A Conceptual Systemic Framework Proposal for Sustainable Technology Development: Incorporating Future Studies within a Co-Evolutionary Approach

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Abstract

This article explores the role of future studies in developing sustainable technologies within a co-evolutionary context. In the first section it clarifies briefly the definition of sustainable development, complexity and co-evolution, in order to establish the frame within which the theoretical exploration will be carried out. The second section provides information about characteristics of sustainable technology development, which requires a radical shift from the current technological paradigm. Other types of innovations in institutional, social and organisational domains, which co-exist with or precede technological innovations, and influence of these on sustainable technology development, are clarified also in this section. The third section reveals the relationship between technology development and future studies. This relationship is projected onto sustainable technology development and the need for radical innovations. Foresighting-backcasting approach is presented as a meta-tool to facilitate the co-evolutionary innovation by allowing a non-reductionist systems approach possible towards development of sustainable technologies. It is concluded that, within the co-evolutionary innovation framework, planning for governance and policy development should have the longest time span and largest operational context in order to link all types of innovations to each other and render radical technological change possible.

Keywords

sustainable technology, sustainable innovation, co-evolutionary innovation, future studies

1. Introduction

1.1. Basic Definition and Brief Clarification

The definition of sustainable development is "meeting the needs of the present without compromising the future generations' ability to meet their own needs" (WCED, 1987, p. 43). As seen, there is no explicit reference to the environment or to the economy, but the full emphasis is on society. Therefore, the conceptual priority of sustainable development is sustaining the society and societal functions through equal distribution of all values at both intergenerational and intragenerational levels. Despite this conceptual priority, the irreversible hierarchical interdependencies dictate the environment to be the operational priority (Figure 1) since both society and economy are dependent on the environment as the provider of resources and services necessary to live and to produce.

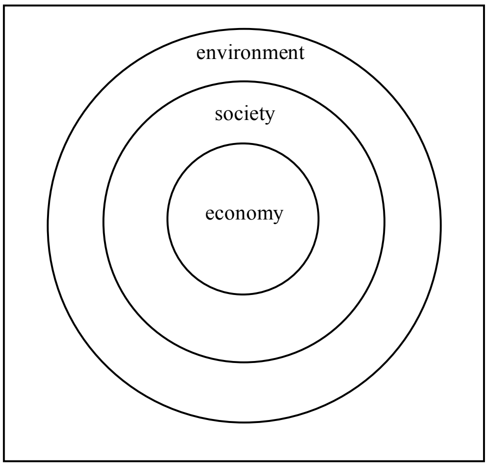

Figure 1. Operational priority of sustainable development

Even though the length of time frame to be used when planning for sustainability is still being debated, the concept intrinsically requires a long-term future orientation. According to the operational context, the long-term coverage should change or, in other words, as the operational context widens, the length of planning should extend in order to cover subsumed operational contexts and connect them, both spatially and temporally.

1.2. Complexity and Co-evolution

When the sub-components of each component and their interrelationships are taken into consideration, it is realised that both the global ecological, economic, and social meta-system and related sub-systems are complex systems. Even though the meta-system of global ecological, economic, and social relationships can be analysed in smaller scales by defining boundaries, any attempt to provide sustainability will be meaningless if this analysis is carried out by not taking interdependencies into account. Linstone (1999) attracts attention to the general illusion or misassumption that we can break complex systems into parts and study these parts in isolation. He calls this as "a crucial assumption of reductionism" (p.15) and points to the fact that such implied linearity is very uncharacteristic to complex systems.

All three components of the meta-system (i.e. environment, economy, society) and most of the sub-systems of these components (e.g. evolutionary processes, market operations, individual animals, companies, etc.) are classified under a special category of complex systems, terminologically known as complex adaptive systems. The distinguishing feature of this type of complex systems is that "they interact with their environment and change in response to a change" (Clayton & Radcliffe, 1996, p.23), that is, they co-evolve. Co-evolution is a term first emerged in the area of evolutionary biology. Then the scope was broadened to cover interactions between two evolving systems including social and ecological systems (Norgaard, 1984, 1995).

Faber, Jorna, and Van Engelen (2005), in their study to determine conceptual foundations conclude that both theoretical (definitions) and practical (operationalisations) contributions to the concept of sustainability evolved from being static/absolute to dynamic/relative. The static conceptualisation assumes no change over time within the subject artefact itself and between other artefacts in its environment. All assessments are carried out with the assumption that our scientific knowledge is complete and by taking present socio-cultural values, technological limitations and resource limits into consideration. Whereas the dynamic conceptualisation of sustainability, realistically, assumes both internal and external change will occur. Hjorth and Bagheri (2006) define sustainability as a "moving target" (p. 76), which is continuously improving as a result of our improving understanding regarding the system. This dynamic approach gives us the opportunity to adapt our goals as we have new findings and/or if there is a change in conditions.

Co-evolutionary (adaptive) change within the wider context of sustainable development does not happen naturally but rather, is aimed at both individual and collective levels by system components in accordance with changing system conditions.

2. Technology Development for Sustainability

2.1. The Need for Radical Innovation

The requirement for substantial dematerialization of production and consumption (Schmidt-Bleek, 1994), and the needed decreases in greenhouse gas emissions (Rennings, 2000), are not likely to happen through current technological path and "Solutions are needed that break existing trends in current development processes." (Weaver, Jansen, van Grootveld, van Spiegel, & Vergragt, 2000, p.44). Also, using current production systems as a starting point carries the risk of providing only incremental improvements and introduction of new and more sustainable systems is delayed or prevented (Andersson, Eide, Lundqvist & Mattson, 1998). Therefore, what we should aim for is path-breaking in current technologies, or, as defined by Dosi (1982), a breakthrough shift from the current 'technological paradigm' towards a new one.

2.2. The Extent of Innovation: A Co-evolutionary Frame

Kemp (1994) points that the core technological framework shared by the entire community of technological and economic actors is an important characteristic of a technological paradigm. He argues that development of radical technologies is a long-term process requiring special skills, infrastructure, fundamental change in production and how people live their lives. He also emphasises the role of policy makers in inducing complex technological systems due to the interrelated necessary change by pointing out governments' role and responsibility in knowledge generation and skill development through science and technology, and education policies. Bell (2005) states that government itself will need to innovate in order to realise the opportunity to leverage constructive change in business transition.

Rennings (2000) and Cleff and Rennings (1999) state that regulatory framework is a key determinant for environmental innovations by referring back to empirical studies of Green, McMeekin and Irwin (1994), Porter and van der Linde (1995) and Kemp (1997). They define this peculiarity as "regulatory push/pull effect" (Rennings, 2000, p. 326; Cleff & Rennings, 1999, p. 192). Rennings (2000) state that specific regulatory support is needed since environmental innovations are generally not self-enforcing and factors of technology-push and market-pull alone are not strong enough. When considering conditions of technological breakthroughs towards sustainability, all relevant mechanisms and agents should be considered within a co-evolutionary systems context where governance being the meta-mechanism overlooking and linking all other relevant mechanisms and agents to regulate interactions (Figure 2) as they co-evolve.

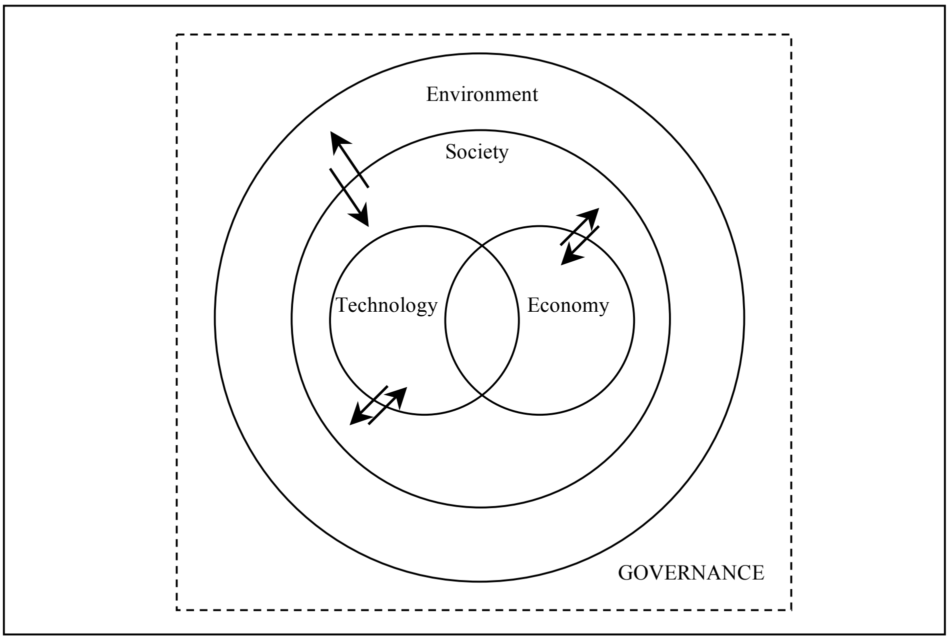

Figure 2. Model for governance

Weaver et.al. (2000) argue that, along with breaking existing trends in technology, a stronger focus on long-term issues and exploring what structural, social and cultural changes are necessary is required. Since, as Freeman (1992) states, "Successful action depends on a combination of advances in scientific understanding, appropriate political programmes, social reforms and other institutional changes, as well as on the scale and direction of new investment. Organisational and social innovations would always have to accompany any technical innovations and some would have to come first" (p. 124). Within the general hierarchy mentioned above, once triggered and realised, technological innovations will influence change in institutional and social structures as well as organisational culture and vision on a continuous basis. The question to be answered in the following section is how to influence this innovation chain towards the needed breakthrough.

3. Incorporating Future Studies

3.1. The Relevance with Sustainable Technology Development

Technology development is an iterative and reflexive process, requiring accumulated knowledge and generation of new knowledge combined with utilisation of both natural and human capital. Technology transforms nature's assets into products through engineering input. For sustainable technology development, the problem at stake, with reference to previous sections, can be summarised as follows:

- Sustainability intrinsically demands *long-term planning* (Sec. 1.1), because the needed change is hard to accomplish within a short-time frame and due to the large extent of complexity at meta-systemic level;
- Both the meta-system and sub-systems demonstrate *complexity* (Sec. 1.2), which cannot be reduced to linearity;
- It requires a *co-evolutionary approach* (Sec. 1.2) to understand the effects of interactions taking place both within the meta-system, sub-systems and in between all and in order to be able to influence change towards the desired path;
- The concept is *dynamic* (Sec. 1.2), therefore sustainability requirements and characteristics change over time both due to new information/knowledge gathered and change taking place both at meta-systemic and sub-systemic level; and
- It requires *radical innovations* at technological level (Sec. 2.1) which are influenced by other types of innovations at institutional/social and organisational level.

These stated characteristics are related to each other. They are, indeed, different facets of the same problem, which is complex and non-reducible in itself. The approach to solve it should be able to conceive the meta-system over a long-term.

Therefore planning for sustainable technology development should:

- Have a *long-term* coverage;
- Be able to address *complexity*;
- Be able to deal with *co-evolutionary change* both as a result and as a cause;
- Should allow continuous feedback, reassessment and adjustment to cope with *dynamic* characteristics and changing requirements of sustainability concept; and
- Provide creative vision to guide the innovation path towards *radical change*.

Future orientation is intrinsic to and a vital element of technology development as well as planning for sustainability. Therefore, incorporating future studies into engineering theory and practice within the context of sustainable development can provide a fruitful ground to plant the seeds of sustainable technology development. Figure 3 shows the theoretical domain of sustainable technology development where it lies at the intersection of engineering, future studies and sustainable development.

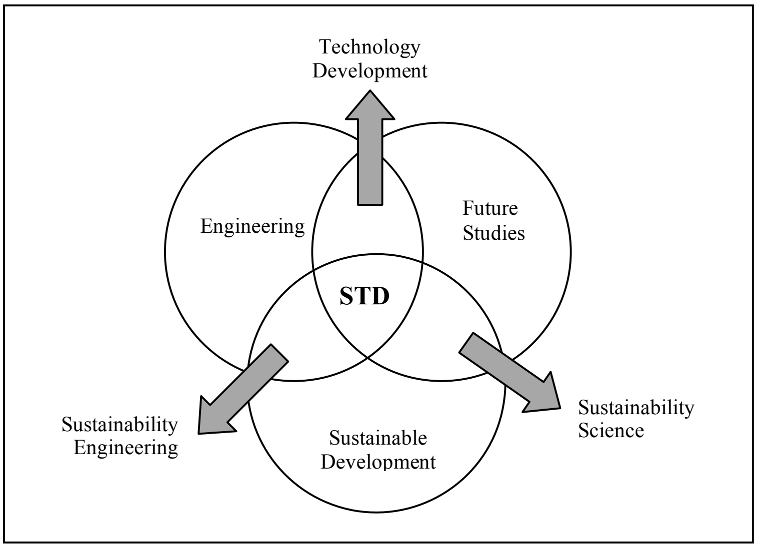

Figure 3. The domain of sustainable technology development.

Eleonora Masini (2006), in her article "Rethinking Future Studies", where she explores historical roots and present role of the discipline, asks the question:

> With time, it became apparent that foresight was important not only in order to know where one was going and how, but also to choose where one *wanted* to go. That is, by identifying futures that were possible and perhaps the most probable, futurists could progress to think about desirable futures. But 'desirable' on what basis? (p. 1159)

The answer to this question for our case is 'on the basis of sustainable development'. Therefore the domain where sustainable technology development lies represent innovation within the ethical ground of sustainable development's conceptual priority (i.e. societal equity, now and in the future) and within the constraints (and opportunities) of its operational priority (i.e. environment).

3.2. Foresighting-Backcasting as a Meta-Tool

Slaughter (1998a) states that the future does exist but cannot be predicted, whereas it can be understood, mapped, and created. So, how can we make use of future studies as a strategic planning tool to achieve a sustainable future? What does tomorrow and fifty years or more to come differ in this planning? What approaches of future studies are suitable for this task?

When the needed radical change is considered, conventional planning methods such as forecasting, which is basically an extrapolation of prevailing trends, remains insufficient (Dreborg, 1996; Höjer & Mattsson, 2000; Wehrmeyer, Clayton & Lum, 2002). Höjer & Mattsson (2000) argue that forecasts can act as an alarm to inform that the prolonging trend will lead us to an undesired future state, but have nothing beyond to offer as a planning tool when radical change is needed. These alarm bells have long been ringing with the demographic forecasts about world population reflected on future material and energy demands, which are impossible to meet with present technologies and social trends. As Slaughter (1998b) argues, creating images of future through 'speculative imagination' can feed our capacities for speculation, imagination and social innovation. This image creation through scenario building is referred as foresighting. Wehrmeyer, Clayton and Lum (2002) state the main applications of foresighting as: 1) to improve long-term decision making; 2) to guide technology choices; 3) to generate alternative trajectories for future developments; 4) to improve preparedness for emergencies and contingencies; and 5) to motive change. The foresighting process involves three phases:

- Working with groups both inside and outside the institutionalised planning processes to identify possible future scenarios;
- Identifying, comparing and evaluating a range of possible future options;
- Backcasting (Wehrmeyer, Clayton & Lum, 2002, p. 29).

Backcasting is not a brand-new concept in planning for the future. It has been used in numerous applications from policy making to sustainable technology development mainly in European countries. For detailed historical development and a summary of past applications see Quist and Vergragt (2004). Backcasting can be defined basically as planning backwards from a desired future state that is the foresighted scenario. Dreborg (1996) states that backcasting is useful when the problem to be studied is complex, affecting many sectors and levels of society, when there is a need for major change since dominant trends are part of the problem and, when the time horizon is long enough to allow considerable scope for deliberate choice. While forecasting is an extrapolation of the present towards an unknown state in the long-term future, backcasting is an interpolation towards present from an already envisioned future state (Figure 4).

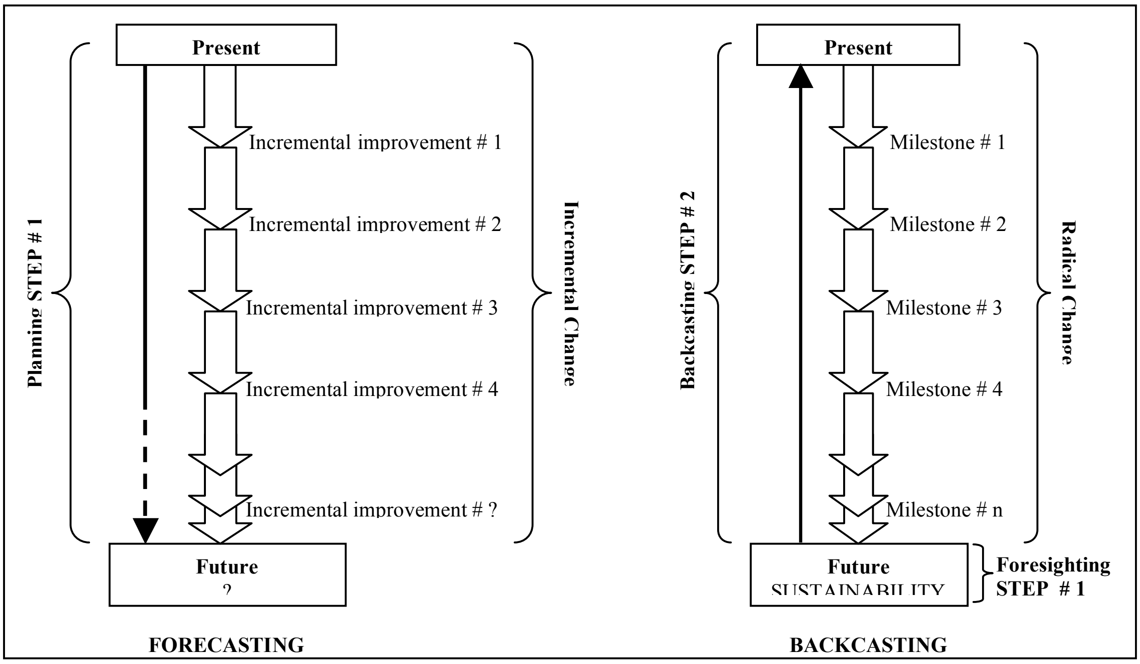

Figure 4. Forecasting versus Foresighting-Backcasting

3.3. The Conceptual Co-evolutionary Framework

Concluding from the previous section, foresighting-backcasting gives us the opportunity to address complex issues within a co-evolutionary systems context and over a long-term, as being a normative (Dreborg, 1996) as well as an analytical and critical (Höjer & Mattsson 2000) approach, and by allowing participation of many stakeholders. The approach is suitable to deal with overall complexity of the meta-system and sub-systems covered through scenario development, which informs about interrelationships, as an intrinsic feature. The iterative nature of the approach allows integration of necessary dynamism through monitoring, assessment and adjustment of milestones during implementation if new knowledge is acquired. Therefore, the foresighting-backcasting approach can be used to deal with interrelated aspects of social, technological, organisational and institutional changes required for sustainable technology development. The ideal case would be carrying out the exercise on different levels of meta-system concurrently as a means to develop an overall, non-reductionist strategy, components of which will inform each other.

Referring back to Figure 2, to the model for governance given in Section 2.2, a foresighting-backcasting exercise should focus firstly on governance. This should have the longest time span and largest operational context covered in order to influence primarily institutional, secondarily social and organisational, and finally technological innovations under a policy development framework. This exercise will intrinsically be able to inform smaller scale, shorter-term foresighting-backcasting exercises and influence the necessary institutional/social, organisational and technological innovations as shown in Figure 5. There will be feedback paths established from smaller-scale, shorter-term exercises informing both each other and policy development as the implementation progresses.

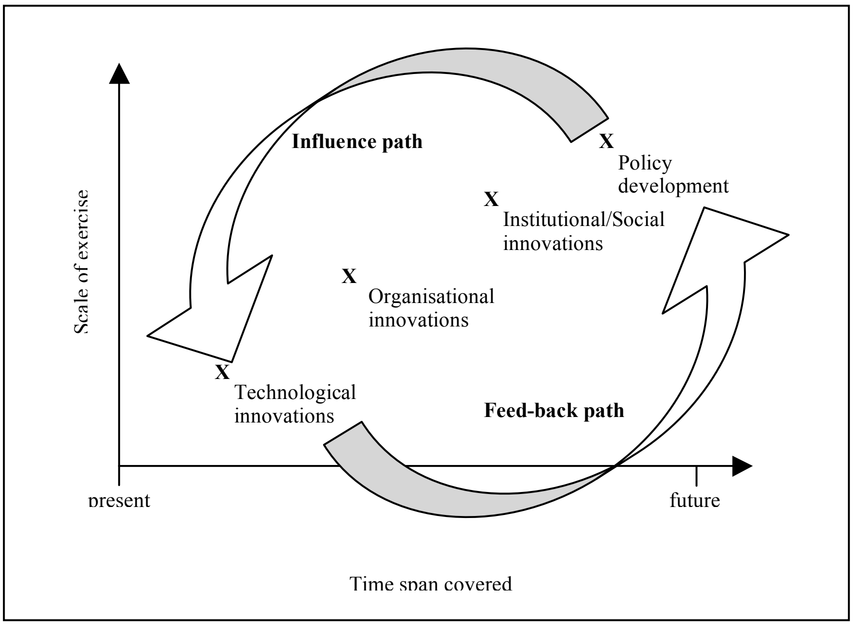

Figure 5. Time Span Covered versus Scale of Foresighting-Backcasting Exercise

This co-evolutionary innovation framework, taking into account the operational priority of sustainable development, should focus on development of an environmental policy as a core policy development framework. All other policies in other areas should be referenced to this framework.

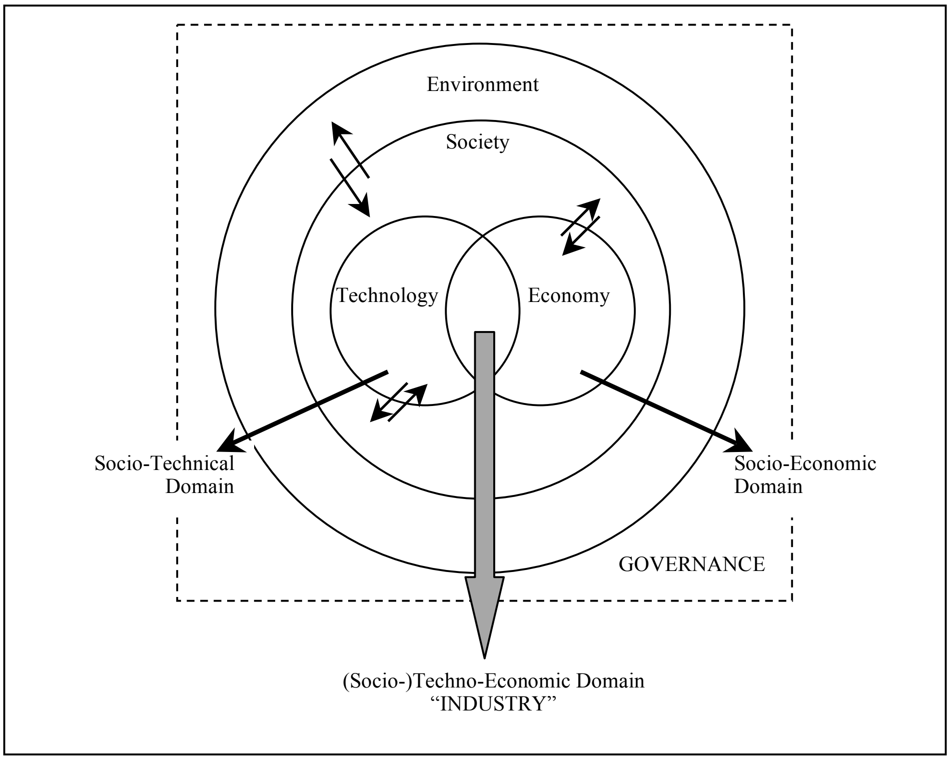

Figure 6. Extended model for governance

Building on Figure 2, Figure 6 shows an extended model for governance. Governance moves co-evolution towards a mature, sustainable society either through enforcement, facilitation, or a combination of these, depending on the characteristics of the aimed change in the overall system. In the meantime, governance also changes in accordance with the feedback from the rest of the system. It should be noted that there is a hierarchy in accordance with the operational priority as mentioned before. Therefore, governance of any system, such as economic, technical, socio-economic or socio-technical systems, are already subsumed by governance of the environment. That is to say, when relevant policies are developed, such as technology policy, governance considers technology as a sub-set of environment and takes all interactions between environment, technology and society (since technology is also a sub-set of society) within a context of sustainable development.

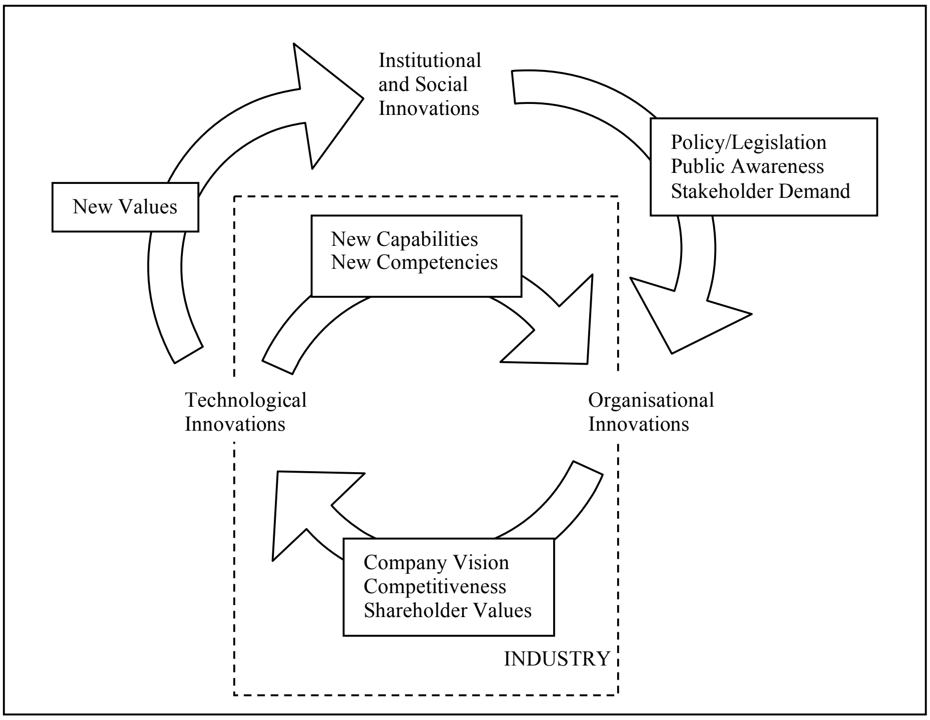

Figure 7. Co-evolutionary innovation model for socio-techno-economic domain: industry

This is more significant when the socio-techno-economic domain, which essentially stands for 'industry', and where sustainable technology development takes place, is considered (Figure 7). When governing for sustainable technology development, besides technological innovations, all other innovations having effect on this socio-techno-economic domain should be considered. This covers establishment of a sound economy policy, which would provide incentives for and support development and diffusion of radical technological innovations.

4. Conclusion

Sustainability is a property of the meta-system rather than of its components handled in isolation. Achieving sustainable development requires understanding and addressing the whole system with a non-reductionist approach. This covers the natural environment as well as the socio-cultural and techno-economical spheres. The interrelationships between these components give way to reciprocal change. Only if this change is managed with a co-evolutionary systems approach, considering the possible effects of change in one component on others, and with a long-term orientation, sustainable development can be achieved.

Planning for development of sustainable technologies should not start from present practices since there is a big gap between prevailing unsustainability in the current technological domain and sustainable technologies. The gap can be crossed by radically innovating in the technological domain but, technological innovation, especially radical changes, either co-exist with or preceded by other innovations taking place in institutional, social and organisational domains. In order to guide radical technological innovations, these innovations in other domains and their reciprocal influence should be understood and managed with a co-evolutionary systems approach.

Sustainable technology development lies at the cross-section of engineering, future studies and theory of sustainable development. Foresighting-backcasting has promising potential to facilitate technology development to achieve sustainability. As an integrative and normative as well as analytical and critical approach, foresighting-backcasting can provide the necessary co-evolutionary framework which should guide governance in influencing needed changes in institutional, social and organisational domains to render radical technological innovations possible within a sustainable development context. Future studies can give us the necessary vision to conceive the larger system boundaries for a long-term planning through scenario building, which intrinsically informs about sub-systems and their interrelationships.

In an exercise of co-evolutionary foresighting-backcasting, planning for policy development should cover the longest time span and largest operational context in order to ensure innovations in different domains are informed of each other and mature towards development of sustainable technologies.

Governance of the socio-techno-economic (namely industrial) domain where sustainable technology development takes place is especially important. Institutional and social innovations generally act as drivers for industry towards undertaking sustainable development objectives. These institutional and social innovations are reflected into organisational innovations, which then become drivers for technological innovations. Technological innovations influence both institutional/social and organisational innovations by generation of new values and new competencies.

5. References

Andersson K., Eidee, M. H., Lundqvist, U. & Mattsson, B. (1998). The feasibility of including sustainability in LCA for product development. *Journal of Cleaner Production,* 6, 289-298.

Bell, D. V. J. (2005). Advancing Corporate Sustainability: A Critical New Role for Government. In Olson, R. L., & Rejeski, D. (Eds.), *Environmentalism & the Technologies of Tomorrow: Shaping the Next Industrial Revolution* (pp. 123-132). Washington: Island Press.

Clayton, A. M. H., & Radcliffe, N. J. (1996). *Sustainability: A Systems Approach*. London: Earthscan.

Cleff, T. & Rennings, K. (1999). Determinants of Environmental Product and Process Innovation. *European Environment*, 9, 191-201. Retrieved June 14, 2006 from Wiley InterScience

Dosi, G. (1982). Technological Paradigms and Technological Trajectories : A Suggested Interpretation of the Determinants and Directions of Technical Change. *Research Policy, 11*(3), 147-162. Retrieved September 5, 2006 from ScienceDirect.

Dreborg, K. H. (1996). Essence of Backcasting. *Futures, 28*(9), 813-828.

Faber, N., Jorna, R., & van Engelen, J. (2005). The Sustainability of "Sustainability" – A Study into the Conceptual Foundations of the Notion of "Sustainability". *Journal of Environmental Assessment Policy and Management*, 7(1), 1-33. Retrieved April 13, 2006 from ScienceDirect.

Freeman, C. (1992). *The Economics of Hope.* London, New York: Pinter Publishers.

Green, K., McMeekin, A., & Irwin, A. (1994). Technological trajectories and R&D for environmental innovation in UK firms. *Futures, 26*(10), 1047-1059. Retrieved September 25, 2006 from ScienceDirect.

Hjorth, P. & Bagheri, A. (2006). Navigating towards sustainable development: A system dynamics approach. *Futures,* 38, 74-92. Retrieved June 14, 2006 from ScienceDirect

Höjer, M., & Mattsson, L. G. (2000). Determinism and backcasting in future studies. *Futures, 32*(7), 613-634. Retrieved October 02, 2006 from ScienceDirect.

Kemp, R. (1994). Technology and the transition to environmental sustainability: the problem of technological regime shifts. *Futures, 26*(10), 1023-1046. Retrieved September 18, 2006 from ScienceDirect.

Kemp, R. (1997). *Environmental Policy and Technical Change: A Comparison of the Technological Impact Of Policy Instruments*. Cheltenham, UK ; Brookfield, Vt: Edward Elgar.

Linstone, H. A. (1999). *Decision Making for Technology Executives : Using Multiple Perspectives to Improved Performance*. Norwood, Mass.: Artech House.

Masini, E. (2006). Rethinking futures studies. *Futures, 38*(10), 1158-1168. Retrieved September 18, 2006 from ScienceDirect.

Norgaard, R. B. (1984). Coevolutionary Development Potential. *Land Economics, 60*(2), 160-173. Retrieved October 02, 2006 from JSTOR.

Norgaard, R. B. (1995). *Development Betrayed: The End of Progress and a Coevolutionary Revisioning of the Future*. London ; New York: Routledge.

Porter, M. E., & van der Linde, C. (1995). Towards a New Conception of the Environment-Competitiveness Relationship, *Journal of Economic Perspectives,* 9(4), 97-118. Retrieved September 25, 2006 from EbscoHost.

Quist, J & Vargragt, P. J. (2004). Backcasting for Industrial Transformations and System Innovations Towards Sustainability: Relevance for Governance?. In: *Klaus Jacob, Manfred Binder and Anna Wieczorek (eds.). 2004. Governance for Industrial Transformation. Proceedings of the 2003 Berlin Conference on the Human Dimensions of Global Environmental Change, Environmental Policy Research Centre: Berlin. pp. 409 – 437.* Retrieved August 02, 2006 from http://web.fu-berlin.de/ffu/akumwelt/bc2003/proceedings/409%20-%20437%20quist.pdf

Rennings, K. (2000). Redefining Innovation – eco-innovation research and the contribution from ecological economics. *Ecological Economics,* 32, 319-332. Retrieved June 08, 2006 from ScienceDirect.

Schmidt-Bleek, F. (1994). *How to Reach a Sustainable Economy.* Wuppertal Papers No. 24. Retrieved August 8, 2006 from http://www.factor10-institute.org/pdf/ wupp94. pdf

Slaughter, R. A. (1998a). Futures studies as an intellectual and applied discipline. *American Behavioral Scientist*(3), 372-385. Retrieved September 26, 2006 from Scopus.

Slaughter, R. A. (1998b). Futures Beyond Dystopia. *Futures, 30*(10), 993-1002. Retrieved October 16, 2006 from ScienceDirect.

Weaver, P., Jansen, L., van Grootveld, G., van Spiegel, E., & Vergragt, P. (2000). *Sustainable Technology Development*. Sheffield: Greenleaf.

Wehrmeyer, W., Clayton, A., & Lum, K. (2002). Foresighting for Development. *Greener Management International, Spring2002*(37), 24-37. Retrieved August 20, 2006 from EbscoHost.

WCED. (1987). *Our Common Future*. (3rd ed.). Oxford: Oxford University Press.