,430,093**	**12,398,000**	**61,828,093**
anaerobic digester	2,713,000	3,570,000	
centrifuge	717,093	228,000	
incinerator	46,000,000	8,600,000	
Marj	**717,093**	**228,000**	**945,093**
centrifuge	717,093	228,000	
Temnine	**717,093**	**228,000**	**945,093**
centrifuge	717,093	228,000	
Iaat	**403,475**	**180,000**	**583,475**
centrifuge	403,475	180,000	
El Laboue	-	-	**0**
Yammouneh	-	-	**0**
Joub Jannine	**1,592,500**	**1,483,250**	**3,075,750**
solar dryer	1,592,500	523,250	
storage	-	960,000	
Saghbine	-	-	**0**
Hermel	-	-	**0**
East Zahlé	-	-	**0**
Fourzol	**-**	**120,000**	**120,000**
storage	-	120,000	
Aitanit	**-**	**240,000**	**240,000**
storage	-	240,000	
Ablah	**-**	**120,000**	**120,000**
storage	-	120,000	
Total €HT/an	**52,860,254**	**14,997,250**	**67,857,504**

Table 12 - Capital expenditures for Scenario 1

Note: The investment cost of the WWTPs of El Laboue, Hermel and East Zahlé were not included in the total investment cost because these treatment plants are still under study and the cost of the additional units may be included in the construction cost of the treatment plant.

I.2. SCENARIO 2

In scenario 2, 70% of the total sludge output is disposed of in a dedicated landfill and the rest is spread in agriculture. The treatment units consist of solar dryers in 3 WWTPs: Zahlé, Iaat, Joub Janine and storage areas in 4 WWTPs: Joub Janine, Ablah, Fourzol and Aitanit.

The investment for all these units at the project end point is € 30 million, or 17.9 € per PE.

WWTP/Post	Equipment	Civil Engineering	Total € excl. tax
Zahlé	**14,215,686**	**8,333,333**	**22,549,020**
solar drying	14,215,686	8,333,333	
Marj	-	-	**0**
Temnine	-	-	**0**
Iaat	**2,388,235**	**1,400,000**	**3,788,235**
solar drying	2,388,235	1,400,000	
El Laboue	-	-	**0**
Yammouneh	-	-	**0**
Joub Jannine	**1,592,500**	**1,483,250**	**3,075,750**
solar dryer	1,592,500	523,250	
storage	-	960,000	
Saghbine	-	-	**0**
Hermel	-	-	**0**
East Zahlé	**-**	**-**	**0**
Fourzol	**-**	**177,000**	**177,000**
storage	-	177,000	
Aitanit	**-**	**240,000**	**240,000**
storage	-	240,000	
Ablah	**-**	**120,000**	**120,000**
storage	-	120,000	
Total €HT/an	**18,196,422**	**11,753,583**	**29,950,005**

Table 13 - Capital expenditures for Scenario 2

Note: The investment cost of the WWTPs of El Laboue, Hermel and East Zahlé were not included in the total investment cost because these treatment plants are still under study and the cost of the additional units may be included in the construction cost of the treatment plant.

I.3. SCENARIO 3

In scenario 3, 70% of the total sludge output is incinerated and the rest is disposed of in a dedicated landfill. The treatment units consist of 1 anaerobic digester in Zahlé, centrifuges in 4 WWTPs: Zahlé, Marj, Temnine and Iaat, solar dryers in Joub Janine and 1 incinerator in Zahlé.

The investment for all these units at the project end point is € 66.4 million, or 39.5 € per PE.

WWTP/Post	Equipment	Civil Engineering	Total € excl. tax
Zahlé	**49,430,093**	**12,398,000**	**61,828,093**
anaerobic digester	2,713,000	3,570,000	
centrifuge	717,093	228,000	
incinerator	46,000,000	8,600,000	
Marj	**717,093**	**228,000**	**945,093**
centrifuge	717,093	228,000	
Temnine	**717,093**	**228,000**	**945,093**
centrifuge	717,093	228,000	
Iaat	**403,475**	**180,000**	**583,475**
centrifuge	403,475	180,000	
El Laboue	**-**	**-**	**0**
Yammouneh	**-**	**-**	**0**
Joub Jannine	**1,592,500**	**523,250**	**2,115,750**
solar dryer	1,592,500	523,250	
Saghbine	-	-	**0**
Hermel	-	-	**0**
East Zahlé	-	-	**0**
Fourzol	-	-	**0**
Aitanit	-	-	**0**
Ablah	-	-	**0**
Total €HT/an	**52,860,254**	**13,557,250**	**66,417,504**

Table 14 - Capital expenditures for Scenario 3

Note: The investment cost of the WWTPs of El Laboue, Hermel and East Zahlé were not included in the total investment cost because these treatment plants are still under study and the cost of the additional units may be included in the construction cost of the treatment plant.

I.4. SCENARIO 4

In scenario 4, 70% of the total sludge output is disposed of in a dedicated landfill and the rest is spread in agriculture. The treatment units consist of solar dryers in 5 WWTPs: Zahlé, Marj, Temnine, Iaat and Joub Janine, and storage areas in 4 WWTPs: Joub Janine, Ablah, Fourzol and Aitanit.

The investment for all these units at the project end point is € 20.5 million, or 12.2 € per PE.

WWTP/Post	Equipment	Civil Engineering	Total € excl. tax
Zalhé	**4,459,000**	**1,465,100**	**5,924,100**
solar dryer	4,459,000	1,465,100	
Marj	**3,640,000**	**1,196,000**	**4,836,000**
solar dryer	3,640,000	1,196,000	
Temnine	**3,412,500**	**1,121,250**	**4,533,750**
solar dryer	3,412,500	1,121,250	
Iaat	**1,228,500**	**403,650**	**1,632,150**
solar dryer	1,228,500	403,650	
El Laboue	**-**	**-**	**0**
Yammouneh	**-**	**-**	**0**
Joub Jannine	**1,592,500**	**1,483,250**	**3,075,750**
solar dryer	1,592,500	523,250	
storage	-	960,000	
Saghbine	**-**	**-**	**0**
Hermel	**-**	**-**	**0**
East Zahlé	**-**	**-**	**0**
Fourzol	**-**	**120,000**	**120,000**
storage	-	120,000	
Aitanit	**-**	**240,000**	**240,000**
storage	-	240,000	
Ablah	**-**	**120,000**	**120,000**
storage	-	120,000	
Total €HT/an	**14,332,500**	**6,149,250**	**20,481,750**

Table 15 - Capital expenditures for Scenario 4

Note: The investment cost of the WWTPs of El Laboue, Hermel and East Zahlé were not included in the total investment cost because these treatment plants are still under study and the cost of the additional units may be included in the construction cost of the treatment plant.

I.5. SCENARIO 5

In scenario 5, 100% of the total sludge output is disposed of in a dedicated landfill. The treatment units consist of solar dryers in 5 WWTPs: Zahlé, Marj, Temnine, Iaat and Joub Janine.

The investment for all these units at the project end point is € 19 million, or 11.3 € per PE.

WWTP/Post	Equipment	Civil Engineering	Total € excl. tax
Zalhé	**4,459,000**	**1,465,100**	**5,924,100**
solar dryer	4,459,000	1,465,100	
Marj	**3,640,000**	**1,196,000**	**4,836,000**
solar dryer	3,640,000	1,196,000	
Temnine	**3,412,500**	**1,121,250**	**4,533,750**
solar dryer	3,412,500	1,121,250	
Iaat	**1,228,500**	**403,650**	**1,632,150**
solar dryer	1,228,500	403,650	
El Laboue	**-**	**-**	**0**
Yammouneh	**-**	**-**	**0**
Joub Jannine	**1,592,500**	**523,250**	**2,115,750**
solar dryer	1,592,500	523,250	
Saghbine	**-**	**-**	**0**
Hermel	**-**	**-**	**0**
East Zahlé	**-**	**-**	**0**
Fourzol	**-**	**-**	**0**
Aitanit	**-**	**-**	**0**
Ablah	**-**	**-**	**0**
Total €HT/an	**14,332,500**	**4,709,250**	**19,041,750**

Table 16 - Capital expenditures for Scenario 5

Note: The investment cost of the WWTPs of El Laboue, Hermel and East Zahlé were not included in the total investment cost because these treatment plants are still under study and the cost of the additional units may be included in the construction cost of the treatment plant.

J. PHASING OF THE INVESTMENT

J.1. ASSUMPTIONS

The project horizon, 2040, is somewhat distant and, especially in the situation of Lebanon, it is very difficult to estimate the evolution of the population in the study area and its pace.

For this reason, the design of sludge treatment units has been carried out in independent units whenever possible and their construction can be spread over time according to the rhythm of sludge produced by the treatment plants.

Every sludge treatment unit lends itself differently to the phasing of its construction according to its operation constraints.

Note: In order to obtain the quantities of sludge per year, a linearization of the quantities was made between 2025 and 2040.

J.1.1. Digesters

In the scenarios where the anaerobic digester of Zahlé needs to be added to the sludge treatment process, the civil works and the installation of equipment will be done directly on the basis of 2040 sludge output levels.

At first the anaerobic digester will operate at two-thirds of its capacity until it reaches its maximum capacity by 2040.

J.1.2. Centrifuges

In the scenarios where centrifuges need to be added to the sludge treatment process, the civil works of the centrifuge hosting facilities will take into account 2040 sludge output levels. However, the centrifuges can be acquired in two phases depending on the quantity of sludge to dewater.

We estimated a one-year period for acquiring the equipment and for their installation.

J.1.3. Solar drying

In the scenarios where solar dryers need to be added to the sludge treatment process, the civil works and the installation of equipment will be done in four phases, depending on the quantity of sludge to dry.

We estimated a one-year period for the construction of the solar dryers, for acquiring the equipment and for their installation.

J.1.4. Storage

The storage areas will need to be constructed in one phase.

J.1.5. Incinerator

The civil works of the incinerator will directly need to be implemented on the basis of 2040 sludge output levels. However, only one furnace will be installed.

The second furnace needs to be operational in year 2036, therefore the construction of the second furnace will need to start in 2034 since it requires a two-year period to be implemented.

Note: The phasing of the investment for scenario 4 includes the dismantling of the sanitary landfill located in Zahlé WWTP.

J.2. SCENARIO 1

Based on the assumptions above, the investment is divided into six phases:

1. Phase 1 – Year 2025: 43.2 M€
2. Phase 2 – Year 2028: 302 k€
3. Phase 3 – Year 2032: 302 k€
4. Phase 4 – Year 2034: 23 M€
5. Phase 5 – Year 2036: 542 k€
6. Phase 6 – Year 2039: 478 k€

The details of the investment phases are shown in the tables in annex N.1.1.

J.3. SCENARIO 2

Based on the assumptions above, the investment is divided into five phases:

1. Phase 1 – Year 2025: 22.68 M€
2. Phase 2 – Year 2028: 618 k€
3. Phase 3 – Year 2032: 2.42 M€
4. Phase 4 – Year 2034: 1.8 M€
5. Phase 5 – Year 2036: 2.42 M€

The details of the investment phases are shown in the tables in annex N.1.2.

J.4. SCENARIO 3

Based on the assumptions above, the investment is divided into six phases:

1. Phase 1 – Year 2025: 41.8 M€
2. Phase 2 – Year 2028: 302 k€
3. Phase 3 – Year 2032: 302 k€
4. Phase 4 – Year 2034: 23 M€
5. Phase 5 – Year 2036: 542 k€
6. Phase 6 – Year 2039: 478 k€

The details of the investment phases are shown in the tables in annex N.1.3.

J.5. SCENARIO 4

Based on the assumptions above, the investment is divided into three phases:

1. Phase 1 – Year 2025: 15 M€
2. Phase 2 – Year 2028: 2.7 M€
3. Phase 3 – Year 2033: 2.7 M€

The details of the investment phases are shown in the tables in annex N.1.4.

J.6. SCENARIO 5

Based on the assumptions above, the investment is divided into three phases:

4. Phase 1 – Year 2025: 13.6 M€
5. Phase 2 – Year 2028: 2.7 M€
6. Phase 3 – Year 2033: 2.7 M€

The details of the investment phases are shown in the tables in annex N.1.4**Erreur ! Source du renvoi introuvable.**.

K. SUMMARY OF THE OPERATING COSTS

The operation and maintenance costs were calculated per wastewater treatment plant. The details for the operating costs are presented in the separate files provided for each wastewater treatment plant (cf. section H).

In our scenarios, we did not include the cost of the personnel needed for the operation and maintenance of the additional sludge treatment units. We considered that the personnel in charge of the operation and maintenance of the rest of the wastewater treatment plants will be operating the additional sludge treatment units.

Therefore, the operation and maintenance costs include only the following expenses divided in two categories:

1. The fixed costs: these expenses are related to the maintenance and the equipment renewal costs for the additional treatment units. Based on our experience in the field of operation and maintenance of wastewater treatment plants, we set a yearly percentage of 1.5% of the total investment cost of the equipment and a yearly percentage of 0.5% of the total investment cost of the civil works.
2. The variable costs: these expenses are related to the reagent consumptions, electrical consumptions, thermal consumption (natural gas) in case of implementing an incinerator, and sludge evacuation. These costs depend on the total quantity of sludge to be treated in these additional units and evacuated to their final destination.

At a later stage, it will be necessary to have a careful reflection concerning an organization of service(s): by perimeter(s)? which contractual organization(s)?; in which the BWE and the LWA will necessarily have to be integrated.

K.1. SCENARIO 1

WWTP	Fixed expenses	Variable expenses	Total € excl. tax/year
Zahlé	803,441	1,874,304	**2,677,745**
Marj	11,896	994,458	**1,006,355**
Temnine	11,896	810,497	**822,393**
Iaat	6,952	574,057	**581,009**
El Laboue	0	0	**0**
Yammouneh	0	49,440	**49,440**
Joub Jannine	31,304	284,162	**315,466**
Saghbine	0	12,648	**12,648**
Hermel	0	0	**0**
East Zahlé	0	0	**0**
Fourzol	600	28,112	**28,712**
Aitanit	1,200	54,277	**55,477**
Ablah	600	22,194	**22,794**
Total € excl. tax/year	**867,890**	**4,704,148**	**5,572,038**

Table 17 - Operating expenses for scenario 1

K.2. SCENARIO 2

WWTP	Fixed expenses	Variable expenses	Total € excl. tax/year
Zahlé	254,902	2,557,860	**2,812,762**
Marj	0	1,079,040	**1,079,040**
Temnine	0	831,440	**831,440**
Iaat	42,824	749,595	**792,418**
El Laboue	0	0	**0**
Yammouneh	0	15,656	**15,656**
Joub Jannine	31,304	284,162	**315,466**
Saghbine	0	12,648	**12,648**
Hermel	0	0	**0**
East Zahlé	0	0	**0**
Fourzol	600	28,112	**28,712**
Aitanit	1,200	54,277	**55,477**
Ablah	600	22,194	**22,794**
Total € excl. tax/year	**331,429**	**5,634,983**	**5,966,412**

Table 18 - Operating expenses for scenario 2

K.3. SCENARIO 3

WWTP	Fixed expenses	Variable expenses	Total € excl. tax/year
Zahlé	803,441	1,874,304	**2,677,745**
Marj	11,896	994,458	**1,006,355**
Temnine	11,896	810,497	**822,393**
Iaat	6,952	574,057	**581,009**
El Laboue	0	0	**0**
Yammouneh	0	49,440	**49,440**
Joub Jannine	26,504	237,165	**263,669**
Saghbine	0	12,648	**12,648**
Hermel	0	0	**0**
East Zahlé	0	0	**0**
Fourzol	0	42,199	**42,199**
Aitanit	0	27,340	**27,340**
Ablah	0	34,624	**34,624**
Total € excl. tax/year	**860,690**	**4,656,732**	**5,517,422**

Table 19 - Operating expenses for scenario 3

K.4. SCENARIO 4

WWTP	Fixed expenses	Variable expenses	Total € excl. tax/year
Zahlé	74,211	1,002,469	**1,076,680**
Marj	60,580	767,327	**827,907**
Temnine	56,794	952,963	**1,009,756**
Iaat	20,446	482,002	**502,448**
El Laboue	0	0	**0**
Yammouneh	0	104,076	**104,076**
Joub Jannine	31,304	284,162	**315,466**
Saghbine	0	12,648	**12,648**
Hermel	0	0	**0**
East Zahlé	0	0	**0**
Fourzol	600	28,112	**28,712**
Aitanit	1,200	54,277	**55,477**
Ablah	600	22,194	**22,794**
Total € excl. tax/year	**245,734**	**3,710,229**	**3,955,963**

Table 20 - Operating expenses for scenario 4

K.5. SCENARIO 5

WWTP	Fixed expenses	Variable expenses	Total € excl. tax/year
Zahlé	74,211	466,187	**540,398**
Marj	60,580	368,842	**429,422**
Temnine	56,794	359,142	**415,936**
Iaat	20,446	130,970	**151,416**
El Laboue	0	0	**0**
Yammouneh	0	0	**0**
Joub Jannine	26,504	159,484	**185,988**
Saghbine	0	30,632	**30,632**
Hermel	12,495	128,717	**141,212**
East Zahlé	0	0	**0**
Fourzol	0	0	**0**
Aitanit	0	0	**0**
Ablah	0	0	**0**
Total € excl. tax/year	**251,028**	**1,643,975**	**1,895,003**

Table 21 - Operating expenses for scenario 5

L. MULTI-CRITERIA ANALYSIS AND RANKING OF SCENARIOS

The different scenarios proposed are compared according to a multi-criteria analysis. The objective is to hierarchize the scenarios. The criteria selected for this comparison are the following:

- Technical criteria:
  - technical reliability (taken from, among other things, previous experience),
  - integration within the wastewater treatment plant and the size of the installations,
  - mass reduction (reduction of organic matter and increase in dryness),
  - nature and status of the by-products,
  - adaptability and scalability of the process in the short, medium and long term.
- Financial criteria:
  - estimated investment costs,
  - estimated operating costs,

The multi-criteria analysis is presented in the comparison table below:

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Technical criteria	Technical reliability	In the current context, not very reliable: high technicity and expensive spare parts	Good reliability	In the current context, not very reliable: high technicity and expensive spare parts	Good reliability	Good reliability
	Integration and the size of the installations	Small footprint needed	Very large footprint needed	Small footprint needed	Large footprint needed	Large footprint needed
	Raw material mass reduction	Very effective	Effective	Very effective	Effective	Effective
	Nature and status of the by-products	70% ashes – 30% dried sludge	100% dried sludge	70% ashes – 30% dried sludge	100% dried sludge	100% dried sludge
	Adaptability and scalability of the process	Not very adaptable and scalable	Adaptable and scalable	Not very adaptable and scalable	Very adaptable and scalable	Very adaptable and scalable
Financial criteria	Investment costs	67.86 M€	29.95 M€	66.42 M€	20.48 M€	19.04 M€
	Operating costs	€ 5.6 million	€ 6 million	€ 5.5 million	€ 4 million	€ 1.9 million

Table 22 - Multi-criteria analysis

From Table 22 above we can rank the scenarios as follow:

1. Scenario 5
2. Scenario 4
3. Scenario 2
4. Scenario 3
5. Scenario 1

M. CONCLUSION

The feasibility study for the sustainable sludge management of the Bekaa region took into consideration the sludge generated by the 13 wastewater treatment plants in the Bekaa valley at the 2040 horizon and a total population of 1,678,650 PE. The design bases and the costs for all treatment infrastructures are set for the 2040 horizon. By 2040, the whole project will output a total sludge production without lime of 32,250 tDM/year and of 137,000 m³/year.

This sludge output was divided into two categories:

- Non-compliant sludge (70% of the total sludge output): Potentially polluted sludge from the WWTPs of Zahlé, Marj, Temnine El Tahta, Iaat, Yammouneh and El Laboue.
- Compliant sludge (30% of the total sludge output): Sludge potentially conforming to the requirements of the green process from the WWTPs of Ablah, Fourzol, Joub Jannine, Saghbine, Aitanit, Hermel and East Zahlé.

Existing laboratory analyses did not show any traces of heavy metals in sludge of both categories.

An exhaustive inventory of treatment processes and potential outlets for sewage sludge, whether tried and tested or innovative but economically viable, was prepared by means of a bibliographical study and by relying on our past experiences and feedback.

It allowed the selection of technologies and final outlets adapted to the specific context of the Bekaa Valley, after having ruled out those that weren't (thermal drying, co-incineration, pyro-gasification, wet oxidation, composting…).

Based on that, and in order to dispose of the sludge produced in the Bekaa, four feasible scenarios were proposed:

✓ Scenario 1 which consists of adding to the existing sludge treatment line the following treatment units for a total investment cost of 67.9 M€ (40.4 €/PE or 140.4 €/TDM) and a yearly operating cost of 5.6 M€ (3.34 €/PE or 11.6 €/TMS) :

- An anaerobic digester in Zahlé
- Centrifuges in four WWTPs: Zahlé, Marj, Temnine and Iaat
- Solar dryers in Joub Janine
- Storage areas in four WWTPs: Joub Janine, Ablah, Fourzol and Aitanit
- An incinerator in Zahlé

➔ 70% of the total sludge output will be incinerated and the rest will be spread in agriculture.

✓ Scenario 2 which consists of adding to the existing sludge treatment line the following treatment units for a total investment cost of 30 M€ (17.9 €/PE or 62 €/TMS) and a yearly operating cost of 6 M€ (3.57 €/PE or 12.4 €/TMS):

- Solar dryers in three WWTPs: Zahlé, Iaat, Joub Janine
- Storage areas in four WWTPs: Joub Janine, Ablah, Fourzol and Aitanit

➔ 70% of the total sludge output will be evacuated in a dedicated landfill and the rest will be spread in agriculture.

- ✓ Scenario 3 which consists of adding to the existing sludge treatment line the following treatment units for a total investment cost of 66.4 M€ (39.6 €/PE or 137.3 €/TMS) and a yearly operating cost of 5.5 M€ (3.28 €/PE or 11.4 €/TMS):
  - An anaerobic digester in Zahlé
  - Centrifuges in four WWTPs: Zahlé, Marj, Temnine and Iaat
  - Solar dryers in Joub Janine
  - An incinerator in Zahlé

  ➔ 70% of the total sludge output will be incinerated and the rest will be evacuated in a dedicated landfill.

- ✓ Scenario 4 which consists of adding to the existing sludge treatment line the following treatment units for a total investment cost of 20.5 M€ (12.2 €/PE or 42 €/TMS) and a yearly operating cost of 4 M€ (2.38 €/PE or 8.3 €/TMS):
  - Solar dryers in five WWTPs: Zahlé, Marj, Temnine, Iaat and Joub Janine,
  - Storage areas in four WWTPs Joub Janine, Ablah, Fourzol and Aitanit

  ➔ 70% of the total sludge output will be evacuated in a dedicated landfill and the rest will be spread in agriculture.

- ✓ Scenario 5 which consists of adding to the existing sludge treatment line the following treatment units for a total investment cost of 19 M€ (11.3 €/PE or 39 €/TMS) and a yearly operating cost of 1.9 M€ (1.13 €/PE or 3.9 €/TMS):
  - Solar dryers in five WWTPs: Zahlé, Marj, Temnine, Iaat and Joub Janine,

  ➔ 100% of the total sludge output will be evacuated in a dedicated landfill.

Note: In case the spreading in agriculture option is not applicable, the part of the output intended for agricultural recovery can eventually be landfilled. And in case the incineration solution is not readily available, the sludge intended for thermal recovery and reuse can eventually be landfilled.

A multi-criteria analysis allowed us to rank the scenarios based on selected technical and financial criteria. Based on this ranking, scenario 5 seems to be the best option for the sustainable management of the sludge generated by the 13 wastewater treatment plants at the 2040 horizon. It is however dependent on the availability of lands for sludge disposal within 5km of the wastewater treatment plants. Moreover, it is important to note that the CAPEX of scenario 5 *does not take into consideration land acquisition.*

N. ANNEXES

N.1. INVESTMENT PHASES

N.1.1. Scenario 1

Investment phases

year	2025		2026		2027		2028		2029		2030		2031		2032	
	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works
Zahlé	**26,191,062**	**12,398,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Digester sludge input in tDM/d	13.55		14.00		14.45		14.91		15.36		15.81		16.27		16.72	
anaerobic digestion	2,713,000	3,570,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	9.5		9.8		10.1		10.4		10.8		11.1		11.4		11.7	
centrifuge	478,062	228,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Incinerator sludge input in tDM/d	31.6		33.1		34.6		36.2		37.7		39.3		40.8		42.3	
Incinerator	23,000,000	8,600,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Marj	**478,062**	**228,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	11.6		11.9		12.2		12.5		12.8		13.1		13.4		13.7	
centrifuge	478,062	228,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temnine	**478,062**	**228,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	4.6		5.3		6.1		6.8		7.5		8.3		9.0		9.7	
centrifuge	478,062	228,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iaat	**403,475**	**180,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	5.6		5.6		5.6		5.6		5.6		5.6		5.6		5.6	
centrifuge	403,475	180,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
El Laboue	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yammouneh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Joub Jannine	**910,000**	**1,259,000**	-	-	-	-	**227,500**	**74,750**	-	-	-	-	-	-	**227,500**	**74,750**
Solar dryer sludge input tonnage t DM/d	3.0		3.3		3.5		3.8		4.0		4.3		4.5		4.8	
solar drier	910,000	299,000	-	-	-	-	227,500	74,750	-	-	-	-	-	-	227,500	74,750
storage	-	960,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saghbine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hermel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
East Zahlé	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fourzol	-	**120,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	0.4		0.4		0.5		0.5		0.6		0.6		0.6		0.7	
storage	-	120,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aitanit	-	**240,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage slduge input tonnage tDM/d	1.9		1.9		1.9		1.9		1.9		1.9		1.9		1.9	
storage	-	240,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ablah	-	**120,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage slduge input tonnage tDM/d	0.8		0.8		0.8		0.8		0.8		0.8		0.8		0.8	
storage	-	120,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total €HT/year	**28,460,661**	**14,773,000**	-	-	-	-	**227,500**	**74,750**	-	-	-	-	-	-	**227,500**	**74,750**
Total €HT/year	**43,233,661**		-		-		**302,250**		-		-		-		**302,250**	
Total €HT/d	118,448		-		-		828.08		-		-		-		828	
Total tonnage tDM/d	59.4		62.3		65.2		68.0		70.9		73.8		76.6		79.5	
Unit price of the tDM in €	1992.9		0.0		0.0		12.2		0.0		0.0		0.0		10.4	

year	2033		2034		2035		2036		2037		2038		2039		2040	
	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works
Zahlé	-	-	**23,000,000**	-	-	-	-	-	-	-	-	-	**239,031**	-	-	-
Digester sludge input in tDM/d	17.17		17.62		18.08		18.53		18.98		19.43		19.89		20.34	
anaerobic digestion	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	12.0		12.3		12.7		13.0		13.3		13.6		13.9		14.2	
centrifuge	-	-	-	-	-	-	-	-	-	-	-	-	239,031	-	-	-
Incinerator sludge input in tDM/d	43.9		45.4		46.9		48.5		50.0		51.6		53.1		54.6	
Incinerator	-	-	23,000,000	-	-	-	-	-	-	-	-	-	-	-	-	-
Marj	-	-	-	-	-	-	**239,031**	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	14.0		14.3		14.6		14.9		15.2		15.5		15.8		16.1	
centrifuge	-	-	-	-	-	-	239,031	-	-	-	-	-	-	-	-	-
Temnine	-	-	-	-	-	-	-	-	-	-	-	-	**239,031**	-	-	-
Centrifuge sludge input in tDM/d	10.5		11.2		12.0		12.7		13.4		14.2		14.9		15.6	
centrifuge	-	-	-	-	-	-	-	-	-	-	-	-	239,031	-	-	-
Iaat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	5.6		5.6		5.6		5.6		5.6		5.6		5.6		5.6	
centrifuge	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
El Laboue	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yammouneh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Joub Jannine	-	-	-	-	-	-	**227,500**	**74,750**	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	5.0		5.3		5.5		5.8		6.1		6.3		6.6		6.8	
solar drier	-	-	-	-	-	-	227,500	74,750	-	-	-	-	-	-	-	-
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saghbine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hermel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
East Zahlé	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fourzol	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	0.7		0.8		0.8		0.8		0.9		0.9		1.0		1.0	
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aitanit	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage slduge input tonnage tDM/d	1.9		1.9		1.9		1.9		1.9		1.9		1.9		1.9	
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ablah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage slduge input tonnage tDM/d	0.8		0.8		0.8		0.8		0.8		0.8		0.8		0.8	
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total €HT/year	-	-	**23,000,000**	-	-	-	**466,531**	**74,750**	-	-	-	-	**478,062**	-	-	-
Total €HT/year	-		**23,000,000**		-		**541,281**		-		-		**478,062**		-	
Total €HT/d	-		63,014		-		1,483		-		-		1,310		-	
Total tonnage tDM/d	82.4		85.2		88.1		91.0		93.8		96.7		99.5		102.4	
Unit price of the tDM in €	0.0		739.4		0.0		16.3		0.0		0.0		13.2		0.0	

N.1.2. Scenario 2

Investment phases

year	2025		2026		2027		2028		2029		2030		2031		2032	
	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works
Zahlé	**10,803,922**	**6,333,333**	-	-	-	-	-	-	-	-	-	-	-	-	**1,137,255**	**666,667**
Solar dryer sludge input tonnage t DM/d	28.52		29.95		31.37		32.79		34.22		35.64		37.07		38.49	
solar drier	10,803,922	6,333,333	-	-	-	-	-	-	-	-	-	-			1,137,255	666,667
Marj	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temnine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iaat	**1,791,176**	**1,050,000**	-	-	-	-	**199,020**	**116,667**	-	-	-	-	-	-	**199,020**	**116,667**
Solar dryer sludge input tonnage t DM/d	5.64		5.82		6.00		6.18		6.37		6.55		6.73		6.91	
solar drier	1,791,176	1,050,000	-	-	-	-	199,020	116,667	-	-	-	-	-	-	199,020	116,667
El Laboue	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yammouneh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Joub Jannine	**910,000**	**1,259,000**	-	-	-	-	**227,500**	**74,750**	-	-	-	-	-	-	**227,500**	**74,750**
Solar dryer sludge input tonnage t DM/d	3.0		3.3		3.5		3.8		4.0		4.3		4.5		4.8	
solar drier	910,000	299,000	-	-	-	-	227,500	74,750	-	-	-	-	-	-	227,500	74,750
storage	-	960,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saghbine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hermel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
East Zahlé	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fourzol	-	**177,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	0.41		0.45		0.49		0.54		0.58		0.62		0.66		0.70	
storage	-	177,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aitanit	-	**240,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99	
storage	-	240,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ablah	-	**120,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81	
storage	-	120,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total €HT/year	**13,505,098**	**9,179,333**	-	-	-	-	**426,520**	**191,417**	-	-	-	-	-	-	**1,563,775**	**858,083**
Total €HT/year		**22,684,431**		-		-		**617,936**		-		-		-		**2,421,858**
Total €HT/d		62,149		-		-		1,693		-		-		-		6,635
Total tonnage tDM/d	40.4		42.3		44.2		46.1		48.0		49.9		51.8		53.7	
Unit price of the tDM in €	1539		0		0		37		0		0		0		124	

year	2033		2034		2035		2036		2037		2038		2039		2040	
	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works
Zahlé	-	-	**1,137,255**	**666,667**	-	-	**1,137,255**	**666,667**	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	39.92		41.34		42.77		44.19		45.61		47.04		48.46		49.89	
solar drier	-	-	1,137,255	666,667	-	-	1,137,255	666,667	-	-	-	-	-	-	-	-
Marj	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temnine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iaat	-	-	-	-	-	-	**199,020**	**116,667**	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	7.09		7.27		7.45		7.63		7.82		8.00		8.18		8.36	
solar drier	-	-	-	-	-	-	199,020	116,667	-	-	-	-	-	-	-	-
El Laboue	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yammouneh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Joub Jannine	-	-	-	-	-	-	**227,500**	**74,750**	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	5.0		5.3		5.5		5.8		6.1		6.3		6.6		6.8	
solar drier	-	-	-	-	-	-	227,500	74,750	-	-	-	-	-	-	-	-
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saghbine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hermel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
East Zahlé	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fourzol	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	0.74		0.78		0.82		0.87		0.91		0.95		0.99		1.03	
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aitanit	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99	
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ablah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81	
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total €HT/year	-	-	**1,137,255**	**666,667**	-	-	**1,563,775**	**858,083**	-	-	-	-	-	-	-	-
Total €HT/year		-		**1,803,922**		-		**2,421,858**		-		-		-		-
Total €HT/d		-		4,942		-		6,635		-		-		-		-
Total tonnage tDM/d	55.6		57.5		59.4		61.3		63.2		65.1		67.0		68.9	
Unit price of the tDM in €	0		86		0		108		0		0		0		0	

N.1.3. Scenario 3

Investment phases

year	2025		2026		2027		2028		2029		2030		2031		2032	
	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works
Zahlé	**26,191,062**	**12,398,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Digester sludge input in tDM/d	13.55		14.00		14.45		14.91		15.36		15.81		16.27		16.72	
anaerobic digestion	2,713,000	3,570,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	9.5		9.8		10.1		10.4		10.8		11.1		11.4		11.7	
centrifuge	478,062	228,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Incinerator sludge input in tDM/d	31.6		33.1		34.6		36.2		37.7		39.3		40.8		42.3	
Incinerator	23,000,000	8,600,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Marj	**478,062**	**228,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	11.6		11.9		12.2		12.5		12.8		13.1		13.4		13.7	
centrifuge	478,062	228,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temnine	**478,062**	**228,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	4.6		5.3		6.1		6.8		7.5		8.3		9.0		9.7	
centrifuge	478,062	228,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iaat	**403,475**	**180,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	5.6		5.6		5.6		5.6		5.6		5.6		5.6		5.6	
centrifuge	403,475	180,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-
El Laboue	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yammouneh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Joub Jannine	**910,000**	**299,000**	-	-	-	-	**227,500**	**74,750**	-	-	-	-	-	-	**227,500**	**74,750**
Solar dryer sludge input tonnage t DM/d	3.0		3.3		3.5		3.8		4.0		4.3		4.5		4.8	
solar drier	910,000	299,000	-	-	-	-	227,500	74,750	-	-	-	-	-	-	227,500	74,750
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saghbine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hermel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
East Zahlé	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fourzol	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aitanit	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ablah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total €HT/year	**28,460,661**	**13,333,000**	-	-	-	-	**227,500**	**74,750**	-	-	-	-	-	-	**227,500**	**74,750**
Total €HT/year		**41,793,661**		-		-		**302,250**		-		-		-		**302,250**
Total €HT/d		114,503		-		-		828		-		-		-		828
Total tonnage tDM/d	56.4		59.2		62.0		64.8		67.7		70.5		73.3		76.1	
Unit price of the tDM in €	2031.9		0.0		0.0		12.8		0.0		0.0		0.0		10.9	

year	2033		2034		2035		2036		2037		2038		2039		2040	
	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works
Zahlé	-	-	**23,000,000**	-	-	-	-	-	-	-	-	-	**239,031**	-	-	-
Digester sludge input in tDM/d	17.17		17.62		18.08		18.53		18.98		19.43		19.89		20.34	
anaerobic digestion	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	12.0		12.3		12.7		13.0		13.3		13.6		13.9		14.2	
centrifuge	-	-	-	-	-	-	-	-	-	-	-	-	239,031	-	-	-
Incinerator sludge input in tDM/d	43.9		45.4		46.9		48.5		50.0		51.6		53.1		54.6	
Incinerator	-	-	23,000,000	-	-	-	-	-	-	-	-	-	-	-	-	-
Marj	-	-	-	-	-	-	**239,031**	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	14.0		14.3		14.6		14.9		15.2		15.5		15.8		16.1	
centrifuge	-	-	-	-	-	-	239,031	-	-	-	-	-	-	-	-	-
Temnine	-	-	-	-	-	-	-	-	-	-	-	-	**239,031**	-	-	-
Centrifuge sludge input in tDM/d	10.5		11.2		12.0		12.7		13.4		14.2		14.9		15.6	
centrifuge	-	-	-	-	-	-	-	-	-	-	-	-	239,031	-	-	-
Iaat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centrifuge sludge input in tDM/d	5.6		5.6		5.6		5.6		5.6		5.6		5.6		5.6	
centrifuge	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
El Laboue	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yammouneh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Joub Jannine	-	-	-	-	-	-	**227,500**	**74,750**	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	5.0		5.3		5.5		5.8		6.1		6.3		6.6		6.8	
solar drier	-	-	-	-	-	-	227,500	74,750	-	-	-	-	-	-	-	-
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saghbine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hermel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
East Zahlé	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fourzol	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aitanit	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ablah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total €HT/year	-	-	**23,000,000**	-	-	-	**466,531**	**74,750**	-	-	-	-	**478,062**	-	-	-
Total €HT/year		-		**23,000,000**		-		**541,281**		-		-		**478,062**		-
Total €HT/d		-		63,014		-		1,483		-		-		1,310		-
Total tonnage tDM/d	79.0		81.8		84.6		87.4		90.3		93.1		95.9		98.7	
Unit price of the tDM in €	0.0		770.5		0.0		17.0		0.0		0.0		13.7		0.0	

N.1.4. Scenario 4

Investment phases																																
year	2025		2026		2027		2028		2029		2030		2031		2032		2033		2034		2035		2036		2037		2038		2039		2040	
	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works
Zahlé	**3,344,250**	**1,098,825**	-	-	-	-	**445,900**	**146,510**	-	-	-	-	-	-	-	-	**668,850**	**219,765**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	12.99		13.43		13.86		14.29		14.73		15.16		15.60		16.03		16.47		16.90		17.33		17.77		18.20		18.64		19.07		19.50	
solar drier	3,344,250	1,098,825	-	-	-	-	445,900	146,510	-	-	-	-	-	-	-	-	668,850	219,765	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Marj	**2,730,000**	**897,000**	-	-	-	-	**455,000**	**149,500**	-	-	-	-	-	-	-	-	**455,000**	**149,500**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	11.12		11.41		11.69		11.98		12.26		12.55		12.83		13.12		13.40		13.69		13.97		14.26		14.54		14.83		15.11		15.40	
solar drier	2,730,000	897,000	-	-	-	-	455,000	149,500	-	-	-	-	-	-	-	-	455,000	149,500	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temnine	**2,047,500**	**672,750**	-	-	-	-	**682,500**	**224,250**	-	-	-	-	-	-	-	-	**682,500**	**224,250**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	4.41		5.11		5.82		6.52		7.23		7.93		8.64		9.35		10.05		10.76		11.46		12.17		12.87		13.58		14.28		14.99	
solar drier	2,047,500	672,750	-	-	-	-	682,500	224,250	-	-	-	-	-	-	-	-	682,500	224,250	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iaat	**1,228,500**	**403,650**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36	
solar drier	1,228,500	403,650	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
El Laboue	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yammouneh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Joub Jannine	**910,000**	**1,259,000**	-	-	-	-	**455,000**	**149,500**	-	-	-	-	-	-	-	-	**227,500**	**74,750**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	3.0		3.26		3.5		3.8		4.0		4.3		4.5		4.8		5.0		5.3		5.5		5.8		6.1		6.3		6.6		6.8	
solar drier	910,000	299,000	-	-	-	-	455,000	149,500	-	-	-	-	-	-	-	-	227,500	74,750	-	-	-	-	-	-	-	-	-	-	-	-	-	-
storage	-	960,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saghbine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hermel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
East Zahlé	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fourzol	-	**120,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	0.4		0.5		0.5		0.5		0.6		0.6		0.7		0.7		0.7		0.8		0.8		0.9		0.9		0.9		1.0		1.0	
storage	-	120,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aitanit	-	**240,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	1.91		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.91	
storage	-	240,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ablah	-	**120,000**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	0.78		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.78	
storage	-	120,000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total €HT/year	**10,260,250**	**4,811,225**	-	-	-	-	**2,038,400**	**669,760**	-	-	-	-	-	-	-	-	**2,033,850**	**668,265**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total €HT/year		**15,071,475**		-		-		**2,708,160**		-		-		-		-		**2,702,115**		-		-		-		-		-		-		-
Total €HT/d		41,291.71		-		-		7,419.62		-		-		-		-		7,403.05		-		-		-		-		-		-		-
Total tonnage tDM/d	40.0		41.8		43.5		45.3		47.0		48.7		50.4		52.1		53.9		55.6		57.3		59.0		60.7		62.5		64.2		65.7	
Unit price of the tDM in €	1033		0		0		164		0		0		0		0		137		0		0		0		0		0		0		0	

N.1.5. Scenario 5

Investment phases																																
year	2025		2026		2027		2028		2029		2030		2031		2032		2033		2034		2035		2036		2037		2038		2039		2040	
	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works	Equipment	Civil works
Zahlé	**3,344,250**	**1,098,825**	-	-	-	-	**445,900**	**146,510**	-	-	-	-	-	-	-	-	**668,850**	**219,765**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	12.99		13.43		13.86		14.29		14.73		15.16		15.60		16.03		16.47		16.90		17.33		17.77		18.20		18.64		19.07		19.50	
solar drier	3,344,250	1,098,825	-	-	-	-	445,900	146,510	-	-	-	-	-	-	-	-	668,850	219,765	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Marj	**2,730,000**	**897,000**	-	-	-	-	**455,000**	**149,500**	-	-	-	-	-	-	-	-	**455,000**	**149,500**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	11.12		11.41		11.69		11.98		12.26		12.55		12.83		13.12		13.40		13.69		13.97		14.26		14.54		14.83		15.11		15.40	
solar drier	2,730,000	897,000	-	-	-	-	455,000	149,500	-	-	-	-	-	-	-	-	455,000	149,500	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temnine	**2,047,500**	**672,750**	-	-	-	-	**682,500**	**224,250**	-	-	-	-	-	-	-	-	**682,500**	**224,250**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	4.41		5.11		5.82		6.52		7.23		7.93		8.64		9.35		10.05		10.76		11.46		12.17		12.87		13.58		14.28		14.99	
solar drier	2,047,500	672,750	-	-	-	-	682,500	224,250	-	-	-	-	-	-	-	-	682,500	224,250	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iaat	**1,228,500**	**403,650**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36		5.36	
solar drier	1,228,500	403,650	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
El Laboue	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yammouneh	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Joub Jannine	**910,000**	**299,000**	-	-	-	-	**455,000**	**149,500**	-	-	-	-	-	-	-	-	**227,500**	**74,750**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	3.0		3.26		3.5		3.8		4.0		4.3		4.5		4.8		5.0		5.3		5.5		5.8		6.1		6.3		6.6		6.8	
solar drier	910,000	299,000	-	-	-	-	455,000	149,500	-	-	-	-	-	-	-	-	227,500	74,750	-	-	-	-	-	-	-	-	-	-	-	-	-	-
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saghbine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hermel			-	-	-	-			-	-	-	-	-	-	-	-			-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar dryer sludge input tonnage t DM/d	3.95		4.03		4.12		4.21		4.30		4.38		4.47		4.56		4.65		4.74		4.82		4.91		5.00		5.09		5.18		5.26	
solar drier	600,600	197,340.00	-	-	-	-	75,075	24,667.50	-	-	-	-	-	-	-	-	75,075	24,667.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-
East Zahlé	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fourzol	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	0.4		0.5		0.5		0.5		0.6		0.6		0.7		0.7		0.7		0.8		0.8		0.9		0.9		0.9		1.0		1.0	
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aitanit	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	1.91		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.99		1.91	
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ablah	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Storage sludge input tonnage tDM/d	0.78		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.81		0.78	
storage	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total €HT/year	**10,260,250**	**3,371,225**	-	-	-	-	**2,038,400**	**669,760**	-	-	-	-	-	-	-	-	**2,033,850**	**668,265**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total €HT/year		**13,631,475**		-		-		**2,708,160**		-		-		-		-		**2,702,115**		-		-		-		-		-		-		-
Total €HT/d		37,346.51		-		-		7,419.62		-		-		-		-		7,403.05		-		-		-		-		-		-		-
Total tonnage tDM/d	40.0		41.8		43.5		45.3		47.0		48.7		50.4		52.1		53.9		55.6		57.3		59.0		60.7		62.5		64.2		65.7	
Unit price of the tDM in €	934		0		0		164		0		0		0		0		137		0		0		0		0		0		0		0	

N.2. SCENARIO 5

In this scenario, both sludge considered "compliant" and "non-compliant" go through the black process.

N.2.1. DESIGN

Solar Drying

The sludge output of each WWTP will be dried in solar dryers constructed on the site of each treatment plant. Except for Ablah, Fourzol and Aitanit WWTPs that already have drying beds, Yammouneh WWTP that produces very limited quantities of sludge and Saghbine WWTP's sludge that is transported to the nearby WWTP of Joub Jannine.

The quantity of sludge produced by the plants and their dryness at the 2040 horizon are shown in the table below:

WWTP	Quantity of sludge produced (tDM/d)	Dryness of sludge produced* (%)	Dryness at output of solar dryers (%)	Quantity of water to be evaporated (m^3/d)	Required solar dryers total area (m^2)
Zalhé	19.5	18	65% ± 5%	78	9,800
Marj	15.4	18	65% ± 5%	62	8,000
Temnine	14.99	18	65% ± 5%	60	7,500
Iaat	5.36	18	65% ± 5%	22	2,700
El Laboue	2.72	18	65% ± 5%	11	1,360
Joub Jannine	6.81	18	65% ± 5%	27	3,500
Hermel	5.26	25	65% ± 5%	13	1,650
East Zahlé	8.02	25	65% ± 5%	20	2,500

*Assumptions: - Sludge dryness at the outlet of centrifugation: 25%.
- Sludge dryness at the outlet of the belt filter press: 18%.

Landfills

The aim of scenario 5 is to dispose the sludge produced and dried in each wastewater treatment plant in a dedicated landfill for each plant.

	Quantity of dried sludge produced over 15 years (tRM)	Required area for the landfill* (m^2)
Zahlé	145,982	27,034
Marj	119,121	22,059
Temnine	87,131	16,135
Iaat	48,140	8,915
Laboue	12,218	2,263
Yammouneh	9,156	1,695
Joub Jannine	44,130	8,172
Saghbine	6,800	1,259
Hermel	41,366	7,660
East Zahleh	36,022	6,671
Fourzol	4,305	797
Aitanit	11,857	2,196
Ablah	4,856	899

*Assumptions: - Maximum height of sludge 6m
- Density of dried sludge 0.9
- No cover or flare for the management of gases

N.2.2. CAPEX

The CAPEX of solar dryers was calculated using the ratio of 465 €/m² and by adding to this cost 30% for contingencies.

The investment and the phasing of the investment are summarized in chapters I and J.

N.2.3. OPEX

The operating costs are summarized in chapter K.

The OPEX was calculated by using the following:

- A percentage of 1.5% of the total price of equipment for the maintenance and renewal of equipment
- A percentage of 0.5% of the total price of civil works for the maintenance and renewal of civil works
- A transport unit cost of 1.44 €/tRM/km
- A gate fee at the landfill of 35 €/tRM

N.3. SLUDGE ANALYSES RESULTS

Limit content of trace elements in sludge										
Trace elements	Limit value in sludge (mg/kg DM)	Sample result AUB lab 16/12/2020 (mg/kg DM)	Sample result LARI lab 06/08/2019 (mg/kg DM)	Sample 1 result IRI lab 29/03/2019 (mg/kg DM)	Sample 2 result IRI lab 29/03/2019 (mg/kg DM)	Sample 1 result AUB lab 29/03/2019 (mg/kg DM)	Sample 2 result AUB lab 29/03/2019 (mg/kg DM)	Sample result IRI lab 24/04/2018 (mg/kg DM)	Sample result AUB lab 26/02/2018 (mg/kg DM)	Sample result AUB lab 11/01/2018 (mg/kg DM)
Cadmium	**10**	0.489		1.4	2.7	<0.5	<0.5	8.2	<1	<1
Chromium	**1 000**	57.1		1.3	0.8	18.8	44.6	0.3		
Copper	**1 000**	9.48		2.2	2	27.6	97	15.9	10	210
Mercury	**10**	0.179		<0.1	<0.1	<0.5	<0.5	0.3	<1	<1
Nickel	**200**	10.8		1.7	1.8	3.28	9.72	1	<1	32.5
Lead	**800**	31.9		5.6	7.5	30.1	65.1	0.8	5	29
Zinc	**3 000**	137	583.1	26.2	30.5	111	368	90.9	18.2	91.2
Cr + Cu + Ni+ Zn	**4 000**	214.38		31.4	34.5	160.68	519.32	108.1		
Selenium	**-**	0.252		0.2	0.2	0.648	0.902	3.5		

Limit contents of organic trace compounds in sludge			
Organic compounds	Limit value in sludge (mg/kg DM)		Sample result AUB lab 05/08/2019 (mg/kg DM)
	General case	Spreading on pastures	
Total of the 7 main PCBs (*)	**0,8**	**0,8**	<0.5mg/Kg for each PCB
Fluoranthene	**5**	**4**	<0.5mg/Kg
Benzo(b)fluoranthene	**2,5**	**2,5**	<0.5mg/Kg
Benzo(a)pyrene	**2**	**1,5**	<0.5mg/Kg

(*) PCB 28, 52, 101, 118, 138, 153, 180

N.4. CURRENT AND EMERGING SLUDGE TREATMENT PROCESSES