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Re-conceptualizing Sludge Management: Focusing on Institutional and Governance Aspects

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Abstract: In order to fulfill the SDG (Sustainable Development Goal) 6.2 of the UN Agenda 2030 for sustainable developments, one needs to re-consider the wastewater management systems. In traditional approaches, sludge management plays a subordinate role in planning and designing wastewater systems since it is considered to be physically and conceptually at the end of the water cycle train. However, this does not take into account that the selection of the most appropriate treatment sequence for the wastewater treatment plants is strongly driven by the final reuse/disposal option(s) available in the specific local situation and consistent with it. Therefore, a re-conceptualization becomes necessary to put sludge management in a driving position of the water cycle train. This includes "technical" aspects and "institutional and governance" ones, which shall comply with general "basic principles" and fall within well defined "boundary conditions". This paper discusses aforementioned items, paying greater attention to institutional and governance aspects.

Key words: Circular economy, regulation, sludge management, sustainability, standardization.

1. Introduction

Across the world, 2.4billion people still lacks improved sanitation facilities [1] and 1 billion people still practices open defecation. In the developing world, as much as 90% of wastewater, including 70% of industrial wastewater, is not treated before discharge [2]. In addition, many types of improved facility, extended sewerage, new work installations and up-grading of existing facilities are resulting in an increased sludge amount whose management in a sustainable manner is a critical issue facing modern society.

This is well recognized by the Goal 6.2 Target of the UN Agenda 2030 which is addressed to "achieve access to adequate and equitable sanitation and hygiene for all…"

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Within this context, a safe management of wastewater has significant health and environmental benefits, and is fundamental for the sustainable development of all communities, considering that wastewaters contain usable resources, energy and nutrients.

Although there are various approaches, sludge often plays a subordinate role in the wider context of planning, designing and regulating water and wastewater systems, and is considered the "last wagon" of the water cycle train, and not the "locomotive", forgetting that selecting and sizing the most appropriate treatment chain to be adopted for the wastewater treatment plant is strongly driven by the final reuse/disposal option(s) more consistent with each specific context.

It follows the need of a "re-conceptualization" to assess management routes capable of maximizing recycle/recovery benefits, and developing and issuing realistic and enforceable regulations adapted to local situations. This re-conceptualization is based on the "locomotive/last wagon" concept and includes both "technical" and "institutional and governance" aspects, the latter often underestimated, which for their effective application must both comply with general and always valid "basic principles", and fall within specific "boundary conditions" [3].

In the following, "basic principles", "boundary conditions" and "technical aspects" are briefly outlined, while the "institutional and governance" aspect is more extensively discussed.

2. Basic Principles

In this section, the "basic principles", i.e. laws of thermodynamics, sustainability and circular economy concepts are summarized.

2.1 Laws of Thermodynamics

All human-operated transformations are "not perfect or not fully reversible" and, as such, subject to the 3 laws of thermodynamics.

In particular, in any process: (i) losses (of energy or material) are unavoidable (1st law), (ii) the "entropy", which is a measure of the disorder in an isolated system, constantly increases, thus involving an energy state lower than before (2nd law), and (iii) perpetual motion, i.e. infinite recycling, is impossible (3rd law).

2.2 Sustainability

For a real sustainability, sludge management must be environmentally bearable, economically convenient, and socially acceptable, i.e. consumption of renewable resources should not exceed nature's ability for their replenishment (Fig. 1).

Sustainability must also be seen from a "relative, not absolute" point of view, because it strictly depends on how the boundaries are set which should include all the processes and operations composing the system, and not only a part of it. It also needs to be tailored to the specific social, economic and environmental level of the involved community, and should include possible alternative reuse/disposal options to tackle market variability or local situation changes [4].

The main problem for sustainability evaluation is that it has a clear and unique "theoretical" meaning which, however, is not supported by "numerical quantifications", thus making it difficult transferring into practice.

2.3 Circular Economy

In general terms, circular economy is defined as an economic system designed to regenerate itself. This conceptual definition is often, and erroneously, represented by a fully closed circle without considering that each cycle is inevitably characterized by some "losses", i.e. a waste that needs to be replaced by a "new resource" (Fig. 2).

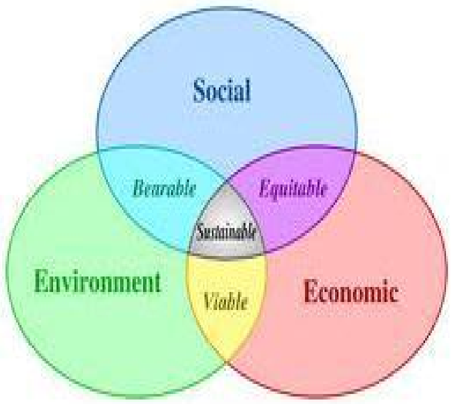

Fig. 1 Conceptual representation of sustainability.

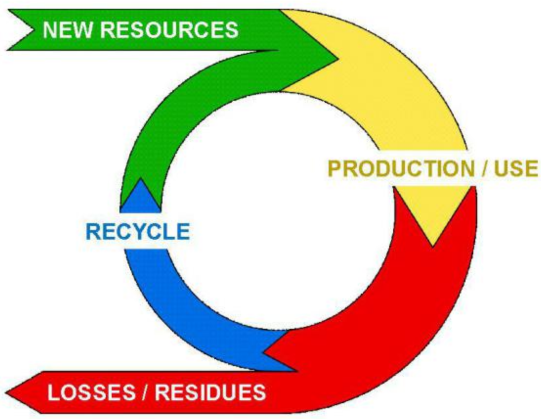

Fig. 2 Correct representation of circular economy.

The challenge is to reduce the amount of losses and the consequential need for new resources, thus quantitatively re-establishing the overall "mass/energy balance" also considering that the dynamics of the recycle flows are substantially different from those of acquiring new resources and/or producing new waste.

3. Boundary Conditions

"Boundary conditions" are those consequent to the dualistic interpretation of apparently opposite terms as a result of the specific technological, economic and social levels of the context where sludge management takes place.

In the case of sludge management the "boundary conditions" include the relationships: "problem/solution", "past/future" and "disposal/recovery".

3.1 Problem/Solution

Sludge management is generally seen as a "problem", while mostly it is the "solution" to the growing availability of household running water with, therefore, the growing quantities of wastewaters to be handled.

According to Rockefeller [5], sewerage should be avoided because "the key to preventing the trouble caused by this homogenized mass of mixed matter is separation at the source", but wastewater collection and treatment are generally necessary and constitute one of the greatest engineering and public health accomplishments since ancient times.

This situation will necessarily evolve towards an ever greater diffusion of extended sewerage and new work installations which, together with up-grading of existing facilities, will result in an increased sludge amount whose management in a sustainable manner is a critical issue facing modern society.

3.2 Past/Future

It is also to be considered that the meaning of "past" and "future" correlates not only with "time units (when)", i.e. ancient or modern times, but also with "spatial units (where)", i.e. developing or developed countries.

That is because what is "future" for some (developing countries) is already "past" for others (developed countries), as an outcome of the different levels in terms of technological, infrastructural and social development [6].

3.3 Disposal/Recovery

Finally, the general objective of developing sustainable strategies requires a shift from solutions aimed at simply "disposing of" sludge to those oriented towards "maximizing recycle or recovery benefits" which are highly context-specific.

It is conclusively evident that sludge management criteria are strictly depending on the local specific situation, thus strongly driving the selection of the optimal treatment sequence to be adopted for the wastewater treatment plants in order to produce sludge with the appropriate quantitative and qualitative characteristics.

4. Technical Aspects

To effectively implement a sustainable sludge management, technical actions having the purpose to maximize recoveries of useful materials and/or energy shall be performed.

Among technical aspects, the "reduction of volume", through thickening and dewatering, and the "improvement of quality", through stabilization and digestion, represent two unavoidable steps in sludge processing train from origin, i.e. production, to destination, i.e. reuse/disposal (Fig. 3).

In the following, they are briefly outlined not being the main purpose of this paper.

4.1 Reduction of Volume

"Reduction of volume" is certainly a pillar for the development of sustainable sludge management. However, the goal should not be pushing the production to an "absolute minimum" but, instead,

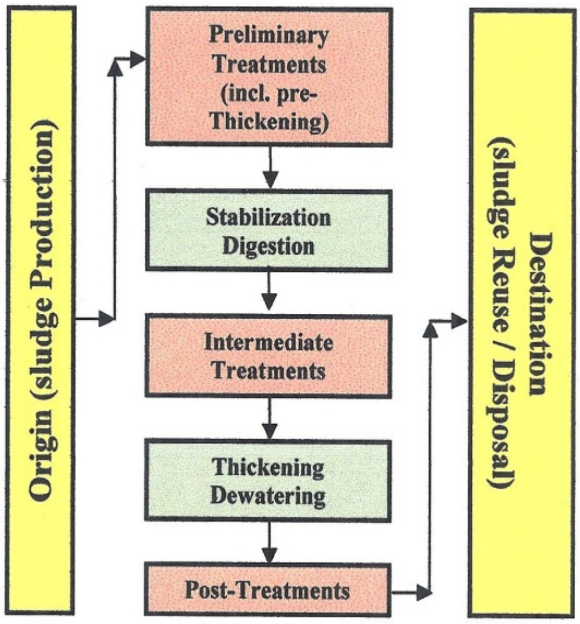

Fig. 3 Generic block diagram of sludge processing.

making sludge production "compatible" with its final destination and the best overall energy/material balance.

Reduction of sludge mass/volume can take place through appropriate technologies and operating procedures in (i) the wastewater treatment stage (e.g. cellular lyses, higher sludge age, ozonation, membrane technology) and/or (ii) the sludge treatment stage (e.g. thickening, dewatering, drying and other thermal processes).

4.2 Improvement of Quality

The "improvement of quality" has the purpose to reduce nuisances, health risks and subsequent treatment costs. Anaerobic and aerobic processes are widely adopted to stabilize sludge thus improving its quality.

Anaerobic digestion reduces sludge organic content and produces biogas. Improvements to enhance process performance included pre-treatments (e.g. disintegration processes), more efficient mixing, and increased reactors loading rate and heat recovery, including biogas upgrading.

Aerobic stabilization at ambient temperature is an energy-consuming process quite easy to be operated. Developments include thermophilic conditions, and a primary auto thermal thermophilic aerobic digestion followed by an anaerobic mesophilic one.

Field of research for sludge quality improvement encompasses estrogenic compounds, enzyme treatment, molecular methods for microbial populations in sludge [7].

4.3 Recovery Maximization

Recovery maximization of useful materials and/or energy is another pillar.

Regarding the recovery of materials, the nutrient content of sludge is of high value, so utilization in agriculture (directly or via composting) is likely to remain the major option, especially where sufficient land for spreading is available and sludge is less contaminated by toxic compounds.

Phosphorus can be recovered through anaerobic digestion or from incinerated ash, while nitrogen can be recovered mostly from sludge treatment reject waters. Innovative technologies for P recovery from sewage sludge ash are discussed by Abis, et al. [8].

Other material recoveries include production of organic matter, carbon source, coagulants, adsorbents, bricks, pumice, slag, artificial lightweight aggregate, ceramsite and portland cement.

Available options for energy recovery range from anaerobic digestion to thermal processes, the latter having also the advantage of reducing the sludge volume and destroying toxic organic compounds.

Technologies, such as wet oxidation, pyrolysis or gasification can generate energy and produce usable/storable fuels and char, but there are still some uncertainties about their performance and cost. The use of microbial fuel cell for direct conversion of sludge to electricity has been reported [9].

4.4 System Optimization

Another often underestimated issue is related to the "optimization" of a system consisting of several processes/operations.

As a matter of fact, a system consisting of a summation of individually optimized processes does not necessarily imply a system "optimized as a whole", because optimizing the generic "i" process of the system sequence will determine an optimized value (vi) which will enter the next "i+1" process whose optimized value (vi+1) will be the optimal for the "i+1" process itself, but not necessarily the optimal one for both processes together, and so on.

For example, a dewatering operation individually optimized to obtain the maximum solids concentration at minimum cost might not be compatible, e.g. not enough flowable, with the equipment to be used if sludge has to be spread in agriculture.

The optimization of a system must also consider the transportation steps and the installation of centralized plants with their advantages and drawbacks.

More detailed information on technologies which help in reducing the sludge volume and improving its quality and possible recoveries, also with reference to low- and middle-income countries, can be found in literature [6, 10-12].

5. Institutional and Governance Aspects

The transition towards a modern sludge management vision not only incorporates innovative changes in technical structures and infrastructural organization, but also introduces significant changes to the culture and practices that underpin the planning, design and management of water, wastewater and sludge systems.

This requires more attention to the "institutional and governance" aspects which are often considered to be of secondary importance with respect to the strictly technical ones and/or dealt with separately from them.

5.1 Regulation/Characterization

The development of "realistic and enforceable regulation" is crucial because an optimal and environmentally safe sludge management can only be achieved through objective, transparent, and legally conducted operations [13].

Regulation needs to be adapted to the local context, including clear rules for penalties and sanctions, and issued to avoid imposition of (i) "generic" and not numerically quantified limits, e.g. a generic "reduce speed" on the road, which may have general applicability but are difficult to be widely applied and prosecuted, and/or (ii) "unjustified" although numerically quantified, limits, e.g. a speed limit too low for a highway or too high for a rural road, which could become dangerous in certain situations.

Further, regulation covers a range of scales from national to regional and local, and falls not only under water and sanitation sectors, but also under health, agriculture and planning and building sectors [14].

The situation of the sewage sludge treatment and utilization in Europe, as well as information about the expected future developments in the field, including the national legislations, is discussed in the questionnaire by EurEau [15].

Also, the term "regulation" is not understood in the same way and there are differing traditions of compliance or non-compliance to any existing regulation.

A comparative study carried out on wastewater and sanitation regulation in Sweden, Mexico, South Africa and Uganda [16] showed that all countries have a well-developed legal system at national level, but the ability to enforce laws is not the same everywhere. Sweden and South Africa have both strong local/municipal institutions which are endowed with the power and the resources to enforce the regulations. Uganda and Mexico either lack strong local institutions, or these institutions fail to make use of the available regulations, thus creating an implementation deficit and can be traced back to the concept of "legal pluralism".

Summarizing, most of the gaps found in all the countries are addressed to the following points:

- non-compliance with the existing legislation and regulation;

- lack of capacity and resources to meet the implementation deficit;
- weak institutions and lack of political will for sanitation, thus not allowing enforcing and following up existing legislation;
- outdated legislation and lack of harmonization of laws;
- perception of human excreta as waste and lack of incentives for reuse in the existing legislation;
- political interest above society's interest;
- political interference which can become a problem when decision-makers (politicians and civil servants) try to change the rules of the game after they have been set.

The key to the compliance dilemma is to create a division of roles and powers, especially at the municipal and regional levels, between the politically elected members and the municipal employees who are in charge of implementation. Sweden and Uganda have this division, while in the Mexican system not only politicians, but most of the employees in the municipality, are replaced every three years. So, the Swedish system allows for strategic, long-term planning and decisions unlike the Mexican case.

A successful example of how circular economy is adapted to sludge management is exemplified by the KrWG (German Circular Economy Act) which places emphasis on resource conservation. Phosphorus recovery is almost exclusively limited to wastewater treatment, mostly due to process-related advantages, and the Federal Government continues to support the industrial-scale deployment and diffusion of new phosphorus recovery technologies.

It is also important and necessary that regulation be supported by "standardized characterization procedures" and guidelines for good management practices, because well-defined procedures allow legal requirements to be fulfilled in a correct and uniform manner, so results obtained under different conditions can be reliably compared and, therefore, stakeholder and public confidence built.

Several parameters are available for characterization of sludge "thickenability" and "dewaterability", such as SVI (Sludge Volume Index), CST (Capillary Suction Time), SRF (Specific Resistance to Filtration), drainability index, limit of dryness, centrifugability, etc..

In this field, great advancements can be expected by the utilization of parameters able to give more basic information on sludge behavior. In particular, the (i) "rheological properties" which are recognized to be very important since the flow characteristics affect almost all treatment, utilization and disposal operations, (ii) "particle and floc size distribution" because it is well known that dewaterability variations may be explained in terms of changes imposed on sludge characteristics by size distribution, the supra-colloidal particles influencing the most, and (iii) "water distribution" which represents the different types of water that can be distinguished according to the physical binding to the sludge particles, thus giving important information on the level of energy to be spent in solid/liquid separation.

With reference to "stabilization/digestion" processes, the evaluation of biological stability is of great importance because its level strongly influences handling of such materials, including acceptability in a landfill, possible reuse for environmental purposes and risks of developments of bad odors.

Although a widely accepted definition of biological stability is not yet available, the one reported in the CEN/TC165 Glossary, where "degree of stabilization" is defined as the "ratio of the mass of degraded organic material to the initial mass of organic material", appears to be of general applicability. To this end, the determination of the "volatile to total solids ratio" is a simple and quite fast method to be possibly carried out in the field. Many other parameters or methods that differ in complexity or duration can be used, such as BMP (Biological Methane Potential) which measures the residual production of biogas from sludge anaerobically treated, oxygen consumption rate (OUR, SOUR), odor intensity as number of volumes of water or air necessary to stop the smell, emission of specific odorigenic compounds by gaschromatography, dehydrogenase activity, calorific value of the dry sludge fraction.

CEN (European Committee for Standardization) and ISO (International Standardization Organization) are working in the development of standardized characterization and procedures for sludge management within the Technical Committees CEN/TC308 and ISO/TC275 specifically devoted to sludge management.

5.2 Local Circumstances

As already mentioned, sludge management system is a “context-specific” issue, so local circumstances play an important role in relation to the governance aspects [12].

Requiring various approaches which involve different solutions that are pivotal and solutions should be subjected to (i) a complex of influences tied to specific local economic, political, and cultural priorities, and (ii) the availability of tools, some of which are expensive and therefore only available to a few [7].

Local circumstances include climate conditions, cultural aspects and market structures, and also space for on-plot systems or possibilities to link on-site systems to higher level city-wide sanitation ones [17].

Climate conditions, whether dry or humid, quality of soil, depth of groundwater tables, etc., determine not only the use of technology, but also culturally shaped preferences (e.g. favoring water-based systems or rejecting dry sanitation technologies) which play a part to find the right solution. The distinction between rural, peri-urban and urban areas or formal and informal settlements, (e.g. slums) are very relevant, considering that in Sub-Saharan Africa alone 62% of the urban population live in slums [18, 19].

5.3 Legal Pluralism

Legal norms and practices are not monolithic constructions, but actually multi-layered ones subject to negotiation and enforcement.

Legal pluralism is characterized by the co-existence of rules from different origin and legitimization, for example as the result of history (like colonialism). This co-existence often leads to an overlap of customary laws, religious laws, national laws and even international principles derived from global water policy concepts [20, 21].

The concept of legal pluralism also includes the distinction between “categorical”, or official (*de-jure*), rights, and “concretized”, or effective (*de-facto*) rights. The formal acceptance of law does not mean that law is really applied into practice: “Obeying the law without complying with it” can be seen as reminiscence from colonial times [14].

The categorical right is embodied in the legal status, while the concretized right is embodied into a social relationship between actual people [22], and this concept helps us to understand why implementation and enforcement of existing regulations (seem to) fail.

5.4 Access Barriers

Barriers towards accessing water, wastewater and sludge management systems need to be understood in order to meet the expectation of the Goal 6.2 of the UN Agenda 2030 for a universal access to them.

Exogenous factors, including economic access to public systems, and endogenous, cultural immanent factors, such as taboos towards handling and re-using human waste, the latter depending on the social norms, may act as barriers.

Understanding how norms evolve within societies and their implication helps to understand endogenous barriers and find their solutions.

Pricing mechanisms can also act as a barrier to enter the system, especially for low-level households. Costs correlate to the quality of the services and can be used as an instrument to fine-tune the social aspects. As a revenue raising instrument, it covers the operation and maintenance costs, ensures long-term investment, and can be configured according to the principle that polluter pays.

An increasing “block” tariff, as promoted by the World Bank since the 70s, is a price structure in which a commodity is priced at a low initial rate up to a specified volume of use (block), then at a higher or several increasingly higher rates for additional blocks used.

The price of water in the initial block is set very low, usually at a rate to ensure that poor people are not discouraged from using the amount of water considered essential for human needs (typically 25-50 L/cap/d). This results in higher marginal prices to the customer and, thus, higher average prices for higher-income households, but helps in discouraging extravagant water use and promotes water conservation [23].

However, this system could result in adverse effects because the assumption that every household owns a water meter does not reflect the reality in many developing countries, where many households in highly dense populated areas (i.e. slums) share one water meter. This means that the marginal and average costs per water meter are automatically placed into a higher tariff system. Further, many households do not have access to any sort of water meter, so they are dependent on water vendors and this system results in adverse unintended effects.

5.5 Institutional Aspects

Setting up an institutional system capable of promoting sustainability and circular economy fundamentally develops along three lines: (a) normative aspect, (b) social embeddedness of the economy and (c) political process [24].

Normative aspects are basically the “rules of the game” or, in other words, the institutional setting.

Social embeddedness implies that the institutional conditions need to be accepted by the people in terms of social norms, while the political process can be described as the “game of the rules” [24, 25].

However, institutions are also subject to change, and this can be described in several ways:

“Path dependency”: historical-cultural traditions and policy legacies influence actual actions and tend not to adapt towards new circumstances, so setting up a system that opts for sustainability or circular economy might be very difficult [26, 27].

“Institutional bricolage”: new elements (such as codified rules, posts in local organization, roles, etc.) are simply mixed or added to traditional local elements which are often embedded in local status concepts and hierarchies, thus possibly colliding with modern ideas and sometimes prevailing on them [27, 28].

“Institutional syncretism”: old and new, traditional and modern, informal and formal elements are interwoven in a creative process. Syncretic institutions are not mere compositions of elements, but form a completely new type of institution. Therefore, all the elements must be altered and adjusted according to the actual needs [27, 29].

And here may lay the answer towards a solution-based approach for a new sludge-management: to continue old institutions under new conditions while acknowledging endogenous (embedded social norms, morality, values etc.) and exogenous (costs, poverty etc.) access barriers.

6. Conclusion

To allow an effective sustainable sludge management and ensure maximization of sludge value within the context of the SDG (Sustainable Development Goal) 6.2 of the UN Agenda 2030 for sustainable development, a “re-conceptualization” of sludge management becomes necessary.

In a new perspective (i) sludge should be considered as the “locomotive”, and not the “last wagon”, of the entire water cycle, and (ii) any action must comply with general “basic principles” (i.e. laws of thermodynamics, sustainability and circular economy concepts), and fall within defined “boundary conditions" (problem/solution, past/future, disposal/recovery).

Re-conceptualization includes technical aspects, and institutional and socio-economic ones. In this paper the "technical aspects" have been briefly outlined, while the "governance aspects", which are often considered to be of secondary importance or underestimated, have been discussed more extensively.

Main technical aspects include the need to (i) assess management routes capable of maximizing recycle/recovery benefits, (ii) use technically, ecologically and economically feasible methods to reduce sludge quantity at the appropriate level, not more not less than needed, (iii) define the treatment(s) necessary to optimize the entire system, and (iv) develop operational systems appropriate to local and site-specific circumstances, including multiple outlet options to be adapted to local market variability or emergency situation.

From the governance point of view, a "re-conceptualized" sludge management system should basically require:

- development of realistic and enforceable regulation adapted to the local context, including clear rules for penalties and sanctions;
- definition of standardized characterization procedures and guidelines for good management practices, thus involving objective, transparent, and legally conducted operations;
- requirement of approaches tied to specific local economic, political, and cultural priorities, and availability of tools;
- issuing of multi-layered legal norms subject to negotiation;
- understanding endogenous barriers to find appropriate solutions;
- adequate pricing mechanisms to avoid that cost services may act as a barrier for many low-level households to enter the system;
- setting up the "rules of the game" to establish an institutional system that promotes circular economy, and also the "game of the rules" that means the political process.

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