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French public policies analysis on agricultural sludge valorization from sewage treatment plants in order to adapt in Morocco

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SYNTHESIS

French public policies analysis on agricultural sludge valorization from sewage treatment plants in order to adapt in Morocco

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RESUME
Le traitement des eaux usées domestiques génère des sous-produits : les boues. En France, en Europe et au Maroc, ces résidus sont considérés comme des déchets et suivent donc les contraintes juridiques liées à ce statut lors de leur valorisation. Parmi les destinations existantes, la valorisation agricole est la plus utilisée en France (73% en tonnes de Matière Sèche (MS)). Elle présente les avantages d'être peu coûteuse et de s'insérer dans une logique d'économie circulaire encouragée par l'Union Européenne. Cependant, certains freins au développement de la filière sont apparus après divers scandales (dioxine, vache folle). Malgré cela, les agriculteurs reconnaissent la valeur agronomique des boues et sont demandeurs, à condition d'avoir une filière de qualité. Le maître d'ouvrage doit donc se poser les bonnes questions en amont, lors de la conception de la filière assainissement-valorisation des boues. Aujourd'hui, de nombreuses filières de traitement des eaux et des boues s'offrent aux collectivités. Les éléments qui sous-tendent le choix de ces filières sont nombreux et dépendent fortement du contexte local. L'environnement marocain ne déroge pas à cette complexité mais il semble qu'il se prête à certains types de traitements.

Mots-clefs : assainissement, station d'épuration, boues, valorisation agricole, épandage, recyclage

ABSTRACT
Domestic waste water treatment produces sewage sludges. In France, Europe and Morocco, these residues are considered as wastes and follow the jurisdiction linked to this status when spread on crop fields. Among the existing value chains, spreading is the first in terms of use (73% tons of Dry Matter). It is cheap and copes with the circular economy. However, brakes in the value chain appeared after the mad cow and dioxin crisis. Despite these draw-backs, farmers still recognize the sewage sludge agronomic value but ask for a quality beyond reproach. In that sense, the contracting authority has to consider different options before investing in a treatment vale chain. Nowadays, various possibilities are on the table. There are many factors behind the sludge treatment processes and strongly depend on the local context. Morocco is not an exception but it seems that some processes are more adapted than others.

Key-words: sanitation, water treatment plant, sewage sludge, recycling, spreading, agriculture

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ABBREVIATIONS

ADEME :	Agence de l'Environnement et de la Maîtrise de l'Energie
AFD :	Agence Française de Développement
CUMA :	Coopérative d'Utilisation de Matériel Agricole
DSP :	Délégation de Service Public
EH :	Equivalents-Habitants
ETA :	Entreprise de Travaux Agricoles
ETM :	Eléments Traces Métalliques
MES :	Matières En Suspension
MS :	Matière Sèche
MESE :	Mission d'Expertise et de Suivi des Epandages
ONEE :	Office National de l'Electricité et de l'Eau potable
CTO :	Composés Traces Organiques
SAU :	Surface Agricole Utile
SATESE :	Service d'Assistance Technique aux Exploitants de Stations d'Epuration
STEP :	Station d'épuration
SYPREA :	Syndicat des Professionnels du Recyclage en Agriculture
pH :	Potentiel Hydrogène
ZNIEFF :	Zone Naturelle d'Intérêt Ecologique, Faunistique et Floristique

APPENDICES :

WHICH ASSETS FOR THE SPREADING SEWAGE SLUDGE VALUE CHAIN FOR THE MOROCCAN CONTEXT

The French Development Agency is a contributor to the water sanitation sector in Morocco. On that matter, the institution would like to have access to a technical note. This document is meant to help the agency for their future projects in Morocco. Indeed, France has chosen to spread most of its sewage sludge (73% in tons of dry matter including 28% of compost) (Fabienne Muller, 2013). Moreover, the French value chain has a well-structured framework with working operational modalities that inspired part of the EU policy (Ministère de l'écologie, de l'énergie, du développement durable et de la mer et al., 2009)**.**

In most European countries, the main elimination or recycling value chains for sewage sludge are: spreading on field crops, dumping, incineration and biogas production. Generally, responsible authorities for sanitation choose the value chain considering various tributary factors from the local context; let us mention here health and environmental legal framework (for instance limit ratio on dangerous substances accepted in water), the nature of the local economy (land available for spreading), or investment and management costs**.**

In the first part of this study, we will look at the value chain framework; sludge origin, the different treatment processes and the role of various stakeholders. In the second part, we will focus on the drawbacks and promoting factors. In the end, we will suggest some application for the Moroccan context**.**

THE ORIGIN OF SEWAGE SLUDGE AND THE VALUE CHAIN FRAMEWORK

SEWAGE SLUDGE ORIGINS, TREATMENT PROCESSES AND RECYCLING VALUE CHAINS

Sludge origin

The sewage collective treatment plants treat domestic sewage. In the end, treated water is discharged into the river. The treatment starts with a macro waste elimination (bottles, wipes…), as well as sand and fats. There, remains suspended solids and a dissolved pollution load. The primary treatment (settling), aims to eliminate the suspended solids (associated with a chemical treatment in specific treatment plants). The secondary treatment eliminates dissolved organic matter through bacterial activity. The bacteria are fixed to a substrate or are free in the basin. Finally, bacteria are separated from water. The result is purified water and sludge as a by-product. Concerning the secondary treatment, we find intensive ways to treat the water (the bacteria are catalyzed) like activated sludge for instance, and in more extensive ways. In the first case, the plant has a reduced footprint but a high-energy consumption and requires investment. On the contrary, extensive treatment, such as lagoons and reed beds have a large footprint but require lower investment .

Different types of sludge and treatment processes

There are three different types of sludge: from primary treatment (settling), from primary treatment with chemicals, and from secondary treatment (biological sludge). In most treatment plants, primary and biological sludge are mixed and stored in a tank before treatment. (Laroche, 2014).

At this stage, the sludge has three major drawbacks. The volume is high, as it is a liquid. Then, it has a high fermentable power which make it smell a lot. In addition, it contains pathogens. That is why it is necessary to apply a treatment to reduce their volume, lower the fermentable activity and insure their innocuity .

Reducing water content (or increasing driest content) can be done through three processes: thickening, dehydration and drying. Concerning thickening, there are two ways of treatment: the mechanic way (dripping and flotation), or by gravity. After this process, the sludge is still called liquid, as the driest content do not exceed 7% to 8% of driest content. Generally, these processes are implemented in small treatment plants (from 2000 to 5000 population equivalent). After thickening, dehydration aims to increase driest content from 18% to 20% with a belt filter and 30% to 35% with a centrifuge; after dehydration, the sludge is called pasty. These types of dehydration processes concern medium treatment plants from 6 500 to 20 000 population equivalents (Fabienne Muller, 2013). Finally, drying can be implemented on an open-air bed (driest content around 50%: solid sludge) or through rising temperature in a tank (95% of driest content: granules or powder). This last process requires high investment, that is why it is mainly implemented in big plants, from 500 000 population equivalents (Ferry et Wiart, 2000) .

To reduce the pathogenic power of the sludge, there is biological stabilization, compost, or liming. Biological stabilization is implemented in aerobic basins or specific tanks, or with an anaerobic process that produces biogas. Biogas production is generally set up in stations from at least 50 000 population equivalents as it is relatively costly. Composting (within the plant structure or on a dedicated platform) is also a biological stabilization process in the open air; the sludge is mixed with ligneous organic matter (from plants) and ventilated, which produces a solid mixture (driest content between 40% to 70%) that is directly used in agriculture or green spaces. Finally, the chemical way to kill pathogens is liming; this process is often coupled with a belt filter especially in medium treatment plants (more the 15 000-population equivalent) (Christophe Chassande et al., 2000).

Different destinations
After treatment, the sludge is recycled or eliminated; there are three main destinations: farming use, which represent 73% of the produced dry matter in France, incineration (18%), and dumping (9%) (Patrick Savary, 2016) and (Jean-Paul Legroux et Claude Truchot, 2009).

Other destinations are possible; soil rehabilitation after mining (or other soil degrative activities) is commonly used in Sweden or Finland (in order 20% and 30% of produced dry matter). Spreading on growing forests is also a possible destination, but only at an experimental stage in France, as authorities consider that risks on the environment are not well contained at the moment (Éric Duvaud et al., 1999).

Agriculture serves the circular economy
Using sludge in farming is an opportunity to combine the natural soil capacity to depollute and have the agronomic value of the by-product. This last characteristic comes from the substantial quantities of Nitrogen and Phosphorus it contains. Limed, the sludge can also be used to increase acid soils ph. By using sludge, farmers can lower their fertilizer consumption. Besides, when a farmer provides land for spreading, it is a benefit for the collectivity that finds a destination for its collective waste. The goal is to take advantage of a natural process, less costly than other destinations .[1]

Risks for the environment and public health
However farming use can be a threat to the environment (soil and water pollution) and for the population (infections). Sludges contains micropollutants; the metal trace elements (Cadmium, Copper, …) that can be a risk for our food supply through a soil-to-plant transfer, and organic trace elements (anthracene, benzene, …) that can be dangerous for the soil micro life, or volatilize. Recently, new substances are emerging (active substances from medication or household detergents for example) and are the subject of new research. However, references are few. These risks can generate tension among different stakeholders[2], although no major incident due to sludge farming use was noticed over the past three decades. Besides, research on the subject tend to show that infection risks or environmental pollution risks are contained within agricultural good practices (Jean-Paul Legroux et Claude Truchot, 2009).

LEGAL AND OPERATIONAL FRAMEWORK

Legal framework
The legal framework on sewage sludge is articulated around two aspects: waste and product.

Framework related to the waste aspect
Most countries made their legal framework in relation to the waste aspect. The legal EU framework is defined by the community directive on different types waste (91/156/CEE). Concerning sludge farming use specifically, it the 12th of June 1986 directive (86/278/CEE) that first defines limit ratios on metallic trace elements .

Regarding France, the general framework is related to the law on water from the 3rd of January 1992, which aims to protect water resources. The juridical status of waste (defined in the 15th July 1975 law) attributed to sludge was clarified in the 18th December 1992 decree (97-1133). Sludge spreading on crops cannot be implemented if the agronomic value is not verified (circular from the 28th of April 1998). This text also determines responsibilities among stakeholders: the territorial collectivity is responsible for sludge recycling or elimination. If the public authority chooses to delegate the sanitation sector to a private structure, the latter has to implement the value chain. The farmer is simply considered as a recycler. They are under

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1 cf. § “Economic aspects on sewage sludge farming use”

2 cf. § “Stakeholder’s positions”

the legal framework concerning rural areas, the contract, the farm rent rights and the Nitrate Directive (91/676/CEE), that determines sensitive areas where spreading sludges follows restrictions. The Code of the Environment sets a compulsory declaration or authorization when spreading. Moreover, this document specifies that the value chain responsible (territorial collectivity or private structure) has to produce documents concerning spreading management, traceability from the plant to the field, and the impact on the environment (French Ministry on Ecology, Energy, Sustainable Development and Sea and al., 2009). Practically, there are three main documents: the spreading management plan, the spreading register, and the annual assessment. The spreading management plan is written before operating and details characteristics and number of fields that will receive the sludge, and who is implied. The spreading register has all the data on how the spreading was carried out. Finally, the annual assessment evaluates the agronomic practices such as how the sludge spreading is part of the fertilization plan of the farmer .

In April 2009, the decree 2009-550 ratifies the creation of a fund in order to cover the risks linked to spreading sludge on crops.

In Morocco, the status of waste is defined by the law number 28-00 concerning waste management and elimination. It defines that the owner of the waste (the territorial collectivity) has to eliminate it with no harm to public health and the environment. However, it does not define any norms in terms of pollutants (limit ratios)

Framework related to the product aspect

In France, sewage sludge is turned from waste to product within three cases: when officially recognized as a fertilizer, when it has a trade authorization, or it follows a standard. The French norm NFU 44-095 related to composts with organic matter from sewage treatment plants defines a market for the sludge as a standard product. Generally speaking, there are very few cases that fall into the different types of products[3] in France, except compost.

Operational framework

Stakeholders

Regarding France, it is public structures that inform stakeholders in terms of good practices and legal framework. For instance, institutions like the Agency for Environment and Energy (ADEME). The agricultural chambers advise the farmer (sludge integration within the whole fertilizing process). Water Agencies finance the different institutions that give technical assistance to the local authorities. Districts give technical assistance, for instance through the “Technical Assistance Services to Treatment Plants Operators” (SATESE); they also have a financing role in rural areas. The territorial collectivity, who own the infrastructure, is in charge of the sludge recycling and/or elimination, or delegates to a private operator. Operations on the ground are performed by agricultural working enterprises, recycling firms, collective structures owning agricultural machines, farmers themselves. It is an obligation to have a contract between the different stakeholders. Engineering offices give assistance to the project owner (choose the treatment plant type, sludge recycling value chain); to the treatment plant

[3] The SIAAP (Syndicat Interdépartemental pour l’assainissement de l’Agglomération Parisienne) tried to launch a project called « GRANUVAL » in 2008 in order to value sludge from Valenton’s treatment plant. The project failed for authorities did not validate the product for public health reasons (Belaïde Bedreddine, 2016).

operator when it comes to producing the different compulsory documents (spreading management plan, register and annual assessment). Farmers are final users. Generally, they keep traceability and communicate their data related to fertilization. Along the value chain, the water police are in charge of checking if rules are respected, especially in terms of effluent releases .

Value chain design by the contracting authority
There is no value chain that is a priori better than another one. The project owner will adapt Their choices according to the local situation; sewage quality and quantity, quality requirements of the environment, the sites constraints, costs, and at last potential nuisances (smell, visual pollution, …). First concerning spreading; it is necessary to assess which sludge quality and quantities are going to be treated; quantity is estimated with the nominal capacity of the plant. Quality can be analyzed directly if the plant already exists. Otherwise, it is possible to diagnose the sanitation grid and estimate contamination risks (J.C. Renat, 2001). Then, the spreading area has to be studied: topography, type of soils, protected areas, (ZNIEFF, Natura 2000), crops (calendar of activities, …). it is also very important to understand famers' perception on spreading as well as the local residents. Then cost scenarios can be made out of these studies. All these steps have to be implemented before the treatment plant is constructed, as the sludge value chain will affect the water treatment type and storage installations.

Sludge farming use operations
The sludge treatment type has an impact on spreading operations; liquid sludge is generally stored within the treatment plant, and crop fields have to be near the storage facility as transporting liquid sludge is expensive. Pasty and dry sludge can be spread on farther fields, as they don't need a proper facility to be stored. In this case, sludge collection and supply on temporary storage points is done by specialized transporters. Then, the project manager locates the crop fields as well as the sludge locations. They have all the necessary information to implement the spreading operations (given by the project owner, the engineering office or the sewage plant operator). Concerning liquid sludge, which are often from small territorial collectivities, the latter makes available a little spreader (many other solutions exists such as spreading without tank) and a local farmer does the spreading. When the sludge is well mixed, the spreading is uniform. It is more difficult for pasty sludge as its structure can require specific machines or smell. It is then necessary to bury the product (same for liquid sludge) after spreading. Finally, it is difficult to spread pasty sludge uniformly. Concerning compost, solid and dry sludge, operations are done with a usual spreader used for fertilizers, and the result is quite uniform (François Thirion et Frédéric Chabot, 2003).

WHICH FACTORS COULD AFFECT THE VALUE CHAIN CHOICE BY THE PROJECT OWNER?

SOME FIGURES ON SLUDGE PRODUCTION AND FARMING USE

The European Union produces around 10 million tons of sludge dry matter (DM) (A. Léonard et al., 2007). France and Spain respectively produce 900 000 tons of DM (15kg DM/inhabit. /year) and 700 000 tons (16kg DM/inhabit. /year), while Netherlands produces around 450 000 tons of DM (22kg DM/inhabit. /year). Germany produces the highest quantities with 2.7 tons of DM (34kg DM/inhabit. /year). Morocco has produced 34 840 tons of DM in 2010, which comes to 1kg of DM per inhabitant per year (Bashar Hassan, 2014). We can explain the differences between the countries through the collective sanitation grid connexion ratio (France has around 20 % to 30 % of individual connexions) and through the sewage treatment performance ratio (38 % in Morocco in 2015). Germany historically has a high ratio of collective connexions to the sanitation grid which explains the high figures for the country.

In France, 73 % of produced dry matter is used in agriculture, it is 50 % in Spain. However, Netherlands only spread 4 % of the dry matter they produce. In Morocco, this destination is very confidential: local residents use the sludge stored around the treatment plants and use it as a fertilizer (Imane Hamdani, 2008). In Morocco, the first destination is dumping, after drying on open beds.

AGRONOMIC FACTORS AND COMPETITION BETWEEN PRODUCTS

Land available for spreading

The differences we highlighted earlier is partly due to land availability. If all the sludge was spread respecting plant needs for growing, France would only need 3 % of its land used for agriculture, while Netherlands would need 22 % (Eric Duvaud et al., 1999). In the case of big cities, it is more difficult to find space for spreading the sludge. A part of it is sent to neighbor localities, but when quantities are too much, it generates conflicts (Patrick Savary, 2016). Moreover, organizing spreading operations can become costly when sludge quantities are high; it is necessary to find more farmers, sign more contracts and eventually stop farmer defection which happens frequently. This is why, when the treatment plants exceed 500 000 population equivalents, the project owner often choose incineration (Déprés et al., 2008) .

Besides, as more and more areas are restricted in order to protect the environment (ZNIEFF, Natura 2000, Nitrate Directive) and as farmers apply different labels on their products (Organic agriculture, AOC, …), land available for a product like sludge is shrinking. In Morocco, land availability does not seem to be a real problem (Soudi Brahim, 2015) .

Competition with manure and fertilizers

When a locality produces high quantities of manure, it competes with the sludge. Indeed, countries that use less sludge in farming are the same where agriculture has a high rate of animal raising. Let us have a look at Nitrogen (N) and Phosphorous (P) origins (manure, fertilizers or sludge). In Netherlands farmers provide around 160 kg N/ha and 100 kg P_2O_5/ha (as a mean figure) to the crops. It covers the crop needs (phosphorous only) and the rest is provided by fertilizers; it is obvious that in this configuration, there is little space left for sludge. In France, it is a more a contrasted situation; the average contribution of manure is around 40 kg N/ha and 20 kg P_2O_5/ha, which is however twice as high as in Spain. (Eric Duvaud et al., 1999). The problem also appears at a local level; for instance, in France, the Bretagne region provides 90 % of the plant needs in organic matter with manure.

ECONOMICAL FACTORS

First, comparing the three main destinations (farming use, incineration and dumping), use in agriculture is the most profitable from an economic point of view for small to medium treatment plants (3 000 PE to 50 000 PE). For farming use, on average (considering all different value chains), treatment represent averagely 56 % of the costs. Storage is around 11 %, loading, transport and spreading 20 %, and specific agricultural practices such as burying the sludge represent 1 %. The part of preliminary studies and audits is 12 % (Ferry et Wiart, 2000). However, it is more relevant to look at the cost of each sludge treatment value chain.

Global cost on sludge value chains fluctuate according to various factors: driest content, investment, management cost and the treatment plant size.
They range from 0.08 € / m³ for the sludge-free sludge industry to 0.17 € / m³ for the solid sludge process with thickening, band-filter drying or biogas production. Concerning liquid sludge, costs range between 0.11 € / m³ and 0.16 € / m³ for plants between 3 000 and 20 000 PE. The pasty sludge with liming increases to 0.13 € / m³ for a STEP of 50 000 PE. For all kinds of treatment, it is noted that the size of the station allows economies of scale.

If we withdraw the treatment, there is a tendency for costs to decrease as the size of the waste water treatment plant increases (regardless of the ratio except for the cost / tMB). If we look at the dry matter indicator, costs increase with the size of the station because it goes together with a higher dry content. For this ratio, drying on beds is the most expensive because it cumulates high levels of dryness (50%) and low a number of PE.

For small treatment plants, the main complication is due to the fact that treatment possibilities are restricted (rather liquid sludge due to the lack of investment capacity for heavier dams), and result in high storage and transport costs.

Who pays for the service?

The value chain distribution costs depend on the mode of management. When managed by the territorial collectivity, the latter pays every cost. However, on a public service delegation, the treatment plant operator manages the costs, except for investment in the infrastructure. In fact, these costs are finally paid by the consumer through the water and sanitation bill. Moreover, costs concerning preliminary studies, or different costs concerning farmer defections are difficult to evaluate *ex-ante.* Consequently, it is common that project owners give up the spreading solution and go for incineration or dumping while it is often costlier (Pierre Roussel, 1999). In France, the farmer does not pay anything because spreading is considered as a service. It is also a condition farmer representative ask to accept sludge on their crop fields. In Germany, farmers are given subsidies. In England, after a strong marketing development, farmers are ready to pay for a product of a branded good quality product. In addition, landowners like when the farmer buys the sludge; indeed, the farmer becomes responsible for the product they buy and spread on the field in any case of pollution (Eric Duvaud et al., 1999). Finally, in France, Germany and Austria, there is a guarantee fund ensuring the farmer, the landowner or the local resident against spreading risks. It is supplied by a tax on the sludge producer (territorial collectivity or plant operator), the financial gains of the fund and government subsidies if damages exceed resources.

POLITICAL FACTORS AND INSTITUTIONAL FRAMEWORK

Stakeholders with diverging points of views

Generally, the European Union and European countries are in favor of sewage sludge farming use. It is in fact the value chain identified as the most environmentally and economically efficient (Pierre Roussel, 1999). However, the sector suffers from a crisis of confidence. During 1990s with the crisis of mad cow disease, dioxin, genetically modified organisms. Unrelated to the agricultural use of sludge, these events revealed a lack of trust from some stakeholders, such as the agro-food industry (IAA). Thus, the latter have largely constrained farming use via clauses prohibiting spreading in production contracts signed with farmers. Nowadays, these clauses are prohibited but persist locally (Déprés et al., 2008). Farmers are in favor of spreading and recognize the agronomic value of the sludge. In a competiting environment, farmers choose between manure or sludge from agricultural or agri-food industries. Finally, landowners are reluctant to spread sludge on their land. Indeed, their agreement is not required for signing the tenancy contract. They feel out of the decision-making process and fear pollution (Christophe Chassande et al., 2000) .

Organise to survive

The implementation of a quality approach makes it possible to "formalize the acts and decisions taken by each" stakeholder, which reinforces user guarantees (Antoine Van de Velde, 2001). However, from the project owner to the plant operator, up to the spreading operation manager, the challenge is to involve everybody. In France, for example, the charter of the FNEDT1, which is not binding but is a professional commitment, or the services certification established by Qualicert for the SYPREA (Association of Professionals for Recycling in Agriculture). At the institutional level, the desire to ensure the sustainability of sludge farming use has resulted in independent organizations among sludge producers: appraisal and monitoring missions (MESE). Agriculture chambers, water agencies, the ADEME and the district council are the main stakeholders. Generally, their implementation is 80% financed by water agencies (Cécile Gallian, 2001). They monitor the spreading plans, accompany project owners on technical expertise, and spread information. This is effective; farmers and professionals become aware of the impact on local residents and feel less suspicious about the product. This state of confidence makes it possible to convince water treatment plants operators to invest in infrastructures such as storage, which are essential for the French agricultural value chain (Déprés et al., 2008).

Incentive tools to guide the value chains

Governments use different tools to guide the sector. Thus, some countries create new taxes; for example, in Denmark and Sweden, other sludge destinations have been taxed in order to orient stakeholders to choose farming use. Other countries use regulation; in the Netherlands, the pollutants limit values contained in the sludge have been considerably increased without accompanying the stakeholders. That is why they turned to other destinations: composting (24 % of the sludge produced), which makes it possible to produce a standardized, hygienic and exportable product, incineration (24%) and landfilling (48%). However, it is interesting to note that Denmark manages both ambitious sanitary standards and high farming use rate (around 70%). It is a strong control integration over the entire sanitation system, which gives confidence to the actors of the sector that allowed this situation. However, Denmark plans to increase the proportion of incinerated sludge for sanitary reasons (Eric Duvaud et al., 1999).

A POSSIBLE ADAPTATION IN MOROCCO

In 2005, Morocco has adopted a national plan for sanitation. Ambitious, this plan increased the connexion ratio to the sanitation grid up to 73 % in targeted cities and succeeded in moving to a 40% volume of purified wastewater in 2015, compared to 7% in 2004. Sludge is also increasing and it is necessary to find recycling destinations.

THE MOROCCAN CONTEXT

Morocco produced 34,840 tons of DM in 2010, which comes to 1kg DM per person and per year (Bahhar Hassan, 2014). The share of farming use is very low and rather informal: residents or small farmers use the sludge stored at the treatment plants to fertilize vegetables (Imane Hamdani, 2008). Farmers seem ready to use sewage sludge, which is already recognized for their fertilizing qualities (Soudi Brahim, 2015). For now, the main destination for sludge is dumping after natural drying.

Regarding quality, sludge from waste water treatment plants managed by the ONEE complies with the norms defined for pollutants by the European Union; it is therefore suitable for use in agriculture (Soudi Brahim, 2015).

In Morocco, the waste status of sewage sludge is defined by the Law No. 28-00 on waste management and its disposal. This law also specifies that the holder (municipality) must eliminate waste in order to protect public health and the environment. However, there is no normative reference (limit values).

EXTENSIVE VALUE CHAINS THAT APPEAR SUITABLE FOR THE MOROCCAN CONTEXT

The majority of constructed or planned treatment plants are lagoons (Soudi Brahim, 2015). In 2015, 79% of plants operated by the National Office of Water and Energy (ONEE) and 70% of projected plants lagoons too (Soudi Brahim, 2015) .

Nevertheless, it is better to adapt each destination according to the local context. For example, recommended value chains can lead to bad odors, and the spraying management is more complex: when deciding to cure (once every ten years), it is necessary to be in a favorable period. Indeed, WWTPs using lagoons do not generally have storage and processing facilities. In addition, it is excluded to be in peak period of effluents levels when curing. In the end, the agronomic value of lagoon sludge is low compared with that of manure, slurry or sludge from activated sludge plants .

WASTEWATER REUSE

In most cases, purified water is released into the environment. In a semi-arid to arid country like Morocco, it may be interesting to explore the destination of reusing wastewater in agriculture. Some experiments have been carried out in France: thus, the commune of Château-Renault has seized the opportunity to renew its treatment infrastructures to implement reuse of wastewater. Farmers have volunteered and now irrigate their cereals thanks to the treated waters of the communal plant. After five years in operation, the experiment has proven to be a success (Nathalie Le Nouveau, 2016). Besides, some countries like Egypt or Israel have been doing this for several years (late 1990s).

SOIL REHABILITATION

In an arid or semi-desert environment, soil rehabilitation can slow soil erosion or contribute to reforestation. It is important to note, however, that pollutant accumulation in the soil does not present a long-term risk in the absence of tillage, for example.

CONCLUSION:

Well-conceived and integrated to the sanitation system, the agricultural valorization of domestic STEP sludge is an interesting destination regarding the environment and from an economic point of view. Today, the value chain is gaining momentum in most countries of the world, but remains fragile. Indeed, it requires a commitment from all stakeholders and a clear institutional framework that defines the responsibilities of everyone in order to avoid a lack of trust between stakeholders. Furthermore, it is important to choose the sludge treatment and their destination after a thorough study of the local context. Morocco has chosen the path of agricultural use and its assets. First, the institutional context is favorable, as the political will is clearly committed and sanitation infrastructure is developing. Secondly, the country has available space, which can allow less costly infrastructure such as lagoon or reed filters. Finally, the arid climate is a major asset because it reduces drying costs, which are among the main expense. However, the country faces major challenges; The national sanitation plan has led to a rapid increase in sludge quantities, whereas dumping is the first destination in Morocco. Secondly, a clarification of the regulatory and institutional framework seems necessary in order for local actors, and in particular elected officials, to seize the sludge problem. Finally, in a country where water is a scarce resource and is available intermittently, it may be interesting to explore techniques such as the reuse of treated wastewater in agriculture. Little developed in European countries, these techniques are widely spread in the Middle East and bring a new resource to farmers. Besides sludge, this may be an opportunity to continue developing the country's agricultural sector, which accounts for about 40 % of Moroccan jobs.

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ANNEXES

	2003	2004	2005	2006	2007	2008 partiel
Quantité de boues produites par les STEP (en T MS/an)	**946700**	**989054**	**1021472**	**1027168**	**1118795**	**1166048**
Quantité de boues utilisées en agriculture (en T MS/an)	537387	573889	633812	624923	776305	846004
Dont compost (en T MS/an)				210781	263377	322129
Quantité de boues incinérées (en T MS/an)	188991	197658	215684	203031	204592	215328
Quantité de boues envoyées en centre d'enfouissement technique (en T MS/an)	193494	180345	133255	199214	137898	104716

	2003	2004	2005	2006	2007	2008 partiel
Quantité de boues utilisées en agriculture (en T MS/an)	57%	58%	62%	61%	69%	73%
Dont compost (en T MS/an)				21%	24%	28%
Quantité de boues incinérées (en T MS/an)	20%	20%	21%	20%	18%	18%
Quantité de boues envoyées en centre d'enfouissement technique (en T MS/an)	20%	18%	13%	19%	12%	9%

ANNEXE 1 : PRODUCTION ET DESTINATION DES BOUES EN FRANCE. CITE DANS (JEAN-PAUL LEGROUX ET CLAUDE TRUCHOT, 2009 ; SOURCE : DIRECTION DE L'EAU ET DE LA BIODIVERSITE)

	Boues de lagune	Fumier	Lisier	Boue aérobie stabilisée
Matière sèche (g/l)	50 - 250	100	250	
Matières volatiles (% de MS)	20 - 50	60 - 80	60	45 - 60
Azote Kjeldhal (mg/g)	0,8 - 3,3	4 - 6	1 - 3	4,5 - 6
Phosphore total (mg/g)	1 - 2,2	2 - 5	0,3 - 2,5	4 - 8,5
Potassium (K_20, mg/g)	0,03	3 - 5	2,5 - 3,5	0,5 - 1,5

ANNEXE 2 : CARACTERISTIQUES AGRONOMIQUES DE DIFFERENTS PRODUITS. SOURCE : (RACAULT, 1997)

Traitement			Avantages	Inconvénients	Siccité atteinte	Station adaptée
Épaississement	gravitaire	décantation + drainage	- exploitation simple et peu couteuse	- faible performance avec les boues biologiques - temps de séjour très long	2-10%	toutes stations
Épaississement	dynamique	égouttage (drainage)	- simple et efficace - peu couteux - technique d'épaississement la plus performante	-	4,5-6%	petite [1] et moyenne station [2]
Épaississement	dynamique	flottation	- bien adapté aux boues biologiques - rapide	- forte demande énergétique - investissement élevé - fonctionnement délicat	3,5-5%	grande [3] station

[1] Petite station <2 000EH [2] Moyenne station : 2 000-10 000EH [3] Grande station : 10 000-100 000EH

Annexe 3 : Differentes techniques d'epaississement ; avantages et inconvenients, siccite et situation adaptee. Source : (Amorce, 2012)

Traitement			Avantages	Inconvénients	Siccité atteinte *	Station adaptée
Stabilisation - Hygiénisation	chimique	à la chaux	- augmentation du pH des boues (>12) - réduction de la contamination fécale et des germes d'origine fécale - pas d'odeur indésirable, augmentation de la siccité et de la valeur agronomique - transport et stockage des boues facilités	- manipulation délicate (chaux vive le plus souvent)	25-35%	-
Stabilisation - Hygiénisation	chimique	aux nitrites	- efficacité contre la plupart des germes fécaux - augmentation de la siccité et fertilité - réaction rapide	-	-	petite station
Stabilisation - Hygiénisation	biologique	digestion aérobie : compostage	- siccité atteinte élevée - pH neutre, produit stable - transport et stockage des boues facilités - logique produit possible	-	35-70%	moyenne et grosse station [1]
Stabilisation - Hygiénisation	biologique	digestion anaérobie : méthanisation	- réduction jusqu'à 1/2 de volume - facile à transporter et à stocker - production de biogaz	- pas efficace pour élimination des germes pathogènes	20-30%	grande station
Stabilisation - Hygiénisation	biologique	stabilisation aérobie thermophile (SAT)	- solution alternative à la méthanisation - faible temps de séjour - investissement faible - boues utilisables directement en épandage - nuisance olfactive réduite	- moins performant que la méthanisation - consommateur d'énergie en comparaison à la méthanisation	22%	tout type de station

[1] Grosse station : >100 000 EH

* siccité atteinte sous réserve d'avoir une déshydratation mécanique en amont

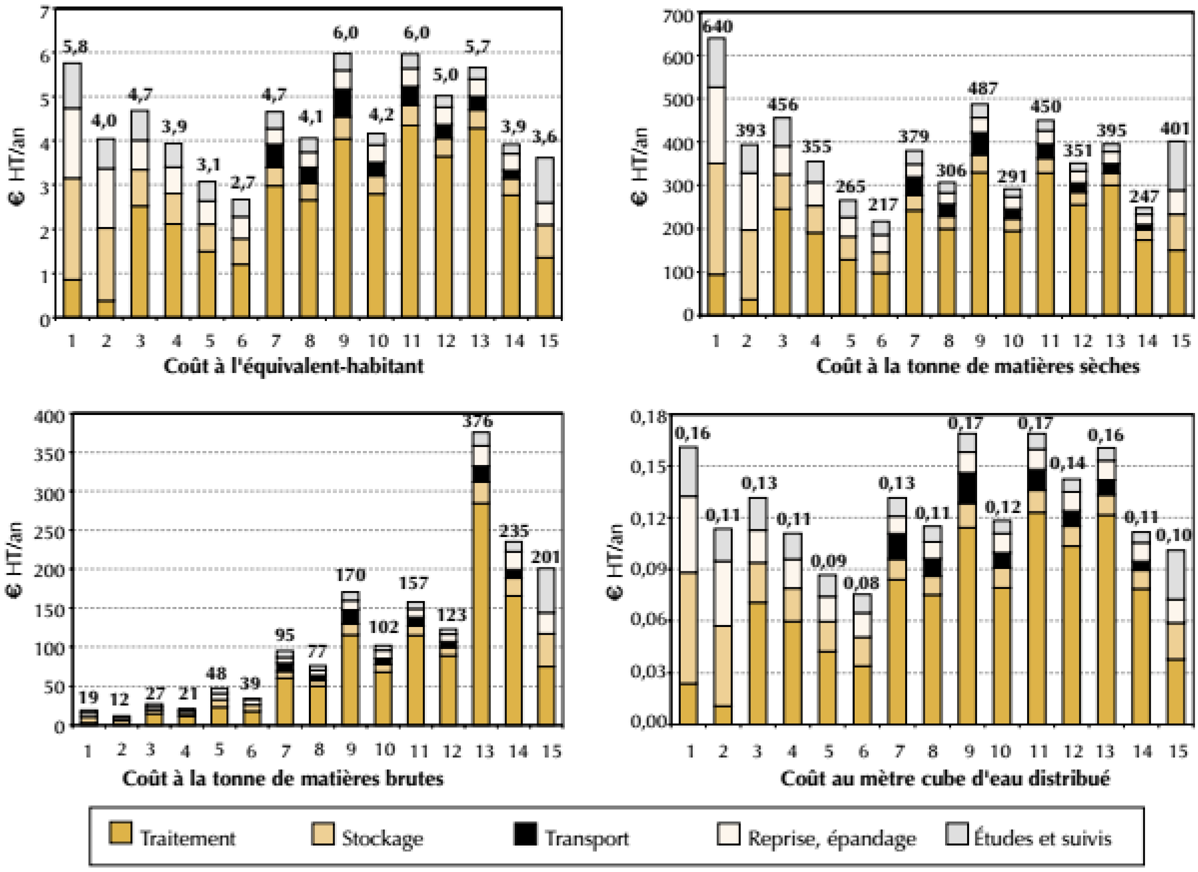
Annexe 4 : Differentes techniques de stabilisation et d'hygienisation des boues, avantages et inconvenients, siccite et situation adaptee. Source : (Amorce, 2012)

Traitement			Avantages	Inconvénients	Siccité atteinte	Station adaptée
Déshydratation	centrifugation		- en continu - totalement automatisé, fermé, donc plus compact que le filtre presse - adapté aux moyennes stations	- coût élevé - nécessité d'un contrôle de la nature de boues	20% (jusque 30% si post-chaulage)	tout type de station
	filtre presse	à bande	- lavage régulier - performante pour boues biologiques - grande productivité - fonctionnement continu	- incapacité de traiter les boues fibreuses	25%	petite et moyenne station (technique abandonnée)
		à plateaux	- entretien limité - tout type de boues (préalablement épaissies)	- inadapté pour les boues collantes - investissement élevé - automatisation impossible	>30%	grande station
		à membrane	- augmentation de siccité par rapport au filtre à plateaux - 40% de productivité en plus que le filtre à plateaux	-	-	peu répandu
		à vis	- bien adapté aux boues fibreuses - en continu - peu d'entretien	- siccité limitée	20%	peu répandue

ANNEXE 5 : DIFFERENTES TECHNIQUES DE DESHYDRATATION DES BOUES - AVANTAGES ET INCONVENIENTS, SICCITES ET SITUATION ADAPTEE. SOURCE : (AMORCE, 2012)

Taille nominale (EH)	*500*	*3000*	*10 000*	*20 000*	*30 000*	*50 000*	*100 000*	*200 000*	*500 000*
Surface (ha/an)	1,6	10	32	65	97	162	324	649	1 623
ha/EH	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003	0,003
Tonne MS/ha	3,7	3,6	3,5	3,4	3,4	3,4	3,3	3,3	3,2

ANNEXE 6 : SURFACE RECEVANT DES BOUES ET QUANTITES DE MATIERES SECHES EPANDUES EN FONCTION DE LA TAILLE DES STEP



ANNEXE 7 : COUTS ANNUELS DES DIFFERENTES FILIERES DE VALORISATION AGRICOLE DES BOUES (€/EH, €/TMS, €/TMB, €/M3 D'EAU DISTRIBUEE). SOURCE : FERRY M., WIART J., 2000.

<u>Boues liquides (épaississement) ; n°1 à 4 :</u>

Pour la filière boues liquides avec épaississement gravitaire (1 et 2), les coûts de traitement sont peu élevés (10%[4] à 15%). Dès que l'on utilise des moyens mécaniques, ce coût grimpe à 53%. Autre fait notable pour la filière par épaississement gravitaire, le coût de stockage est élevé (40%), en raison des volumes occupés par des boues à siccité de 2% à 3%. Le coût à la tonne de matière sèche est au-dessus des autres filières en raison du stockage mais également du transport (non détaillé ici).

<u>Boues pâteuses (épaississement puis filtre à bande) ; n° 4 à 8 :</u>

Sur la filière sans chaulage (5 et 6) les coûts de traitement représentent 45%, et 65% pour la filière avec chaulage. On remarque par ailleurs que quelle que soit l'unité utilisée, les coûts totaux de la filière 5 et 6 sont toujours performants.

<u>Boues solides (épaississement, puis filtre-presse ou digesteur + centrifugeuse) : n°9 à 12 :</u>

La filière boues solide engendre des coûts de traitement importants (de 67% pour les boues solides chaulées à 73% lorsqu'on ajoute la digestion).

<u>Boues séchées (centrifugeuse + séchage thermique) ; n°13 à 14 :</u>

Les coûts de traitement de cette filière représentent de 70% à 76% du total. Conséquence des lourds investissements de départ, ainsi que des coûts liés à l'exploitation de ce type d'ouvrage.

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4 Pourcentage du coût total de la filière concernée. Nous avons préféré présenter les coûts de cette façon car l'étude date de 2000, les coûts en euros ont beaucoup variés.

La filière lit de séchage (n°15), pratiquée en milieu rural sur de petites stations est moins coûteuse que la filière liquide pour une taille de STEP équivalente (3 000 EH). Seul le coût à la t/MS est plus élevé car la siccité monte à 50%.

Coûts en € HT	% du total	Par eh	Par t MS	Par t MB	Par m³ d'eau	% du total	Par eh	Par t MS	Par t MB	Par m³ d'eau
Boues liquides (siccité 3 %), épaississeur statique ou hersé, silo sur la station										
	Filière-type **n° 1** (3 000 eh)					Filière-type **n° 2** (10 000 eh)				
Traitement	15	0,85	94,9	2,8	0,02	9	0,38	37,1	1,1	0,01
Stockage	40	2,30	255,2	7,7	0,06	41	1,65	160,3	4,8	0,05
Reprise, transport, épandage	28	1,59	176,2	5,3	0,04	33	1,34	130,6	3,9	0,04
Études et suivis	18	1,02	113,5	3,4	0,03	17	0,67	65,3	2,0	0,02
Total hors traitement	85	4,90	544,9	16,3	0,14	91	3,66	356,3	10,7	0,10
Total	100	5,76	639,7	19,2	0,16	100	4,04	393,4	11,8	0,11
Boues liquides égouttées (siccité 6 %), table d'égouttage (ou centrifugeuse), silo sur la station										
	Filière-type **n° 3** (10 000 eh)					Filière-type **n° 4** (20 000 eh)				
Traitement	54	2,52	244,9	14,7	0,07	54	2,12	191,2	11,5	0,06
Stockage	18	0,82	80,2	4,8	0,02	17	0,68	61,4	3,7	0,02
Reprise, transport, épandage	14	0,67	65,3	3,9	0,02	15	0,60	54,1	3,2	0,02
Études et suivis	14	0,67	65,3	3,9	0,02	14	0,53	48,1	2,9	0,02
Total hors traitement	46	2,16	210,8	12,6	0,06	46	1,81	163,7	9,8	0,05
Total	100	4,68	455,7	27,3	0,13	100	3,93	354,8	21,3	0,11

Coûts en € HT	% du total	Par eh	Par t MS	Par t MB	Par m³ d'eau	% du total	Par eh	Par t MS	Par t MB	Par m³ d'eau
Boues pâteuses (siccité 18 %), filtre à bandes ou centrifugeuse, plate-forme sur la station										
	Filière-type **n° 5** (30 000 eh)					Filière-type **n° 6** (50 000 eh)				
Traitement	49	1,49	128,9	23,2	0,04	45	1,20	98,2	17,7	0,03
Stockage	20	0,62	53,5	9,6	0,02	22	0,58	47,7	8,6	0,02
Reprise, transport, épandage	17	0,51	44,3	8,0	0,01	19	0,50	40,5	7,3	0,01
Études et suivis	14	0,44	38,1	6,9	0,01	14	0,38	31,1	5,6	0,01
Total hors traitement	51	1,58	136,0	24,5	0,04	55	1,46	119,2	21,5	0,04
Total	100	3,07	264,9	47,7	0,09	100	2,67	217,3	39,1	0,08
Boues pâteuses chaulées (siccité 25 %), filtre à bandes ou centrifugeuse, chaulage, plate-forme sur la station, plate-forme extérieure et/ou dépôts de bord de champ										
	Filière-type **n° 7** (50 000 eh)					Filière-type **n° 8** (100 000 eh)				
Traitement	64	2,97	242,3	60,6	0,08	65	2,65	200,2	50,0	0,08
Stockage	9	0,42	34,3	8,6	0,01	9	0,38	28,9	7,2	0,01
Reprise, transport, épandage	19	0,88	71,8	17,9	0,02	17	0,70	53,0	13,2	0,02
Études et suivis	8	0,38	31,1	7,8	0,01	8	0,32	24,2	6,0	0,01
Total hors traitement	36	1,68	137,2	34,3	0,05	35	1,41	106,0	26,5	0,04
Total	100	4,66	379,4	94,9	0,13	100	4,06	306,2	76,6	0,11

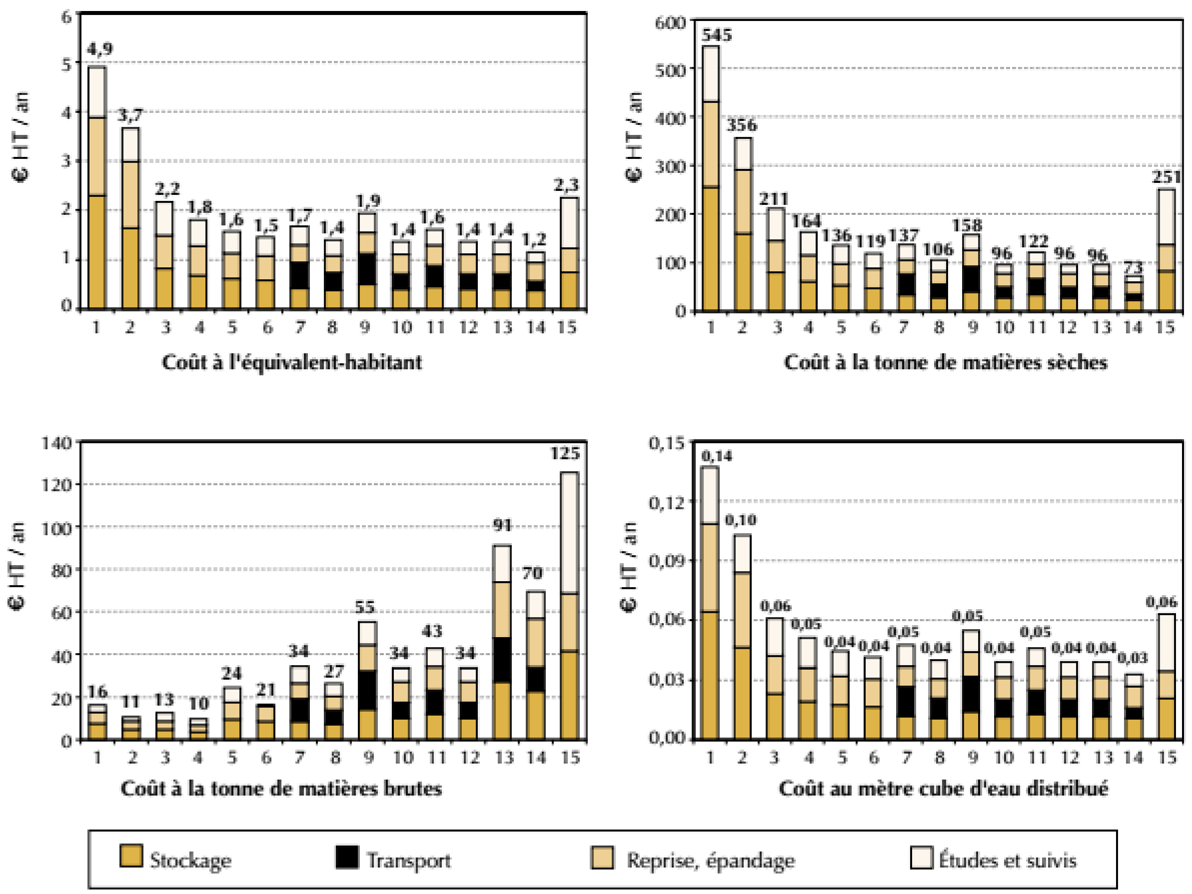
Annexe 8 : Couts au m3 d'eau, a la tonne de MB et MS, et par EH des differentes filieres (1 a 8) de traitement des boues et de valorisation agricole. Source : Ferry M., Wiart J., 2000.

Coûts en € HT	% du total	Par eh	Par t MS	Par t MB	Par m³ d'eau	% du total	Par eh	Par t MS	Par t MB	Par m³ d'eau
Boues solides chaulées (siccité 35 %), filtre-presse (conditionnement à la chaux), plate-forme sur la station, plate-forme extérieure et/ou dépôts bord de champ										
	Filière-type **n° 9** (50 000 eh)					Filière-type **n° 10** (200 000 eh)				
Traitement	68	4,04	329,3	115,2	0,11	67	2,79	195,0	68,2	0,08
Stockage	8	0,50	41,0	14,4	0,01	10	0,41	28,8	10,1	0,01
Reprise, transport, épandage	18	1,05	85,7	30,0	0,03	17	0,70	49,0	17,2	0,02
Études et suivis	6	0,38	31,1	10,9	0,01	6	0,26	18,1	6,3	0,01
Total hors traitement	32	1,94	157,8	55,2	0,05	33	1,37	95,9	33,6	0,04
Total	100	5,98	487,0	170,5	0,17	100	4,16	290,9	101,8	0,12
Boues solides digérées (siccité 35 %), digesteur, centrifugeuse (+ chaulage), plate-forme sur la station, plate-forme extérieure et/ou dépôts bord de champ										
	Filière-type **n° 11** (100 000 eh)					Filière-type **n° 12** (200 000 eh)				
Traitement	73	4,34	327,9	114,8	0,12	73	3,64	254,7	89,1	0,10
Stockage	8	0,46	34,5	12,1	0,01	8	0,41	28,8	10,1	0,01
Reprise, transport, épandage	14	0,84	63,3	22,1	0,02	14	0,70	49,0	17,2	0,02
Études et suivis	5	0,32	24,2	8,5	0,01	5	0,26	18,1	6,3	0,01
Total hors traitement	27	1,62	122,0	42,7	0,05	27	1,37	95,9	33,6	0,04
Total	100	5,96	449,9	157,5	0,17	100	5,02	350,6	122,7	0,14

Coûts en € HT	% du total	Par eh	Par t MS	Par t MB	Par m³ d'eau	% du total	Par eh	Par t MS	Par t MB	Par m³ d'eau
Boues sèches (siccité 95 %), digesteur, centrifugeuse, sécheur thermique, silo métallique sur la station, plate-forme extérieure et/ou dépôts bord de champ										
	Filière-type **n° 13** (200 000 eh)					Filière-type **n° 14** (500 000 eh)				
Traitement	76	4,28	299,4	284,5	0,12	70	2,76	174,2	165,5	0,08
Stockage	7	0,41	28,8	27,3	0,01	10	0,38	24,1	22,9	0,01
Reprise, transport, épandage	12	0,70	49,0	46,6	0,02	14	0,56	35,6	33,8	0,02
Études et suivis	5	0,26	18,1	17,2	0,01	5	0,21	13,5	12,8	0,01
Total hors traitement	24	1,37	95,9	91,1	0,04	30	1,16	73,2	69,5	0,03
Total	100	5,66	395,3	375,6	0,16	100	3,92	247,4	235,0	0,11

Coûts en € HT	% du total	Par eh	Par t MS	Par t MB	Par m³ d'eau
Boues solides (siccité 50 %), lits de séchage, plate-forme sur la station					
	filière-type **n° 15** (3 000 eh)				
Traitement	38	1,36	150,8	75,4	0,04
Stockage	21	0,75	83,0	41,5	0,02
Reprise, transport, épandage	14	0,49	54,2	27,1	0,01
Études et suivis	28	1,02	113,5	56,7	0,03
Total hors traitement	62	2,26	250,7	125,3	0,06
Total	100	3,61	401,4	200,7	0,10

ANNEXE 9 : COUTS AU M3 D'EAU, A LA TONNE DE MB ET MS, ET PAR EH DES DIFFERENTES FILIERES (9 A 15) DE TRAITEMENT DES BOUES ET DE VALORISATION AGRICOLE. SOURCE : FERRY M., WIART J., 2000.



ANNEXE 10 : COUTS ANNUELS DES DIFFERENTES FILIERES DE VALORISATION AGRICOLE DES BOUES HORS TRAITEMENT (€/EH, €/TMS, €/TMB, €/M3 D'EAU DISTRIBUEE). SOURCE : (FERRY ET WIART, 2000).

ANNEXE 11 : ASPECTS OPERATIONNELS DES EPANDAGES D'APRES FRANÇOIS THIRION ET FREDERIC CHABOT, 2003.

Institutions / Organismes	Entités ministérielles ou départementales	Autres entités relevant de ces ministères	Principales attributions par rapport à l'assainissement	Relations fonctionnelles possibles avec les boues
Ministère de l'Intérieur	tutelle des Collectivités Locales		▪ Assistance technique et la coordination en matière de distribution d'eau potable et d'assainissement	▪ Intégration de la gestion des boues dans l'élaboration de schémas directeurs ▪ Assistance pour le transfert du secteur de l'assainissement liquide et solide aux opérateurs privés (la gestion des boues et des traitements de déshydratation mobiles peut être déléguée)
		Collectivités Locales	▪ Gestion des services de l'eau potable et de l'assainissement	
		Direction de l'Eau et de l'Assainissement	▪ Coordonner les actions dans le secteur ▪ Appuyer les Collectivités Locales en matière de suivi des études et des travaux	
		Régies Autonomes (autonomie financière)	▪ Distribution de l'eau potable, de l'électricité et l'assainissement dans les grandes villes pour le compte des communes	
		Bureaux Municipaux d'Hygiène	▪ Chargé des aspects sanitaires liés à l'eau	▪ Aspects de la santé liés à l'usage des sous produits des STEP (eaux usées et des boues). ▪ Elaboration des directives sanitaires ▪ Contrôle et surveillance
Ministère de la Santé	DELM		▪ **Suivi des maladies en relation avec l'eau**	▪ **Surveillance sanitaire des usages des boues**
	Institut National d'Hygiène		▪ Mission de contrôle et de surveillance sanitaire	▪ Proposition de normes en matière de bilogie sanitaire

Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement	▪ MDE ▪ MDEnv	▪ Protection de l'eau et de l'environnement ▪ Planification et orientations des secteurs ▪ Initiation des réglementations dans ces domaines ▪ Gestion du domaine public hydraulique ▪ Evaluation et de la planification des ressources en eau ▪ Assure la tutelle des ABH et de l'ONEP	▪ Réglementation (SEEE/DEnv) ▪ Planification (SEEE/DEnv) ▪ Valorisation énergétique des boues (SEEE/Energie) ▪ Valorisation des boues en tant que biomasse (Stratégies de SEEE/Energie)
		▪ Planification de l'approvisionnement en eau potable à l'échelle nationale ▪ Étude, réalisation et gestion de la production d'eau potable en milieu urbain ▪ Distribution d'eau potable et assainissement (à travers les délégations de service par les communes)	▪ Gestion de la filière boues dans les STEPs ▪ Acteur essentiel dans la gestion des boues et la mise en œuvre de la stratégie
		▪ Gestion et protection du patrimoine hydraulique et dont les conseils d'administration regroupent l'ensemble des acteurs impliqués dans la gestion de l'eau, chargées d'organiser et de conduire la gestion de l'eau à l'échelle des bassins	▪ Autorisation d'épandage en zones vulnérables ▪ Suivi et surveillance ▪ Aides financières et l'assistance technique

ANNEXE 12 : REGLEMENTATION SUR LES BOUES AU MAROC (SOURCE : BAHHAR HASSAN, 2014)

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