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Sustainability research as inter- and trans-disciplinary activity: the case of German *Energiewende*

Inter- i trans-dyscyplinarne badania nad zrównoważonością: przypadek niemieckiej *Energiewende*

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Abstract
Sustainability research shall provide knowledge for action and is therefore deeply related with social and political issues such as regulation, behaviour, value-added chains, daily routines of users, consumption patterns, economic incentives, perceptions, attitudes and values. It needs cooperation with social actors in diagnosing sustainability deficits and challenges, in determining priorities for research and action, in defining indicators for measuring empirical developments and deciding on sustainability targets to go for, in setting the research agenda, in bringing knowledge and values of stakeholders and affected persons into the game and in looking for making sustainability strategies work in practice. This holds in particular for the transformation of the energy supply system to a more sustainable status. This transformation goes far beyond the substitution of traditional technology by new ones, because the energy system is not a purely technical system consisting of power plants, supply lines, storages etc. Rather it also includes a complex set of human actors such as users, regulators, decision-makers, planners, innovators, employees in the supply companies, citizens affected by side effects of energy technologies and infrastructures and also citizens in their role as the democratic sovereign. The main thesis of this paper is that the energy system is a *socio-technical* system and *that its transformation* is a *social transformation* including technological change but going far beyond. The German *Energiewende* is used as an example. *Energiewende* means the (relatively) fast transformation of the German energy infrastructure to a more sustainable status based on a high share of renewables and strongly increased energy efficiency, including an accelerated nuclear phase-out after the Fukushima disaster.

Key words: sustainable energy supply, socio-technical systems, transition management, social learning

Streszczenie
Badania na zrównoważonością powinny dostarczać wiedzy praktycznej, powiązanej z takimi zagadnieniami społecznymi i politycznymi, jak: regulacja, zachowanie, wartości dodane, codzienne zachowania, wzory konsumpcyjne, zachęty ekonomiczne, percepcja, postawy i wartości. W diagnozie wyzwań zrównoważoności niezbędne jest uwzględnienie perspektywy społecznej, pozwalającej określić priorytety dla badań i praktyki, zdefiniować wskaźniki pozwalające zmierzyć rozwój i wyznaczyć cele, ku którym powinniśmy zmierzać. Należy ustalić program badań, uwzględnić wiedzę i wartości odnoszące się do interesariuszy i innych osób, które w tym procesie uczestniczą, a także poszukiwać strategii zrównoważoności, które sprawdzą się w praktyce. W szczególności odnosi się to do przekształcenia systemów zaopatrzenia w energię. Ta transformacja wykracza daleko poza zastąpienie tradycyjnych technologii nowymi, ponieważ system energetyczny nie ma charakteru jedynie czysto technicznego, złożonego z elektrowni, linii przesyłowych itp. Uwzględnić w nim należy także złożony zespół czynników ludzkich, takich jak użytkownicy, moderatorzy, decydenci, planiści, innowatorzy, pracownicy kompanii energetycznych i obywatele dotknięci efektami ubocznymi wynikającymi tak ze stosowania technolo-

gii energetycznych jak i rozwoju infrastruktury. Główna teza tej pracy jest następująca: system energetyczny jest systemem *społeczno-technicznym* i *jego przekształcenia* zachodzą na płaszczyźnie *społecznej* z uwzględnieniem zmian technologicznych, wykraczając jednak daleko poza nie. Niemieckie *Energiewende* może służyć za przykład. *Energiewende* oznacza (relatywnie) szybką transformację niemieckiego systemu energetycznego w kierunku zrównoważoności, co oznacza oparcie go na odnawialnych źródeł energii i silnie zwiększonej efektywności energetycznej, a także przyspieszonym po katastrofie w Fukushimie wycofywaniu się z rozwijania energetyki jądrowej.

Słowa kluczowe: zrównoważone zaopatrzenie w energię, systemy społeczno-techniczne, zarządzanie zmianami, edukacja społeczna

1. Introduction and overview

As is well-known for now about two decades, sustainability research must be highly inter- und trans-disciplinary in nature in order to be able to successfully cope with the challenges of its very subject (Kates et al., 2000; Spangenberg, 2011, Grunwald, Kopfmüller 2012). Sustainability research shall provide knowledge for action and is therefore deeply related with social and political issues such as regulation, behaviour, value-added chains, daily routines of users, consumption patterns, economic incentives, perceptions, attitudes and values (Kowalski et al., 2007). It needs cooperation with social actors in diagnosing sustainability deficits and challenges, in determining priorities for research and action, in defining indicators for measuring empirical developments and deciding on sustainability targets to go for, in setting the research agenda, in bringing knowledge and values of stakeholders and affected persons into the game, and in looking for making sustainability strategies work in practice. This holds in particular for the transformation of large infrastructures such as energy supply, water supply, and transportation to more sustainable systems. Such transformation processes are only conceivable as processes of co-diagnosis of deficits, co-shaping of future alternatives, co-determining of the targets to be met, and co-designing solutions for the respective next steps of the transformation. In this way, the transformation towards a more sustainable society is an issue of culture (Banse et al., 2010, 2011; Banse, Parodi, 2011).

However, often the transformation of the energy system is regarded as – more or less – solvable by new and much more efficient technology including strong integration of renewables, assuming implicitly or explicitly that social issues will – again more or less – not be touched upon, except that that the new technologies needed must be *accepted* by society. Thus, the role of social sciences is frequently seen by managers and engineers in providing socio-technological knowledge how to achieve this goal of acceptance (know-how). The aim of this paper is to criticise this technocratic approach as deficient and misleading, using the German *Energiewende* as an example. *Energiewende* means the (relatively) fast transformation of the German energy infrastructure to a more sustainable status based on a high share of renewables and strongly increased energy efficiency, including an accelerated nuclear phase-out after the Fukushima disaster. This transformation goes far beyond the substitution of traditional technology by new and more sustainable ones because the energy system is not a purely technical system consisting of power plants, supply lines, storages etc. Rather it also includes a complex set of human actors such as users, regulators, decision-makers, planners, innovators, employees in the supply companies, citizens affected by side effects of energy technologies and infrastructures and also citizens in their role as the democratic sovereign. The main thesis of this paper is that the energy system is a *socio-technical* system and *Energiewende* is a *social transformation* including technological change but going far beyond[1].

The paper is structured as follows. First, some general issues of the recent debate on trans-disciplinary sustainability research will be recalled (Sec. 2). The interpretation of the energy system as a *socio-technical* system (Sec. 3) is crucial for the analysis and conclusions presented. It will be argued that the many uncertainties involved – will force us to shape it as an ongoing societal learning process far away from any classical planning approach. The Helmholtz-Alliance ENERGY-TRANS will be introduced as a step in this direction (Sec. 4) opening up further perspectives for trans-disciplinary energy research.

2. Inter- and trans-disciplinary knowledge integration for sustainability

Sustainable development requires that societal processes – including consumption and production patterns, value-added chains and technology development – are re-orientated so as to ensure that present generations can satisfy their needs without endangering that the needs of future generations can also be fulfilled (WCED 1987). Thus sustainable development necessarily involves long-term and

[1] The arguments presented in this chapter have partly been discussed and developed in the Helmholtz Alliance ENERGY-TRANS (www.energy-trans.de). Some arguments build on earlier work (cp. primarily Schippl, Grunwald 2012). I would like to express thanks to Jens Schippl and my colleagues cooperating in the Helmholtz Alliance.

normative considerations (von Schomberg, 2002). It includes taking into account aspects of the distant future, of the impact of our present use of technology and concepts of society on this future, and considering the impact of such reflections on our present-day individual and collective behaviour. The transformation of current social realities to more sustainable ones will have to take into account complex pieces of knowledge about current trends and developments, about systems and their driving forces, about orientation *where* to go to in order to reach a more sustainable world, and about measures *how* to go there. It is evident that scientific research and advice is needed to support this really *grand* transformation (WBGU, 2011).

The necessity of crossing the borders between scientific disciplines on the one hand, and between science and society on the other, in order to be able to contribute significantly to problem solutions in the *real world*, e.g. in the field of sustainable development, has long been a subject of scientific and public debate. This necessity is primarily related with the very subject of study. Obviously, real world challenges such as the transformation to a more sustainable energy system cannot be dealt with successfully within individual scientific disciplines. Problem-oriented research orients itself on the scope of social challenges and problems, not on discipline-immanent research programmes (Bechmann, Grunwald, 2002), and must therefore be inter-disciplinary in nature.

Beyond inter-disciplinarity, the issue of trans-disciplinarity enters the field at different occasions, for example by responding to the challenge *how* the problem is identified and shaped, and *who* will and should contribute to shaping the problem and designing research to meet its need (*co-design*), by taking knowledge and perspectives of stakeholders, civil society and other extra-scientific actors into account in the knowledge production (*co-production*), and by creating specific measures and strategies of implementation together with relevant actors in the respective field (*co-creation*): *Thus in transdisciplinarity, the sources of intelligence are extended to include non-scientific knowledge (…), the research question is defined together, and the quality of the work is checked by both groups, as those affected are the experts for relevance, while scientists are the exports for rigour* (Spangenberg, 2011). Accordingly, the issue of *integration* is at the heart of trans-disciplinarity:

> Transdisciplinarity is a critical and self-reflexive research approach that relates societal with scientific problems; it produces new knowledge by integrating different scientific and extra-scientific insights; its aim is to contribute to both societal and scientific progress; integration is the cognitive operation of establishing a novel, hitherto non-existent, connection between the distinct epistemic, socio-organizational, and communicative entities that make up the given problem context (Jahn et al., 2012).

For providing integrative orientation and strategies for sustainable development research has to operate with different types of knowledge from various scientific disciplines and, on demand, also from outside science. This knowledge can be categorized in the following way (extended after Weber, Whitelegg, 2003; Grunwald, 2004):

- *Systems Knowledge*: Insight into natural and societal systems, as well as knowledge of the interactions between society and the natural environment are necessary prerequisites for successful action in the field of sustainable development. Explanatory knowledge about relevant systems, in particular in the form of cause/effect-relationships, is the knowledge, the production of which is the familiar object of scientific disciplines. This type of knowledge is often provided in the form of models (e.g. Schellnhuber, Wenzel, 1999).
- *Prospective knowledge*: The time dimension of sustainable development, in particular the issue of taking over responsibility for future generations (Jonas, 1979), requires considering possible, probable or desirable future developments, based on today’s knowledge and assessments. Prospective knowledge allows for imagining where current developments could develop to. A lot of research-based methods such as scenario techniques and model-based simulation techniques are available to provide prospective knowledge (Rescher, 1998).
- *Orientational knowledge*: The appraisal of societal circumstances and developments, of global trends, and of measures must build on sustainability goals, criteria and targets which permit reliable and transparent differentiation in *sustainable* and *non-* or *less sustainable*. These must be based on good reasons which operate on the basis of normative premises. Orientation knowledge serves as a *compass* to identify sustainability deficits, to determine priorities, to find out the direction where to go to and to distinguish between alternative paths of action (e.g. Kopfmüller et al., 2001; Ott, Döring, 2004).
- *Strategic knowledge*: To the tasks of sustainability research indispensably belongs contributing to the *therapy* of sustainability problems. In the final analysis, science for sustainability aims at coherent and integrative action-guiding knowledge for politics and society by elaborating on pos-

sible measures and strategies, taking into account the uncertainty and incompleteness of the knowledge produced (Grunwald, 2004, 2007; von Schomberg, 2002).

Research for sustainable development usually aims at *transformation* and is thus *transformative research* (WBGU, 2011). Therefore, all of the types of knowledge alluded to are indispensable to be able to do this: explanations of cause/effect chains provide the cognitive basis for every sort of action; orientating criteria are equally indispensable for diagnosis as for therapy, prospective knowledge shows possible future developments and in strategic knowledge for action, they combine. Now, regarding the sources of these different categories of knowledge it is obvious that:

a) interdisciplinary integration must take place. Positive sciences such as geography, ecology and climatology but also social sciences do provide systems knowledge; normative sciences such as ethics and legal sciences do contribute to orientational knowledge, and action-oriented sciences such as political and economic sciences deal with measures to reach specific targets. Beyond these necessities of disciplinary integration,
b) knowledge from outside science must be integrated at different places, e.g. by perceptions and values entering the field of orientation and by stakeholder's and citizen's views on future developments in the field of prospective knowledge.

However, the most relevant entry points of and needs for trans-disciplinarity do concern the entire field and are related with questions such as:

- How can the problem under consideration be understood adequately – and what does *adequate* mean in that case?
- Which knowledge is required to understand the challenge and to elaborate on strategies of response?
- Which targets should be addressed with high priority?
- Which disciplines and outer-scientific activities are needed to provide the knowledge required?

Accordingly, trans-disciplinarity has to address the overall constellation, beginning with framing and understanding the problem at hand, determining processes and actors of knowledge acquisition and reaching up to defining strategies or response to the identified sustainability deficits. To choose a strong formulation: trans-disciplinarity is the *conceptual, pragmatic and integrative medium* of interdisciplinary and disciplinary sustainability research.

This conclusion does not imply that each research project aiming at contributions to sustainable development must be inter- or trans-disciplinary in nature to a maximum extent. In particular, explanatory systems knowledge often can be created by disciplinary research and modelling, e.g. on specific eco-systems, or by inter-disciplinary projects without cooperation partners of society. Accordingly, there might be mono- or interdisciplinary projects contributing considerably to sustainable development issues without any trans-disciplinary parts. However, these projects should be integrated in an overarching framework of sustainability assessments and diagnoses which should have been established in a trans-disciplinary way. Mono- or interdisciplinary research should be embedded in a common and thus trans-disciplinary agenda of sustainability research. This constellation will allow for providing integrative *products* combing the knowledge types mentioned above in order to meet specific sustainability challenges. It also provides orientation how to arrange methods in order to arrive at the envisaged common product. It will also be possible to argue that particular disciplines using particular methods will have to address specific disciplinary subjects for contributing to reaching the common goals (in my eyes, the following quote also holds for the *trans*-disciplinary integration of extra-scientific knowledge):

> Science for sustainability can be mono-disciplinary or multidisciplinary, but it must be at least *interdisciplinarity-ready*, conducted with the broader picture of sustainability in mind, and therefore ready for integration with results from other disciplines (Spangenberg, 2011).

As a side-effect it becomes clear that, by developing and exercising inter- and trans-disciplinary sustainability research, science leaves the niche of formerly presumed value-freedom and takes on a politically relevant role in the identification of problems, in making assessments and diagnoses and in determining the range of adequate options for response: *It may be basic or applied research, but it must be purpose-bound, as opposed to the 'value-free' stance of natural sciences* (Spangenberg, 2011; see also Funtowicz, Ravetz, 1993 and the consecutive debate on *post-normal science*). Science in this sense works inevitably with evaluative premises, which influence the societal processes of assessment of sustainability and its political realization. It must therefore carefully reflect the borderline between knowledge and evaluation, in order to be able to uphold its legitimisation as a knowledge-providing societal subsystem and to retain its constitutive role as a producer of specific knowledge (Luhmann, 1990). The application of value judgements is inevitable but must not lead to the situation that science appears in the sustainability discussion in the role of a *stakeholder* among many others. In this case, science would loose its specific character and legitimisation. Specific attention is required to re-define issues of scientific independence beyond positivistic claims of value-neutrality. Experiences from the field of technology assessment with a strong need for transparently uncovering normative issues (Grunwald, 2009) could be of use also in the field of sustainability research.

Historically speaking, inter- and trans-disciplinary knowledge integration is a counter-movement compared to the self-dynamics of scientific progress. Scientific progress can over centuries be regarded as successful processes of differentiation, specialisation and fragmentation. Disciplines, sub-disciplines, sub-sub-disciplines and specialised small communities developed and stabilised themselves by more and more specialised journals, specialised languages and formalisms, conferences and university courses. Even stronger it appears that disintegration in this sense is one of the main reasons for scientific advance. Accordingly, inter- and trans-disciplinary integration works against this historic trend and, therefore, requires high and continuous effort.

Beyond the efforts to be taken there is an additional element which seems to be strange to science in its traditional understanding: the mission of trans-disciplinary research is an *extra-scientific one*, e.g. a need from *outside* science, from the political system or from society such as in the case of sustainable development. Because of that external influence trans-disciplinary integration also touches upon the issue of *scientific autonomy*. To really engage in sustainability research implies a partial renunciation of independence, in particular concerning determining the scientific agenda – sustainability research is not free in determining its own agenda but must respond to identified problems in the *real world*. Also the degree of freedom in the determination of methods and subjects could be reduced by the external diagnoses, expectations and boundary conditions. In order to be *relevant* in the sense of contributing to sustainable development in the *real world* science has to accept that its own agenda has to be *co-designed* with other actors[2].

3. The energy system as a subject to change[3]

In the light of the accelerated nuclear phase-out and the political decisions to initiate a more sustainable energy supply – including an extensive reduction of the usage of fossil energy carriers and an ambitious increase of energy efficiency in order to meet the international agreed CO_2 goals – the energy system in Germany, and certainly many other countries, will have to change radically. Today, fossil and nuclear energy carriers account for 85% of the primary energy supply. Until 2050, this share shall be reduced to a maximum of 20% in Germany, specifically to prevent major climate change and to decrease the dependence on geopolitically problematic resources.

Currently, the key to reach these ambitious goals is primarily seen in developing and implementing innovative technologies increasing the efficiency in energy conversion, transport and use, and increasing the share of renewable energy carriers. In the triangle of sustainability strategies of efficiency, consistency, and sufficiency (Huber, 1995) the focus is put clearly on efficiency and consistency while sufficiency is not addressed at all. Also social and political boundary conditions influencing the chances of reaching the efficiency and consistency goals are not debated; instead there is a strong focus on technical and economic issues only. The impression was created by policymakers and mass media that society, in particular energy consumers and the population at large would almost not *really* be affected by *Energiewende* – with the exception that society would have to *accept* new technologies and infrastructures changing landscapes, life-worlds, and the environment. New high-voltage transmission lines, onshore wind-power plants, agro-industrial biomass production for energetic purposes, geo-thermal drilling and new infrastructures for e-mobility will probably deeply influence the daily life of parts of the population. Concerns are currently been expressed that missing acceptance, e.g. in the field of transmission lines, could endanger the further transformation process. More participation frequently is regarded as appropriate means for increasing the acceptance level – which is in line with the technocratic thinking considering *Energiewende* as a more or less technological endeavor. There are high expectations that the population simply should accept those new technologies including management strategies lowering their degree of autonomy as would be the case in the so-called *demand side management*[4].

To address these complications, social sciences frequently are asked for providing mechanisms of creating acceptance. Asking for the involvement of social sciences could be seen, on the one hand, as progress, because it includes conceding that natural and engineering sciences alone will not be capable to support and enable the energy transformation. However, on the other hand it is clear that the role of creating acceptance attributed to the social sciences is at least problematic: this role is neither feasible nor does it belong to the self-understanding of social sciences as being research-oriented rather than to be a kind of public relations activity. Social sciences are able to conduct acceptance *research* but will neither be able nor willing to *create* ac-

[2] The new international research programme on sustainable development *Future Earth* will be arranged in line with the idea of co-design.

[3] The ideas presented in this Chapter refer to the common point of departure of the Helmholtz-Alliance ENERGY-TRANS. (see www.energy-tans.de).

[4] By the way, this approach also ascribes responsibility in a specific way: people rejecting particular measures are made responsible for an eventual failure of the entire *Energiewende*.

ceptance. Accordingly, this constellation would not allow for inter-disciplinary knowledge integration but would rather embed the social sciences into a technological or technocratic picture of the entire energy transformation.

However, this technology-oriented, partially technocratic picture primarily drawn by managers, politicians and some scientists is dramatically oversimplified. It suffers from shortcomings in at least two respects:

1) the assumed *mind-model* of the energy system is one-sided and under-complex. It focuses on technology, controlling and organization and regards the transformation of the energy system as a more or less technical task, involving some organizational aspects.
2) *governance* is assumed to be top-down with the political system, managers and engineers being decisive while energy consumers and the population at large including people affected are seen as passive and are expected to be adaptive to what has been decided upon in a top-down manner. Bottom-up engagement is regarded as more or less disturbing.

Of course, my picture described above is oversimplified in itself, and in reality there are many nuances and grey tones. But nevertheless, for analytical reasons it seems adequate to sharpen alternatives and to make the basic bifurcations and underlying concepts as clear as possible in order to increase clarity.

In the remainder of this section I would like to paint a different picture of the energy system and its transformation. In order to do this I will start from some more general considerations on infrastructures which are not single technologies or single artifacts but:

(a) grids of technologies forming highly interconnected technological systems. Their transformation requires high effort already because of technical and economic reasons as is easily imaginable looking at the infrastructures of transportation, water supply, telecommunication, and energy, for example.

But (b) the challenges and difficulties go far beyond the technical and economic sphere (Elzen et al., 2004; Rohracher 2008). Infrastructures shape and even dominate strongly not only economic value added chains and business models but also social processes of usage and human behavior. For example, the extremely stable availability of rather cheap electricity and gasoline all the time allows comfortable patterns of behavior which developed to an essential part of our current culture and of social life – obviously it would be very difficult to change those patterns deeply inscribed to modern lifestyles and behavior. Infrastructures are so closely interlinked with routines and patterns of social life and culture that the transformation of an infrastructure simultaneously affects those routines and patterns – and this is, due to my thesis, the really ambitious challenge in transforming infrastructures.

This observation is neither present in public debate nor in research on the energy transformation. Mostly, the impression is communicated that transformation processes should not – and more or less will not – affect end users. One example is the debate on fuels from biomass some years ago. If fuels from biomass would simply replace fuels from fossil oil, then end users would not have to change anything. Change would only affect the production chain of gasoline. And in the initial debates on German *Energiewende,* directly after the Fukushima disaster, there was an overwhelming consensus related with a hidden conviction that again there would be almost no effect on end users, even not concerning the energy price (things changed in the meantime, and the consensus is no longer that overwhelming).

Because of the extremely close relations between infrastructures and social and economic issues it seems adequate to model them as *socio-technical systems* (Ropohl, 1979). They can only fulfill their function if supply and demand are balanced, if adequate regulation and incentive mechanisms take care for stability, if the required changes can be integrated into the existing societal processes, or if new routines can be established in a legitimate way. Taking this observation seriously the energy system is not, as frequently described by engineers and managers, a system of power plants, power lines, control and steering elements, storages and cables. Far beyond being a purely technical system the energy supply infrastructure also includes elements such as regulatory mechanisms, existing or missing acceptance, business models, power constellations, user behavior, geopolitical issues, partial globalization, national policies, economic competition, and probably much more (Schippl, Grunwald, 2012).

Because of the socio-technical nature of the energy infrastructure it is not enough to replace today's dominant technologies (such as coal-fired or nuclear power stations) with renewable energy sources. The new energy carriers can only provide a reliable and socially-compatible supply if the accompanying infrastructure solutions, their management, and the demand behavior are adjusted accordingly into their social context (HGF, 2013). Energy supply and distribution technologies as well as other elements of the infrastructure are not automatically embedded but rather processes of embodiment need special attention.

Therefore, not only is technical competence necessary for the analysis and design of future (sustainable) energy infrastructures, but so are insights into organizational and societal circumstances such as political-legal framework conditions, economic boundary conditions, individual and social behavior patterns, ethical assessment criteria, participation needs, and acceptance patterns. This is the basic motivation to consider energy research, or better: research for supporting the transformation of the energy system, to be necessarily interdisciplinary, involving social and political sciences as well as humanities together with technical sciences.

Several arguments for the necessity of research to be trans-disciplinary in the field of sustainable development have already been mentioned in Section 2. In addition to those arguments I would like to make a further point. The uncertainty and incompleteness of our current knowledge about the future transformation process and its results make it impossible to pursue *Energiewende* by means of traditional planning in the sense of *rational comprehensive planning* (Camhis, 1979). The transformation to a more sustainable energy system has to be conceptualised and implemented under conditions of uncertain knowledge and of provisional assessments. *Ex ante* we cannot know for certain whether and to what extent a political measure, a technological innovation, the economic competitiveness or a new institutional arrangement will support *Energiewende*. Every complex transition process has to confront this situation and must become – in a certain sense – *experimental* (Braybrooke, Lindblom, 1963; Geels, 2012).

This diagnosis implies, first, that the hope to establish a general master-plan leading us directly to reaching the goals of the German energy transformation by simply follow the plan cannot be fulfilled because of the non-eliminable uncertainties involved. Current lamenting in politics and the mass media about the absence of a master-plan ignores this epistemologically grounded observation. It seems that society is still not ripe to cope with an open future in the sense that we today cannot know where the decisions on *Energiewende* will lead us in detail in some future.

Second, this diagnosis makes clear that there is no chance for a technocratic approach looking for a *one best solution* facing the many alternatives of developing *Energiewende* further. In traditional scientific thinking, e.g. in energy systems analysis, the energy system should be mapped to a mathematic model which then could be used for simulations and scenario-building allowing for identifying the *optimal* path into the future. However, for the same reason as above this approach is not feasible and would only lead to many and diverging pictures of the future, depending on premises and presuppositions (Grunwald, 2011).

What remains is to model the energy transformation as a collective learning process. There is no master-plan but only a more *soft* orientation towards sustainable development. This orientation does not allow for direct deduction of the adequate steps of the transformation but only can help orientating the selection of the respective next steps. By implementing these steps and monitoring their consequences new knowledge is created which then can be used to enrich the determination of the next steps, and so on. In this way the energy transformation is an open and incremental *but oriented* process preventing it from becoming arbitrary or random (this model was named *directed incrementalism*, Grunwald, 2000).

At this point the announced further argument in favor of trans-disciplinarity can be presented. All the steps of *Energiewende* mentioned are *interventions* into real-world systems rather than only options to be calculated in model worlds. They influence social life, economic relations, and political structures. Shaping interventions must not be left to science alone, even it may be interdisciplinary. Shaping interventions has, instead, to involve stakeholders, practitioners, citizens and people affected, in order to integrate their knowledge and their perspectives into the intervention process. This is necessary from the perspective of deliberative democracy as well as simply with regard to prudency. Transdisciplinary research is therefore needed as part of the overall transformation process which should be modeled as a complex interplay of observation and intervention, reflection and action, monitoring and evaluation – and thee may be further tandems of activity types which have to be brought together in transformative research (Schneidewind, 2010; WBGU, 2011) and which is necessarily inter- and trans-disciplinary.

4. The Helmholtz Alliance ENERGY-TRANS

Generally, and particularly in Germany, there has been a lot of research into the energy supply side, reaching from considerations and assessments of new energy technologies to analyses of future challenges to the grid and possible technical solutions to face those challenges. However, until now there was little research into the demand side and the contextual conditions related to energy generation, distribution and consumption. In the traditional energy system the demand side played only a minor role while the transformation to a new energy infrastructure based on increased efficiency, innovative co-production of electricity and heat and the decentralized use of renewable energy sources makes a huge difference. The novel perspective of the Helmholtz alliance (HGF, 2013) is that the energy system is not primarily viewed from the supply side, the provision of technical artifacts (machines, power stations, pipelines, control elements, etc.), but above all *from the societal demand and user side* (Rohracher, 2008). The focus is on the links between supply options and demand requirements, between services offered and social or individual requests, between performance potential and actual performance. This perspective requires clarification and categorization of the many interfaces and interrelations between social and technical aspects. The alliance (HGF, 2013):

- investigates the interface between energy supply systems and demand considering the societal and political objectives and targets and taking into account the boundary conditions under which these systems operate or will operate in the future;
- analyses the interconnections between the services provided by future energy supply systems and the service requirements by industrial or private users;
- contributes to the understanding of society's capability to adapt itself to a new energy infrastructure and the willingness of consumers to change their own behavior;
- designs promising transformation strategies and transition management processes using innovative technologies and services, including new governance models that provide participatory opportunities for stakeholders and the affected population.

In summary, the alliance aims:

a) at providing *knowledge for action* by applying an integrative research approach to the transformation of the energy system and to the governance of this process, and
b) allows for testing that knowledge to some extent, e.g. through regional modeling and related empirical research.

That means that scientifically sound knowledge shall be created, according to the familiar excellence criteria of scientific work. This knowledge will then be the point of departure for drawing consequences for decision-making and action at the different governance levels of the transformation process considered, as well as a springboard for future technology development (in the sense of Constructive Technology Assessment, Rip et al., 1995). In this sense, the entire alliance might be considered as a type of *mode 2* science (Gibbons et al., 1994) or *post-normal science* (Funtowicz, Ravetz, 1993) while parts of the research proposed are designed to be mainly disciplinary.

Different scientific disciplines and fields of research are involved: philosophy and ethics, social and political sciences, economics and psychology, energy systems analysis and foresight methodologies, sustainability research and innovation research, risk and governance research. All these disciplines and fields are working in a so to speak *lose connection* defined by the common working program. Within the common frame disciplines do follow their own strategies and methodologies to respond to the questions ahead. The quote on the *interdisciplinarity-readiness* which has already been cited above (Spangenberg, 2011, 277) reads in my words after replacing the *inter* by *trans* and two complements:

> Science for sustainability can be mono-disciplinary, inter-disciplinary or multi-disciplinary, but it must be at least *trans-disciplinarity-ready*, conducted with the broader picture of sustainability in mind, and therefore ready for integration with results from other disciplines and from outside science.

In this way, the alliance is highly inter- but not really trans-disciplinary. The research agenda has been agreed upon among the contributing researchers and disciplines without perspectives from outside science. During conducting the research a lot of exchange with policymakers, stakeholders, civil society organisations and people affected is foreseen or has already been realised. By doing this, the *transdisciplinarity-readiness* of the alliance is proven as well as improved. As a desire, however, it remains an open chance to really engage in specific transformation processes, thereby making use of the *trans-disciplinarity-ready* knowledge which has been provided so far. It seems that this could be done best in an engagement at the regional level.

5. Concluding remarks

Strategic knowledge for sustainable development consists of combinations of orientation-, prospective, explanatory, and action-guiding knowledge. The generation of this strategic knowledge is a challenge to the traditional science system. The classical structure and development of the sciences in the direction of increasing specialization has to be complemented by a new *culture* of integrative research, which crosses disciplinary borders; which treats questions of values transparently, but without contact anxieties; which is open for the integration of knowledge and perspectives from outside science; which involves social actors; and which extends from distant research and observation to concrete intervention.

While traditionally energy research is regarded as a domain of natural and engineering sciences the transformation of a *socio-technical* system requires (a) strong interdisciplinary involvement of social sciences and humanities.

Furthermore, research must (b) go even beyond inter-disciplinarity because the future and by intention more sustainable energy system must be the result of trans-disciplinary processes of co-creation and co-construction of knowledge and actions paths among researchers, decision-makers and all the other groups of actors being involved in the energy system in very different roles and at very different places.

Science provides, in view of the provisional nature and the uncertainty of sustainability-relevant knowledge, *strategic knowledge for an experimental sustainability policy*. This knowledge has, in case it should actually be implemented, influence on societal practice, which then, in its turn, becomes a subject of scientific research, the results of which, again, should enter into continuing measures (Voss et al., 2006; Grunwald, 2007). Transdisciplinary sustainability research is, therefore, no matter of simply implementing scientific knowledge, but rather of establishing a learning cycle, which comprises elements of normative premises, political stipulations, empirical analyses with regard to monitoring, and theoretical investigations. It is in itself part of an emerging culture of sustainable development (Banse et al., 2010).

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