

Dynamics in socio-technical systems: Typology of change processes and contrasting case studies

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Abstract

This paper deals with fundamental change processes in socio-technical systems. It offers a typology of changes based on a multi-level perspective of innovation. Three types of change processes are identified: reproduction, transformation and transition. ‘Reproduction’ refers to incremental change along existing trajectories. ‘Transformation’ refers to a change in the *direction* of trajectories, related to a change in rules that guide innovative action. ‘Transition’ refers to a discontinuous shift to a *new* trajectory and system. Using the multi-level perspective, the underlying mechanisms of these change processes are identified. The transformation and transition processes are empirically illustrated by two contrasting case studies: the hygienic transition from cesspools to integrated sewer systems (1870–1930) and the transformation in waste management (1960–2000) in the Netherlands.

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1. Introduction

This paper is about stability and change at the systemic level. Ever since Schumpeter [1], innovation is viewed as an important source of change, with actors reacting to new economic possibilities. Every age seems to have its own type of innovation, specific to the socio-technical systems. In the past decade, we witnessed mobile telephony as a new system that competes with fixed telephones. But also well-established systems, for instance concerning automobiles, are experiencing change—cars are getting cleaner, navigation systems assist drivers and dynamic traffic management devices make it possible to influence traffic flows on highways [2]. This paper is concerned with dynamics in socio-technical systems, patterns of system change, for which we will develop a typology.

What do we mean by ‘system’? There are many kinds of systems in literature. For instance, the *large technical systems* (LTS) approach looks at infrastructural systems such as electricity systems [3,4]. LTS

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researchers have developed the seamless web approach, highlighting the alignment of many heterogeneous elements, e.g. physical artefacts, organisations, natural resources, scientific elements and legislative artefacts. Another approach is formed by *sectoral systems of innovation* [5,6], defined as “a system (group) of firms active in developing and making a sector’s products and in generating and utilizing a sector’s technologies ([5], p. 131).” Likewise, the *technological systems approach* [7,8] looks at “networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse and utilize technology ([7], p. 111).” The last two approaches widen the attention from firms to broader networks of actors, focusing attention on interaction, knowledge flows, network dynamics and co-evolution. But the above approaches say more about the *functioning* of systems than about their *change*. In a review of sectoral systems of innovation, Malerba ([6], p. 259) noted that one of the key questions in need of in-depth analysis is “how do new sectoral systems emerge, and what is the link with the previous sectoral system?” This question is addressed in this paper.

Building on the seamless web approach, we understand systems at the sectoral level as socio-technical systems, made up by a cluster of elements, involving technology, science, regulation, user practices, markets, cultural meaning, infrastructure, production and supply networks [9]. This cluster of elements forms a socio-technical system. The elements of socio-technical systems are created, maintained and refined by supply-side actors (firms, research institutes, universities, policy makers) and demand-side actors (users, special-interest groups, media).

In Section 2, we describe a multi-level perspective on change in socio-technical systems. While this perspective was initially developed to understand transitions, we will elaborate on it to explain two other change processes: reproduction and transformation. Section 3 presents two historical case studies for the most difficult change processes (transformation and transition). These case studies are the hygienic transition from cesspools to integrated sewer systems (1870–1930) and the transformation in waste management (1960–2000) in the Netherlands. The paper ends with conclusions in Section 4.

2. Multi-level perspective and types of change: reproduction, transformation and transition

The multi-level perspective (MLP) was originally developed to understand transitions and regime shifts [10–15]. The basic ontology behind the multi-level perspective stems from the sociology of technology, where three inter-related dimensions are important: (a) socio-technical systems, the tangible elements needed to fulfil societal functions; (b) social groups who maintain and refine the elements of socio-technical systems, and (c) rules (understood as regimes) that guide and orient activities of social groups (see Fig. 1).

The arrows of influence go in all directions. The elements are co-structuring each other. Actors in social groups do not act autonomously, but in the context of social structures and regulative, normative and cognitive rules. Companies react to problems posed by existing technology based on engineering insights and managerial lessons. Products are embedded in consumption patterns, through routines and cultural meanings. Infrastructures very much determine the economics of use. Practices are reproduced because of economics and rules. The rules consist of search heuristics and may include problem agendas, guiding principles, standards, government regulations, and a sense of identity for companies and the persons in it. Consumers have developed certain ways of life, routines and understandings that may be viewed as rules too. The rules do not

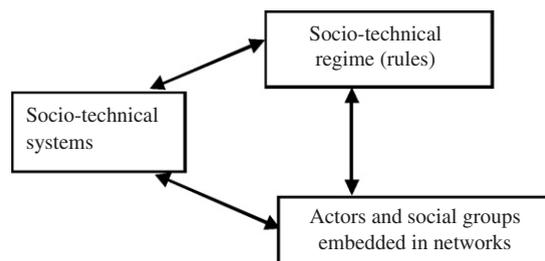


Fig. 1. Three inter-related analytic dimensions ([9], p. 903).

exist individually, but are linked together in semi-coherent sets of rules, called regimes. Nelson and Winter [16] coined the term ‘technological regimes’, which referred to the cognitive routines (e.g. search heuristics) that are shared in a community of engineers, guiding their R&D activities. Rip and Kemp ([11], p. 340) have widened the definition of technological regimes to the sociological category of ‘rules’.

A technological regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures.

The regime concept has been further widened to ‘socio-technical regimes’, which include scientists, users, policy makers and societal groups besides engineers and firms [9]. These social groups interact and form networks with mutual dependencies, resulting in the alignment of activities. This inter-group coordination is represented with the concept of socio-technical regimes.

The *socio-technical regime* forms the meso-level in the multi-level perspective (MLP). Socio-technical regimes account for the stability of existing socio-technical systems. Cognitive routines make engineers and designers look in particular directions and not in others [16]. This can make them ‘blind’ to developments outside their focus. The dominance of certain technologies and practices is thus not only a matter of economics as the literature on path dependence [17,18] suggests, but very much a matter of rules. Established systems are stabilised by roles, routines, ways of thinking, ways of doing [9,14,19] and also by legally binding contracts [20]. Systems are also stabilised because people have adapted their lifestyles to them, because favourable institutional arrangements and formal regulations have been created, and accompanying infrastructures are set up. The alignment between these heterogeneous elements leads to technological momentum [21]. Existing systems are further stabilised by social relationships, mutual role expectations and the organisational commitments and vested interests of existing organisations [22]. Finally, the material aspects of socio-technical systems contribute to stability, because of sunk investments and the economics of use. Once artefacts and material networks are in place, they are not easily abandoned and acquire a logic of their own [20]. So, for many reasons, existing socio-technical systems are characterised by stability.

Much of the change we observe is of a reproducing kind; the socio-technical system is being reproduced. This is different from the way most people define it. There is not always ‘incessant transformation’ [1] in ‘restless capitalism’ [23], but also stability.

So how do system changes occur? Scholars in sociology of technology and evolutionary economics have highlighted the importance of *niches* as the locus of radical innovations around which new systems may develop [24,25]. Niches act as ‘incubation rooms’ for radical novelties, shielding them from mainstream market selection. New technologies need such protection, because “most inventions are relatively crude and inefficient on the date they are first recognized as constituting a new invention. They are, of necessity, badly adapted to many of the ultimate uses to which they will eventually be put ([26], p. 195).” Niches may have the form of small market niches, where selection criteria are different from the existing regime. Or they may have the form of technological niches, where resources are provided by public subsidies or private strategic investments. Niches provide space for learning processes and the build-up of social networks that support the new innovation and invest in its development [10,12,13,27].

Niches may be viewed as a micro-level phenomenon, interacting with the established regimes at the meso-level, within a macro-landscape. The macro-level is formed by the socio-technical landscape, which refers to aspects of the exogenous environment that is beyond the direct influence of actors. The content of the socio-technical landscape is heterogeneous and may include aspects such as economic growth, broad political coalitions, cultural and normative values, environmental problems and resource scarcities. The landscape metaphor is used to emphasise the large-scale material context of society, e.g. the material and spatial arrangements of cities, pervasive technologies that affect all of society [11]. The material landscape is changing very slowly. The political landscape is more dynamic; we may witness revolutions, new coalitions and new ideas, creating room for novelty and system change.

The key point of the multi-level perspective (MLP) is that system innovations come about through the interplay between processes at different levels in different phases. In the first phase, radical innovations emerge in niches, often outside or on the fringe of the existing regime. There are no stable rules (e.g. dominant

design), and actors improvise, and engage in experiments to work out the best design and find out what users want. The networks that carry and support the innovation are small and precarious. The innovations do not (yet) form a threat to the existing regime. In the second phase, the new innovation is used in small market niches, which provide resources for technical development and specialisation. The new technology develops a technical trajectory of its own and rules begin to stabilise (e.g. a dominant design). But the innovation still forms no major threat to the regime, because it is used in specialised market niches. New technologies may remain stuck in these niches for a long time (decades), when they face a mismatch with the existing regime and landscape. The third phase is characterised by wider breakthrough of the new technology and competition with established regime, followed by a stabilisation and new types of structuring.

The MLP emphasises that both internal niche dynamics and external regime and landscape developments are important for wider breakthrough and diffusion (see Fig. 2).

In the multi-level perspective, there is no simple ‘cause’ or driver in transitions. For a transition to occur, dynamics at different levels should come together and reinforce each other. System changes are emergent outcomes of interactions between social groups with myopic views and differing interests.

The conceptual perspective enables a systematic distinction between three kinds of change processes: reproduction, transformation and transition. Table 1 summarises the differences between these change processes in terms of underlying mechanisms.

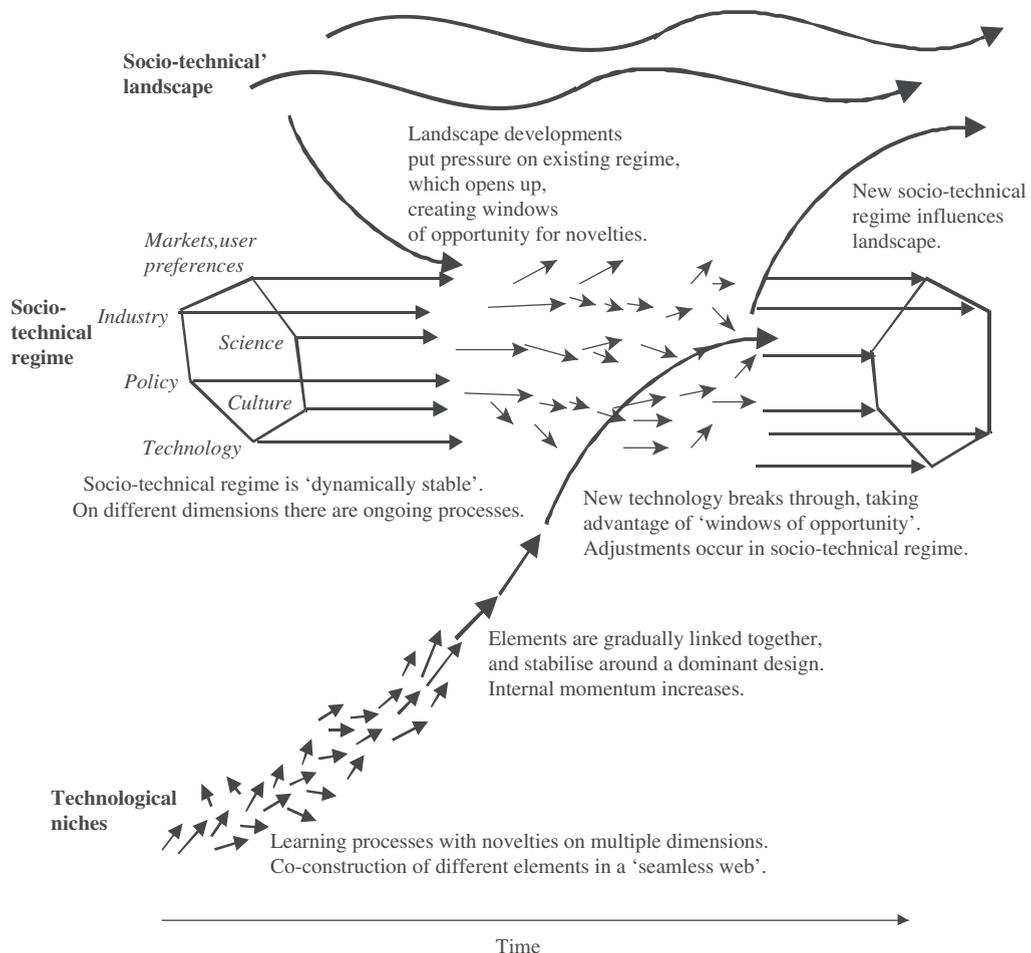


Fig. 2. A dynamic multi-level perspective on system innovations ([14], p. 1263).

Table 1
Different mechanisms in change processes

	Reproduction	Transformation	Transition
Levels involved	Regime dynamics	<ul style="list-style-type: none"> ● Pressure from landscape ● Adaptation and reorientation in regime 	<ul style="list-style-type: none"> ● Pressure from landscape ● Increasing problems in regime, and attempts at re-orientation ● New innovation in niches that eventually break through
Role of actors	Incumbent regime actors	<ul style="list-style-type: none"> ● Pressure from outsiders ● Incumbent regime actors respond through re-orienting innovative trajectories 	<ul style="list-style-type: none"> ● Pressure from outsiders ● Incumbent actors fail to solve regime problems ● Outsiders develop new innovations

2.1. *Reproduction*

In this change process, there are only dynamics at the regime level, not at the landscape and niche level. The existing socio-technical system and regime form a stable context for (inter)action of social groups. Existing rules are reproduced by the incumbent actors, and elements in the socio-technical system are refined. The orientation of dominant actors, key technology and knowledge base do not change fundamentally. There is an incremental and cumulative change along trajectories. This is the normal situation at the regime level. As indicated above, there are many reasons why existing regimes and systems are stable (e.g. sunk investments, role expectations in networks, standards, contracts, cognitive routines). This is dynamic stability, meaning that incremental innovations still occur. Incremental innovations in stable regimes are important, because, over time, they can accumulate and result in major performance improvements.

A large portion of the total growth in productivity takes the form of a slow and often invisible accretion of individually small improvements in innovations. (...) Such modifications are achieved by unspectacular design and engineering activities, but they constitute the substance of much productivity improvement and increased consumer well-being in industrial economies ([28], p. 62).

2.2. *Transformation*

In this change process, there are interacting dynamics at the regime and landscape level, but little influence from niches. The basic mechanism is that changes at the landscape level create pressure on the regime, leading to re-orientation of the direction of innovative activities. This happens through a change in the regime rules that coordinate actions of regime actors, e.g. changes in technical problem agendas, visions, goals and guiding principles, relative costs and incentive structures, regulations and perceptions of opportunities. The adjustment and re-orientation to external landscape pressure does not happen in a mechanical fashion, but through negotiations, power struggles and shifting coalitions of actors. Because incumbent regime actors initially tend to downplay the need for transformation, a change in the social network is often important to start a transformation process. Outsiders, public and regulatory pressure, or the entry of new actors may help to challenge previously held assumptions and place new issues on the problem agenda [29]. Such outsiders may express concerns over negative externalities of the existing system and demand responses from regime actors [30]. But, in the transformation process, these outsiders do not develop competing technologies to replace the existing system. So, the survival of incumbent regime actors is not threatened, and they are the ones to enact the redirection of the development trajectory of the existing system. In the transformation process, a new system may grow out of the old one, through cumulative adjustments in a new direction.

2.3. Transition

A transition refers to a shift from one socio-technical system to another. It is not about the re-orientation of an existing trajectory, but about a shift to a new trajectory. An example is the transition from a transport system based on horse-drawn carriages to a transport system based on automobiles. This transition involved changes in the socio-technical system (e.g. technologies, knowledge base, infrastructure, regulations, user practices, cultural preferences), social groups and regime rules. In a transition process, there are interactions between dynamics at landscape, regime and niche levels. Landscape developments create pressure on the regime, leading to major problems. Regime actors react with adjustments in the system (as in the transformation process), but they are not able to solve the problems. This creates a window of opportunity for new innovations, developed in niches and carried by a new network of social groups. If a new innovation breaks through and replaces the existing system, this will be accompanied by ‘creative destruction’ and the collapse of (some) incumbent actors. Once a transition has taken place, a new period of dynamic stability and reproduction sets in.

3. Case studies

To illustrate the usefulness of the MLP and the three change processes, this section presents two case studies about the two more complex change processes: transition and transformation. Both cases are about the Netherlands, because of the practical consideration of ease of data collection. The first case is the hygienic transition from cesspools to integrated sewer systems (1870–1930), and the second is the transformation of waste management (1960–2000). Both cases are often seen as goal oriented. In response to pressing problems (bad hygiene and disease, pollution), new goals and visions were developed and subsequently implemented. The case studies are chosen to challenge this rationalistic and functionalistic view. They will show that dynamics were more complex and that there was a lot of contestation and struggle going on.

The case studies will show that different kinds of multi-level interactions result in different change processes. The first case study will show the crucial importance of external landscape changes to create pressure on the regime and opportunities for niches. The second case study is more about interactions between regime and landscape and will show in more detail the role of rule changes and actors in the transformation process.

3.1. *The hygienic transition from cesspools to integrated sewer systems in the Netherlands (1870–1930)*²

3.1.1. *Problem articulation (1840–1870)*

For most of the 19th century, urine, faeces and other domestic wastes were the largest waste streams in Dutch cities [32]. People commonly relieved their bowels in public space, dumping urine and excrements on streets and in canals. Middle and upper classes had personal, in-house privies, where excrements were collected in cesspools that were emptied only a few times a year. Local public authorities issued regulations and prohibitions against waste dumping on public roads and in canals, but with little effect, because of a lack of policing ([33], p. 82). The presence of organic waste on streets and in canals created problems of stench, especially in summer and in dense urban areas [34]. Many people were concerned because it was widely believed that bad smells (so-called *miasmas*) caused diseases.

In the 1840s and 1850s, a new group of Dutch doctors emerged, the so-called ‘hygienists’, who began to investigate the relationship between bad hygiene and infectious diseases using quantitative data and medical statistics [35]. The doctors presented their findings in tables and maps, showing clear relationships between disease and hygienic variables such as waste heaps, insufficient street cleaning, canals with still water and decaying organic material ([36], p. 38). The hygienists thus articulated a problem that was subsequently discussed in city councils, newspapers and public associations. But there was uncertainty about underlying causal mechanisms that linked hygiene and disease. Pasteur developed a new micro-organism theory between 1860 and 1865, but many doctors were sceptical, because micro-organisms were too small to see. Many doctors in the established Dutch medical community hung on to the traditional miasma-based theory, and

²This section draws on Geels [31].

developed alternative hypotheses, for instance how quality and level of groundwater affected soil conditions that, in turn, affected the blossoming of cholera germs that were then spread through miasmas ([35], p. 132).

As cities grew in size, waste-disposal problems increased. Heaps of waste accumulated in canals, which blocked water circulation and hindered the supply of fresh water and the removal of waste ([32], p. 34). It also caused stench and fears about miasmas. Between 1850 and 1880, the faeces problem was hotly debated in city councils and newspapers. In other countries, visions about encompassing and radical solutions for urban hygiene were developed in the 1840s and 1850s by engineers and hygienists, e.g. Virchow in Berlin, Von Pettenkofer in München, Villermé and Parent-Duchâtelet in Paris, Liernur in Amsterdam, Shattuck in Boston and Chadwick in London ([37], p. 141). Foreign cities began building integrated sewer systems to deal with waste problems, first in the German city of Hamburg in 1843. London commissioned Joseph Bazalgette in 1852 to plan and design a sewer system. Actual work began in 1859, and the 'Main Drainage' was completed in 1865. In Paris, design of an underground sewer system began in 1863, as part of Haussman's reforms. By 1871, an integrated sewer system of 560 km length had been created [38]. In the United States, the first sewer systems were built in Brooklyn in 1855, Chicago in 1856 and Jersey City in 1859 ([39], p. 166). In Germany, sewer systems were built in Berlin (1873), Breslau (1875), Karlsruhe (1877) and München (1880) ([40], p. 220).

Dutch cities did not follow the examples from abroad. There was limited interest in alternative niches for waste management because of conditions at the landscape and regime level. The Dutch political culture was highly liberal with a very small state that hardly interfered in society. The Municipal Law (1851) gave local authorities much autonomy and made them responsible for public works, public health and hygiene. To keep taxes low for voters, city governments did not involve themselves much in public life. Voters included only a small part of the population, because the census was limited. In 1850, around 10.7% of Dutch men above 23 years could vote for Parliament and 18% for local city councils ([41], p. 340). So, in terms of political accountability, there was little incentive for public authorities to care much about the health of poor people who were without voting privileges. Health was seen as an individual responsibility, not as a responsibility of public authorities ([33], p. 82).

In the waste-disposal regime, city governments remained inactive in dealing with accumulating waste problems, despite public concern about hygiene and disease. They mainly implemented incremental changes within the existing regime, such as measures to improve water circulation in canals, so that waste would be flushed away ([32], p. 37). Canals were dredged more frequently to maintain sufficient depth and sometimes steam engines were implemented to pump in more fresh water. Another option was to fill up canals that smelled the worst and had little water circulation [42].

At the niche level, there was a small reform network, consisting of hygienist doctors and some city engineers, which lobbied for sewer systems. Stimulated by foreign examples, many Dutch cities set up local commissions in the 1850s and 1860s to investigate the option of sewer systems. These commissions produced an endless number of reports, which were discussed in city councils. But concrete sewer designs were rejected by city governments because of technical and financial uncertainties related to characteristics of the Dutch landscape. One characteristic was that much of the soil was wet and sponge-like. Because the soil was unstable, it could subside, leading to tensions and fractures in fixed sewer pipes ([43], p. 58). So there was uncertainty if the Dutch soil was suitable for sewers. Another problem was the flatness of the country. Ideally sewers functioned by gravity, water flowing over natural slopes with sufficient speed to prevent sedimentation and clogging. Pumps should be added to the system to stimulate water flows because many places in the Netherlands had an insufficient slope. This would increase costs, making sewers less attractive to city governments. So decisions were postponed and cities stuck to incremental solutions.

3.1.2. Experimentation and co-existence of multiple niches (1870–1890)

In the 1870s and 1880s, waste problems grew worse, because of wider landscape developments. As industrialisation gathered speed, poor farmers moved to the cities, leading to rapid urbanisation [44]. Many people lived under crowded and unhygienic conditions without sanitary facilities ([45], p. 44). Hence, waste dumping on streets and in canals continued, resulting in exacerbating problems of stench as urban populations expanded. Human excrements and water pollution issues received more attention after the cholera epidemic of 1866/7. In 1868, the National Drinking Water Commission concluded that drinking water in the Netherlands was highly polluted with organic compounds from human excrements. The commission recommended that

public authorities should play a more active role with regard to drinking water and waste disposal [32]. The commission's report was widely discussed, but did not lead to action. City governments continued to rely on traditional solutions such as the improvement of water circulation through dredging and using steam engines to pump fresh water into canals.

Nevertheless, city governments supported some experimentation with new technologies in niches. This minor, but important, change in attitude was related to several macro-developments. The economic situation in the Netherlands began to improve somewhat in the 1870s and 1880s, leading to higher tax revenues. Another landscape change was the emergence of the 'social issue' on the political agenda. Labour unions became more politically active, particularly the socialist labour union, the SDB, created in 1880. The SDB drew attention to social issues such as poverty, socio-economic inequality and class struggle. Public health was increasingly seen as a social issue, and city governments wanted to show that they took the issue seriously. Another factor was the expansion of the social network that wanted hygienic reform. Hygienist doctors were increasingly joined by engineers, a new group that enjoyed high societal esteem. Public opinion and discussions in newspapers also increased pressure on city governments to do more about waste problems. The coalescence of these developments created more willingness to experiment with alternative waste-removal options.

One alternative solution was the barrel-collection system; people deposited their excrements in barrels, which were collected several times a week ([32], p. 79). Full barrels were transported to a central collection place, where their contents were processed into compost and then sold to farmers as fertilizer. The barrels were cleaned and then reused. Many cities became interested in this niche, because it looked like a win-win solution, dealing with the faeces problem and at the same time earning money. Most engineers opposed the barrel-collection system because of its imprecision and leakage during the process. But hygienists and agricultural experts praised the system, because excrements fulfilled a useful function as fertilizer. Many cities implemented the barrel system in the 1870s to some extent (e.g. Groningen, Leeuwarden, Rotterdam and Amsterdam). Amsterdam and Rotterdam used barrel collection until the 1910s, and small cities like Alkmaar used it until after World War II ([46], p. 110). But the niche was not always viable, because prices of human excrements varied between locations, depending on soil conditions, needs of farmers and availability of other types of fertilizer (such as guano).

The second niche was the pneumatic Liernur system. This system consisted of a toilet, a funnel and underground pipes that connected the house to main pipes that ended in a collection reservoir. A steam pump was used to create a vacuum and collect faeces in the reservoir. Excrements were collected daily, processed and sold as fertilizer. A benefit of the system was its cleanliness. Faeces were collected without spilling, and it did not involve labourers carrying dirty barrels. Hygienists favoured this system because it was clean and produced faeces for agriculture. But the system was relatively complex and expensive. City governments feared that high construction costs could not be recovered from excrement sales. Experiments were done on a small scale in Leiden (1871), Amsterdam (1872) and Dordrecht (1873). The results were not convincingly positive. Only in Amsterdam the system continued to be used in some neighbourhoods until 1916 [42].

The third niche was formed by sewer systems. Individual sewer pipes had already been created in the 1850s and 1860s to facilitate rainwater runoff when canals were filled up. Dutch municipal engineers made many plans to link these individual pipes into an integrated sewer system. These plans were discussed but not implemented in practice (Table 2).

The unwillingness of city governments was due to the liberal political climate and high costs for underground infrastructures. For city governments, financial considerations were more important than solving hygienic problems ([43], p. 55). A third reason was that the barrel system and the Liernur system emerged just when many cities began taking sewers seriously. The co-existence of multiple niches created much uncertainty, resulting in an 'information chaos' ([47], p. 48). Different kinds of experts made competing claims about the advantages and disadvantages of different niches.³ Uncertainty further increased due to many local

³Most engineers opposed the barrel-collection system, because of its imprecision and leakages during the process. Hygienists, on the other hand, praised the system, because excrements fulfilled a useful function as fertilizer. But hygienists liked the pneumatic system even better because it was clean in operation and made good use of faeces. Agricultural experts were also in favour of separate faeces collection (either barrel collection or pneumatic), because of its economic use in agriculture. Engineers were mainly in favour of sewer systems which removed faeces efficiently. But many hygienists and agricultural experts opposed sewer systems because of the loss of fertilizer value from excrements.

Table 2
Rejected plans for sewer systems ([43], p. 59)

Year	City	Engineer
1858	Rotterdam	Scholten
1863	Arnhem	Van Gendt
1870	Amsterdam	Van Niftrik
1870	Tilburg	Havelaar
1872	The Hague	Van der Waayen Pieterszen
1872	Arnhem	Henket
1876, 1878	The Hague	Reinders
1897	Amsterdam	Lambrechtsen van Ritthem
1902	Amsterdam	Van Hasselt

factors which influenced the technical and economic feasibility of the different niches, e.g. geo-hydrological conditions, soil conditions, city size, population density, vicinity and needs of agriculture [48]. Even when cities implemented the same waste-removal option their assessments and evaluations could differ substantially. Given the uncertainties, most cities opted for the cheapest option, the barrel system. So the sewer niche, that was seriously discussed in the 1850s and 1860s, was placed on the back burner in the 1870s and 1880s, as the Liernur and barrel-collection niche received more attention.

3.1.3. Transition to sewer systems (1890–1930)

In the 1890s and early 20th century, several important macro-changes took place that affected the choice between waste-removal options. One important development was the change in the perception of the role of public authorities from liberal avoidance to more active intervention. It came to be seen as legitimate that city governments would intervene to improve urban life for *all* residents. This change was related to cultural and political concerns about the condition of the working classes. More vocal labour unions and the socialist movement forced the social issue onto the political agenda. Awareness of the social issue was also stimulated by several Parliamentary Inquiries (e.g. in 1887 into working conditions in factories) and by further democratisation. In 1887, the census was lowered and the right to vote widened. In 1896 the attributive right to vote was installed, and in 1917 the general right to vote was extended to all men and in 1919 to all women. The widening voting rights formed an incentive for public authorities to pay more attention to living conditions of all people. More active public involvement was also made possible by strong economic development between 1890 and 1914 as industrialisation finally took off ([44], p. 314). Economic growth led to higher tax revenues, providing financial means for public interventions.

Population growth and urbanisation continued to exacerbate problems in the waste-removal regime. Increased sensitivity to social issues and the new role perception of public authorities created a widespread feeling that something had to be done to improve hygienic conditions. Better financial conditions enabled local authorities to implement more expensive solutions such as sewer systems. But the turn towards sewers was also strongly influenced by developments in other regimes such as agriculture, water supply and housing. These regime developments strongly influenced the relative competitiveness of the three alternative waste-removal options. One such development was the diffusion of piped water. By 1900, around 40% of the Dutch population was connected to piped water [37]. The diffusion of piped water systems was accompanied by the breakthrough of water closets. As a consequence, waste streams had higher water content, reducing the fertilizer value and economic feasibility of the Liernur system. And water closets stimulated sewer systems because flushing became easier. An influential development in the agricultural regime was the emergence of artificial fertilizer factories in the 1890s that produced cheap fertilizer based on phosphates or sulphates. As a result, farmer's demand for human excrements decreased and faeces prices dropped, having a negative effect on the Liernur system and barrel system. In the housing regime, continued urbanisation was a driver for cities to build new neighbourhoods. These new neighbourhoods provided good locations for the construction of underground infrastructures, since pipes could be laid cheaply before houses were built.

As a result of niche, regime and landscape interactions, the Liernur system disappeared, the barrel-collection system was gradually phased out and sewer systems became more popular. Sewer systems were first implemented in large cities because construction was expensive and required a certain threshold to be worthwhile, e.g. the Hague in 1893 and Amsterdam in 1913. The transition to sewer systems in small cities was much slower. Financial means were often lacking but also hygienic problems were less pressing since pollution was more diluted. In 1938, 47% of all municipalities had sewers ([40], p. 242). In small cities and in the countryside, cesspools and barrel-collection systems remained in use until after World War II.

3.1.4. Conclusion

For a transition to occur, developments at different levels had to coalesce, an accomplishment that took very long for sewer systems. In response to problems of hygiene and expanding quantities of waste and excrements, the barrel system was implemented in the 1870s and 1880s because it was cheap and promised to make money. Sewer systems eventually broke through in the 1890s when changes in other regimes (piped water supply, agriculture and housing) and landscape changes on economic, social and political dimensions created more favourable conditions.

This case study also shows that outside actors are important to get problems on the agenda and support niche innovations (hygienist doctors, engineers, local health councils). The transition witnessed major changes in the network of social groups. There was some ‘creative destruction’ with the disappearance of existing groups (actors in the collection, processing and distribution of faeces). New groups appeared (municipal sewage organisations) and some existing groups took on new roles (more active public authorities). Because of these social processes, the transition path is different from the transformation path (see the next case study).

3.2. *The transformation of Dutch waste management (1960–2000)*⁴

For the past 40 years, the Netherlands witnessed a transformation in waste management; from uncontrolled land-filling (waste dumping) towards a differentiated waste-handling system of recycling, incineration with energy reuse and controlled land-filling. It is unclear whether this transformation has ended. Changes at the European level (the disappearance of waste borders) may lead to further change (even backwards), which is why we speak of a transformation and not of a transition.

In some ways, the transformation meant a return to the old practice of recycling. One-hundred-and-fifty years ago, recycling was a common practice in the Netherlands: glass, metals, old fabrics and certain types of organic waste were collected by individual traders [49]. At the end of the 19th century, such activities became less economical and more and more private entrepreneurs stopped collecting waste. There no longer is the ‘schillenboer’ with his horse collecting shells of vegetables. Waste collection became a public task handled by municipalities.

Most of the waste (including rising quantities of chemical waste) was land-filled; a small part was reused or incinerated in newly built incinerators. In 1912, the first incineration plant was opened in Rotterdam, while Amsterdam and Leiden followed, respectively, in 1918 and 1914. In Den Haag in 1918, a small incineration plant was opened that even generated electricity on a small scale. The incinerators were built in urbanised areas lacking landfill sites in the vicinity.

Waste was also used for filling swamps and ditches to generate new land for settlements. No record was kept of the types of waste disposed. The Netherlands basically had an uncontrolled waste-management subsystem in which waste was disposed off with few environmental considerations. The principal issue was to get rid of waste.

In the 1970s, waste and unsustainable waste-management practices received increasing attention; concerns were raised about how waste was being managed, there were growing problems with creating new landfill sites because of local resistance. The 1972 Report to the Club of Rome and the oil crisis in 1973 called additional attention to the scarcity of materials. Waste disposal was increasingly seen as a problem.

Special legislation for waste was passed and responsibilities were given to provinces. With the introduction of the *Hazardous Waste Act* (1976) and the *Waste Act* (1977), the Dutch provinces were charged with the task

⁴This part draws on contributions of Derk Loorbach and Saeed Parto.

of planning and co-ordinating, while the implementation, to a large degree, remained with (co-operating) local authorities (collection and disposal). The reason for this change in responsibilities was to put an end to the (uncontrolled) dumping on landfills and to benefit from economies of scale for incineration. Provincial borders were closed for waste transports and the operators were given the exclusive right and obligation to collect waste in a certain region. Operators were guaranteed necessary supply (*processing certainty*) and transporters had a guaranteed demand. The activities were organised as a municipal service, controlled by local politicians in control and responsible for funding [51].

A central theme in policy formation was the idea of ‘waste hierarchy,’ proposed in the parliamentary motion of Ad Lansink in 1979. The waste-management hierarchy went from prevention, through re-use (of products), recycling (of materials) and incineration (with energy production) to land-filling as the last option. The motion became law in 1986 and was an important cognitive institution [50]. From the late 1970s onwards, waste was increasingly seen as ‘a waste of resources’ by the polity. Business also started investigating ways to reduce waste as part of its environmental policy.

To reduce the volume of waste for disposal, the Dutch government opted for a *differentiated waste-stream* approach in which certain types of waste (notably paper and glass) were singled out for recycling. The initial reluctance to adopt the separate waste system came from the municipal waste-collecting services that had to change their practices. Other actors such as NGOs and private businesses performed new activities such as the collection of paper and glass. The systematic collection of the bulk of recyclable waste and organic materials would only become institutionalised in the 1990s ([50], p. 7).

Despite intentions to upgrade waste practices, many waste-management activities still suffered from their small-scale and inadequate environmental protection. For example, until the 1990s, soil protection measures were absent in virtually all landfills and flue gas scrubbing in waste incineration facilities was inadequate [51]. There was considerable political and community resistance to the construction of new landfills and incineration plants, which reached a peak in the 1980s, following the discovery of leaking landfills (Vogelmeerpolder) and contaminated land (Lekkerkerk and Griftpark). Scandals associated with waste were frequent news items in the 1980s. The two most important ones were Lekkerkerk, where it was discovered in 1980 that new houses had been built on soil containing chemical waste which had been land-filled, and Lickebaert, where in 1989 dioxins (coming from incinerators of AVR and AKZO) were discovered in the milk of grazing cows. Five waste incinerators were closed because of dioxin emissions and at least one plan for a new landfill (Does in Leiden) was abandoned because of opposition. While capacity was decreasing, waste volumes kept growing, leading to problems in capacity. In 1991, as a result of a lack of regular waste-management capacity, it even became necessary to store waste in barges.

At the end of the 1980s, the Dutch waste-management system was in a state of crisis. The system was reviewed by the National Coordination Committee Waste Policy (Commissie Welschen) in 1989, which concluded that “the current organisation is fragmented, dispersed and small scale”. It argued for the creation of a nationally oriented organisation for disposal to manage overall waste volumes and keep disposal costs under control. For incineration, but also for organising waste management from cradle to grave (chain management), four waste regions (encompassing several provinces) were envisaged, each with three to four million inhabitants [51]. This advice led to the appointment of the Waste Management Council (AOO), through the co-operative agreement for waste disposal VROM/IPO/VNG (1990). The AOO would play an important role in the modernisation of the waste system.

From the beginning, there were problems with the four waste-regions system. Municipalities wanted to sign contracts with waste companies in other regions and, because of capacity problems, waste had to go to other regions for incineration. In 1996, at the advice of the Commission Epema, it was decided to centralise the responsibility for waste control at the national level. The legal basis for the centralisation is the last amendment of the Environmental Management Act that came into force in May 2002. Efficiency considerations especially were behind this decision. The centralisation was very much favoured by new private collection and transport companies, which wanted to operate nationwide.

In the 1977–2000 period, the number of landfill sites fell from 450 in 1977 to 34 in 2000 (Fig. 3), thanks to the differentiated waste-handling approach and targeted policies (such as the packaging covenants). The ban of 32 waste-stream facilities for land-filling, and the steadily increasing costs of land-filling, created an incentive to move up the waste ladder. The amount of waste being land-filled fell from 14 Mton in 1990 to

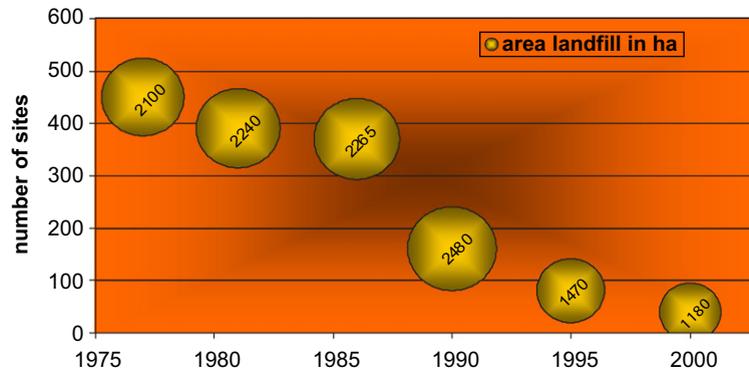


Fig. 3. Reduction of landfill [52].

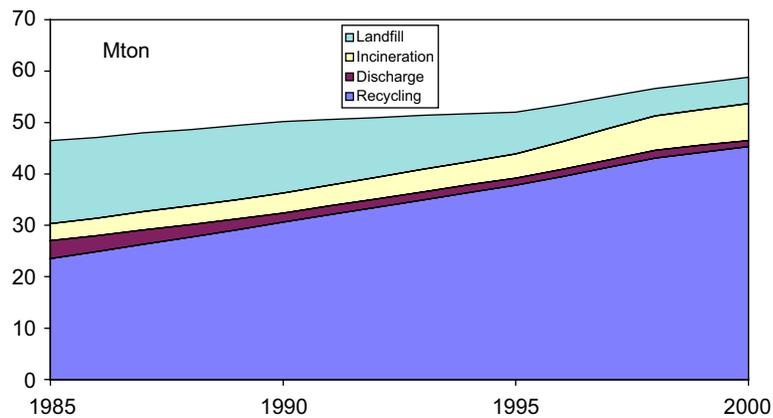


Fig. 4. Transformation of waste management [52].

5 Mton in 2002. Today, all landfills have advanced systems of soil protection and systems of methane extraction. In the same period, the capacity of incineration increased gradually, from 2.2 Mton in 1980 to 4.9 Mton in 2000. Between 1995 and 2000, incineration capacity increased by 2 Mton. Recycling increased between 1985 and 2000 from 23.5 to 45.3 Mton (Fig. 4).

The Dutch transformation to a system of recycling and increased incineration with controlled land-filling, as a last resort, is often viewed as the result of policy. Such a view, although not wrong, overlooks the fact that policy itself was the result of various changes—the growing volumes of waste, the scandals associated with waste in the 1980s and early 1990s and changes in beliefs (such as the belief that waste, in fact, is ‘a waste of resources’ and the belief that land-filling should be done in a hygienic manner and only be used as a last resort) in a period in which the environment was very much on the minds of people. Scandals helped close down old incinerators and build better ones. Various waste acts implemented stricter policies and led to the creation of the AOO in 1990. The AOO was a network organisation that brought together the three layers of government (local, provincial and central) and stakeholders. The AOO served an important coordinating function, acting as a change agent and mediator (Interview with Daemen and Huisman from AOO, 7-9-04).

The AOO played an important role in the transformation process. Negotiations between different layers of government and with private waste companies took place within the AOO, with the actors agreeing on the general direction of creating a modern and efficient system of waste management with less waste being land-filled. The environmental movement, while being officially opposed to incineration, was not creating too much opposition because its leaders understood that the high costs of advanced systems of incineration necessitated

a high tax for land-filling of burnable waste,⁵ which encouraged waste prevention and recycling. The waste companies were happy with the greater scale at which they could operate. The reorganisation of the sector, with big companies from North America such as Waste Management Inc and BFI taking over small companies, was seen by the AOO as a blessing. The big companies were committed to full compliance and had a strong incentive to respect the law.

3.2.1. Conclusion

We found that the case study had a good match with the multi-level perspective. Changes at the landscape level (environmental consciousness and changed beliefs about waste) created pressure on the waste-management regime. But this did not automatically lead to transformation. Pressure from outsiders was important, in particular public outrage over waste scandals, which led to stricter policies. Stricter regulations changed the selection process and the organisational framework of responsibilities. Important changes in rules occurred in the form of a range of policies and the development of new concepts, visions and guiding principles (e.g. the waste hierarchy, seeing waste as resource, ‘cradle to grave’ chain management of material streams). Incentive structures were changed through a gradual increase in the landfill tax. These rule changes led to a marked transformation in waste management in the direction of less landfill, much more recycling and more incineration.

The case study not only illustrated that rule changes drive transformations, but also showed that changes in social networks were limited. Incumbent regime actors (municipal waste-collection agencies, municipalities, provinces, national policy makers, the public) were responsible for redirecting developments, although their responsibilities and roles changed. The only new actors were private waste-collecting and transport companies and the AOO. These limited network changes represent one of the key differences with the transition process to sewers. Another is that niches did not play an important role in the transformation process. The transformation process depended more on the adaptive capacity of regime actors than on radical technological innovations such as the sewer system in the first case study.

4. Conclusions

In Section 2, we distinguished three kinds of change processes: reproduction, transformation and transition. The differences depended on the kinds of interactions in the multi-level perspective and kinds of social groups that took the initiative in the change process. In *reproduction processes*, the system is improved but maintains its basic structure. The system is dynamically stable, implying that innovation is mainly incremental along trajectories. Dynamics are mainly at the regime level and driven by regime actors who reproduce existing rules as they move along trajectories. In *transformation processes*, the development trajectories are re-directed through changes in regime rules. Interactions between landscape and regime level are important, as well as pressure from outsiders. But the enactment of transformation is done by regime actors. In *transition processes* there is a shift to a new socio-technical system and development trajectory. Transitions come about through interactions between all three levels, and the main drive comes from outside actors that develop radically new innovations. Incumbent regime actors may disappear in transitions, giving way to new social groups and networks.

The case studies challenged the existing view that they were coordinated, planned and goal-oriented processes. The case studies showed that dynamics were more complex and that there were multiple groups involved with different interests and views, leading to contestations and struggles. In the mid-19th century, it took a lot of effort (e.g. by hygienic doctors) to get the problems of hygiene and disease on the agenda. Once these problems were accepted, hygienic doctors, agricultural experts, engineers and city governments had different views and visions about the best solution. There were contestations and struggles instead of a central plan and a widely accepted vision. Furthermore, the eventual implementation of sewer systems depended as much on wider changes at regime and landscape level as on actor strategies. The second case study also showed that none of the actors involved could oversee or control the entire transformation process. Problem agendas, goals, guiding principles and strategies evolved during the process as actors gained experience and

⁵In 2002, the landfilling tax for burnable waste amounted to € 79 per ton (62% of the price to be paid).

responded to wider ongoing developments (growing waste volumes and increased environmental awareness). Furthermore, sudden events such as waste scandals and public outrage created unexpected windows of opportunity that accelerated the transformation. So, both transitions and transformations are non-linear and endogenous change processes, emerging from the interactions between social groups. Both cases showed, however, that these endogenous processes are situated in and influenced by external landscape developments. Neither a regime perspective nor an actor perspective is sufficient for understanding transitions and transformations; they must be combined, as we have done in this paper. In so doing, we have developed a theoretical framework that understands change as caused by both systemic processes and agents and their decisions.

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