Biosolids are wicked to manage: Land application regulations in Sweden and B.C. Canada

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ABSTRACT

Management of biosolids is primarily handled as a technical matter. Land application is a cost effective and commonly used method of disposal that offers additional ecological and agricultural benefits. Implementation is, however, often met by public concerns regarding potential human and environmental health impacts. It is commonly agreed that the effectiveness of a policy hinges on its ability to describe clear, attainable goals. It also requires transparency in the process underlying trade-off decisions, in particular those related to the distribution of risks and benefits. Consequently it is critical to not only specify what the problem *is* but also offer an overarching hierarchy amongst stated objectives. This study examines biosolids land application policies in Sweden and the Province of British Columbia, Canada, focusing on the prioritization of objectives. The regulators' intention is clearly spelled out in both jurisdictions: to mitigate the residual's double nature as something that has both the potential to cause harm and the potential to be a great resource.

The study shows that sub-objectives are not explicitly spelled out and the objectives hierarchy is consequently concealed, as is the process underlying trade-off decisions. Not least important: predicted outcomes are also not explicitly spelled out, including how risks and benefits are distributed. Neither jurisdiction pays any attention to social implications of land-application, such as unequal distribution of risks and benefits. We propose that the conflicts so often seen in relation to the implementation of biosolids management policies in part result from approaching the problem as if it were a 'tame' one, even though it represents a classic 'wicked problem', requiring trade-offs among conflicting objectives. We forward that an objectives hierarchy must be transparently developed where ethical aspects of biosolids management are clearly identified to avoid increased polarization and thus hardened conflicts.

Keywords:

1. INTRODUCTION

Sewage management is first and foremost handled as a technical challenge: Since the late 19th century the dominating solution in Europe and North America has been the so-called linear, end-of-pipe solution (Morales, 2015). A sewer system conveys sewage from water toilets to a centralized treatment plant where it is treated or discharged as is. Various concerns related to human and environmental health have led to increasingly stringent effluent standards, in turn leading to more advanced treatment. Many jurisdictions started to implement standards for wastewater effluent well over a century ago. The standards that have been iteratively developed for wastewater effluent mirror the concerns of society: Pathogen removal was the initial concern, followed by human and environmental health concerns related to heavy metals, eutrophication, organic pollutants and, as of late, so called emerging contaminants. An often-overlooked consequence by those not directly involved in sewage management is that treatment leads to the production of a semi-solid residual – called biosolids in North American jurisdictions and sewage sludge in European ones; Higher water quality standards thus lead to that a larger portion of matter is removed, resulting in cleaner wastewater but also larger quantities of biosolids. For example, the introduction of more stringent effluent standards in Canada in 2012 led to a doubling of the annual amount of biosolids produced reaching close to 700,000 dry metric tons, and is expected to continue to grow (Canadian Council of Ministers of the Environment, 2012a).

Many jurisdictions encourage land application because the alternatives are estimated to be more costly and deemed worse for both human and environmental health. Land-application of biosolids is, however, often surrounded by controversies due to that it is feared to have a negative impact on human or environmental health (e.g. Mason et al., 2014). As a result, some jurisdictions such as Switzerland and Holland, have chosen to ban the practice.

There are literally thousands of studies that deal with technical, health and environmental issues related to biosolids management (Brisolara and Sandberg, 2014; Clarke and Cummins, 2014; Environment Canada et al., 2012), and hundreds that deal with the problem from economic or management perspectives (e.g. Axelrad et al., 2012; Ikehata et al., 2010; Laha and Parker, 2003), and a handful studies deal with the perception of risks (e.g. Beecher et al., 2005; Robinson and Robinson, 2006; Parkin et al., 2004). Very few studies, however, focus on the policy process, the ethical aspects, or the ‘wickedness’ of the problem. This study is an attempt to help fill this gap.

The aim of this study is explore in what ways biosolids management is a ‘wicked’ problem, and why it is problematic to handle it as if it were ‘tame’. The intention is to provide evidence-based support for policies that take the wickedness of the problem into account. It is commonly agreed that the effectiveness of a policy hinges on its ability to describe clear, attainable goals. Consequently it is critical to not only specify what the problem *is* but also offer an overarching hierarchy amongst stated objectives (Crawford and Ostrom, 1995; Sabatier and Mazmanian, 1980).

Previous studies show that it is problematic to approach so called ‘wicked problems’ as if they were ‘tame’. In their definition of wicked problems, Rittel and Webber (1984) clarify that they do not use the term to indicate that the problem is ‘evil’, but rather that it is impossible to define, and that all solutions will distribute risks and benefits unequally. They argue that it is morally objectionable to approach a wicked problem as if it were tame as this hides the fact that risks and benefits are unequally distributed. While tame problems, those that are purely technical or scientific in nature, can be clearly defined and solved once and for all, most policy problems are not tame. Such problems have no final solution, as all solutions create other problems. Take the issue of increasing crime rates, for example. Is it a problem of too few policemen? Changing attitudes towards drugs? Poor street-lighting? Homelessness? Wicked problems are thus ultimately ethical decisions that require an open examination of the values and preferences guiding management decisions (Balint et al., 2012; V. A. Brown et al., 2010).

> The formulation of a wicked problem *is* the problem. The process of formulating the problem and conceiving of a solution (or re-solution) are identical, since every specification of the problem is a specification of a direction in which a treatment is considered
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> (Rittel and Webber, 1973 p. 137)

Land application of biosolids, as well as all other disposal options, entails unequally distributed risks and benefits, is charged with scientific uncertainty, and requires value-based trade-offs. Thus it is not surprising that the area is charged with conflicts. In general, governments have responded by commissioning more research (see for example: Canadian Council of Ministers of the Environment, 2012b; Iranpour et al., 2004). Such an approach is efficient when disputes are mainly technical in nature. Research on other wicked problems, however, shows that the sticking points in such cases are less a question of scientific uncertainty, and more a question of conflicting values and preferences, and therefore different perspectives on desirable outcomes (Balint et al., 2012; Russell, 2010). The only way to resolve such conflicts is through a transparent identification of objectives, explication of underlying trade-off decisions and, not least important, predicted outcomes, including how risks and benefits are distributed.

Others have established that the numerous conflicts surrounding biosolids are in part due to poor communication. For example, the communication strategy ‘Primer for Biosolids Professionals”, which was published in 2011 by the Water Environment Federation (WEF) and the International Water Association (IWA) strongly encourages utility managers to integrate knowledge on risk-perception in communication strategies. The document stresses that communication strategies must go beyond traditional one-way communication and adopt “a systematic, science-based approach to building and conducting effective outreach and dialogue with key stakeholders” (WEF 2011, p 6). WEF’s communication strategy has, however, only been successfully implemented in a handful of cases such as Tacoma and King County, and it remains unrecognized by a majority of utility managers. We suggest that the poor uptake of the proposed communication strategy results from a deeply rooted perception that biosolids management is purely a technical problem, and a total lack of recognition of its wickedness. While a systematic and science-based communication strategy is necessary, it is not in itself sufficient.

We focus on land application and limit our study to two jurisdictions: Sweden and the Canadian province of British Columbia, both of which, at the time of writing, were in the process of revising their regulatory frameworks pertaining to the land application of biosolids. We have chosen these two jurisdictions in part because of their many geographic similarities, as elaborated further below.

First, we introduce the two cases. We then identify objectives and sub-objectives in documents outlining biosolids management policies of both jurisdictions, develop objectives hierarchies, and analyze the prioritization of those objectives and how each context influences the prioritization of its objectives. In both cases land application emerges as a means of mitigating pressing soil health concerns, but we find that the concerns differ between the jurisdictions, resulting in widely variant policies.

We note that neither jurisdiction explicitly defines objectives nor do they define an objectives hierarchy. Nor is the process underlying trade-offs transparent and neither jurisdiction gives much attention to the ethical implications of management decisions. We conclude that the problem is currently treated as a tame one, essentially technical in nature, and that this hides the unequal distribution of risks and benefits among stakeholders. We argue that there is a need for more adaptive policies designed to resolve rather than solve problems, as there is no final solution to problems that change with time and context.

2. METHOD

Central documents in the policy framework guiding management of biosolids in the two jurisdictions, as well as documents that are central to the revision processes were identified through Internet searches of relevant websites, such as the Canadian Council of Ministers of the Environment (CCME), the BC Ministry of Environment, the Swedish Government, the Swedish Ministry of Environment and the Swedish Environmental Protection Agency (SEPA).

The Swedish *Notification on Regulations to Protect the Environment, in Particular Soil, when Sewage Sludge is Used in Agriculture* (SNFS, 1994:2) and the BC *Environmental Management Act and Public Health Act. Organic Matter Recycling Regulation* (OMRR, B.C. Reg. 18/2002, O.C. 84/2002) were coded following Crawford and Ostrom's institutional grammar (1995). The coding was guided by questions such as: What is the objective of the regulation? When does it apply? What is allowed/not allowed? How is the process initiated? What kind of documentation is required? Who is responsible for what? What are the implications if the regulations are violated?

The problem(s) that the regulations aim at mitigating were identified through a review of the identified documents guiding the policy processes in the two jurisdictions, references therein, as well as central documents in the revision process. Inspired by Rittel and Webber (1973) and Metz and Ingold (2014), we asked: what problem(s) are the regulation aiming at mitigating? What are the causes, effects, temporary and spatial scales of the problem(s)? We analyzed the regulations and their supporting documents to identify explicit and implicit problems, causes and effects described in each regulation. We then carried out a second systematic analysis of the material, asking:

1. What are the objectives?
2. How are the objectives prioritized (objectives hierarchy)?
3. What risk management approaches are taken in each regulation?
4. Do the prioritization of objectives and the risk management approach have an impact on the regulation? - case study of heavy metals
5. Are social and ethical aspects taken into account in the regulation?

3. CASE DESCRIPTIONS

British Columbia and Sweden are located in the northern hemisphere and only a small portion of their land is used for agriculture, as the majority of the land consisting of forests and mountains (Figure 1; Table 1). The average population densities are low in global terms with BC approximately four times lower than Sweden (BC's land area is approximately twice that of Sweden, yet its population is approximately half as large). The population in both cases is concentrated in urban areas; over 60% of BC's population lives in the two major metropolitan areas, Vancouver and Victoria, as compared to 30% of the Swedish population living in Stockholm, Malmö and Gothenburg.

Table 1. Some basic geographic data for Sweden and BC of relevance for land application of residual from sewage treatment facilities.

	Sweden	BC
Land area (km^2)	410,330	945,000
Average population density (people km^{-2})	22	5
Population (million)	9.7	4.4
Population in urban areas larger than 300,000 inhabitants	30%	60%
Arable land	8%	5%
Percent of residual currently applied to agricultural land	~25%	~50%

3.1. The regulatory framework in Sweden

Land application of biosolids (referred to as sewage sludge in the EU regulation) in Sweden is governed through the EU Directive 86/278/EEG. Member states are allowed to impose stricter regulations and many, including Sweden, have done so. Application of residual on agricultural land in Sweden is regulated through the "Regulation on protection of the environment, in particular soil, when sewage sludge is used in agriculture" (SNFS 1994:2 after the Swedish acronym Statens Naturvårdsverks Författningssamling), under the Environmental Code (Miljöbalken, 1998:808). A revision of this framework was launched in 2002, triggered by a growing concern regarding rapidly decreasing access to easily mined phosphorous with low cadmium content (SEPA, 2013). A decision regarding the adoption of the updated regulation is yet to be made.

3.2. The regulatory framework in BC, Canada

Land application of biosolids in BC is governed by both provincial- and federal-level regulations. At the provincial level, BC's Organic Matter Recycling Regulation (OMRR), of the Environmental Management Act (EMA) and Health Act (B.C. Reg. 18/2002, O.C. 84/2002) all inform biosolids management. The BC OMRR is largely inspired by the US EPA's Part 503 Biosolids Rule.

Similar to Sweden, BC is also undergoing a revision process of its regulations, triggered by the BC Ministry of Environment's requirement that they "evaluate the management of the regulation within three years of [it] coming into force to determine if any modifications are appropriate" (BC Ministry of Environment, 2006, p.2). A series of intention papers for consultation were published in 2006, 2008 (C. Rankin & Associates, 2008), 2011 (C. Rankin & Associates, 2006; Environment, 2011) and 2012 (C. Rankin & Associates, 2012). At the time of this writing, the BC revision is still ongoing.

4. WHAT IS THE PROBLEM?

To identify the problem(s) each regulation aims to mitigate, we identified explicit and implicit objectives and sub-objectives in each jurisdiction's regulation, and analyzed the problems, causes and effects implied by these objectives (Öberg & Morales, 2016). The overarching objective of the regulation is in each jurisdiction is explicitly spelled out and is divided in two parts:

1. minimize risks for humans and the environment.
2. encourage beneficial/correct use[1]

It is clear that the regulators' intention is to mitigate the residual's double nature as something that has both the potential to cause harm and the potential to be a great resource. The regulations thus aim at minimizing potential problems while maximizing benefits. In both BC and Sweden, this double-edged objective is explicitly spelled out in the original version of the regulations, but an increased emphasis on the second leg is seen in the ongoing revisions, i.e. recycling of resources. For example, BC's 2002 regulation does not contain the word 'beneficial use' whereas the concept is mentioned 40 times in the 2008 guidelines, and the driving concept in the Swedish revision is resource efficient recycling of phosphorous.

Sub-objectives are not made explicit in the regulations. We identified these by tabling and analyzing the problems, effects and causes that are mentioned in the regulations or supporting documents (Table 1). This process led to the identification of 11 sub-objectives.

An analysis of the reasoning behind the cause-effect links revealed a conglomerate of interrelated problems, which each regulation works to address. Deconstructing these revealed three key types of problem(s) discussed in the regulations:

- Problems caused by 'stuff' in the biosolids: eg odor, disease, nutrient leaching (caused by organic matter, pathogens, and nutrient presence in the biosolids, respectively).
- External problems that application of biosolids on agricultural land can help mitigate: depletion of soil organic matter, dependence on (imported, expensive and dirty) fertilizers and oversized waste streams.
- Problems related to the management itself: operational costs for the treatment facility and stakeholder concerns.

[1] While the BC regulation (and US 503 rule) speaks of 'correct use' the Swedish regulation speaks of 'correct use' (as does the EU regulation).

Explicit objectives	Problem	Cause	Effect	Sub-objective
Reduce risk to human and environmental health	Odour	Anaerobic conditions	Discomfort	Reduce/eliminate odour, discomfort & public concern
	Pathogens	Faeces from sick people	Human health issues, socio-economic consequences	Reduce contact between pathogens and humans
	Nutrients	Human feces, detergents	Reduced yield	Increase yield by encouraging land-application
			Groundwater pollution	Reduce risk of groundwater pollution
			Surface water eutrophication	Reduce risk of groundwater pollution
			Eutrophication of oceans	Reduce risk of eutrophication of oceans
	POPs	Plastics, Electronics, Pesticides, etc	Human & Environmental health	Reduce public concerns
	ECs	Personal care products, pharmaceuticals, electronics, etc	Human & Environmental health	Reduce public concerns
	Accumulation of heavy metals in soil	Excessive application rate	Reduced yield	Reduce risk for heavy metal accumulation
Encourage beneficial/correct use	Depletion of soil organic matter	Agricultural practices	Increased food-costs and decreased food-security	Reduce risk for soil organic matter depletion
	Dependence on imported, expensive and dirty fertilizers	• Geopolitics • Geology	Increased food-costs and decreased food-security	Reduce dependence on P-import
	Oversized waste streams	• Urbanization • Population growth • 'Development'	Socio-economic-environmental costs	Reduce waste streams
	GHG emissions	Fossil fuel use	climate change bad reputation	Reduce GHG emissions
	Unduly expensive operations	Public concerns Access to land Distance to land Changing regulatory requirements	Cannot apply on land Increased tariffs	Reduce operational costs

Further analysis of the regulations suggests that there is an unstated overarching objective of safeguarding the use of land application, carried out via two sub-objectives (illustrated through an umbrella above Table 1): Protect and promote farmers' willingness to use the residual while reducing the risk of public concerns, as this might make it politically impossible to apply the residual on land even if farmers are willing to do so. This includes regulating the concentration or application rate of pollutants in the biosolids and/or the soil (heavy metals, nutrients, pathogens, odour) and justifying why other pollutants do not need to be regulated (persistent organic pollutants (POPs) and emergent contaminants (ECs).

Explicit risks to humans can be divided into four major groups:

- discomfort (caused by odor, effect: people complain),
- illness (caused by pathogens, effect: increased costs for health care etc; public complain, gets worried etc),
- other well-known health effects (caused by certain heavy metals and certain organic pollutants, effect: increased costs for health care etc, public gets worried)
- unknown health effects (caused by certain heavy metals, certain organic pollutants and certain mixtures of various pollutants, including emergent contaminants, effect: public gets worried).

Explicit risks to the environment can be divided into the following categories:

- negative effects on soil productivity (caused by certain heavy metals and organic pollutants, effect: more expensive food, nation's self reliance decreases, scale: national),
- negative effects on aquatic ecosystems (caused by nutrients, certain heavy metals, organic pollutants and emergent contaminants, effect: decreased income for fisheries and other water-based activities, decreased public access for leisure, public gets worried)
- negative effects on the climate (due to emission of GHGs).

Implicit risks related to non-use of biosolids on land are (deduced from explicit reasons why jurisdictions wish to encourage land-application):

- reduced soil health (due to soil organic matter depletion etc)
- increased dependence on (increasingly expensive) imported (and Cd-contaminated) mineral P
- oversized waste streams (not space to store biosolids on site, expensive to transport elsewhere)
- negative effects on the climate (due to increased emission of GHGs caused by transport, import of P, methane emissions from storage etc etc)
- increased food costs, reduced food sovereignty (due to farmers' forced to increase the use of other more expensive fertilizers and soil conditioners)

4.1. Objectives hierarchies

As mentioned above, neither of the regulatory frameworks explicitly defines the objectives. Consequently, objectives hierarchies have not been developed. Our study shows that biosolids regulations inherently harbour a variety of competing objectives, which is caused by the many possible solutions in combination with its double nature (risks and benefits). It is well known that efficient policies require that objectives are clearly defined and an objectives hierarchy is developed. This is also a pre-requisite for multi-criteria decision analysis (Gregory et al., 2012). To that end, we identified top-priorities by analyzing the relative emphasis and space given to different problems. Our analysis suggests that the top-priority in BC is to reduce the risk for soil organic matter depletion, while the top priority in Sweden is to reduce the risk of the risk of running out of easily accessible phosphorous with low cadmium content.

4.1.1. Organic matter depletion of agricultural soils

It is not explicitly stated in the BC regulation that organic matter depletion is a problem of high priority but through references to the literature (e.g. Brown et al., 2011), it is inferred that low levels of organic matter in soil inevitably lead to reduced soil health, with lower productivity and higher uptake of heavy metals. Land application of biosolids is consistently described as a suitable solution to this problem and described as an excellent source of organic matter. The OMRR gives considerable attention to the many positive effects that land application may have on soil health: increased water holding and cation exchange capacity , enhanced microbial activity and diversity, reduced heavy metal availability and nutrient leaching.

In contrast, the Swedish framework pays very little attention to organic matter depletion of agricultural soils. In the central 2013 report from SEPA, soil health is only mentioned more or less in passing in reference to an LCA analysis of socio-economic costs and benefits related to land application of the residual, where increased productivity due to land-applied solids is included as one of several (small) benefits to the farmer.

4.1.2. The risk of running out of phosphorous

Like BC, Sweden's regulations give top-priority to the productivity of arable land. Instead of a focus on soil organic matter content, the regulation revision process focus has been explicitly undertaken to address the risk of running out of easily accessible phosphorous with low cadmium content. Considerable attention is given to the risks related to this threat and sewage sludge is consistently described as a significant part of the solution.

> The majority of the phosphorous that flows through homes, i.e. via food-intake to excreta (approximately 4 900 ton yr^{-1}; 64 % in urine and 36 % in feces) and grey water (showers, dishes and laundry; 520 ton yr^{-1}) ends up in sewage sludge in the treatment plants.
>
> (SEPA, 2013 p. 35, translated by authors)

In contrast, phosphorous is not even mentioned in the BC Ministry of Environments' two intentions papers for consultation (C. Rankin & Associates, 2006; Environment, 2011) or the 2008 (C. Rankin & Associates, 2008) or 2012 (C. Rankin & Associates, 2012) Summary of Consultation papers. The 231-page long Land Application Guidelines (BC Ministry of Environment, 2008) dedicates two pages to phosphorous, which are placed as a sub-section under the heading *Nutrient management – general information*, which in turn is a sub-section under the heading *Considerations for the Use of Residuals for Fertilization or Soil Amendment*. The revision of the BC regulation draws on recent investigations carried out by the Canadian Council of Ministers for the Environment and references in their *Canada-Wide Approach for the Management of Wastewater Biosolids* (Canadian Council of Ministers of the Environment, 2012a). The main concern related to phosphorous in the BC documents as well as the CCME documents is eutrophication of receiving waters. The BC documents make no reference to the risk of running out of mined phosphorous, nor is concentration of cadmium in mineral fertilizers mentioned as a potential risk that needs to be mitigated. The CCME document mentions the issue twice, albeit in passing, once stating, "Phosphorus is a limited non-renewable resource that should be recycled from municipal biosolids" (p2)

Table 2. Illustration of differences in prioritization among objectives, based on the assessment of the strength of the causal links and uncertainly of scientific information in the frameworks regulating biosolids management in BC Canada and Sweden.

Problem	Cause	Scale		Effect	Strength of causal link		Uncertainty	
		temporal	spatial		BC	Swe	BC	Swe
Risk of running out of P	Geopolitics and geology	decades	N/A	Increased food-costs and decreased food-security	Weak	Strong	High	Medium
Depletion of soil organic matter	Agricultural practices	decades	all agricultural land	Increased food-costs and decreased food-security	Strong	Medium	Low	High

Our review shows that while the two jurisdictions are similar in that they explicitly regulate the problems related to the first objective: minimize risks (odour, pathogens, metals, nutrients), they diverge when it comes to prioritizing among the problems related to the second objective: beneficial use. While P-depletion is a top-priority in Sweden, BC and North American soils are often P saturated, and we get the impression that this is what makes it a lower priority in that context. In contrast, while many soils in North America are threatened by low organic matter content, this is less so in Sweden, which appears to be the reason this issue is given lower priority there.

This is indicative of a classic wicked problem: it is unique and context specific and it is thus a slew of entangled problems, where solving one has repercussions on others:

> There are explicit characteristics of tame problems that define similarities among them, in such fashion that the same set of techniques is likely to be effective on all of them. Despite seeming similarities among wicked problems, one can never be certain that the particulars of a problem do not override its commonalities with other problems already dealt with. The conditions in a city constructing a subway may look similar to the conditions in San Francisco, say; but planners would be ill-advised to transfer the San Francisco solution directly.
>
> (Rittel and Webber, 1973, p 141)

"P vs Organic Matter" is just one example but the differences present indicate the vast array of complex issues that residual management touch (e.g. future access to P-fertilizer, soil health, food security, energy efficiency and cost-effectiveness).

4.2. Measures to handle problems

Some problems are complex but have straightforward solutions:

- Example problem 1: Biosolids increase agricultural productivity in the short term as they contains nutrients and soil conditioner but there is a risk of long-term reduced productivity due to increased heavy metal concentrations.
  - *Measure*: monitor application rates and concentrations in biosolids and soil
- Example problem 2: Nutrients that leak from soil may cause eutrophication of surface waters and pollution of groundwater.
  - *Measure*: limit the amount of sewage sludge that may be added on land and forbid use under conditions and in locations where the risk of leakage is high.

Other problems require trade-offs:

- Example problem 3: GHG emissions
  - Solution 1: maximize biosolids application on arable land to reduce consumption of mined phosphorous, which is energy demanding to produce and transport.
  - Solution 2: maximize methane production on-site as this will reduce the need for fossil fuels
  - Solution 3: incinerate the biosolids to maximize energy recovery and recover phosphorous from the ashes

All three solutions will reduce GHG emissions, but it is impossible to determine the most beneficial solution without an analysis of risks and benefits of the trade-offs. None of the regulations provide a systematic risk-benefit analysis for example using multi-criteria analysis.

5. SOCIAL AND ETHICAL ASPECTS ARE MISSING

Both Sweden and BC express concerns regarding the public perception of risks related to land application and how this might limit the solutions at hand. Still, neither case acknowledges residual management as a social problem, firmly embedded in a complex web of societal practices and expectations with profound and rippling effects upon a large number of stakeholder groups. Nor does either jurisdiction give any attention to the ethical aspects of residual management. The SEPA report (2013) does include a cost-benefit analysis. Though references are made to such studies in the background material to the BC regulation, in neither case is the problem of unequal distribution of costs and benefits discussed.

Rittel and Webber (1984) argue that it is morally questionable to approach a wicked problem as if it was a tame one, as it hides the unequal distribution of risks and benefits. No doubt, this is the case for land application of the solid residual remaining after sewage treatment. Among the 'winners' are:

- the collective urban population, as they are rid of their waste in a cost-efficient manner,
- polluters as they do not carry the cost of handling their discharge once it has entered the waste stream,
- sewage treatment plants, who receive reduced storage and disposal costs, and
- farmers, because of reduced fertilizer costs (Laha and Parker, 2003; Leschber, 2002; Mason et al., 2014; Ochsenhirt, 2012).

Among the 'losers' we find the collective rural populations as they face fears of odour, reduced property value, and perceived risks related to potential negative health and environmental impacts of land application. They are also exposed to a number of other risk factors and liabilities such as increased truck traffic, which brings increased risks of spills and traffic accidents, and increased road maintenance.

Stakeholder categories are not so simple though, and rural populations also include winners: the local economy generally benefits from land application through the creation of job opportunities (Mason et al., 2014). Finally, as for all complex and multifaceted problems, the majority of the potential winners and losers are future generations, whether it is a question of negative health/environmental effects caused by stuff in the residual (1st objective) or by problems that weren't mitigated because land application was not allowed (2nd objective). The distribution of risks and benefits would look different if the residual instead was incinerated, landfilled or dumped in the ocean.

6. WHERE TO GO FROM HERE?

As outlined above, management decisions regarding sewage residual involve interrelated positive and negative impacts on human and environmental health that are unequally distributed. Negative impacts, such as the introduction of pathogens, heavy metals and other pollutants to food and water sources, are pitted against potentially positive outcomes tied to land-use, food security, and GHG emissions. Here lies the wickedness of the problem: it evades definition, it is unstructured, it requires trade-offs between competing and non-commensurable objectives, risks and benefits are unequally distributed, it is fraught with scientific uncertainty and all solutions to date have had unforeseen consequences. Yet, it is framed as a technical and scientific problem. We propose that the difficulty apparent in the management of the solid residual from sewage treatment plants arises from a simplified, and thus misleading, problem definition.

Leaning on policy studies (e.g. Crawford and Ostrom, 1995; Sabatier and Mazmanian, 1980) we suggest that such conflicts are likely to be resolved through a transparent identification of objectives, a clear explication of underlying trade-off decisions and, not least important, predicted outcomes, including how risks and benefits are distributed. The ethical aspects of land-application of biosolids in particular need to be transparently identified to avoid increased polarization and thus hardened conflicts, and it is necessary, but not sufficient, to apply a science-based and rigorous communications strategy. Other situations that concern complex and multifaceted problems have been successfully re-solved by the use of a structured and strategic process to identify sub-objectives and determine a hierarchy among them, for example through the use of structured decision making and multi-criteria decision analysis (Gregory et al., 2012). A central component in such a scheme would be to identify and be explicit about underlying values, assumptions and interests, including identification of the multiple ethical positions, worldviews, and ways of constructing knowledge that are at play (Brown et al., 2010). Drawing on the literature and our results, we argue that there is a need for more adaptive policies designed to resolve rather than solve problems related to management of the solid residual from sewage treatment, as there is no final solution to problems that change with time and context.

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