Radical innovation and time bindings: the case of bioenergy

Egon Noe (corresponding author): Aarhus University Foulum, Blichers Allé 20, 8830 Tjele, Denmark, Email: Egon.Noe@djf.au.dk

Hugo F. Alrøe: Aarhus University Foulum, Blichers Allé 20, 8830 Tjele, Denmark, Email: Hugo. F.Alroe@gmail.com

Uffe Jørgensen: Aarhus University Foulum, Blichers Allé 20, 8830 Tjele, Denmark

Jens Bonderup Kjeldsen: Aarhus University Foulum, Blichers Allé 20, 8830 Tjele, Denmark

Abstract

The increased utilization of bioenergy is an example of a technological transition that requires radical innovation. Transitioning to bioenergy utilization involves a co-development of biological, technological and agricultural systems and it involves a range of social systems, such as the economic, political and scientific systems. We define innovation as ‘radical’ when it is both novel and multifunctional and takes place in a network involving many different systems. Radical innovation is a process where time and timing is crucial. Bioenergy development projects are faced with the problem of handling different time bindings and time horizons in the involved biological and social systems. In the present paper, we analyse the problems facing radical innovation in a case of bioenergy development from the perspective of social systems theory. Social systems theory is suitable for analysing the temporalities of systems. A key point in the analysis is that time bindings and time horizons are perspectival phenomena. That is, they are connected to certain perspectives and cannot generally be observed from the perspective of other systems. We conclude that radical innovation requires polyocular or multi-perspectival communication for synchronising to succeed between the systems involved, and that this synchronization must be based on second order communication.

Keywords: Radical innovation; social systems; biomass utilization chain; synchronization; perspectivist approach; polyocular communication.

Introduction

Innovation is often mentioned as one of the main solutions to sustainability problems, such as food security, climate and environmental problems, and rural development. A number of national and European projects have studied innovative initiatives that try to find radical and multifunctional solutions and paths of development. But it is characteristic of most of these initiatives that they either stay very small or turn out to be less novel and radical than first imagined. A core example of this is the transition to an increased use of bioenergy instead of fossil fuels, undertaken to ensure a more sustainable development (Cornelissen *et al.* 2012, Noe and Jørgensen 2009). Social, political and technical transitions and transformations have recently received considerable attention, and it is being studied how they emerge over time, how they are shaped by different actors and their interaction, and how they are intertwined with material, technology and infrastructure and with natural environments (Pfister 2013). Such transitions are often considered to have as their prerequisite the conceptual and methodological development of (solely) technological innovation systems (e.g. Suurs and Hekkert 2009, Godin 2009, Walrave and Raven 2016). However, the concern for sustainable development tends to demand a broadening of perspective in innovation studies, often from the framework of science and technology studies (STS), including both a broadening of the problem framing towards current interest in innovating entire systems of production and consumption, and a broadening of the analytical framing into a variety of innovation systems perspectives (Smith et al. 2010). In particular, innovation in bioenergy production networks involves biological, agricultural and technological systems as well as a range of general functional systems in society, such as the economic, political and scientific systems.

Recently, such complex problems of innovation have been analysed in a range of systems approaches (cf. Coenen and Lóepez 2010), including multi-level perspective approaches focusing on a co-evolutionary concept of technological transition (e.g. Geels 2002, 2007, Genus and Coles 2008, Geels and Kemp 2007) and the notions of technological regimes (e.g. Vanloqueren and Baret 2009, Leiponen 2007) and technological transition pathways (e.g. Geels and Schot 2007, Geels et al. 2016).

Innovation is a process in which time and timing are crucial and, further pursuing Smith et al.'s (2010) call for a broadening of the analytical perspectives for innovation studies, we argue that the above approaches all lack a sufficient theoretical foundation for observing time bindings (*sensu* Esposito 2011). In this paper, we complement the above diachronic approaches, which focus on the evolution and historical dynamics of technologies and systems on multiple levels, with a synchronic approach that focuses on questions of time and timing between different systems. Specifically, we investigate the problems of radical innovation involving multiple systems and actors, using the utilisation of Miscanthus for bioenergy as an analytical and illustrative case. We will, in particular, look at the problems of radical innovation due to different time bindings and time horizons in the involved biological and social systems from the perspective of Niklas Luhmann's social systems theory (Luhmann 1995), which is useful in analysing the temporalities of systems (cf. Harste 2007).

Data and methods

The case study of utilisation of the giant grass Miscanthus in bioenergy production has been conducted using a mixture of available written material and qualitative interviews in Denmark and the United Kingdom. The study was first conducted under the EU-funded BioMob project (Noe and Jørgensen 2009) and is now updated with new sources of information and a discussion of the innovation framework in which its development is situated. But first, we introduce the two main theoretical concepts used in the case analysis, unfolding, respectively, a social systems conception of radical innovation and a social systems conception of time bindings.

Radical innovation

To distinguish what we propose here to call radical innovation from other types of innovation, we offer a typology of different types of innovation and discuss what characterizes each form.

Innovation is often defined as inventions and ideas that are brought to market to meet a real challenge or need, and innovation is mostly seen from the perspective of the innovative company or organization. Some scholars distinguish between incremental and radical innovation, where incremental innovation consists of smaller, step-by-step technological improvements to an existing product while radical innovation involves a technological leap to a fundamentally new product or service (Johannessen et al. 2001). In the same vein, Gregory Unruh (2000) argues that the techno-institutional complex has been “locked-in” to unsustainable carbon energy through a path-dependent co-evolutionary process involving positive feedback, and that this lock-in is consistent with incremental change but constrains path-breaking, radical innovation. Clayton Christensen (1997), in contrast, emphasizes that the distinction between and incremental vs. radical innovation is orthogonally aligned to the distinction between sustaining and disruptive technologies, as seen from a market perspective. Richard Leifer et al. (2000) have a somewhat different definition of radical innovation: “Radical innovation transforms the relationship between customers and suppliers.” This is closer to the definition of radical innovation that we will employ from a networks perspective.

In STS studies, there is a tradition to see innovation from an actor-networks perspective, where innovation involves the mobilization (or creation) of a whole network of actors and certain ensuing translation processes (e.g. Degelsegger and Kesselring 2012, Vadrot and Pohoryles 2010:377ff). The automobile is often used as an illustrative example of such network innovation, with its need for the simultaneous development of a system of roads, new rules of the road, a network of gas stations, garages, etc. These different systems have co-developed over a longer period, but arguably the development trajectory of the automobile was defined at a very early stage in its history and since then, only minor, incremental innovations have been made, including faster and safer cars, better roads, traffic regulation measures, etc.

Analytically we distinguish between three different kinds of development and marketing network innovations: 1) incremental innovation 2) novel innovation and 3) multifunctional innovation (cf. Noe and Jørgensen 2009), which we describe with examples from bioenergy networks below.

Incremental network innovation

An example of incremental network innovation is the production of biodiesel from rapeseed oil or sunflower seed oil, the introduction of which into the fossil energy consumption systems is relatively uncomplicated. In a supply chain perspective, only the process of refining rapeseed oil into diesel needs to be developed. The primary production of rapeseed oil is based on well-established technology, knowledge and practice, and vegetable oil is already available on the market. Biodiesel is a marketable product that can substitute diesel made from fossil fuels and it can readily be used in various kinds of diesel engines, although it depends on a policy regime that supports the utilization, either by directives or tax incentives.

Initially, it was anticipated that, due to its annual biological production, biodiesel would become a sustainable source of fuel and beneficial against global warming (Demirbas 2007). It is also likely that the acceptance of rapeseed oil for use as bioenergy was facilitated by the already wide acceptance of the rapeseed oil as a foodstuff. Rapeseed oil already had the strong support of farming organisations due to its easy market introduction by simple incremental innovation and the prospects of rising prices due to demand for the crop in several, distinct markets. However, recent analyses including possible indirect Land Use Changes (iLUC) have concluded that the climate would have been better off by not substituting fossil fuels by rapeseed biodiesel (Tonini & Astrup 2012).

Novel network innovation

The production and utilization of other kinds of biomass for energy consumption, such as willow and Miscanthus, become much more complicated from a network perspective. New knowledge and infrastructure is needed to plant, grow, harvest, store, market, and convert these crops into energy carriers for the market outlet. To develop such chains, a whole range of actors need to adjust to each other more or less simultaneously to obtain the full bioenergy potential of the utilization chain. An investment in any of these links relies on investments in the other links too.

From an STS perspective, most novel innovations need the involvement of many different kinds of systems and require for different actors to co-evolve, both of which means development over time. However, such a process of co-evolution often either develops only very slowly or fails outright, and even when this is not the case, the outcome often tends to resemble existing systems, thereby not radically contributing to sustainable development. From a systems-theoretical perspective, we argue that the analytical problem with co-evolution is that it can only be observed from a second order perspective. From each first order perspective co-evolution is seen as an adjustment to its environment (cf. Noe and Alrøe 2012, Alrøe and Noe 2012, 2014).

Multifunctional innovation

To complicate matters, many types of biomass may not be commercially attractive from a pure energy marketing perspective or from a reduction of greenhouse gas (GHG) emission perspective alone. However, they could be very attractive including other aspects, like the harvesting of biomass as part of an environmental protection, nature conservation, and landscape management scheme. The income from the sales of the bioenergy produced may not come near to covering all the expenditure involved in harvesting and transportation; however, from an overall perspective, there may be a net benefit. It takes a much more complex organisation and more complex procedures of redistribution of added value in the biomass utilization chain to provide the necessary incitement for stakeholders to participate in this kind of innovation.

In this paper we define *radical innovation* as innovation that is both novel and multifunctional, and which takes place in a network involving many different systems. This is in line with Blackwell *et al.* (2009), who consider interdisciplinary cooperation a source of radical innovation, but it takes the idea beyond science: Radical innovation requires the coordination of multiple different social systems, including multiple scientific disciplines. This approach to radical innovation might seem very similar to the systems approach to innovation based on a multi-level perspective on socio-technical systems (e.g. Geels 2004, Raven and Verbong 2009). But the autopoietic systems theory we apply here, in which systems are understood to be operationally closed systems that produce and organise their own elements (cf. Luhmann 1995), is distinctly different from the conception of a system as ‘elements that interact’ in the Frank Geels-tradition (e.g. Markard and Truffer 2008).

Thus, we argue that radical innovation is part of the solution to global sustainability problems. Yet, simultaneously, we hold that it is comparatively rare because it demands not only for the involvement of different systems and the co-development of these systems, but also for a more radical theoretical understanding of development. The mainstream trajectories of development seem like obstacles to radical innovation (cf. Unruh 2000), despite the fact that many such ideas to innovation could provide very promising market-driven solutions when observed from technical and economical points of view. An example is the cultivation of the new agronomic crop Miscanthus (grass species within the genus *Miscanthus*) as a bioenergy source. Miscanthus is close to being a bioenergy crop ideotype for temperate climates (Zegada-Lizarazu *et al.* 2013) as it is a potentially very high-yielding crop which needs only a small input of chemicals, and since growing the most common Miscanthus species entails very little risk of invasiveness (Jørgensen 2011). It also reduces nitrogen leaching and binds CO2 to the soil (Hamelin *et al.* 2012). But despite the involvement and efforts of a range of actors from researchers to farmers to energy utilities in Denmark (Jørgensen & Hansen, 1994), where the crop domestication was initiated (Heaton *et al.* 2010), it was not possible to develop the concept into a commercial production of bioenergy in Denmark. However, such a production did subsequently begin in the United Kingdom (Jørgensen 2011).

Our claim is that radical innovation cannot rely on co-evolution between systems with different time codes and time bindings, and that such processes of innovation need to be able to synchronize the systems involved. We will use this position to analyse the case of bioenergy production with Miscanthus. But first we will briefly discuss the concept of time binding and certain related concepts.

Time bindings – time as a perspectival concept

Acceleration, or the change in speed, is a basic trend in the development of society, and this puts pressure on structural couplings and leads to a need for the synchronization between systems (Rosa 2003). When we think about acceleration and synchronization, we think in terms of space and time, where time is a dimension like the three spatial dimensions. And usually we think of time in terms of the time of physics and engineering, which secures the synchronisation of airline transportation, financial transactions, GPS navigation, television shows, drone attacks, space flight, etc.

However, the idea of time as one-dimensional is inadequate to address the problems of temporalities in modern society. Consequently, in this paper, we will consider time as a perspectival concept. According to Aristotle, time is a measure of change, and this definition is still valuable. Change is always something that is observed by a system; change belongs to a perspective and depends on the ability of the observer to observe it (as illustrated by Gregory Bateson's (1979: 98) quasi-scientific fable that if you put a frog in a pot of slowly heated water, it will never jump, it will get boiled).

A good example of the perspectival nature of time is the shifts in what the measurement of physical time has historically been grounded in. Until around 1967, time was Earth-bound and astronomical, based on the perspective of the solar system. The second was long defined as a fraction (1/86,400) of an earth day, and from 1956 as a fraction of the tropical year 1900 (Lombardi et al. 2007). But days and years change compared to other physical processes, and atomic physicists had a hard time dealing with what they saw as a variable second. In 1958 a new definition of atomic time was published, where the second was defined as exactly 9,192,631,770 periods of the radiation of the ground-state hyperfine transition in a caesium atom - an entirely new perspective on physical time. And eleven years later, in 1967, the international SI system was redefined based on atomic time.

In line with Esposito (2011), we define *time bindings* as *restrictions on change that are produced by a system*. "Time bindings bind the system and not the world" (Esposito 2011: 22). This definition is slightly different from (but not incompatible with) the definition by Harste (2000) of a time binding (or "temporal binding" in Harste's terms) as the operational code that a system has and which binds the present and the future together for the system. As an example, the discount rate, or discount factor, is the rate used to transform present value to future value. This is a key example of a time binding in the economic system that has great consequences for communications about public investments in green technologies, more sustainable transport structures and other public decisions that have a long time horizon and which are important for future sustainability.

Time bindings are not necessarily reflexive. Using Harste's terms, they are operational codes that form the dynamics of the system, are integral to the system, and are part of characterizing the system. However, time bindings can be observed by the system itself or other systems and enter into their reflexive processes. The existence of a "Time binding means, among other things, that the system remains the same, and recognizes itself as the same …" (Esposito 2011: 23).

Norms and standards are another example of how time bindings can manifest themselves in social systems (Esposito 2011: 29). We already discussed the example of standard time in physics.

Another, very concrete example is organic poultry production, under which farming is governed by a rule that restricts the rate of growth of chickens for slaughter as a means to ensure better animal welfare. If it is not slow-growing, it is not organic, by definition. A third and much more complex example of a time binding norm is that of sustainability, which we have already touched upon, and which is one of the overall drivers of the entire transition to bioenergy (cf. Harste 2000, Noe and Alrøe 2015).

The *time horizon* of a system, or of an operation (such as a decision made within the system), is the period of time in the future that is communicated about in the system and is taken into consideration by the system or in the decision. A system may have an overall time horizon, or it may have different time horizons for different operative processes. *Time codes* are concepts that express key time bindings in the system, like growth, rate, sustained, resilient, etc., and which characterise certain types of differences in time, or in other words certain types of change.

The case of bioenergy production with Miscanthus in the United Kingdom

In the following, we will use the concepts of radical innovation and time bindings to analyse the case of innovation in the Miscanthus utilisation chain, but first we offer a brief chronological overview of the development of Miscanthus utilisation in Denmark and the United Kingdom.

If we compare the development of Miscanthus utilisation in Denmark and United Kingdom, it started in Denmark first, already in the late 1960s. At that time, the very innovative entrepreneur Flemming Juncker planted a small field of Miscanthus to see if it could be grown as an agricultural crop to deliver future biomass for his wood pulp factory (Jørgensen & Schwarz 2000). In the early 1980s, he was supported by research and development projects on the commercial propagation, growing and handling of Miscanthus (Sloth, 1985). But whereas the interest faded in Denmark in the late 1990s, by which time only a few hectares of Miscanthus were grown, and mainly used for thatching (Kjeldsen et al., 1999), Miscanthus started to gain momentum in the United Kingdom. Here, the number of hectares grown for biomass production increased from almost zero in 2002, culminating at approximately 9,000 hectares grown in 2009, after which development ceased and areas grown seem to have decreased to about 7,000 hectares by 2013 (DEFRA 2013: 13ff).

This raises the question of why commercial development of Miscanthus did not occur in Denmark, where the technology was first developed, but in the United Kingdom.

One of the most important developments in the domestication of Miscanthus was a reduction in establishment costs by approximately 80 % obtained by moving to a mechanised rhizome planting and harvest, the result of a joint venture project between Danish Institute of Plant and Soil Science, and the for-profit company Nordic Biomass (Jørgensen & Schwarz 2000). However, despite there being multiple important reasons for initiating a large-scale production of Miscanthus (such as solving the nitrate leaching problems faced by Danish agriculture by increasing biomass production; Jørgensen, 2003), and despite the fact that the knowledge and technology for a commercial crop establishment and production were becoming ready and would fit well into the existing straw combustion heat and power sector (Fenger 2003), the political and commercial interest in growing and utilizing Miscanthus as an energy source in the Danish sector faded out.

This had several reasons amongst which were the abundant straw resources and that the first commercial field trials revealed lower yields than expected (Jørgensen & Kjeldsen, 2000). The lack of commercial development also meant that the research and development on Miscanthus more and less stopped in the early 2000s.

In contrast to the scenario in Denmark, political interest in utilising Miscanthus increased in the United Kingdom where planting and growing Miscanthus became supported under the Energy Crops Scheme (ECS) as part of the EU Rural Development Programme beginning in the year 2000. Meanwhile, in Denmark, supporting energy crops was deprioritized (Hansen et al., 2005). In the West Midlands region, farmers and local entrepreneurs started to form cooperative organizations to manage the production and handling of Miscanthus. There are two organisational forms of the Miscanthus biomass utilization chain in the United Kingdom, exemplified by Lugg Valley Growers and International Energy Crop (IEC).

Lugg Valley Growers are strong on collaboration on planting and knowledge exchange, and have different forms of collaboration in handling and marketing of Miscanthus. Lugg Valley Growers are owned by the farmers that founded the company in 2001, and decisions are taken jointly. IEC takes care of all aspects from planting to sales of Miscanthus on the shareholders' land. In addition, IEC manages Miscanthus plantations, harvest and sales for other farmers.

Prior to the year 2000 only limited research and development was conducted in the United Kingdom on practical aspects of growing Miscanthus, and planting its rhizomes takes special equipment, which was not yet developed and available in UK. Therefore, the first Miscanthus fields in the United Kingdom were planted by Nordic Biomass, which had developed a rhizome planter that had only been used to a limited degree, for demonstration projects in Denmark (Jørgensen, 2003). Rhizomes were transported from Denmark for these first plantings. The Miscanthus planting has now been further optimised in the United Kingdom. In in most cases, planting of rhizomes is now handled by IEC, which have constructed several new generations of planting machines.

Given the knowledge and technology developed in Denmark, the policy support of the energy support scheme, and the organizational capacity of the farmers and local entrepreneurs, a rapid increase in the growth of Miscanthus could occur.

In the case of the United Kingdom, the obstacles to growth emerged in the other end of the utilisation chain. Miscanthus is relatively easy to harvest, store and transport, and only required for conventional technology to be adjusted slightly. However, it takes straw combustion facilities to achieve an effective and economic combustion and utilisation of the biomass. The Miscanthus initiatives in the West Midlands were linked to plans of a new Combined Heat and Power (CHP) plant specialised in straw combustion, which was to be located centrally to the Miscanthus growers in the region. Investors willing to support the construction had been found. But due to a delay in the permission for the project the potential investors lost interest and instead invested in offshore wind turbines[1]. This meant that the produced straw from the Midlands had to be transported all the way

[1] Personal communication in 2010 with John Amos, one of the Lugg valley growers.

to the Ely Power Station in Cambridgeshire, near London. This worsened the economic prospects of growing Miscanthus: Firstly, because of the long distances involved and secondly, because the bargaining power is distributed very asymmetrically between the growers and the power station since the power station has alternative sources of fuel (e.g., common straw) while the Miscanthus growers have no real alternative outlets. Compared with annual agricultural crops,[a] the growing of Miscanthus is a long-term decision that requires early investments in establishing the crop and in equipment; moreover, the production cannot be adjusted to yearly fluctuations in crop prices.

Lately, widespread planting of Miscanthus has begun in the United States (Simet 2014), where a focus on agricultural development, environmental protection and flexible market outputs from the bio-refinery might finally support a sustainable business development. Harvesting the Miscanthus green in autumn and extracting its protein content for feed production in the bio-refinery may prove to be a more sustainable solution to both the critical food/fuel issue of dedicated energy crops and to the associated iLUC sustainability issues than the previous strategy of harvesting dry, senescent straw for direct combustion in spring (Jørgensen 2011).

Among plants in the temperate zone, Miscanthus is one of the most effective at converting solar energy to biomass due to its cold-tolerant C_4 photosynthesis which makes it more productive than maize (Dohleman & Long 2009). However, the economic and technical rationale of using Miscanthus is not only dependent on new technology, knowledge and organisations to produce Miscanthus, but also on new knowledge, technology and organisations to effectively convert Miscanthus biomass into heat and electricity or other energy carriers.

Developing a radically new biomass supply chain takes a more or less simultaneous development within all links of the chain, from the production of the biomass to harvest, storage and transport to the conversion into various forms of energy and applications such as district heating, industrial production, etc. The Miscanthus case is a simple and clear illustrative example.

To summarise, in Denmark money was invested in research on how to plant, grow, harvest and utilise Miscanthus, but no subsidy was given to farmers to grow the crop as a way of monetizing the value of the environmental benefits of reduced nitrate leaching and soil carbon storage. In the United Kingdom, the government saw an interest in promoting the growing of Miscanthus, the Danish knowledge was exported to the United Kingdom and much effort has been made to develop planting and harvesting equipment and an to create organisation to support and disseminate this knowledge to involve more growers. The production of Miscanthus was supported by the government, but the utilisation link of the chain was not in place, and the parallel development of the two sectors meant that the Miscanthus biomass had to be transported all the way from the western to the eastern part of the country. The present situation is that there are many growers but a declining market for the utilisation of the Miscanthus biomass in the United Kingdom. In the long run this could mean that not only the technological advances and knowledge of development but also that the organisational infrastructure and the experience with cooperation obtained will be lost. The cessation of commercial development occurred despite of a large scientific body of evidence on the potential economic, energy and environmental benefits from the production of Miscanthus as an integrated part of the British energy transition away from fossil fuels (Christian & Riche 1998; Smith *et al.* 2014). However, this research seems to be largely decoupled from the commercial development and the perception of farmers, both of which are important factors in determining the success of the implementation of a new agricultural crop.

The case shows the challenges that radical innovation is facing. Even when there is ample shared rationale, synchronisation and co-development between the systems as seen from a technical point of view, the initiatives often do not succeed. In the BioMob project, only the initiatives succeeded that could be characterised as very incremental, that is, those projects which remained close to existing production chains, or which had a very high capacity to coordinate, such as the example of the regional bioenergy development in Güssingen in Austria where a single person held a key position in coordinating the whole project (Noe and Jørgensen 2009).

The framework conditions for radical innovation in bioenergy may be established via long-term policies across sectorial boundaries – policies that are based on multifunctional studies including social, economic and environmental effects. As an example, the long-term energy policy in Denmark following the energy crisis in 1973 paved the way for establishing efficient production chains for agricultural straw for CHPs and for a profitable wind-power industry (Cheon & Urpelainen 2012). However, the benefits of this development was questioned around the year 2000, and the new government in 2001 changed the policy framework surrounding sustainability, which hampered (or changed, depending on one's perspective) further radical innovation of the complex biomass-to-energy matrix, and it is still heavily debated which conversion technologies are sustainably applied to which types of biomass to supplement especially wind energy (Tonini & Astrup 2012).

If such perspectival analysis and coordination do not take place, radical innovation is very unlikely to occur. Instead, innovation will take place as a trial and error-type process, probably leading development down a number of cul-de-sacs. This is likely to be the case not only when a project sets out on a wrong course from the start, but also when there is a deficit of synchronisation, communication and common understanding between different links of the production chain.

Multifunctional innovation requires the involvement of many different organisation systems and as we will demonstrate that the time perspective and time bindings of the involved systems can help us to understand the depth of the challenge of securing this involvement.

Analysis of time bindings, time horizons and time codes in the bioenergy case

In the following section, we will take a closer look at how different time codes, time bindings and time horizons can help us understand the barriers to radical innovation. Table 1 shows an analysis of the different time horizons and time bindings of the systems involved or potentially involved in the radical innovation process of aligning a CHP system with the supply of Miscanthus biomass.

As described above, the process of innovation that led to the development of the production of Miscanthus as a source of bioenergy involved a whole array of different systems. The political system played a central role in this case in several ways: It lent normative support to bioenergy as a salient issue that needed to be addressed in terms of future sustainability; it also acted as a supporting system in terms of providing the necessary means to develop the production and utilisation of Miscanthus until the chain became fully developed, e.g., by valorising the environmental benefits; and it acted legislatively to create the necessary regulations, e.g., in terms of goals for the percentage of biomass in electricity production (Schwarz et al. 2012). In this case, radical innovation involved different policy subsystems, like the Ministry of Agricultural Affairs and the Ministry of Environmental Affairs. In a European context, it also pitted EU legislation against national legislation. The case also involved the energy supply, which itself can be seen as two subsystems: The electric grid system that convert biomass into electricity and heat and which technically distributes energy to the customer, and the energy supplier that buys and sells electricity. The production of Miscanthus also involves farming systems to grow the crop. This system, too, works through an internal differentiation into crop rotation, technology, and knowhow. Research also plays an important role in innovation. In this case we have primarily looked at research into planting and growing Miscanthus. Technological development and the commercialisation of equipment to plant, harvest, store, and combust Miscanthus are also crucial to the innovation and dissemination of Miscanthus. Transport systems also play a central role since the energy density of biomass is low in comparison with fossil energy carriers, which puts special demands on how to handle and transport the many tons of Miscanthus straw, and economically and environmentally the production chain is sensitive to distances of transportation. The agricultural extension system is also central to the innovation process because completely new knowledge and knowhow is needed to grow Miscanthus successfully. Finally, we have also included the financial system in our analysis. Farmers may, for example, need investments to grow and are dependent on the financial system to trust them and provide any necessary loans (Table 1).

[See Table 1 at the end of the document]

Discussion and conclusions

This case of developing a wild grass to be domesticated for agricultural production, and harvested and handled for bioenergy, demonstrates how barriers to radical innovation are linked to the different time bindings and time horizons of the systems involved: legislative, agricultural, energy, financial and environmental. The involved systems cannot cross the boundaries of the other systems in terms of their time codes, bindings and horizons. Neither planning nor project management provides any simple solutions to this problem. The different systems involved cannot adjust their internal system codes to each other.

The analysis supports the understanding that systems are not only applying or choosing a timeframe but that, on the contrary, time codes, bindings and horizons characterise fundamental mechanisms within the system. As Esposito (2011) claims, a time binding is one of the ways that the system recognises itself, and so is a part of its autopoiesis.

The inclusion of time bindings and time horizons in the analysis of the conditions for radical innovation has some fundamental consequences for our understanding of these conditions. It becomes clear that radical innovation cannot rely on co-evolution for several reasons. The acceleration of the tempo of society as a whole, and in its different systems, and the increase of complexity caused by the differentiation of systems also increase the demands for speed and capacity to deal with complexity in relation to radical innovation. Co-evolution is a non-reflexive development, in which each system reacts to its own observation of differences made by other systems. Given the insights from the analysis of this specific case, we argue that such processes will be very slow. First the government (e.g., the Ministry of Environmental Affairs) has to recognise that there is a problem concerning the climate. Then another part of the government (e.g., the Ministry of Agriculture) has to find resources on the national budget to support research into biomass production. The research system must then develop hypotheses on how the research system can best deal with and address these problems, and prepare a project application. Several years later the first research results are out. If the Ministry of Agriculture finds the results promising (and if the topic is still politically salient), the Ministry could then draft a bill to support the production of bioenergy. Some farmers may recognise these new resources and take up the production of bioenergy, if the financial support available were strong enough. Machine developers would then recognise the budding demand from farmers for equipment to handle this production. By then, however, at least 15 years would have passed since the first debate on bioenergy began.

The conclusion from our analysis is that radical innovation requires multi-perspectival communication for synchronising to succeed between the systems involved. Project planning cannot deliver the required kind of synchronisation because it is not possible to adjust different systems to the same diachronic time codes and time bindings within the project period, and the project will thus not be able to establish the necessary structural couplings with the systems concerned. In order to act on these insights, the involved systems need to establish a reflexive foundation of second order communication about communication concerning temporal synchronisation (Alrøe and Noe, 2014). This communication has to be polyocular or multi-perspectival (cf. Alrøe and Noe 2011, 2014), since none of the involved systems can make plans for the other systems. Such a perspectivist approach is the only way for the involved systems to observe the time codes, bindings and horizons of the other systems.

The need for synchronisation and new structural couplings is evident when it comes to radical innovation, and only projects that are able to establish a common framework based on second-order communication will be able to successfully develop it.

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Table 1: Time bindings in connection with radical innovation in the case of utilizing Miscanthus as bioenergy

System	Internal differentiation	General media	Media for Change	Time codes Change differences	Time bindings	Time horizons	Time and radical innovation
Policy	Government	Attitudes	Policy support bioenergy	Value Fight	Norms	Decades	Long feed- back mechanism lack of internal synchronising
	Governmental support	Money	Support	Distribution of means Ability to absorb	Finance act	1-3 years	Support single systems
	Governmental regulation	Law	Regulation of biomass and energy	Circulars Agreements	Legislation process	3 months – few years	Regulation of individual systems
Energy	Electric grid/ energy system	Infra-structure	Adjustment to use of Miscanthus	Change of combustion equipment	Investments	2-40 years	Uncertainty of the long-term development in combustion technology
	Energy supplier	Energy/ money	Energy price of biomass	Energy price differences	Marked prices	1 second to several years (contract)	Long-term contract with farmers already includes the possibilities of low prices on other bioenergy sources
Farming	Production of biomasses	Biomass	Crops	Choice of Miscanthus as a crop	Establishment and Production (min 3 years)	3- 20 years	Long time horizon in marketing and asymmetrical price negations in marked farmers have one outlet supply chain has several inputs
	Technology	Farm equipment	Machines to pant and harvest Miscanthus	Rateability of technology investments	Transcription	10 years	Expensive to and risky to invest in new technology
Research		Knowledge	New knowledge about growing and uses Miscanthus as bioenergy sources	Hypothesis, tests and trails	Projects publishing	3-6 years	Long time from research application to results
Techno-logy		Technique	Equipment to plant, harvest and combust Miscanthus.	Technology innovation from idea to production	Development time	1-3 years	Path dependency. No existing marked, timing in product development and marketing.
Transport		Distance	Place dependency and geography	Tonnage distance and timing	Transportation opportunities	0 - months	No existing transport logistics for transportation of Miscanthus and production far form combustion
Extension		Praxis knowledge (Know-how)	Extension and exchange of knowledge and experiences	Change in Praxis	Local norms habits and advisory contracts	Less than 1 year	Great uncertainty lack of experiences, difficult in translating research results into practice
Financial		Money	Loans	Rate of interests and instalment And expectation of Proceeds	Return on investment	0 – 30 years	Very conservative evaluation of expectation, looking at historical data.