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Population dynamics, adaptive capacity & regulation of supply systems

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Abstract

The paper introduces into a social-ecological perspective of population dynamics, focusing on structural relationships and mutual interactions between demographic changes and transformations of supply systems for water, food, energy, etc. Demographic changes, e.g. population growth or decline, urbanization and migration processes, changes in population distribution and density, household size and changing life styles are systematically related to transformations of supply systems as 'social-ecological systems'. In this way population developments can be observed in their embeddedness in societal relations to nature and within the latter's crisis-prone development. The social-ecological approach focuses on the adaptive capacity of supply systems to react to demographic changes. Against this background, problems of uncertainty, interrelated short- and long-term dynamics can be identified as most relevant challenges for the regulation and more sustainable management of supply systems.

1. Introduction

The causes and consequences of ‚demographic change', as well as possibilities to govern population development in terms of a 'demographic sustainability' are currently subject of debate within science, politics and among the general public. However, the connection between demography and sustainability itself is highly contested. Problems associated with population dynamics are complex, often contradictory, and cannot be simply separated into either ecological or societal problems. Within interdisciplinary scientific debate on population, development and the environment (PDE) it is widely agreed that demographic developments depend on socio-cultural, economic and ecological conditions, and vice versa impact society, economy, resource use and ecosystems services in each specific contexts.

However, there is still a lack of integrative concepts and methods allowing to model the interactions of population, societal development and environment as 'social-ecological problem complex' and to consider the growing regional heterogeneity and contradictions of demographic development at different temporal and spatial scales. The paper deals with demography from a transdisciplinary perspective, which relates population dynamics systematically to supply systems for water, food, energy etc. as 'social-ecological systems'. It thereby presents the major findings of the interdisciplinary research project "Supplying the population. Interactions among demographic trends, needs & supply systems (*demons*)"[1]. In this approach, the analysis of population dy-

[1] The project of the interdisciplinary junior research group was carried out between March 2002 and November 2007 and was a joint project of the Institute for Social-ecological Research (ISOE) and

namics is related to the problem of societies' adaptation to demographic changes, the shaping of social-ecological transformations and development capacities of societies. The social-ecological approach focuses on the forms the regulation of societal relations to nature takes, and not on attempts to steer population development.

2. Heterogeneous trends in global and regional population dynamics

The 20th century saw the fastest changes in population ever. At the beginning of the century, global population was about 1.5 billion people, current world population stands at 6.7 billion people (United Nations 2007). Demographers describe the fundamental demographic changes which have occurred since the middle of the last century as part of a "new international population order" (Chaimie 2000). At the global level, future population changes will be determined by the following development trends: growth of the world population, decline in fertility, increasing life expectancy, increasing aging, migration, and urbanization (Population Reference Bureau 2006; Swicaczny 2005; Lutz et al. 2004; Lutz et al. 2008):

- *Growth of world population*: The 2006 Revision of the United Nations World Population Prospects present a medium variant projection of 9.2 billion people in 2050, assuming that fertility levels continue to decline. By this time, the annual additions to global population will be by about 30 million persons annually, down from the current 78 million annually. All of the projected population growth is expected to occur mainly in developing countries, while the population of 'developed countries' is expected to remain virtually unchanged.

- *Decrease in fertility rates*: According to demographic models, future global population growth will depend decisively on further developments with respect to birth and fertility. Global population growth has slowed because the fertility rate has dropped worldwide. Globally, fertility is assumed to decline to 2.02 births per woman (below replacement) by 2050, today it is globally at 2.55 children per woman. This has been described as a "globalization of fertility behavior" (Caldwell 2001).

- *Increase in life expectancy*: In the period 1950-55 the global average age was 47 years; 2000-2005 it was 65 years (Bongaarts 2006). According to projections of the United Nations, global life expectancy is expected to keep on rising to reach 75 years in 2045-2050 (United Nations 2007: xi).

- *Aging of world population:* Because of the drop in the fertility rate and the rise in life expectancy the global population will grow older on average. This means that the relative proportion of older people will increase. By 2050 the percentage of people worldwide over 60 years of age will triple.

- *Increasing migration*: As a result of globalization, international migratory movements, above all among less developed countries, but also between newly industrializing countries and less developed countries have increased in intensity. In 2005, the number of

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people living outside their land of birth was 191 million and had almost doubled over the previous 50 years. However, the greatest part of this migratory movement is internal migration within a country and thus no part of global statistics.

- *Increasing urbanization*: Already today there are probably more city dwellers than those living in rural areas. The average growth rate of the urban population (2.68%)has been considerably higher than that of global population at a whole (1.75%).

At a global level these development trends appear as overall, general demographic patterns. However, they mask the heterogeneity of population changes. On closer inspection of individual regions and countries, considerable divergences and asynchronous dynamics become visible, which differ spatially and temporally; for example, with respect to the pace of population growth, increase in life expectancy, childhood mortality and fertility development. For example, the current average total fertility rate is for Africa at around 5 children born per woman, in Latin America at 2.5 children (United Nations 2007).

Disparities and asynchronies of demographic developments appear between as well as within countries and regions, and are an essential characteristic of population dynamics worldwide. Given these demographic transitions, one can describe the various social, economic and ecological consequences of population dynamics as both a problem of population growth and population shrinkage:

Population growth mainly in southern countries can be regarded, on the one hand, as a key symptom of poverty and underdevelopment; while on the other, it can be seen as the cause of risks and dangers such as rising emissions, desertification, deforestation and crises in water and food supplies. In this context, it is often argued, that population growth raises the demand for basic goods and, with rising incomes, for consumer goods.

Population shrinkage in developed countries is increasingly seen as the cause of economic, social and political problems, while at the same time providing relief for ecological problems. Demographic changes, especially dropping fertility rates and aging populations, are central topics of discussion, in particular in connection with their effects on social welfare systems, economic development, employment and consumption.

On the one hand, population developments are seen as connected to problems such as economic development or the structure of the social welfare system, on the other hand, they are linked to environmental problems. In both cases, often a causal connection is seen between population development as independent variable and different societal or environmental problems. A closer look, however, shows that demographic changes are linked, both in northern and in southern countries, to social-ecological problems, problems of a kind that cannot be assigned to one or the other of two exclusive categories: ‘nature’ or ‘society’.

3. Population dynamics as subject of Social Ecology

In the context of sustainable development, the issue of demographics was for long time widely referred to population growth, mainly in developing countries. For example, the World Commission on Environment and Development stated, that “rapidly growing populations can increase the pressure on resources and slow any rise in living standards; thus sustainable development can only be pursued if population size and growth are in harmony with the changing productive potential of the ecosystem (WCED 1987: 9). Today, instead of demographic growth, it is 'shrinking populations', falling fertility rates and an aging society, that dominates the discussion about demographic change in most industrialized countries. Against this background, population development has been recently discussed in terms of a concept of 'demographic sustainability' (Kaufmann 2005: 25; Roca/ Leitão 2005; Kuckshinrichs/ Schlör 2005): Just as in a forest were more trees are cut than planted, so a population violates the principle of sustainability, if, over the long term, there are less births than deaths. These separate problem descriptions and also displacements – from the issue of 'overpopulation' to 'demographic shrinking' - are the result of particular political debates; at the same time they point to new forms of societal problems and how these are perceived - societally and scientifically.

Efforts to understand the *relationship between demographic and environmental change* have a long tradition, beginning with Thomas Malthus' famous Essay on the Principle of Population (1798). 1970s, the debate was largely concentrated on the impacts of global population growth and high fertility rates in developing countries. For example, Paul Ehrlich's Book "The Population Bomb" (1968) gained wide public attention, where he focused on the issue of population growth, food production, and the environment. By 1972 the Club of Rome predicted in its World Model, which represented the first computer-based population-environment modeling effort, an 'overshoot' of global carrying capacity in the coming hundred years. Since then, many studies dealt with the question about the impact of population dynamics on the environment. One widely cited model is the IPAT formulation, in which environmental impacts (I) are the product of population (P), affluence (A) and technology (T) (Ehrlich/ Holdren 1971) This model was widely critized because it does not account for interactions among the terms and omits explicit reference to important variables such as institutions, culture, and social organization etc. (Curran/ de Sherbinin 2004)

Current state of art in the PDE literature reveals that mono-causal explanations which focus on population size and growth are mostly simplifying complex realities and are thus little instructive. Therefore, recent studies analyze specific population changes (e.g. in density, composition or numbers) and their impacts on specific environmental changes such as climate change, deforestation, land degradation etc. (de Sherbinin et al. 2007).

In contrast to studies on the demographic impacts on environment (or specific components), the social-ecological approach centers at the *interactions* between specific population dynamics and *social-ecological problems*, by relating demographic changes systematically to supply systems. The preeminent research questions are: In which way interact demographic changes and transformations of supply systems? What are prerequisites for their adaptation and sustainable regulation?

Theoretically, Social Ecology relates demography to the interactions between 'nature' and 'society': All demographic changes – rising or falling population numbers and fertility rates, changes in age structure, migration and urbanization processes, as well as qualitative alterations such as the pluralization of lifestyles or changes in norms and values indicate transformations of *societal relations to nature*, that is, the relational network formed by individuals, societies and nature in interaction (Becker/ Jahn 2006). This concept represents the historically and culturally specific structures and practices, by means of which individuals and societies regulate their relationship to nature, both with respect to material-energetic dimensions as well as with respect to cultural-symbolic aspects. Societal and natural elements are fused in all spheres of action, with each sphere having its own specific form of societal relations to nature. Specific forms of regulation take shape at different levels. At the micro-level, regulation is tightly bound up with human bodily existence, and with cultural forms of need satisfaction. At the meso-level, specific patterns of regulation shape the organization of provisioning activities, resource utilization and the respective technological structures. At the macro-level, regulatory patterns of societal reproduction and social integration congeal into production, property and gender relations. Regulation patterns vary at different levels, at the same time, must interact successfully with one another, something that can also fail (Becker et al. 2006; Becker/ Jahn 2003: 104; Hummel 2000: 320).

Every society must address the task of providing its population with food, energy, water, housing, education and health services in such a way that simultaneously meets basic human needs, ensures a decent quality of life, and preserves the natural bases of life. Supplying the population with these goods and services, in appropriate quality and quantity, is therefore essential to sustainable development, and to a society's ability to reproduce itself and maintain its potential for further development. In this context, demographic developments are of major importance: The issue, where, and when how many people live and to where they migrate, is a major concern of sustainable development in general and for the sustainable provisioning of the population in particular. On an *analytical* level, one thus can ask: How can complex sets of social-ecological problems such as conflicts over the use of scarce resources be adequately described and explained? What significance will demographic processes have thereby? On a *normative* level, the question is: What conditions are necessary for the sustainable organization of an historically and culturally specific set of societal relations to nature? Instead of inquiring the preconditions of a 'sustainable population development' this perspective focuses on the conditions needed for *a sustainable provisioning of a population*. Then, regulatory problems and conditions of adaptation take center stage.

4. Supply systems as social-ecological systems

Within Social Ecology, structures of provision developed by societies are conceptualized as supply systems, emphasizing the dynamic relation patterns between the natural and societal sphere. As an analytical concept, supply systems aim at conceptualizing structures which provide the population with basic goods such as water, food, energy, transportation or housing as societally regulated. Thereby, supply systems based on ecosystems are pointed out, so that connections between natural resources and their utilization can be emphasized in the analysis. Accordingly, supply systems cover material-energetic dimensions (e.g. environmental conditions, resources, technical artifacts etc.)

as well as cultural-symbolic aspects of life (lifestyles, gender roles, knowledge forms etc.); the 'social' and the 'natural' are linked in a certain way and develop specific problem dynamics in which economic, technical, political and ecological problems closely interact. Usually, these problem dynamics do not concern individual, isolated environmental threats that can be avoided through sector-specific measures. Rather, the dynamics involve complex and potentially critical developments in which social practices are linked to ecological disturbances. In this context, demographic developments are vitally important: Scale and functional capability of supply systems such as water and food depend on present and future number of persons who have to be provided, their needs and income, patterns of consumption and lifestyles. The functioning of supply systems is therefore closely correlated with population dynamics, differentiation in social structures and culture as well as macro-economic trends.

Supply systems are conceived as complex social-ecological systems (Hummel et al.; forthcoming; Hummel et al. 2004; Lux et al. 2006), for they are characterized by a coupling of natural and social elements which are in tight relationship to another. They are regulated by societies, and at the same time they stand in relations of dependency to natural conditions. Graphically, supply systems can be structured and simplified as follows:

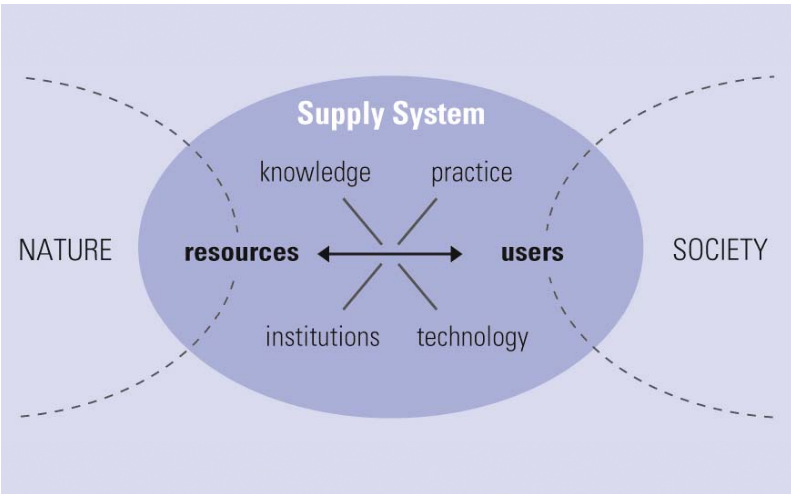

Fig. 1: Supply systems as social-ecological systems. Source: Hummel et al. 2004

Natural resources and their users are major components in the process of resource utilization for particular purposes. *Resources* comprise material-energetic, organic and spatial structures within an ecological and biophysical complex that are relevant and useable for supply systems such as food, water, and energy. Renewable and nonrenewable natural resources as well as further ecosystem services such as climatic regulations or sinks for pollutants and waste are considered as resources. Regulation of access to resources determines the level of provisioning and the degree of provisioning security. *Users* are understood to be an integrated part of supply systems. The term refers to actors and actor constellations, and includes both providers and receivers of supply system services, i.e. producers and consumers; it can be distinguished between direct and indirect as well as quantitative and qualitative use of resources. The users of supply system goods and services, are not, however, identical with a population; each group of users must be analyzed for specific supply systems. Different categories of users correspond to different parts of the population: For instance, water supply systems user groups include various items such as individuals, households, public water utilities, industry, agriculture. Within food supply, only individuals and households as well as the groups of people who process foodstuffs, form user groups. Depending on specific supply systems, differentiations must be made between and within different user groups (individuals, households, urban or rural habitants, consumer sectors etc.).

However, the process of resource utilization is no direct relation between users and resources. Rather, their specific interactions are determined by mediating elements, particularly knowledge forms, practices, institutional arrangements, and technology. These elements determine the scope and options of actions and describe ways and means of access and allocation of resources. *Knowledge* comprises both scientific and expert knowledge as well as everyday life and indigenous knowledge. *Practices* include both social, discursive practices, and material ones, all of which are carried out by various societal actors. They can be regarded as routinized types of behavior which encompass forms of bodily and mental activities, practical activities and their representations, and their interactions (c.f. Reckwitz 2002: 249f.) *Institutions* can be regarded as societally established rules of action, as (informal) constraints and (formal) rules that structure political, economic and social interaction and perform the frame of action (c.f. North 1991). *Technology* comprises all material structures designed, built and controlled by humans for achieving specific purposes, implying physical forms of infrastructure, lgistics and other technical elements used by producers or consumers of provided services. These four dimensions are shaped by society and specify in their context-dependent pecularity and interaction the specific relation between users and resources. Hence, depending on problem situations, regional and cultural context, kind and purpose of provision, the specific relevance and relation between knowledge, practices, technology and institutions must be identified. The interior dynamic of supply systems leads to specific configurations of the relations between users and resources. At the same time, the interior dynamic has feedback effects on societal relations to nature: the relations between society and nature transform as the relations between users and resources change.

In sum, supply systems can be conceived as complex social-ecological systems, where non-linearity, emergence, and self-organization are key characteristics. For example, the urban water supply system with its technical components for resource exploitation, its different patterns of water use, its institutions and its management practices can be described as a social-ecological system.

Social-ecological problems that arise within supply systems are marked by the fact that social action and ecological effects are tightly entangled. These problems are not a matter of individual, isolable environmental problems that could be solved by means of sector-specific measures, rather they must be regarded as problem complexes: different social practices, together with their different rationalities of action and societal actors, and different culturally specific interpretative paradigms are fused with ecological problems. Environmental degradation and their social and economic causes are woven together with societal methods of problem resolution and their social, economic and ecological consequences. As a result, conflicts of interests and goals can agglomerate. Supposedly successful scientific, political, technical and economic solutions to problems can lead to unintended and undesirable side effects and to new post-intervention problems. They can be called second-order problems: Solutions to problems become moments of a complex problem and crisis dynamic (Becker/ Jahn 2006: 59).

Changes in numbers, distribution and social composition of the population in a given area influence the spatial-temporal dynamic of supply systems. However, the general assumption is that there is no linear causal relationship between demographic processes and transformations of supply systems; rather, each mutually affects the other by means of feedbacks. Demographic processes influence supply systems and, vice versa, the organization of a supply system has impacts on demographic development. Performances of supply systems depend on societal demand. Thus, requirements for the supply systems' performance depend also on population dynamics. The number of persons in a given society implies regulatory problems of societal relations to nature. However, the sheer number of people and demographic growth rates do not seem to be adequate indicators to assess the quality of different regulation forms.

Therefore, we do not concentrate on the total size of a population; rather, we place the demographic *dynamics* at the center of analysis, by asking how supply systems, and qualitative as well as quantitative demographic changes influence one another.

5. Case studies

Different empirical case studies have been carried out in the *demons*-project, applying the general conceptual model of supply systems. In order to appropriately take into account the temporal and spatial heterogeneity seen worldwide and as described above, these case studies concentrated on selected demographic aspects: migratory movements, population distribution, population growth, urbanization and decreases in population size. In this way a broad spectrum of population dynamics could be analyzed in detail. In order to consider different temporal and spatial scales, countries and regions were selected in which strong population dynamics dominate: Middle East, Namibia, Ghana, Indonesia, and Germany. Thereby, supply systems for water or supply systems for food have been focused. In the following, we briefly sketch the results of the case study of the Middle East and the one about Germany, which both focus on water supply. Although these regions differ extremely with respect to their historic and cultural, socio-economic, political and environmental conditions, some noticeable common patterns with respect to the interactions of demography and transformations of water supply can be described.

The *Middle East case study* (Hummel 2007; Hummel, forthcoming) analyzed interactions of population growth and water supply systems in the Jordan River Basin and their consequences for resource management. The region suffers from an ever larger water deficit since the 1970s, while, at the same time, experiencing enormous population growth. In addition, demographic developments have taken place within a complicated political situation, i.e. the Arab-Israeli conflict. As could be demonstrated in the case study, it is demographic factors that are difficult to predict, such as inter-regional and intra-regional migration, that are decisive for the precarious state of water supply, rather than population growth per se. In addition to interstate competition for water resources, there are also intrastate tensions that arise as a result of population dynamics (certainly, among other causes). These include conflicts over the distribution of scarce water resources and over how these resources are to be used, on the one hand, between urban and rural residents, and, on the other hand, among water use sectors, in particular between agriculture and private households.

It is here that the relationship between supply systems for water and food becomes clear, for irrigated agriculture accounts for the lion's share of water use, while contributing scant added value. From the point of view of economic efficiency, the best strategy to deal with water scarcity and a growing demand for drinking water would be to reallocate water from irrigated agriculture to sectors with greater added value, such as industry and tourism, and to urban households. This transformation of the water supply system, however, may lead to unintended consequences, such as a marginalization of rural regions, which, in turn, would encourage migration into the cities and thus raises the strain of urban water supply system. This leads to the question of an appropriate form of regulation, one which takes into account both population dynamics and the relationship between water and food security. The study showed that strategies for a demand-oriented resource management are required, which are not only concerned with water availability in terms of quantity, but also the forms of demand and purpose of use of water resources.

However, social-ecological problems arising from the links between supply systems and demographic developments can also be found in more developed regions, as the example of Germany demonstrates (Lux 2007; Lux, forthcoming). Shrinking populations and other demographic factors such as increasing household numbers by decreasing household sizes mix with the region's overall trend to less water use. If the population of a municipality decreases, then so does the number of its consumers, total demand for water drops, and its spatial distribution changes. This has technological, ecological, and economic effects. These effects interact with demographic changes, with the result that both sides are reinforced. Technical problems that may arise from underutilization are superimposed on economic consequences. Thus prices rise for individual households, for, as the number of customers drops, fewer persons must bear the high fixed costs of water supply pipelines and facilities. There is a time lag before this effect appears, with repair and modernization work on the technical facilities only strengthening it. Thus, different feedback loops can be identified, which are marked by demographic changes and consumer behavior on the one hand, and path-dependency in relation to technical infrastructure and economic basis of water supply, on the other. (Fig. 2).

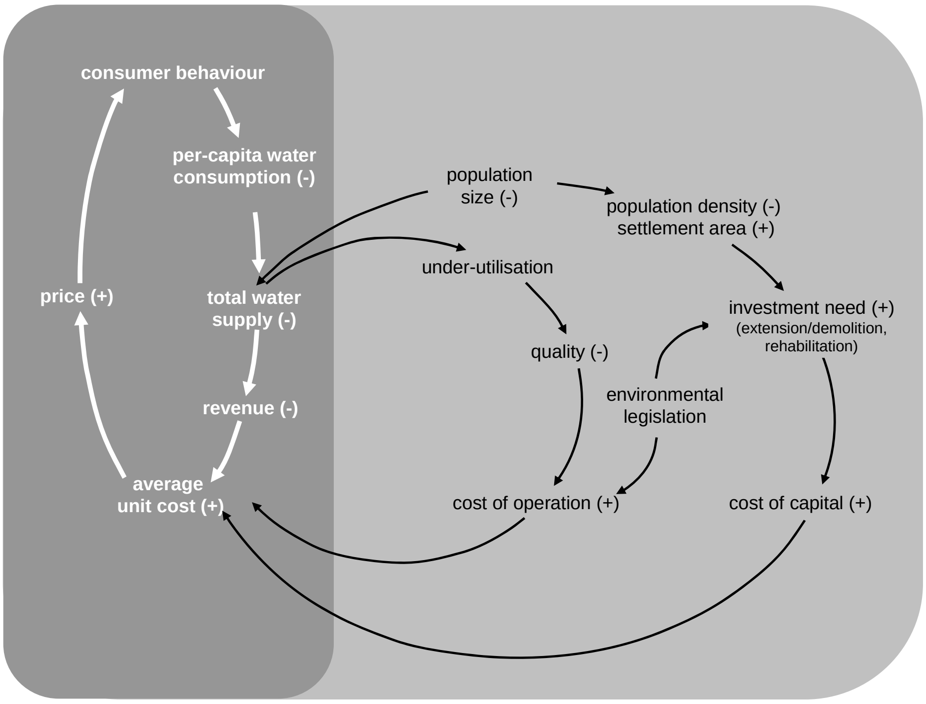

Fig. 2: Feedback loops of reduced water consumption (Source: Lux 2007).

The study made clear that demographic shrinkage represents a many-sided phenomenon that cannot be reduced simply to a drop in population size. It includes the concurrence of decreasing population, a drop in population density, as well as changes in household structures. In the region studied, one sees a growing heterogeneity: a juxtaposition of demographic growth, stability, and shrinkage. A central conclusion of the study was that less people do not necessarily mean less water will be used. Much more it is the case that the structural effects of changes in population and in household structures are superimposed on one another. Thus, with the growth of smaller households, and of the number of households, one can expect higher levels of water use. Moreover, changes in household technology and behavior also play an important role in the relationship between population size and water use.

As both case studies revealed, there is no linear or proportional relation between decreases/ increases in the number of residents to be supplied and a drop/ rise in water use. Although extremely differing in their historical and cultural contexts, there are some striking similarities with respect to impacts of demography: Demographic patterns are quite heterogeneous, containing asynchronous and sometimes contrary processes. Changes in household structures, i.e. the trend towards growth in the number of households coupled with a reduction in the average household size, could be found in both regions. They significantly affect water demand and consumption. As a result, new demands are made on the adaptive capacity and regulation of supply systems. Both case studies revealed the central importance given to the factor of migration, and its spatially and temporally specific configurations. While in the Middle East serious challenges for supply systems arise from sudden immigration, in eastern Germany it is emigration that has been causing problems. In both cases, migration processes are tied to changing population distribution and settlement patterns, which represents a challenge for the short and middle term adaptivity of supply systems.

6. Adaptive capacity & regulation of supply systems

What is often described in public discussions of demographic changes simply as destructive growth or shrinkage, becomes, from a social-ecological perspective, a problem of unsuccessful adaptation to changed demographic (and societal) *boundary conditions*. Somewhat simplified one can say: it is not population developments as such that are the problem; rather it is the inability of societal supply structures to adapt adequately in the face of demographic changes, together with a limited or missing capability on part of the supply systems to regulate themselves adequately. For, societal, ecological and demographic developments are interdependent, yet undetermined, and societies can actively shape the effects of demographic changes. Against the background of the case study results, governance concepts are required that recognize the relevance of institutions, different forms of knowledge, technology and practice.

Crisis-prone developments of supply systems are produced by neither direct causal impact nor individually identifiable factors. However, it is possible to determine, and weigh the importance, of certain driving forces critical to the formation of the kinds of social-ecological problem complexes that emerge in the course of population development. One of the most important results of the case studies within the *demons* project is that, with respect to population dynamics, in particular migration, changes in population distribution and density present challenges to supply systems. Such changes are accompanied by specific problems of adaptation and regulation, since they are associated with fluctuations in demand and use, and are therefore difficult to predict. Special challenges arise in addition as the result of divergent and a-synchronic developments, the superimposition of short and long term processes, and the absent spatial-temporal congruence of supply structures and population dynamics. Depending on historical context and specific geographic, economic, and social-cultural conditions, these factors may contribute to regionally specific problems and crisis-prone changes that can threaten supply security. A major challenge for supply systems such as water and sewage systems is to consider long-term as well as short-term demographic developments because of the long life cycles of supply and disposal networks and their high costs. One problem is that past decisions, especially in the area of material infrastructure, are difficult to rectify in the short or medium term. Adaptive capacity and sustainable regulation of supply systems means dealing with uncertainty. Unexpected developments such as technological change and modification in usage patterns as well as climate factors cause insecurity that make precise water demand forecasts almost impossible. Furthermore, short-term migratory processes are difficult to predict. Therefore, the future flexibility and limited reversibility of planning decisions must be taken into account (cf. Hummel/ Lux 2007). A high degree of path dependency – that is, the strongly irreversible character of current structures and processes due to past decisions – lessen the reaction capabilities of supply systems with respect to changes in demand. In this way path dependencies can trigger feedback effect affecting both population structure and supply systems.

Sustainability with respect to supply systems is difficult to determine in general, as it always depends on specific regional and historical contexts, as well as on specific cultural background. Moreover, sustainable or non-sustainable development of supply systems is not exclusively determined by demographic development, but also by economic structures, institutions etc. A general description of particular sustainable conditions for supply systems is therefore as little possible as the formulation of a set of instructions for concrete political, economic or societal action that could be put directly into practice. However, it is possible to identify certain basic conditions that need to be satisfied if sustainable supply systems are to be designed and their regulation capabilities strengthened. They can be described as transformation openness, integration, adaptivity and operational functionality (c.f. Kluge/ Schramm 2006; Hummel et al. forthcoming):

Transformation openness refers to the ability of a system to form new structures and processes, and thus to develop further. With respect to supply systems it means the ability to provide supplies reliably, as well as the ability to respond to changes in demand in a timely manner, which often means quickly. Openness to transformation includes quantitative, qualitative and spatial aspects.

Integration: Resource management decisions, as well as those concerning development of infrastructure, pertain to different kinds of expertise and affect different groups of actors which have to be integrated. At the core of this participatory approach is the need to expand the knowledge base available to all interested parties and to develop a common understanding of the problem at hand. Assessing alternative options for action and revealing conflicting interests is crucial.

Adaptivity refers in general to the ability to adapt to changing targets within a given process. With respect to supply systems it means that they can adjust to changing initial conditions. In the context of designing sustainable supply systems it means that the system is flexible enough to be able to revise decisions already made in the face of possible future changes in initial conditions. An important presupposition is the productive use of existent feedback loops linking consequences and effects to decisions made and measures taken. In our context, the ability of supply systems to adapt to demographic changes particularly means the loosening up of path dependencies and tendencies to persistence. For example, flexible infrastructures are needed, ones which are capable of adapting to changed boundary conditions. Adaptivity also includes the efficient use of resources and a resource productivity that takes various purposes of use and different consumption practices into account. For example, ecological, economic and social aspects must be combined during the implementation of decentralized combined systems for water supply and sewage, systems which must be differentiated according to type of resource: drinking water, water for sanitary and industrial use and recycled water and nutrients.

Functionality refers to the stability of supply systems and to a system’s economic and, especially, managerial requirements, its need to ensure the interruption-free fulfillment of its goals, and the requirement that its quality standards be met (for example, a supply of drinking water satisfying technical and hygienic standards). Both, the functionality of ecosystem services and of societal supply structures must be reflected.

This leads to enhanced paradigms in management and evaluation that are geared to

- predictive uncertainty, non-knowledge or non-attainable knowledge and a limited ability to plan future developments;
- the complexity of the structural conditions governing supply and the causal connections inside the supply system;
- feedback effects.

Such management and evaluation principles are meant to ensure that natural, societal and technical processes of regulation can be integrated with specific goals in mind. In our context it is important that adaption to changing boundary conditions and reactive goal setting management processes are assured. The most important element of management practice, from the perspective of social-ecological regulation, is an awareness of the different effects actions have on ecological conditions, on the interests of society's resource users, and on economic boundary conditions, and a relational understanding of these effects in terms of feedback loops, so that such feedback loops can be taken into account when putting together further, possibly altered regulatory measures (Hummel/ Kluge 2006: 257; Kluge/ Schramm 2006: 63). In this way, particular feedback loops can be designed for specific purposes, or they can function as a component of an ecological system. However, it is also possible that they are formed as the consequence of the unintended side-effects of steering actions or sectoral regulations. Thus, social-ecological regulations open in this way the possibility of assuming an actor-oriented perspective, with economic, civil society and scientific actors all becoming a part of the regulatory network. Participative forms of feedback allow for the inclusion of actor's perceptions of the effects on them of actions taken. The subjects of regulation can perceive the effect their actions have and take these into account, adapting in this way to changing target states. This is particularly important when considering whether to modify regulatory measures or not.

Social-ecological regulations, with respect to transformations of supply systems, become in this way iterative, adaptive learning processes. Since knowledge about the consequences of measures is, due to predictive uncertainty, always limited, targets can only be reached with the help of repeated evaluations and adaptations. Feedback cycles ought to be, therefore, short and targeted, and they should include relevant stakeholders (Kluge/ Schramm 2006: 63). The assessment of effects is particularly important in this context. What is necessary are temporally and spatially scaled assessments of the intended, as well as the unintended effects, of strategies for action; in short, a productive use of feedback processes (for instance, with respect to given process of economic restructuring or of levels of local resource use). Forms of feedback can be used systematically, such as monitoring, information systems, or participatory procedures such as decision support systems.

Adaptivity and regulatory capability of supply systems then means in the context of sustainable development, that regulation must be seen as an open, dynamic process that is always in a process of constitution, a process that must always maintain and continually replenish its own natural and societal foundations.

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