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Changing The Metabolism Of Coupled Human-Built-Natural Systems

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Abstract

The archetypal metabolism of the city is defined by the flows of energy and materials (carbon (C), nitrogen (N), phosphorus (P), water) entering the city from the rest of the global economy, then circulating around and through its economic, social, and industrial life, before returning to the city's environment (and the global economy). The change we argue for is that of viewing nutrients not as pollutants — a perception entailed in the historic success of water-based systems for securing public health in cities — but as resources to be gainfully recovered. We expect such change to propagate from change in the "human" (local and very personal scale), through the "built" (city-wide scale), hence eventually to better stewardship of the "natural" (and global scale) component of coupled human-built-natural systems. We begin with a discussion of moral positions on the Man-Nature relationship and the material flows resulting therefrom. In theory, if material flows are to be changed, a map of the plural contending moral positions is first needed, in particular, in respect of contending notions of fairness. Empirical evidence from the renewal of London's housing stock in the 1970s and 1980s, the siting of hazardous waste treatment facilities in Austria, and European work on decentralization and source-separation in wastewater management, is used to illustrate the theoretical basis of our opening argument. Two more in-depth case studies, in changing the metabolisms of the cities of Atlanta, USA, and London, UK, primarily through technological innovations, are then introduced. Foresight regarding future distributions of financial costs and benefits amongst multiple stakeholders, should the change of outlook be made, is generated from a Multi-sectoral Systems Analysis (MSA) model (covering the water, energy, food, waste-handling, and forestry sectors). Upon these specific results is built the closing argument of the paper regarding matters of fairness in constructing (or dismantling) social legitimacy around the policies of urban infrastructure re-engineering that would be needed to recover the resources currently treated as pollutants.

1 Introduction

Until public health had been secured for citizens living cheek by jowl in the confined spaces of cities, cities were arguably prevented from realizing their full potential as the engines of national (and now global) economies (Glaeser, 2011; McGreevey *et al.*, 2009). One hundred and fifty years ago — when the introduction of the Water Closet (WC) was becoming widespread — the configuration of the water infrastructure, into which most cities of the Global North were to become ever more comprehensively locked, could not have been imagined. And not until just some two decades ago did we then question whether the predominant style of environmental engineering of such infrastructure, especially that for managing wastewater (on the "downside" of the city), was self-evidently "doing good by the environment" (Niemczynowicz, 1993). If it was not, moreover, how might we re-engineer a way out of this technological "lock-in" and seek to learn how to avoid it in the first place, from socially and economically successful cities of the Global South (Beck, 2011; Crutzen *et al.*, 2007)? We stand presently on the threshold of what some, therefore, are calling a decisive change of paradigm (Larsen *et al.*, 2009; Larsen *et al.*, 2012).

In the fullness of time, that small, seemingly humble, yet utterly vital innovation of the household WC has indeed brought about its own form of earth systems engineering. Consider this. The WC, together with subsequently evolved sewerage, cuts the short feedback loop between pathogenic excretions and drinking water and conveys our (human) metabolic residuals out of the confined spaces of the city and into the environment. The materials we need in food for sustaining ourselves — nitrogen (N), phosphorus (P), carbon (C), embodied energy, and so on — pass through our bodies and, given the WC, are then headed to some form of aquatic environment. Prior to comprehensive installation of the WC and sewerage, this was not naturally so. Public health in the city has been acquired at the expense of water pollution. Thus did (and does) the environmental engineering of the city's wastewater infrastructure progress through eras driven successively by the need to control pathogenic pollution, gross organic pollution, nutrient pollution, and toxic pollution — all in respect of water bodies. Had the Reverend Moule's Earth Closet (EC), or some kind of Vacuum Closet (VC), instead gained supremacy ahead of the WC popularized by Mr Crapper, might none of these eras of *water* pollution control ever have been entered into.

From another perspective, given the extraordinary success of the Haber-Bosch process for manufacturing fertilizers based on nitrogen (Erisman *et al.*, 2008), the WC and sewerage — in the absence of their effective coupling with wastewater treatment — have participated in fueling coastal eutrophication on a global scale (Beck, 2011; Grote *et al.*, 2005). Artificial fertilizer is applied to the land, to produce foodstuffs in North America, for example. These products are shipped around the globe, to become imports into, say, Asian countries and their cities. There, once consumed — and in the absence of wastewater treatment[8] — all the residuals of the nutritious nitrogen (N) and phosphorus (P) materials end up (untreated) in coastal seas and oceans, with distorting consequences for the structures of marine ecologies and their associated fisheries (Jackson *et al.*, 2001). Moreover, given the current staggering successes of membrane technologies, hence the burgeoning of desalination facilities around the world (Frenkel and Lee, 2011), there is every prospect of yet more earth systems engineering being wrought — and with complex, unfolding, unraveling social consequences. For desalination amplifies the capacity for supplying potable water

[8] Installation of which component of infrastructure tends to lag some 20 years behind the introduction of infrastructure for potable water supply on the "upside" of cities (McGreevey *et al.*, 2009).

to people in coastal cities. In principle, this greater access to water should sustain greater populations of citizens in such cities, all of whom may thereby be placing themselves increasingly at risk from the threats of sea-level rise (Beck, 2011).

There are many reasons, therefore, to judge that we stand on the threshold of constructive, pivotal change — change, arguably, of proportions entirely consistent with the scale and scope of earth systems engineering. Consequently, we should address, first, the prospect of a change in mindset: from viewing the C, N, P, and other materials entrained into the water metabolism of the city (as a result of the WC), as pollutants to be rid of (at a cost); to their being viewed as resources to be recovered (with profit). Second, the commonplace of talking about a global water crisis tends to limit thinking about the city's water infrastructure to matters of water supply, water recovery, and water re-use (Beck and Villarroel Walker, 2011). It accords inadequate, if not scant, recognition to the role and place of wastewater in that infrastructure — or rather the "waste" in the water. Given then this altered apprehension of the city's metabolism — as not being solely that of water fluxes, but that of the multiple C, N, P, energy, water, and other material fluxes — we are obliged to change our outlook further: from policy and engineering analysis of the water sector alone; to that of integrated analysis of the water *and* nutrient *and* energy sectors (Villarroel Walker *et al.*, 2012). This is entirely in line with the emerging global agenda item of the "Water-Food-Energy (WFE) Climate Security Nexus", deriving from nothing less than the World Economic Forum (WEF, 2011).

We examine the potential for technological innovations within city-watershed systems (specifically Atlanta and London) to achieve substantial rates of resource-energy recovery, in a multi-sectoral context. From this foresight exercise flow back a number of economic implications, not least an emerging appreciation of fairness: of who might pay and who might gain, for example, should these potential innovations be introduced. Monetary matters are crucial, of course. But they are not the only considerations in any debate within a community with plural aspirations for the future of their city and its cherished environment. Acceptance of the innovations, especially if they are disruptive of personal and household behavior, i.e., they require a change in habits, will be just as important in the community witnessing the formation of policy decisions as socially legitimate.

Our analysis of the change we advocate begins with the subject of valuation, hence the manner in which mind-sets may change. There is a theory for this and there is empirical evidence of its workings, in matters of renewing the housing stock in London, UK, and managing hazardous waste in Austria, which is briefly recounted. The subsequent task is to frame the debate surrounding the issue of recovering (or not) the nutrients/energy in sewage according to this theoretical structure and to assemble further empirical evidence of the nature of the debate, notably across Europe (Larsen *et al.*, 2012). This framing of the issues extends our earlier work on governance for re-engineering city infrastructure (Beck *et al.*, 2011). We ask then, could computationally generated foresight about such inter-generational matters — foresight generated, that is, in a manner consistent with the theoretical structure — have an impact on either the debate or achieving progress towards change in practice?

2 Framing the Problem: Understanding What Might Spark the Change

In *Rubbish Theory: The Creation and Destruction of Value*, Thompson (1979) writes of how the way we value things changes over time. The object remains the same: city house, chair, nutrient in sewage. It is just that our perspective rotates around the object and with that change of perspective the object may come to be valued quite differently. Thus, as we all know, the inner-city property once viewed as a rat-infested slum — to be rid of as quickly as possible through demolition — may in due course become a very highly valued piece of real estate (and endure for much longer than might have been expected). Thus might it also be for the C, N, and P materials in sewage, and their embodied energy: conventionally treated across the 20th century as pollutants to be utterly rid of; from hereon (arguably) to be viewed instead as valued resources to be recovered (see, for example, Beck (2011); Larsen *et al*. (2012)). The essential question is: what might spark such a transformation in outlook — through what kind of policy or technological innovation — and with what promise of greater social well-being?

If we understood something of the mechanics of similar transformations, we might then be able to sense how the re-valuation from nutrients-as-pollutants to nutrients-as-resources might occur. And it may well be that the transformation is not a function of better policy, or new and better technologies, or even of financial incentives, but of the interplay, for example, amongst the plural and contending notions of fairness that are abroad in society. We should be open to such being the case.

2.1 Plurality of Perspectives in Society

Writing more recently, in a paper on "Material Flows and Moral Positions", Thompson (2011) provides a framework within which to contemplate how the change we seek could come about, as follows:

> A prevalent view, among those who are concerned about the material flows we are generating, is that they are excessive and environmentally unsustainable. Greed, the triumph of competition over cooperation, the inequalities between North and South, and anthropocentrism are then blamed for this state of affairs. The solution is obvious: more altruism, a worldwide equalising of differences, a reining-in of market forces, and a whole new relationship with nature — ecocentrism. This clearly is a moral position, and those who act from that position will certainly be having some effect on material flows. But there are other moral positions, and other ways of framing the problem and its solution, and it is the plurality of moral positions, and their modes of interaction, that are actually determining the material flows. If we are to understand these flows, and to come up with ways of lessening them [and making them more "circular"], then the first essential is a map of these moral positions.

While elaborated more fully in Thompson (2011) and Thompson and Rayner (1998), enough of this "map of these moral positions" has already been aired elsewhere, in respect of assessing the kind of institutional governance that might enable (as opposed to stifle) strategies for re-engineering cities such that they may become forces for good in the environment (Beck *et al.*, 2011). Two case histories — one of London's housing stock, the other of siting hazardous waste disposal facilities in Austria — reveal the key insights for our present discussion (Thompson, 2011).

In the case of London, government-associated planning experts were largely responsible for the provision of housing during the 1960s and 1970s. For brevity, let us label these actors, i.e., the upholders of one of the moral positions, as "hierarchist" (Beck *et al.*, 2011; Thompson *et al.*, 1990). Then, beginning in the 1970s (Thompson, 2011),

> [A] creative and motley assortment of owner-occupiers ... were able, through their myriad individual and uncoordinated efforts, to derail the planners' singular and unrelenting vision of The New Jerusalem.

These others are the upholders of a second moral position, which we shall dub "individualist". In effect, they privatized what had once been viewed (by the hierarchists) as the despised communal, public burden. Where they were successful they reduced to a trickle what were elsewhere the massive flows of materials and embodied energy liberated by demolition and reconstruction. Materials and objects, in principle destined for the landfill, were instead recycled; and local, small-scale, higher-skilled, and labor-intensive trades flourished. In the eyes of those we would now recognize as upholders of the moral position of ecocentrism — call them "egalitarians"(with their new relationship between Man and Nature) — the competitive, greedy, and profligate individualists *are* the problem, not the driving force behind the solution (as here).

Nor was this solution of the individualists a matter of the preservation of the old ways of history for the sake of preservation and, therefore, against innovation. New technologies were developed and diffused, such as timber treatments, damp-proofing, forced ventilation, thermostatically controlled heating systems, and so on. Today, the re-valued housing stock combines very high-speed and high-volume technologies of information flows with impressively slowed-down and shrunken material flows. As Thompson (2011) puts it:

> Revaluing ... is altogether different from re-cycling. In re-cycling the building itself disappears and its physical components are then re-used in the construction of a new building ... Re-valuing, however, is something that happens in our heads, and the building itself stays in place. The only change, to begin with, is in our attitude to the building. But of course, once we see it as sadly-neglected glorious heritage, rather than as awful rat-infested slum, our behaviour towards it changes, and that ... leads to all sorts of changes in the material flows associated with our built environment.

In the second case history, one of selecting sites for hazardous waste treatment facilities in Austria, the hierarchists (of the government) were at the outset again in control of the process, with the local communities of the candidate sites nonetheless not ignored. Essentially, they were accepting of the government-planning moral position (Thompson, 2011):

> [I]n their deference to expert opinion, and their willingness to sacrifice themselves for the common good, the citizens conformed to the hierarchical expectations of their government, and the government, for its part, marshalled the required technical expertise and shouldered ultimate responsibility.

The hierarchists' sense of fairness — that the least burden (here) should be borne by the greatest number of citizens (Linnerooth-Bayer and Fitzgerald, 1996) — was intended to prevail.

Despite the ubiquity of the orthodox duopoly of markets and hierarchies, the alternative approach of the market (favored by the individualists) was largely absent. That approach, which might have taken the economically efficient form of transporting the waste out of Austria for disposal in another country, or in some other relatively poor, disadvantaged community (Summers, 1991), would surely evoke the opposition of the egalitarians. For despite the claims of the individualists — about the fair and successful movement of Adam Smith's invisible hand (by which the process of benefits accruing to individuals benefits everyone else) — their approach tramples over the egalitarians' contending sense of fairness. To wit, a survey conducted at the time revealed an unusually high commitment amongst Austrian citizens to solutions that might derive from this third (and often over-looked) egalitarian moral position. 84% of the citizens surveyed expressed their strong sense of being responsible for, hence doing something about, their *own* local wastes — as opposed to unfairly transferring the burden to some quite other, possibly distant, disadvantaged community or nation (Linnerooth-Bayer, 1999). Here, in contrast to the London case, i.e., in contrast to an individualist-inspired solution, it could have been the egalitarian-inspired way, whereby material flows of hazardous wastes would desirably extend over but small distances.

To summarize, we find from these case histories four insights of potentially general applicability, that:

(I1) the value of material objects and things can change dramatically over time (the creation and destruction of value);
(I2) there is a triad of three moral positions on the Man-Nature relationship, i.e., those behind the hierarchist, individualist, and egalitarian solidarities in a society or community;
(I3) the vitality and significance of these positions — for the extrusion of policy — is dependent upon their opposition one to another (including implacable opposition), even though each would prefer to have things "all its own way"; and
(I4) the respectively attaching plural notions of fairness may be especially important in determining the fate of wastes, in particular.

2.2 Change: Nutrients as Pollutants or Resources?

To re-iterate, the change we are looking for is this: the transformation from nutrients-as-pollutants to nutrients-as-resources *under* the priority of maintaining public health in densely populated cities.

For a variety of reasons, our problem setting cannot be identical with those of material flows and moral positions in London and Austria. Not the least of the differences is that place, context, and local, regional, and national cultural attitudes matter to the outcomes of problem-solving. In addition, it is obvious that there may be differences between re-valuing previously despised property (real estate) and re-valuing human excrement, towards which we should always (arguably) have an instinctive, self-preserving sense of revulsion (but see Mehta and Movik (2011); Sim (2011)). Like the hazardous waste flows of the Austrian case study, such material is something of which to be most wary, in particular in the context of material flows in confined, localized spaces. Still, with the prospect of 9 billion fellow citizens, many of whom will live in cities, we may be approaching a threshold when habits must perforce be modified in some way, in order to attain and maintain personal and public health, now under such profoundly changed circumstances (since the mid-19th century). Indeed, it should not escape notice that, given the historic solution to public health of the (nutrient/resource-wasting) WC and urban sewerage, those of us fortunate enough have become wholly accustomed to someone else taking care of our "wastes". An intensely local/personal challenge has been solved at the expense of more regional (pollution) problems. Our personal problems have been "exported" away — out of house, home, and the city — to somewhere else. We know only too well these aphorisms: "out of sight, out of mind"; "flush and gone".

To the surprise of some, re-valuation is already taking place. It is happening through an interesting collaborative partnership amongst a public-sector utility (Clean Water Services (CWS), Durham, Oregon, USA), a private-sector start-up company (Ostara, Vancouver, British Columbia, Canada), and a non-governmental organization, the British Columbia Conservation Foundation (BCCF).[9] Without going into the details, suffice it to say that "The Ultimate Recycling" was the accolade accorded to the partnership by (Force, 2011) in the magazine *Treatment Plant Operator*, followed by the qualification:

[9] This partnership and its *modus operandi* are unusually (and surprisingly) significant in the context of our work on cities as forces for good in the environment, as elaborated in more detail elsewhere, in (Beck, 2011).

> An Oregon plant uses a proprietary process to extract nutrients from wastewater and uses them for salmon restoration and a high-quality fertilizer.

Irony, if not disbelief at the change in perspective, is in the air. Here again is Force (2011), quoting Rob Baur, wastewater professional and senior operations analyst of CWS at the Durham, Oregon, facility:

> For 35 years, I've been removing phosphorus and ammonia from wastewater. It's hard to believe that now I'm putting them back into a river.

The question is, will this early *practical* (and far-reaching) incursion into an alternative way of valuing what were previously thought pollutants, ignite any subsequent "herd instinct", i.e., a mass buy-in to this alternative way of thinking?

2.3 Empirical Evidence of the Push for More Radical Change

Transforming though it may seem, the (profitable) innovation of CWS-Ostara-BCCF works nevertheless within essentially the paradigm of the conventional, centralized urban (waste)water infrastructure, into which most cities are comprehensively locked (certainly in the Global North). The designation "centralized" — connoting the conventional sewer network, with all its dendritic branches leading from individual WCs (in individual households), eventually coming together in the trunk that connects the sewer to the single wastewater treatment facility — has become the paradigm of the past and present, against which we are bidden constructively and creatively to react (Larsen *et al.*, 2012; Niemczynowicz, 1993). The end-point of this now radically different logic — of de-centralization — is that of the on-site, resource-recovering, water-nutrient-energy "re-plumbing" of the quasi-autarchic household.

This logic of de-centralization is the subject of many of the chapters in Larsen *et al.* (2012), together with the companion logic of source separation, wherein the sources of material flows in households, offices, public buildings, industries are to be kept strictly separate and not discharged to, hence mixed in, the conventional, centralized catch-all of the urban sewer network. Nothing epitomizes the notion of source separation so magnificently as the urine-separating toilet. It simply matches the evolved design of the human body (Larsen *et al.*, 2009; Lienert and Larsen, 2007). N and P are concentrated in urine, C and pathogens in faeces, whereas the water of the WC is the added other material flow. And from this elementary mix has followed decades of earth systems engineering.

Its appeal notwithstanding, the theoretical structure of the three moral positions introduced above cannot be brought into alignment with the empirical evidence in Larsen *et al.* (2012) of the multiple agencies and actors pushing, pulling, or resisting the logic of de-centralization (and source separation). For while behavior of some of the actors, and their most obvious institutional descriptors (public, private, or civil-society sector, for instance), might be strongly redolent of the hierarchist, individualist, or egalitarian positions, the source material is not sufficiently rich to infer such alignments. Furthermore, none of these actors is (nor are we ourselves) resolutely an upholder of one or the other positions in respect of all social, economic, and environmental issues, or even in respect of the same, single issue for all of time (Price and Thompson, 1997; Thompson, 2002). Time, place, culture, and country matter so very greatly.

To discern this, we must begin by aggregating the multiple actors, across the several countries from which the evidence derives (Lienert, 2012; Londong, 2012; Swart and Palsma, 2012; Truffer *et al.*, 2012; Vinnerås and Jönsson, 2012), into the following groups:

(A1) *Households*;
(A2) *Communities*, as realized in housing associations and schools;
(A3) *Professionals*, variously identified as engineers, civil engineers, wastewater professionals, DWA (Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall eV; essentially, the German association for water professionals), and STOWA (Stichting Toegepast Onderzoek Waterbeheer; the Dutch Foundation for Applied Water Research);
(A4) *Private sector*, e.g., sanitary hardware firms, small- and medium-size enterprises manufacturing pipes, tanks and small bioreactors, and manufacturers of packaged on-site industrial wastewater treatment systems;
(A5) *Public sector*, such as municipal governments, public authorities, and public utilities;
(A6) *Law*, as in regulations, legal liability, and codes of practice;
(A7) *Farmers*, as the recipients of the nutrient (fertilizer) resources to be recovered, in principle.

Table 1 summarizes the "instigating" and "resisting" categories of actors across Europe, in respect of the issue of de-centralization and on-site technological innovation, hence, by strong association, our issue of change in valuation (from nutrients-as-pollutants to nutrients-as-resources).

It would be dangerous to draw too many conclusions from Table 1, not least because it could be argued that each of the authors of the narratives would consider themselves both professional actors and members of the instigating camp, hence biased. In addition, both the foregoing US-Canadian practical realization of the sought-after revaluation of nutrients in sewage, and our own computational studies for the Atlanta-Chattahoochee system (Beck *et al.*, 2010), demonstrate how doing better by the environment does not oblige us to adopt de-centralization or even source-separation (Beck, 2012). Furthermore, Table 1 deals with evidence of a change in the valuation of nutrient-energy materials in sewage, but in the absence of hard supplementary evidence of this re-valuation occurring under the abiding priority of maintaining public health in densely populated cities, which is crucial to our present discussion.

Table 1 Classification of empirical evidence from the book of Larsen et al. *(2012) in favor of, and opposing, a change of perspective on "human-waste-into-the-water-cycle" (Crutzen* et al.*, 2007).*

Country	Instigating Generic Actor	Resisting Generic Actor
Europe (Lienert, 2012)	Households Private sector (Communities)[a]	Professionals (Farmers)[a]
Europe/Germany (Truffer *et al*, 2012)	(Private sector)	Law Professionals
Sweden (Vinnerås and Jönsson, 2012)	Law	
Germany (Londong, 2012)	(Public sector)[a]	Professionals Law
Netherlands (Swart and Palsma, 2012)	Professionals Communities Private sector	(Professionals)[a]

[a] Actors indicated in parentheses (...) signal mild support according to our inferences for their placement in the instigating or resisting category.

Nevertheless, the debate about the possibilities and options for *radical* change (of on-site, household technologies) has not only been opened, but appears to be gathering pace. And we confess to a commitment to engage in it.

2.4 System-wide Change: Multi-sectoral Stance

If the C, N, P, embodied energy, and other materials in sewage were to be recovered, any further analysis of policy and technological options on the basis of water, water infrastructure, or the water economic/industrial sector alone would obviously be quite inadequate (Beck, 2011; Beck and Villarroel Walker, 2011). The arguments in favor of the more appropriate multi-sectoral perspective, to be elucidated and applied below, are already well rehearsed and, lest it be overlooked, both their origins and implications are of the global proportions consistent with earth systems engineering (Beck and Villarroel Walker, 2011; Villarroel Walker *et al.*, 2012).

One further observation is due, however. The debate may have been opened, as noted above, but it has yet to recognize those who may have the most to contribute to it and, in return, benefit financially from it (Beck and Villarroel Walker, 2011). Given the sectoral origins of the food imported into the city and the sectoral destinations of its recovered products exported out of the city, candidate technologies for potential introduction into the traditional urban water sector — hence the possible instigators of change (as owners of these services and technologies) — might *not* presently be associated with the water sector.[10] These (non-farmer) instigators may currently be acting and conducting their businesses in the agricultural, food, process chemicals, and energy sectors, for instance, and perhaps even the information technology (IT) industry.

There is some irony, therefore, in the observations of both Olsson (2012) and Truffer *et al.* (2012) on the role of the IT sector. Indeed, these have a bearing on fairness, on the moral position of taking care of one's own wastes, and even on matters of civil liberty (not to mention issues of system-wide

[10] However, while Veolia Environnement might be most familiar to us as just a water utility, it is already a diversified, multi-utility enterprise, with the ambition to provide its services in an integrated, seamless, multi-sectoral manner (Veolia, 2008).

risk; (Beck, 2005b)). As responsibility for treating household sewage is progressively devolved down to individual, *private* households, overseeing the maintenance of *public* health increasingly motivates the market need and niche for "remote professional service supervision" (Olsson, 2012; Truffer *et al.*, 2012), presumably because some individuals cannot be trusted to take care of their own wastes, day-in, day-out (see also Beck (2011)). Progressive de-centralization of the physical, civil-engineering infrastructure, it is suggested, should go hand-in-hand with the creation of a progressively centralized (virtual, IT) control-engineering infrastructure. Or should it? In the UK — one of the world's most closely monitored nations — a recent proposal by a previous government, to place IT devices in household rubbish bins, has been overturned by the current (2012) government. The purpose of the proposal was to reveal and punish those households who were not recycling a sufficient proportion of their wastes. Besides being a popular reversal of proposed legislation, there seems to be little, if any, evidence of "free-riding", i.e., taking advantage of a *public* service by, in effect, not acting *privately* and personally in a socially constructive manner.

Our essential point, however, is that none of the *non*-water-centric actors — as agents of change in the water sector — are cited in any of the categories of (A1) through (A7) associated with Table 1 and the original source material of Larsen *et al.* (2012).

3 Approach: Foresight & Reachable Futures

In the modern (and over-worked) phrasing, a "tipping point" is presenting itself. Under scrutiny is change in an infrastructure with arguably the greatest and deepest of technological and social lock-ins, according to the criteria of Collingridge (1981). This lock-in has taken decades to mature, a century and more in places. The technical freedom to operate differently the legacy of its physical infrastructure is akin to the (lack of) movement afforded by a straitjacket (Beck, 2005b). From a societal perspective, if the asserted benefits of source separation and de-centralization are to be realized (Larsen *et al.*, 2012), the intensely personal and intimate matters of the dietary and toilet habits of a life-time (for every one of us) are subject to serious challenge. The prospect of change, and the uncertainty clouding its distant, inter-generational outcomes (which opponents may readily exploit to stifle attempts at instigating any such change of outlook in the first place; Lienert (2012); Truffer *et al.* (2012)), could hardly be more profound and radical.

We presume that some sort of computationally-generated foresight should, therefore, be fruitfully employed to inform the gathering debate (witness Borsuk *et al.* (2008)). How this might be achieved, as a matter of identifying the seeds of structural change in the behavior of a system — the first hint of the imminent tipping point — and then (crucially) of generating foresight in the expectation of such dislocations in behavior, has been set out in its general form in Beck (2005a, 2002).

More specifically, a procedure of Adaptive Community Learning (ACL) is to be followed. In principle, the plural solidarities within the community where the change is being contemplated start by expressing their aspirations for the distant future, including from their respective moral positions (Beck, 2011; Beck *et al.*, 2002b). The attainability, or "reachability", of these plural futures (under gross uncertainty) is then assessed according to the "inverse" computational analyses proposed and demonstrated by Beck *et al.* (2002a) and Osidele and Beck (2003). What results, *inter alia*, are indications of those factors — technologies, policy components, elements of the uncertain science bases — upon which critically hinges the reachability (or not) of the community-imagined futures.

And that, their reachability or not, can be expected to be of visceral interest to those various solidarities.

On this occasion, the foresight-generating procedure will be illustrated by two case studies of London and the Atlanta-Chattahoochee system, using the Multi-sectoral Systems Analysis (MSA) software of Villarroel Walker and Beck (2012) and Villarroel Walker *et al.* (2012). The MSA is based on an analysis of material flows within the city-watershed system, i.e., the flows of water, N, P, C, and energy, into, around, and out of five interacting economic sectors, for water, energy, food, waste-handling, and forestry.

3.1 Moral Positions, Material Flows, and Neutrality in Our Analyses

To account for the interplay amongst the plural moral positions, which interplay determines the eventual material flows, as Thompson (2011) has argued, we presume further that (Beck, 2011):

i. each of the actors on the scene (such as those listed under (A1) through (A7) above) has a set of greatest hopes (and worst fears) for the distant future, under the re-valuation we are contemplating;
ii. each is deeply interested in whether — if it does not get things “all its own way” — the immediate, first step in the resulting policy/technology intervention is *not* going to foreclose on the possibility of that solidarity’s greatest hopes being the object of (revised) policy at some future date; and
iii. each is just as interested (to the core of their being) in who might pay, and who might benefit, should the contemplated change occur.

We, the authors of this paper, as well as the contributors to Larsen *et al.* (2012), want to see the change come about: from nutrients-as-pollutants to nutrients-as-resources. We are accordingly *not* neutral onlookers.

In practice, the “change” should emerge (if ever it does) from the interplay amongst the plural perspectives on the Man-Environment relationship (of which the contending views of fairness are a part), irrespective of whether members of any of these solidarities within the given community are necessarily aware of that advocated change. There could well be, and perhaps should be, instigators of the change and resistors of it active within the present solidarities, even at the outset of the process. Equally, there will surely be those who care neither one way nor the other about the change; and their aspirations and views too are to be heard and respected (Beck, 2011; Beck *et al.*, 2011)). But we do not base our analysis, for the moment, on any of these presumptions. What follows is but a first preliminary, almost surrogate, analysis of the terms of a debate that has been forming for two decades, with probably just as long to run into the future. To that extent, we are presuming that the foresight generated by the analysis would be a timely projection of some elements of the change we seek into the disputatious (and iterative) process of the debate (Beck, 2011).

In fact, the debate would not be entirely new. A few years ago, this was one of the challenges set down in the *Sanitation 21* document of the International Water Association (IWA, 2006):

> Can people who have no previous experience of recycling human wastes be persuaded to adopt such practices and who pays for the promotion of the approach?

The so-called "ecosan" dry toilet is just such a means of recycling. In particular, it is one already the subject of vigorous debate in professional circles, with accusations circulating of its epitomizing the expensive luxury of sustainability — for the multitudes of the poor and unserved, that is (and "eco-insanity" was the jibe leveled at it; McCann (2005)). Kwame's field study (2007) of the social acceptability of these toilets — amidst the tough realities of life on the ground in peri-urban Accra, Ghana — could hardly have been more timely (Kwame, 2007).

Adoption there of the new technology promised not just sanitation but the benefit of nutrient recovery (instead of environmental pollution) and the personal and community obligation to confront the actuality and proximity of our very human biological residuals. Those in the community with a strong individualist flare wanted to know whether a market for the sale of personal, composted residues could be created, not least to compensate them for the waste of their own personal time in achieving the composting. Hierarchical types, if they could not have the status symbol of a WC, preferred legislation — for punishing non-compliant members of the community — and trusted, certified experts, such as community health nurses and sanitary inspectors, as the bases of their scheme for managing the introduction and operation of the new ecosan technology. Egalitarian participants meanwhile, understood the benefits (without further expert endorsement), would allocate land to collective, community composting, even in favor of land for individual shelter, and stood ready to overcome the single obstacle to adoption. Their agenda was to change the perceptions of the individualists and hierarchists who had yet to be persuaded of the benefits of recycling human wastes through introduction of the ecosan toilet (Kwame, 2007).

Now we can see how, by our simply having an agenda to persuade, our position is not neutral.

3.2 "Rigging MSA Every Which Way"

The challenge we face for cities of the Global North is indeed a problem embedded in the complexly compounded behavior of coupled human-built-natural systems. One might expect deployment, therefore, of some agent-based model; and that may well be necessary in due course (Beck *et al.*, 2011). MSA is no agent-based model, however. Our current preference is instead to implement it along the lines of the work of van Asselt and Rotmans (1996) on uncertainty and the formation of policy for combating climate change. We therefore provide an outline of the procedure. It is expressed in greater detail in Beck (2011).

In the interests of precision and succinctness in setting out our procedure, MSA relates inputs ($\boldsymbol{u}$) to the model ($\boldsymbol{M}$) of city-watershed material flows and $\boldsymbol{M}$ transcribes the consequences of $\boldsymbol{u}$ into the perceived output response behavior ($\boldsymbol{y}$) of the system. In other words, we have the triplet [$\boldsymbol{u}$,$\boldsymbol{M}$, $\boldsymbol{y}$], which can be arranged to specify three variations on the basic problem-solving paradigm of elementary mathematics: "given two knowns, find the third unknown". Like any model, $\boldsymbol{M}$ is populated with many parameters ($\boldsymbol{\alpha}$), which characterize the physical and economic (even quasi-social) behavior of all the unit processes participating in the formation of the material flows across the city-watershed couple (wastewater treatment, incineration, power generation, urban drainage, citizens' dietary patterns, and so on).

Recognizing and labeling the three previously introduced perspectives of the hierarchists, individualists, and egalitarians as H, I, and E respectively, we fully expect each to come to the table of the debate more than ready to express their aspirations (greatest hopes; worst fears) for the distant, inter-generational future of their cherished city-watershed, i.e., respectively target outcomes (behavior) $\boldsymbol{y}(H)$, $\boldsymbol{y}(I)$, and $\boldsymbol{y}(E)$. We further acknowledge that $\boldsymbol{y}(H)$, $\boldsymbol{y}(I)$, and $\boldsymbol{y}(E)$ will inherently be subject to gross uncertainty.[11]

In addition, we allow the possibility of *H*, *I*, and *E* holding to their own respective convictions about the physical and economic knowledge bases undergirding the relationships encoded within the triplet [$\boldsymbol{u}$,$\boldsymbol{M}$, $\boldsymbol{y}$], as did van Asselt and Rotmans (1996) with climate science. In other words, there can be an $\boldsymbol{\alpha}(H)$, $\boldsymbol{\alpha}(I)$, and $\boldsymbol{\alpha}(E)$ determining how the plural $\boldsymbol{y}(H)$, $\boldsymbol{y}(I)$, and $\boldsymbol{y}(E)$ might be attained, given a singular set of assumptions and choices for the inputs $\boldsymbol{u}$. In general, this allows for exploration of the reachability of one solidarity's aspirations, say $\boldsymbol{y}(I)$, given the presumption of another's science and technology preferences and convictions, as in $\boldsymbol{\alpha}(E)$, for instance (see van Asselt and Rotmans (1996)).

Conversely, the inverse analysis of reachable futures seeks that singular (policy) $\boldsymbol{u}$ capable of delivering the expressed plural futures {$\boldsymbol{y}(H)$, $\boldsymbol{y}(I)$, $\boldsymbol{y}(E)$}, according to the MSA model $\boldsymbol{M}$, where now there can be plural "takes" on the inner workings of the model, as a function of the different parameterizations of {$\boldsymbol{\alpha}(H)$, $\boldsymbol{\alpha}(I)$, and $\boldsymbol{\alpha}(E)$}. Overall, the analysis seeks to express something (such as a probability) of the plausibility, or attainability, or reachability, of the various hoped-for futures. Such insight may be welcome or unwelcome to the upholders of the various moral positions. In particular, the inverse analysis also seeks to identify which elements of $\boldsymbol{\alpha}$ — which processes, which economic factors, which quasi-societal habits, which material flows within the behavior of the city-watershed system, and so on — are *key* in determining whether a future aspiration is reachable or not. It searches for the $\boldsymbol{\alpha}_{key}$, as we may call them. And, by reflection, considerations of those factors and features that are redundant to such attainability may be "screened out" of consideration (for the time being).

Bringing together these two products of the inverse analysis — the reachability assessments (and their plausibilities) and the $\boldsymbol{\alpha}_{key}$ — it may be of very special and deep interest to the negotiating parties to apprehend whether there are any elements within $\boldsymbol{\alpha}_{key}$ that appear to be key in *not foreclosing* on the reachability of any of *their* own plural futures {$\boldsymbol{y}(H)$, $\boldsymbol{y}(I)$, $\boldsymbol{y}(E)$}. Thus, while one solidarity, let us say the egalitarians (*E*), might be obdurately opposed to a policy $\boldsymbol{u}$ pandering to the aspirations of the hierarchists (*H*), i.e., to embark on a path to attaining the distant, inter-generational $\boldsymbol{y}(H)$, this snubbed (*E*) solidarity is not yet obliged to abandon what it cherishes for that future. For this would be what lies at the core of their convictions about the way the world is: the abiding and reasonable prospect of some day attaining $\boldsymbol{y}(E)$ instead.

4 Case Studies: Computational Results

In 2010, about 5.45M people were living in the Atlanta Metropolitan Area (AMA), which occupies roughly 22,000 km^2. The Greater London Area (GLA), in comparison, has a population of 7.8M and occupies just 1,570 km^2. The population of Atlanta has grown by 100% since 1985, London's by 15%. The proportion of land-use classified as "urban" in the GLA has fluctuated between 57% and 62% over the past 25 years, while that of the AMA was projected to increase from 20% in 1987 to 34% in 2010 (Hu, 2004). Food consumption by the two populations is estimated to be 0.6-0.8 tonnes per capita each year in the GLA and 0.8-1.4 tonnes per capita in the AMA. Densely populated London is served entirely by a conventional, centralized sewerage and wastewater

[11] In practice, it is not at all straightforward either to elicit such stakeholder aspirations (Fath and Beck, 2005) or to translate them into the numbers required by a computer model (Osidele and Beck, 2003).

infrastructure, whereas almost 40% of Metro Atlanta's population occupies dwellings utilizing septic tanks, *ergo* a decentralized arrangement. Both are locked into the prevailing mind-set of nutrients-as-pollutants.

Our position, as currently bystanders to any debate in either city, is this: what might it take to create value in the nutrients as recoverable resources? There are no solidarities into whom we can tap to provide us with authentic expression of *their* plural futures $\{\boldsymbol{y}(H), \boldsymbol{y}(I), \boldsymbol{y}(E)\}$. Instead, we must substitute for them by the following, plural, detached target behaviors for resource savings and recovery: (i) a reduction in water use, $\boldsymbol{y}(1)$; (ii) an increase in the ratio of energy generated to energy consumed, $\boldsymbol{y}(2)$; (iii) the mass of N-bearing materials gainfully recovered, $\boldsymbol{y}(3)$; and (iv) the mass of P-bearing materials likewise gainfully recovered, $\boldsymbol{y}(4)$.[12]

The influence of four promising innovations in the water sector are assessed, as candidates for attaining the target behaviors, starting from the *status quo* (and with the eventual prospect of their 100% penetration of their respective niches):

(T1) Urine-separating toilets (UST; Larsen *et al.* (2009); Lienert and Larsen (2007)), for the production of struvite (a P- and N-based product) and ammonium sulfate (an N-based product);

(T2) Consolidation and co-treatment of household organic (food) waste, through its conveyance in the sewerage system (COW), which implies the use of food-waste grinders and the mixing of kitchen organic waste with the usual contents of household sewage, i.e., laundry and bathroom/toilet fluxes (Malmqvist *et al.*, 2010);

(T3) Pyrolysis of separated sewage sludge (PSS), by which organic material is decomposed at high temperatures and in the absence of oxygen to produce gas, bioliquids, and biochar (Furness *et al.*, 2000); and

(T4) Algae production in wastewater treatment facilities (AWW; Srinath and Pillai (1972); Sturm and Lamer (2011)); for subsequent biofuel extraction, utilizing any remaining nutrients in treatment plant effluent flows, for example, in the event AWW is implemented jointly with UST.

Innovations (T1) through (T4) are incorporated into the model $\boldsymbol{M}$ via parameters that are elements of the overall parameter vector $\boldsymbol{\alpha}$.

The purpose of our inverse analysis can now be stated succinctly as:

> What factors in $\boldsymbol{\alpha}$, in particular, those associated with (T1) through (T4), are found to be key in discriminating between whether $\boldsymbol{y}(1)$, and/or $\boldsymbol{y}(2)$, and/or $\boldsymbol{y}(3)$, and/or $\boldsymbol{y}(4)$ are reachable or not, i.e., what is contained within the subset of parameters $\boldsymbol{\alpha}_{key}$?
>
> Given these identified $\boldsymbol{\alpha}_{key}$ which of its elements, if any, are key to the reachability of all $\{\boldsymbol{y}(1), \boldsymbol{y}(2), \boldsymbol{y}(3), \boldsymbol{y}(4)\}$, i.e., which factors in the coupled human-built-natural

[12] "Detached" would conventionally provoke us purportedly neutral analysts into asserting "objectivity" about the expression of these goals!

system encapsulated in $\boldsymbol{M}$ might be key to the potential for none of the target futures to be foreclosed upon, in principle?

4.1 A Pre-eminently Non-foreclosing Innovation

The set of elements of $\boldsymbol{\alpha}_{key}$ found to be key in some way for either the London or Atlanta case study, or both, are identified and defined in Table 2. It is apparent that they cover not only technological features, but other properties of the interactions between infrastructure and the rest of the environment (sewer leakage and infiltration), as well as societal features having to do with diets.

Table 2 Key constituent technologies and features of the multi-sectoral metabolisms (of both Atlanta and London) for reducing water use, improving the energy ratio, and nutrient recovery.

ID	Description Of System's Features
F1	Water supply leakage
F2	Inflow/infiltration to sewer network
F3	Urine separating toilets (UST) [a]
F4	Diet and nutrient content in bodily waste
F5	Pyrolysis of sewage sludge (PSS) [a]
F6	Wastewater treatment (nutrient removal performance)
F7	Algae production in wastewater effluent (AWW) [a]
F8	Consolidation of organic waste (COW) [a]
F9	Water use by domestic/residential users
F10	Water use by commercial users
F11	Water use for coal-based power generation
F12	Water use for natural-gas-based power generation
F13	Direct energy use for water supply
F14	Industrial discharges to the sewer network

[a] Treated as an aggregate of two or more constituent features, such as degree of implementation, separation efficiency, and process conditions.

Tables 3 and 4 show how the various elements of $\boldsymbol{\alpha}_{key}$ govern the reachability (or not) of the target futures $\{\boldsymbol{y}(1), \boldsymbol{y}(2), \boldsymbol{y}(3), \boldsymbol{y}(4)\}$ for Atlanta and London respectively. In fact, these futures have each been graded into progressively more ambitious target levels of resource savings and recovery, such as, for example, exceeding a 5%, then a 10%, and finally a 15% reduction in water use, or recovering at least 500, then 1500, 3000, and finally 5000 tonnes of P per annum.

Table 3 Summary of RSA results associated with Atlanta for achieving a set of suggested targets.

Water use reduction, %			Energy ratio increase, %				Nutrient recovery tonnes N/a x 10^3				Nutrient recovery tonnes P/a x 10^3			
5	10	15	20	50	100	150	2	4	8	12	0.5	1.5	3.0	5.0
F1	F1		F2	F2	F2	F2	F2		F2		F3	F3	F3	
F3	F3		F3		F3		F3	F3	F3	F3		F4	F4	F4
F9	F9	F9	F5	F5	F5	F5		F4	F4	F4	F5	F5	F5	F5
F10	F10		F6	F6	F6	F6						F6		
F11	F11	F11	F7	F7	F7	F7								F7
		F12	F13	F13	F13	F13							F8	
				F14		F14								

[a] See Table 2 for nomenclature.

As the salient interpretation of these results, we find that UST (feature F3 in Tables 3 and 4) is the single innovation consistently of critical significance across all the savings/recovery targets, i.e., for saving water, increasing the energy production/consumption ratio, and recovering N and P nutrients. Put the other way around (and in a less detached context), UST extends the promise of *not* foreclosing upon any of the (imagined) community-societal aspirations for the future. It is the one feature all solidarities — upholders of each of the plural moral positions — might have a strong interest in adopting in order to change the material flows coursing around and through the metabolisms of both London and Atlanta; and it happens to be a technological innovation. We might call it a "privileged" candidate innovation.

Table 4 Summary of RSA results associated with London for achieving a set of suggested targets.

Water use reduction, %			Energy ratio increase, %				Nutrient recovery tonnes N/a x 10^3				Nutrient recovery tonnes P/a x 10^3			
5	10	15	20	50	100	150	2	4	8	12	0.5	1.5	3.0	5.0
F1		-	F2	F2		F2	F2	F2		F2	F2		F2	F2
F3	F3				F3		F3	F3	F3	F3	F3	F3	F3	
F9	F9		F5	F5	F5	F5		F4	F4	F4			F4	
F12	F12		F6	F6	F6	F6	F5				F5	F5	F5	F5
			F8	F8	F8	F8				F6			F6	
				F9							F7			
			F13	F13	F13	F13								F8

[a] See Table 2 for nomenclature.

Many other deductions from these results are possible, of which we cite just five (in passing). First, reaching the targets for N and P recovery are also found to be sensitive to the dietary choices of the two populations (feature F4 in Table 2). Second, there is no scope for attaining the most aggressive rate of savings in water use (above 15%) in the case of London. Third, while the candidate innovation of algae biofuel production (AWW; feature F7 in Table 2) is identified as key in Atlanta's ambitions for increasing the "energy independence" of its water sector, this is clearly not so for London. Interactions among the features are complex. In this instance, antagonisms are present among the degree of centralization/decentralization of sewerage and sewage collection, the amounts of nutrients available for recovery through the alternative UST technology and, therefore, the amounts available for supporting algae generation (AWW) when UST-directed nutrient recovery is also in place. Fourth, pyrolysis of sewage sludge (PSS; feature F5 in Table 2) is promising in respect of both energy and P recovery, but not at all for N recovery. Last, the uncertainties notwithstanding, recovery of some 12,000 tonnes P per annum is a reasonable expectation by 2050 in the case of London, were PSS to be installed by then at 100% market penetration (Villarroel Walker *et al.*, 2012).

4.2 Fairness: Who Pays, Who Gains

Estimates of the potential financial returns attaching to the reachability of the performance aspirations in Tables 3 and 4 are summarized in Table 5. The benefits listed there under the energy ratio increase ($\boldsymbol{y}(2)$), N recovery ($\boldsymbol{y}(3)$), and P recovery ($\boldsymbol{y}(4)$), for example, should be returned to the water utility, in principle, since *it* is the entity introducing the various technological changes leading to the generation of the benefits.[13]

Table 5 Potential annual economic benefits of each performance aspiration in millions of US Dollars. Figures in the second row are for London, when these differ from those of Atlanta — the water and energy targets are relative (percentage) changes, hence a function of differing initial (base-case) conditions for the two metropolitan areas.

Water use reduction, % [a]			Energy ratio Increase, % [a,b]				Nutrient recovery[a]							
							tonnes N/a x 10^3				tonnes P/a x 10^3			
5	10	15	20	50	100	150	2	4	8	12	0.5	1.5	3.0	5.0
50	101	151	0.4	1.1	2.1	3.2	2.5	5.0	10.1	15.1	1.7	5.2	10.3	17.2
32	64	-	1.2	2.9	5.8	8.7								

[a] Values considered the following information: U.S. farm prices per ton for Urea fertilizer (46% N) and Super Phosphate (46% PO_4) are about \$526 and \$633 respectively (data from USDA); electricity price for industrial users is 6.8 cents per kWh (data from EIA); average U.S. residential water cost of \$1 per cubic meter (averaged data from www.circleofblue.org), assuming an industrial water rate is 30 per cent less than the public supply water rate.
[b] Benefits estimated as average total savings in the electricity bill.

It is, of course, one thing to generate foresight regarding estimates of benefits (and costs) on a broadly undifferentiated and societally-detached system-wide basis (as in Table 5), covering multiple sectors, utilities, and stakeholders, with their quite different and frequently strongly opposed aspirations. It is quite another to reveal who might bear the future cost and who might reap the future rewards of making the transformation from nutrients-as-pollutants to nutrients-as-resources. What lies below the headline numbers of Table 5 must be examined in somewhat greater detail.

Thus, to begin, the benefits of attaining the target savings in water use ($\boldsymbol{y}(1)$) are those of the consumers of the water, not the utility/enterprise supplying the water. More specifically, at a more dis-aggregated level, Table 2 shows that features F9, F10, F11, and F12 allow us to distinguish respectively amongst water use by domestic/residential consumers, commercial users, coal-based power generation, and natural-gas-based generation. The financial benefits associated with the reduction of water use shown in Table 5, therefore, are benefits accruing collectively to *just* the two groups of domestic and industrial/commercial users. This is because the costs (and savings) attaching to acquiring water for power-station cooling may be very different from those of the domestic and industrial users, since such water is clearly not supplied by a water utility (but taken

[13] Still, we cannot resist remarking upon this. While the utilities for Atlanta and London ought to be rewarded for “wasting their time” recovering the N and P resources (as the individualists of Kwame’s study of ecosan toilets would have put it), it is each and everyone of us who buys the food that results in the N and P to be recovered. We wonder, therefore, whether this implies some kind of ownership thereof.

directly by the generator from the environment). Accordingly, any financial benefits to the power generators resulting from savings in water consumption have been omitted from Table 5.

In more detail and in London specifically, there are just three centralized wastewater treatment plants where the three performance targets for energy, N, and P recovery can be beneficially improved. And it is to the water/wastewater utility/operator to whom the benefits thereof accrue. Yet there are literally millions of household water users, amongst whom the cost savings in water-use reduction are to be distributed. If, therefore, a household of three individuals was able to reduce its water consumption by 10%, it would save \$24 annually. The same relative percentage saving in Atlanta would be worth \$57 each year (on an identical unit cost basis), because of its currently larger per capita consumption of water. The change to using USTs, we note, could be just what might be needed to achieve such savings of water and money (albeit modest) within individual households. It is, of course, precisely this same innovation that could yield the beneficial gains in energy, N, and P recovery, i.e., that nutrients would by then be viewed as resources, not pollutants. Would introduction of the UST be perceived, therefore, as a “win-win” opportunity, at least for both householders and the utility?

While acknowledging the preliminary nature of our numerical analyses and results, we can begin to discern the magnitudes of the incentives — and to whom they relate — for making any change towards improved city-wide resource-use performance. Our point, moreover, is this. To be able to have such foresight about the *future* distribution of costs and benefits amongst these several stakeholders (water utility, power generators, other industries/commerce, and householders), would surely have a bearing on how they would today negotiate with each other in building (or dismantling) the social legitimacy of the policy and technology options necessary for making any change towards realizing the various target-performance ambitions of Tables 3 through 5 (Beck *et al.*, 2011).

5 Where Do We Now Stand With Respect To The Change We Seek?

At a computational level, we can draw the conclusion that even a non-agent-based model can be formulated, parameterized, and implemented so as to mimic the interplay among, first, the plural aspirations plural community agents and solidarities can have for their futures and, second, their plural convictions about the technologies and science underpinning the future behavior of the coupled human-built-natural system under scrutiny. It is this *interplay* among the plural contending notions of fairness, for example, that Thompson (2011) argues is the determining factor in the material flows associated with the metabolism of a city and its surrounds. In our computational studies of London and Atlanta, while technically no account has been taken of the plural convictions about how the world is understood to “work”, such accounting *has* been demonstrated elsewhere (van Asselt and Rotmans, 1996). Unlike an agent-based model, however, it is acknowledged that the human elements of adaptation and learning over time are absent from the above computational foresight exercises. Such elements would inevitably determine the future co-evolution of the natural and built environments with the human “environment” (see Janssen and Carpenter (1999) in respect of coupled rural-farmer systems). Generating foresight, through our analysis of reachable futures, within the over-arching and iterative procedure of Adaptive Community Learning, would itself be repeated, as community learning and adaptation recursively progress through time (Beck, 2011; Beck *et al.*, 2002b).

Technically too, what has been demonstrated with the MSA model of material flows has been uniquely enabled by the Regionalized Sensitivity Analysis (RSA) in which it is embedded (Hornberger and Spear, 1981; Osidele and Beck, 2003; Villarroel Walker *et al.*, 2012). First, RSA originated historically in the late 1970s in the need to analyze the behavior of environmental systems under *gross* uncertainty, i.e., largely in the absence of conventional, quantitative observational data. Gross uncertainty prevails under our present circumstances of a society contemplating its plural aspirations for the future. This uncertainty, moreover, is of two broadly different categories: that deriving from disagreement amongst solidarities (if not experts; Beck (2011); Patt (2007)), which we fully expect to envelope the change we are here contemplating; and the more familiar kinds of statistical and probabilistic uncertainties wherever consensus obtains. This enabling feature of RSA, however, comes with the technical difficulties of transcribing the spoken words of lay individuals into the numerical language of the computer model (to which difficulties we have already alluded; Osidele and Beck (2003)). Second, the sensitivity analyses of RSA are conducted uniquely in the setting of a model (with many *internal* parameters $\boldsymbol{\alpha}$) whose responses are being calibrated against some form of required *external* patterns of manifest behavior ($\boldsymbol{y}$).

Last, on technical grounds, we note that our economic accounting of the change we seek — from nutrients-as-pollutants to nutrients-as-resources — is as yet rudimentary. Evidence of its potential improvement is foreshadowed variously in Jiang *et al.* (2012), Truffer *et al.* (2012), and Maurer (2012).

At a deeper non-technical level, it has to be acknowledged that the kind of advocacy this paper and its supporting analyses has espoused — because *we ourselves* are convinced change is desirable — cannot be seen to stand clinically and neutrally detached from the fray of the debate. We are part of it. And no reminders of such apprehension are needed (Beck *et al.*, 2011; Hare *et al.*, 2006). It is possible that our seemingly detached (numerical) aspirations for the future $\{\boldsymbol{y}(1), \boldsymbol{y}(2), \boldsymbol{y}(3), \boldsymbol{y}(4)\}$ are therefore no less authentic — albeit less legitimate — than those ($\{\boldsymbol{y}(H), \boldsymbol{y}(I), \boldsymbol{y}(E)\}$) of any of the other solidarities who hold a stake in the future of *their* human-built-natural system, if it is not *ours*. Should we then also pose the question: is our (purported) knowledge of how the world works, symbolized by an uncontroversial parameter vector $\boldsymbol{\alpha}$, privileged relative to any of theirs (amongst $\{\boldsymbol{\alpha}(H), \boldsymbol{\alpha}(I)$, and $\boldsymbol{\alpha}(E)\}$)?

As to progress in practice, we suggest the experience of the Nepal Water Conservation Foundation (NWCF) in respect of the Kathmandu-Bagmati system in Nepal is exemplary (NWCF, 2009).

6 Conclusions

Our discussion has focused on the prospects for a strategic change of mind-set: in coming to view as resources to be profitably recovered the nutrient materials and energy we currently view as the "wastes" entrained into what is generally seen (and analyzed) as solely the water metabolism of cities. In other words, we seek changes in the "human" and "built" components of the coupled human-built-natural systems that *are* our cities and their environmental surrounds. This is change moreover of a scope and scale consistent with the evolving definition of Earth Systems (Re)Engineering. In particular, given the inter-generational nature of the change being contemplated, we have asked: how might some form of computational foresight inform the debate, which after more than two decades, appears to be coming to a head (witness Larsen *et al.* (2012))?

To structure our analysis, we have drawn upon two theories from Anthropology: *Rubbish Theory* (Thompson, 1979), which treats the creation and destruction of value in objects and materials; and *Cultural Theory* (Thompson *et al.*, 1990), which deals with contending notions of fairness — along with other contending notions entailed in inevitably plural world views (on the Man-Environment relationship) — in how Man views what is to be done with what we currently consider as our Wastes.

Our conclusion is that there is indeed a *prima facie* case for the value of computational foresight exercises, as already established elsewhere in respect of policy for climate change (van Asselt and Rotmans, 1996). Yet these exercises raise not only technical questions, but also social and philosophical questions regarding the place, role, and oft-claimed "neutrality" of supposedly objective research conducted by just as supposedly value-free researchers.

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