Transitioning towards a sustainable bio-based economy: A few systemic roadblocks to overcome

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Abstract: *The process of phasing out fossil resources and replacing them by renewable resources itself does not guarantee sustainability. Key will be to learn from the mistakes of the past, avoid bottlenecks and lock-in effects and develop new ways and systems that promote genuine sustainability. Transitioning away from unsustainable structures and practises thus requires a systems level redesign of our socio-ecological regime and economic system in a way that it sustains instead of reduces the life support mechanism of earth. New interdisciplinary approaches based on the principles of nature such as biomimicry and craddle-to-craddle may be especially promising in this regard.*

Keywords: *bio-based economy, bio-energy, sustainability standards, environmental economics, ecosystem services*

Highlights

In this paper we present three important systemic roadblocks that complicate the transformation of our current unsustainable fossil-based economy towards a low carbon (bio-based) economy. These theses show that small incremental changes will not suffice to decarbonize our economy but that strategic preparation and navigation of the transition process is compulsory to allow the necessary radical changes that are needed to develop genuinely sustainable systems of the future. These roadblocks are summarized in the theses below and discussed in more detail in the discussion section.

These 1: To guarantee sustainability in a bio-based economy solutions to the trade-offs between the marketable and non-marketable services and goods of biomass resources are urgently needed. To achieve this, a more active role of multidisciplinary scientific approaches (e.g. environmental economics, ecosystem services) is required in fora and platforms of e.g. green chemistry and bio-energy.

The ongoing discussions about a bio-based economy focus predominantly on the marketable roles of biomass whereas the non-marketable goods and services of biomass (e.g. their role in the supporting and regulating ecosystem services) receive little or no attention. Design and establishment of genuinely sustainable systems of the future requires a comprehensive system approach addressing all perspectives collectively. To achieve this, recognition of the importance of biomass in sustaining life supporting ecosystem services – a fuzzy discipline in comparison to exact sciences - is crucial. A more active role of experts in the non-marketable services and goods of biomass (e.g. experts in ecosystem services, biodiversity etc) in relevant platforms and fora related to a bio-based economy is thus imperative.

These 2: New renewable technologies are not allowed to follow similar learning curves as traditional technologies since they must meet environmental/sustainability standards from the start. In the absence of effective incentives to discourage unsustainable traditional technologies, this difference might decelerate the transition towards a more sustainable society.

A striking example to illustrate this these can be found in the promotion of biofuels, and their indirect effect on the leakage of greenhouse gas emissions from land conversions (indirect land use change).

These indirect emissions overreach one of the most important advantages of biofuels in comparison to fossil fuels, namely their carbon emission reduction capacity. Concerns about these indirect effects of the promotion of biofuels have allowed extreme positions to take hold in the public debate and thereby augment the risk of polarizing and paralyzing policymakers. In the same time, indirect effects and indirect greenhouse gas emissions caused by the exploration and exploitation of fossil resources hardly receive any attention in the ongoing debate about the energy transition while the bulk of our energy demand (80-90%) in 2020 will still be nurtured by these fossil reserves. Such a biased point of view disturbs a level playing field for the renewable energy sector because of its decelerating effect on the commercialization of renewable resources. To promote sustainability, the system as a whole should be taken into regard.

These 3: The common practice of simplifying complex problems might complicate transitioning contemporary society to a more sustainable future. Generally, such simplifications result in simplified, silver bullet solutions. Silver bullet solutions are very attractive for the media which is exemplified in the way the media praise and blame new technologies or approaches. Such a strategy however, may create false expectations that impact public acceptance, confidence and willingness to change.

The general public will play a vital role in the transition towards a bio-based economy. Next to a collective sense of urgency, a collective sense of willingness to accept and adopt more sustainable practices is of vital importance. The tendency of media and industry to hype silver bullet technologies does often not meet reality and therefore reduces public confidence and acceptance thereby decelerating the phasing out of unsustainable practices. Next to rethinking the way we think about things and remaking the way we make things, we should also revise the way we communicate about things.

Discussion

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To guarantee sustainability in the transition towards a bio-based economy, a more active role of biologists and experts in ecosystem services/biodiversity is urgently needed.

Just after the 15th United Nations Climate Change Conference (COP15) in Copenhagen, there is no need to enlighten the dominant role of the topic of climate change in the current international political, scientific, business and society scenes. Reducing greenhouse gas emissions is without doubt one of the major key challenges for the decades to come. Striving towards low carbon societies therefore is high on the global agenda and the progression towards renewable, bio-based resources is steadily emerging. This process is generally referred to as the transition towards a bio-based economy. In contrast to fossil resources, bio-based resources play numerous functions that are not marketable in our current economic system (MEA, 2005). This causes strains between the marketable biomass services/goods and non-marketable services/goods (usually regulatory, supporting and cultural ecosystem services; see Cowling et al., 2008; Fisher et al., 2009).

In a world with a growing demand for energy and food, society (e.g. agriculture) relies profoundly on these regulatory and supporting ecosystem services while climate change reduces average land productivity and extreme weather events increase vulnerability (IPCC, 2007). To meet the future demand for food and energy society can either expand the area of agricultural land (including plantations for bio-energy) to increase gross biomass production or increase yields on existing agricultural land (RTB report, 2009). Both strategies will have impacts on the natural environment: expanding agricultural land will lead to losses in vital ecosystem and biodiversity services and increasing yields might re-allocate water resources and require increased use of fertilizers and pesticides (MEA, 2005). Such activities are likely to elevate greenhouse gas emissions due to the removal of terrestrial carbon sinks and increases in fossil fuel use and nitrogen fertilizers. In addition, regulatory ecosystem services (such as climate control, water cycling, flood protection, carbon and waste sinks) and supporting ecosystem services (such as soil formation, pollination, nutrient cycling) which are of vital importance to safeguard agricultural production, might be undermined (MEA, 2005). Hence policies and practices of resource management need to take into account issues beyond just agricultural production because the capacity to deliver from the system what is required and to be able to do this consistently over generations requires a continuity of agroecosystems (e.g. Costanza et al., 2000; RTB report, 2009).

Next to the trade-off between the marketable and non-marketable goods and services of biomass, the multifunctionality of this renewable resource complicates management strategies, especially in the light of climate change adaptation and mitigation. In one respect, biomass can be used as a bio-based resource that can replace fossil-based resources. It is already clear that biomass resources will be an important part of future energy systems and as renewable materials and fibers (see WBGU report, 2008). The application of biomass as an energy carrier is growing rapidly. Examples include biofuels for transport and stationary applications of combined heat and power. It is also expected that biomass will play an important role in future electricity grids since it can be stored and used to provide control energy in power grids to stabilize solar and wind electricity supplies (WBGU report, 2008). Examples of application of biomass fibers and materials for instance can be found in green chemistry (e.g. bioplastics) and in the building sector where more and more renewable construction materials are used (e.g. bio-insulation such as wood wool).

Conversely, biomass plays an important role in the biological systems to store carbon and reduce emissions and thus has a large potential as a tool for mitigation (e.g. CC synthesis report, 2009). Since deforestation in tropical countries results in higher greenhouse gas emissions than the global transport sector, a mechanism to financially reward developing countries that actively reduce deforestation rates has been proposed in 2007. Since then, this REDD-mechanism (reduced emissions from deforestation and forest degradation) has been one of the most important topics in the international climate change negotiations (CC synthesis report, 2009). But biomass is also essential in respect of adaptation to climate change: in the form of land cover does biomass prevent soil erosion (e.g. mud floods) while providing protection to extreme weather events (floods, storms, droughts; MEA, 2005). As necessary and effective as each of the above mentioned approaches are individually, it is obvious that integration of biomass functions and management activities and strategies in a systems framework is paramount to avoid deleterious outcomes and to capture the synergies that enhance sustainability throughout a bio-based economy.

Yet at the moment, the focus of the bio-based debates (e.g. about sustainability standards for biofuels and bio-energy) lies predominantly on the strains between the different marketable biomass services (food versus fuel debate) and on their effectiveness in reducing greenhouse gas emissions. This incomplete view has polarized the public discussions and consequently influences both consumer behaviour and policy makers. In order to come to a pluriform debate, the perspective of the non-marketable functions and goods of biomass resources needs to be acknowledged and integrated. To achieve this, biologists, experts in ecosystem services and the like urgently need to participate and take active roles in the existing platforms and fora that are related to a bio-based economy. In other words, integration of knowledge and expertise of biological sciences such as ecosystem functioning and environmental economics in the energy, agriculture and chemistry sector needs to be enhanced and increased in the short term to guarantee genuinely sustainable bio-based systems of the future. This implies a more pro-active participation of biological science experts in disciplines other than their own.

These 2: New renewable technologies are not allowed to follow similar learning curves as traditional technologies since they must meet environmental/sustainability standards from the start. In the absence of effective incentives to discourage unsustainable traditional technologies, this difference might decelerate the transition towards a more sustainable society.

The most striking example of this these can be found in the ongoing energy transition debate which focuses on setting though sustainability criteria related to land use for the production of renewable energy resources while leaving fossil resource exploration and exploitation untouched. This fact will complicate the transition away of fossil resources.

In order to reduce greenhouse gas emissions the EU adopted in 2009 the Renewable Energy Directive (2009/28/EC) which specifies an increase of renewable energy to 20% by 2020 and an increase of renewable transport fuels (biofuels and/or electricity) to 10% by 2020 in each member state. Because of the societal debate that was evoked when evidence came to light about potential negative impacts of the promotion of biofuels on food prices and land conversions, the European Commission adopted in their Directive sustainability criteria for the production of renewable feedstocks for biofuels. These sustainability problems of biofuels relate mostly to the negative direct and indirect effects associated with land use change (LUC) and the resulting greenhouse gas emissions (due to burning, decomposing or oxidizing carbon) that are induced by the conversion of land since such emissions are considered to be one of the most important anthropogenic greenhouse gas sources (Ravindranath et al., 2009). In the same time LUC also directly or indirectly affects the life support mechanisms and services of our natural landscape by influencing ecosystem services and biodiversity. These sustainability requirements described in the Directive have triggered a sharply polarized debate among researchers, policy makers and the general public about the benefits of biofuels (e.g. Tilman et al., 2009).

However, exploration and exploitation of fossil resources can also induce LUC (especially in the case of unconventional heavy oil resources) and pose direct and indirect threats to biodiversity and ecosystem services when the reserves are located in fragile or biodiverse areas (Finer et al., 2008; Suarez et al,. 2009; Gorissen et al., in press). In other words, LUC and associated indirect sustainability problems apply to the fossil energy sector as well as to the bio-energy sector. This fact nonetheless hardly receives any attention in the ongoing debate about LUC while the bulk of our energy demand (80-90%) in 2020 will still be nurtured by these fossil reserves. From this perspective, it makes sense to expand our view of promoting the most beneficial biofuels only (from an environmental and socio-economic point of view; see Tilman et al., 2009), to the non-renewable fuels as well (Gorissen et al., in press). This way, we can ensure that only those non-renewable (e.g. fossil) resources that entail the least harmful effects on environmental and socio-economical conditions are eligible for future exploitation. In other words, smart resource management is not only about promoting the most beneficial biofuels but also about not reclaiming those fossil resources that are located in ecologically important and fragile environments.

From the perspective of a transition towards a sustainable energy sector, implying sustainability criteria on only 10-20% of the energy resources and only on renewable resources is questionable in strategic terms. Concerns about these indirect effects of the promotion of biofuels has allowed extreme positions to take hold in the public debate. Such a confrontational approach based upon extreme statements is seldom based on a systems perspective (which allows a more balanced and complete view) and thus augments the risk of polarizing and paralyzing policymakers (see Costanza et al., 2000), which in turn influences the transition process to a more sustainable fuel supply. In a worst case scenario this may lead to a locked-in effect or may distort a level playing field for the renewable sector while the fossil sector is not affected and rather benefits from this biased point of view because of its decelerating effect on commercialising alternative resources. Thus, if the goal of the overall transition process is to come to a clean, reliable, affordable and sustainable energy supply, the focus should be on the energy system as a whole.

Wagner and Llerena (2008) conclude that relevant knowledge needed to achieve sustainability goals (e.g. in biofuel production) may not be as readily available as policy makers assume. This implies that strong incentives are crucial and furthermore that policy makers need to take up an active role in the creation and diffusion of such knowledge. Wagner describes this as "a co-evolving system of regulatory demands and knowledge needed to meet these demands in which both aspects need to be in a balance for the system to function". In addition, development and design of strategical and tactical management approaches that deal with differences in learning curves and allow a fair ranking of options outweighing the costs and benefits on a economic and ecologic scale is needed to overcome such problems. This is a prerequisite in selecting the best pathway to a sustainable endpoint. A successful approach would therefore combine an encouraging policy approach to stimulate sustainability of new technologies or practices with a discouraging approach that promotes the transition away from the unsustainable technologies or practices. In the described example above, this would advocate extending the sustainability criteria such as the prohibition of biomass production on land with high carbon stocks (e.g. peatlands) or on land previously covered by primary forests (e.g. tropical forest) to fossil exploitation as well. Furthermore, policy should be flexible enough to be able to incorporate new knowledge (e.g. insights on biodiversity preservation) and take up an active role in knowledge creation and diffusion (co-evolution).

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The tendency of media and industry to hype 'silver bullet' technologies does often not meet reality and therefore reduces public confidence and acceptance thereby decelerating the phasing out of unsustainable practices. The road to sustainability is in need of a major revision of the way we communicate about things.

The problems facing our society today all show that our appreciation of interconnections, feedback and spill-over effects, indirect effects, trade-offs etc. between key elements constituting our societal and natural system hitherto received insufficient recognition. Lack of appreciation of such interactions has led to numerous examples of problem shifting in the past. Simplification of complex problems gain popularity because they fit in prevalent worldviews, suggest simple solutions and may serve the interests of critical groups (Lambin et al., 2001). Such practices of simplification are also dominant in the communication of research results to the general public. Scientific breakthroughs are often depicted as silver bullet solutions without relevant preconditions and without an integral perspective.

A recent example can be found in the energy domain. Biofuels came into the picture in the quest to find solutions to tackle the carbon intensity of our present transport system. To many, biofuels provided the ultimate alternative to replace fossil fuels and to safeguard energy security. Since then, it became obvious that a switch from fossil to biofuels was not so simple. Issues of compatibility and perverse side effects such as increasing food prices and the clearing of forests for biofuel feedstock production shed a negative light on this alternative fuel type. Such controversial issues are very popular in the media and it is then not surprising that biofuels degraded from the 'silver bullet solution' a decade ago to the 'global headache' at present. Since biofuels are no longer the ultimate answer to decarbonise transport, the new silver bullet solution has been put forward in the form of electric cars. Without doubt, in the coming years electric cars will follow the same pathway that biofuels did as more and more, limitations, shortcomings and unforeseen sustainability issues associated with electric transport will come to light and find their way to the media.

Our society's need for silver bullet solutions to tackle problems will in the real world only result in disappointment and lack of confidence in research and development. It will create false expectations with the general public since no approach or technology is optimal from the start or is free of sustainability problems. Extreme statements (in the form of silver bullet solutions) as such and the traditional confrontational approach of the media is thus seldom based on a systems perspective which would allow a more balanced and complete view. This thus augments the risk of polarizing and paralyzing policymakers, and consumers in general. It is clear that the above entails a significant impact on the transition process to a more sustainable transport system as a whole and in a worst case scenario might even lead to a locked-in effect. In other words, the consequences related to simplifications might negatively influence public support and consumer behaviour, which in turn might influence investors and policy makers.

Furthermore, another example to illustrate how simplifications can slow down the transition towards more sustainable systems can be found in the problem of LUC that has been described above. Fundamental differences in goals, interests, stakes and strategies complicate attempts to find shared solutions and often prevent cooperation and consensus (Loorbach, 2007) resulting in the fact that a systems perspective about LUC remains absent from the ongoing debates. Assigning negative consequences of LUC to only a part of a sector (bio-energy) will therefore disturb a level playing field for the renewable energy sector thereby affecting the transition away of fossil resources. The non-renewable (fossil) energy sector will not be affected and rather will benefit from such an incomplete and biased point of view because of its decelerating effect on the commercialization of renewable resources. This might result in a prolongation of our dependency on fossil resources, increasing the pressure and incentive to explore and exploit both conventional and unconventional fossil reserves. So far little is known about the negative consequences of LUC (in terms of indirect GHG emissions) associated with fossil exploration and exploitation. Good practice consequently would advocate researching these as well, especially in the case of exploitation of unconventional oil resources like heavy oil and tar sands and methane emissions caused by deep see oil drilling (Gorissen et al., in press).

In addition, good practice requires impartial and objective reporting of findings in a real world context. It is thus no surprise that problems of sustainability actually originate from patterns of thinking and acting that have rooted deeply within existing structures and institutions. Ultimately this means that they cannot be solved by traditional means and approaches (Loorbach, 2007). Obviously, solely relying on incremental changes will no longer suffice: we need to rethink the way we think about things (De Bono, 2009), remake the way we make things (Mc Donough and Braungart, 2002), revise the way we govern things (Chapin et al., 2009) and revisit the way we communicate about things. The necessary radical changes towards genuinely sustainable systems imply a strong orientation towards system thinking and system innovation (see Tukker et al., 2008). This consequently implies that our information transfer regime (sender: e.g. by the media) should be revised in a way that information will always be approached from a systems perspective and provided in the appropriate context to receivers.

Synthesis

The process of phasing out fossil resources and replacing them by renewable resources itself does not guarantee sustainability. The transition towards a bio-based economy however provides a unique opportunity to reform current systems and practices for the better. Key will be to learn from the mistakes of the past, avoid bottlenecks and lock-in effects and develop new ways and systems that promote genuine sustainability. In other words, transitioning away from unsustainable structures and practises requires a systems level redesign of our socio-ecological regime and economic system (Beddoe et al., 2009) in a way that it sustains instead of reduces the life support mechanism of earth. It also requires new institutional and organisational arrangements interlinking a range of topics and policies previously addressed independently such as economy, ecosystem services, energy, climate mitigation and adaptation, agriculture, land use and management, natural resources, environment, biodiversity and so on. The example of bio-energy shows that transdisciplinarity in practice is more complicated than in theory. A transdisciplinary framework should thus not only be comprised by the combined viewpoints of specialists of various disciplines but also by the viewpoints of generalists originating from multiple backgrounds and experiences. In addition, a special focus to issues of social embedding, change and transition management and evolutionary concepts and processes will be compulsory. The societal transformation needed to decarbonise our economy thus presents us both with challenges and opportunities. Seizing new opportunities, overcoming roadblocks, reducing inertia in social and economic systems and avoiding lock-in of unsustainable practices, structures and infrastructures need to be pursued concurrently. Visionary approaches that rethink and reorient our relationship with the planetary environment need to be developed so that instead of exploiting our natural environment, society should work together with nature to promote resilience, adaptability and productivity of the natural and man-made landscape. New interdisciplinary approaches based on the principles of nature such as biomimicry and craddle-to-craddle may be especially promising in this regard.

References

Beddoe, R., Costanza, R., Farley, J., Garza, E., Kent, J., Kubiszewski, I., Martinez, L.; McCowen, T., Murphy, K., Myers, N., Ogden, Z.; Stapleton, K. and J. Woodward (2009) Overcoming systemic roadbloaks to sustainability: The evolutionary redesign of worldviews, institutions and technologies. *PNAS* 106: 2483-2489.

Chapin, F.S, Carpenter, S.R., Kofinas, G.P., Folke, C., Abel, N., Clark, W.C., Olsson, P., Stafford Smith, D.M., Walker, B., Young, O.R., Berkes, F., Biggs, R., Grove, J.M., Naylor, R.L., Pinkerton, E.; Steffen, W. and F.J. Swanson (2009) Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends in Ecology and Evolution* 25: 241-249.

Climate change. Global risks, challenges and decisions (CC synthesis report 2009) International alliance of research universities. Denmark.

Costanza, R., Daly, H., Folke, K., Hawken, P., Holling, C.S., McMichael, A.J., Pimentel, D. and D. Rapport (2000) Managing our environmental portfolio. *Bioscience* 50: 149-155.

Cowling, R.M., Egoh, B., Knight, A.T., O'Farrell, P.J., Reyers, B., Rouget'll, M., Roux, D.J., Welz, A. and A. Wilhelm-Rechman (2008) An operational model for mainstreaming ecosystem services for implementation. *Proceedings of the National Academy of Sciences of the United States of America* 2008,105(28): 9483-9488.

De Bono, E. (2009) Think!: Before it's Too Late: Twenty Three Reasons Why World Thinking is So Poor. Vermillion, Ireland.

Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. European Commission (2009) Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF

EC 2008. The economics of ecosystems and biodiversity (TEEB), Interim report, European Communities. Available at http://www.teebweb.org/InformationMaterial/TEEBInterimReport/tabid/1278/language/en-US/Default.aspx

Finer, M.; Jenkins, C. N.; Pimm, S. L.; Keane, B. And C. Ross (2008) Oil and Gas projects in the Western Amazon: Threats to wilderness, biodiversity and indigenous peoples. *PlosOne* 3, e2932.

Fisher, B., Turner, R. K. and P. Morling (2009) Defining and classifying ecosystem services for decision making. *Ecological Economics* 68(3): 643-653.

Gorissen, L., Buytaert V., Cuypers, D., Dauwe, T. and L. Pelkmans (2010) Why the debate about Land Use Change should not only focus on biofuels. *Environmental Science and Technology* In press.

IPCC (2007*) Climate change 2007*. Synthesis report. Available at http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm

Lambin, E. F., Turner B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O. T., Dirzo, R., Fischer, G., Folke, C., George, P.S.; Homewood, K., Imbernon, J., Leemans, R., Li, X.B.; Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skanes, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T.A., Vogel, C. and J.C. XU (2001) The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11: 261-269.

Loorbach, D. (2007) *Transition Management, New mode of governance for sustainable development.* PhD dissertation, Utrecht, the Netherlands.

McDonough, W. and Braungart, M. (2002) *Cradle to cradle. Remaking the way we make things*. North Point Press, New York, USA, 193pp. ISBN 0865475873.

MEA - Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-being: Synthesis.* Washington, DC., Island Press.

Ravindranath, N.H., R, Fargione, J., Canadell, J.G., Berndes, G., Woods, J., Watson, H. and J. Sathaye (2009) Greenhouse Gas Implications of Land Use Change and Land Conversion to Biofuel Crops. In *Biofuels: Environmental consequences and interactions with changing land use*. Howarth R. G., Bringezu S. (Ed) SCOPE Island Press, New York, pp. 111-125.

RTB report - Reaping the benefits (2009) Science and the sustainable intensification of global agriculture. The Royal Society.

Suarez, E., Morales, M., Cueva, R., Utreras Bucheli, V., Zapata-Rios, G., Toral, E., Torres, J., Prado, W., Vargas and J. Ollalla (2009) Oil industry, wild meat trade and roads: indirect effects of oil extraction activities in a protected area in north-eastern Ecuador. *Animal Conservation* 12: 364-373.

Tilman, D., Socolow, R., Foley, J. A., Hill, J., Larson, E., Lynd, L., Pacala, S., Reilly, J. Searchinger, T., Somerville, C. and R. Williams (2009) Beneficial biofuels – The food, Energy and Environment Trilemma. *Science* 325: 270-271.

Tukker, A., Charter, M., Vezzoli C., Sto E. and M. M. Andersen (2008) System innovation for sustainability. Perspectives on radical changes to sustainable consumption and production. Greeleaf Publishing, Sheffield, UK.

Wagner, M. and P. Llerena (2008) *Drivers for sustainability related innovation: a Qualitative analysis of renewable resources, industrial products and travel services*. Presentation held at Dime International Conference on Innovation, Sustainability and Policy, GREThA, University Montesquieu, Bordeaux, France, 11-13 sep 2008.

WBGU report (2009) *The world in transition*. Future bio-energy systems and sustainable land use. Berlin.