NATIONAL SYSTEM OF INNOVATION AND EMERGING TECHNOLOGY : THE CASE OF A SUSTAINABLE TECHNOLOGY , BIODEGRADABLE MATERIALS IN GERMANY

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NATIONAL SYSTEM OF INNOVATION AND EMERGING TECHNOLOGY : THE CASE OF A SUSTAINABLE TECHNOLOGY , BIODEGRADABLE MATERIALS IN GERMANY

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The aim of our work is to understand the reasons why specific technologies will emerge in differentiated ways in space. This paper is in keeping with the general pattern of a current research programme[1] concerned with a comparative study of the industrialisation in France and Germany of starch based biopolymers used in the field of packaging.
From a theoretical point of view, the spatial dimension of the innovation phenomenon has been introduced by the concept of national systems of innovation. Rooted in differentiated national systems, firms will have different innovation attitudes. However, it remains to analyse how the concept of national systems of innovation will permit us to understand the differentiated emerging of a specific technology - in this case, biodegradable materials - in different countries. So, it is proposed to discuss, from a theoretical point of view, the utility of the concept of national system of innovation in relation to a specific technology (I), and to identify the operational character of this concept in the frame of an empirical study (II).

[1] This programme entitled " the role of national contexts for the industrialisation of starch based biopolymers. Application on the sector of packaging : identification of emerging industrial structures in Germany and France and development scenario for France labelled by Europôl'Agro and financed by the town council of Reims and the Conseil General de la Marne. However, the points of view expressed here engage only their authors. The program is carried out by the members of the ESSAI laboratory.

I National system of innovation and emerging technology : a problematic conjunction.

It will not be proposed to come back to the concept[2] of national systems of innovation as developed by Freeman[3], Lundvall[4], Porter[5] or Nelson[6] but to present its limits, in itself (1.1.), and in relation to a specific emerging technology (1.2).

1.1 Of the intrinsic limits of the concept

The limits of the concept of national systems of innovation are about the three elements which constitute it : the innovation (1.1.1), the national character (1.1.2) and the systemic character (1.1.3).

1.1.1. Innovation or innovations?

If the authors of the analyses in terms of national systems of innovation have not the same definition of innovation[7], they refer to innovation in general. Thus, the concept of national system of innovation does not only refer to different analyses, but even within a same analyse, innovation can be of a very different nature : as shown by evolutionary scholars, innovations are themselves also heterogeneous.

Without detailing all the taxonomies which have been developed to understand the different kinds of innovations, we can retain several points.

1) As underlined by Dosi[8], it is necessary to distinguish between two kinds of technological changes : major technological changes defined as changes of paradigms and "normal" technological changes corresponding to the "normal" innovation activity of the agents, within a paradigm into which these technological changes fit. If a paradigm is "*a set of procedures, a definition of the relevant problems and the specific knowledge related to their solution*" trajectory constitutes "*the direction of advance within a technological paradigm*" [9]. Thus, the determinants of innovations at the time of the apparition of technological paradigms and at the time of the evolution along technological trajectories are not identical. Along a trajectory, the innovations are more incremental, founded on routines already established ; the firm innovates today in connection with its passed innovations while the innovations related to the emerging of paradigms will often lead to a rupture[10] with the passed state of knowledge. So, it should be

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[2] If we suppose the existence of a single concept of national systems of innovation, the realities which recover that concept differ for the different authors. Indeed, the analyses differ both from the methodological point of view, for the one they opt (micro- or macro-economical) , the conceptualisation of the technology they refer to and the definition they give to the concept, cf. M. Delaplace, 1994 and 1999.

[3] C. Freeman, 1988.

[4] B. A. Lundvall, 1988 and 1992.

[5] M.E. Porter, 1993.

[6] R.R. Nelson, 1988 and 1993.

[7] M. Delaplace, 1994 and 1999.

[8] G. Dosi, 1982.

[9] G. Dosi, 1982, p. 148.

[10] The notion of rupture will not be understood as something “fallen from the sky”. Indeed, even if these new paradigms break with something existing before, they are partially a result of this something. In other terms,

necessary to distinguish the influence of national systems of innovation in accordance with the different kinds of innovations : incremental innovations along a technological trajectory or the emerging of new technological paradigms. Indeed, a national system of innovation can be propitious for rupture innovations and not for incremental ones. So, for example, while the national system of innovation of the United States favours the emerging of fundamental innovations, it seems less adapted, compared to the Japanese one, for the imitation and the development of product or process innovations.

2) The aim of the authors of the concept of national systems of innovation is to explain variations in national technological performances. The concept is considered in a large sense : the aptitudes and capacities to innovate form the subject matter of the studies without getting on to sectoral distinctions. Thus, the studies of technical change have noticed that the latter shows sectoral regularities[11]. In his taxonomy, K. Pavitt has proposed a sectoral typology of technical change[12], to show that the technological trajectories of the firms depend on their core activity. In the same way, if the Yale study[13] has allowed to identify the factors acting on the innovation efforts, it has also showed inter-sectoral differences in relation to the importance of the identified factors. Thus, if industries differ in the parameters which are relevant for innovation, the differences are principally related to the institutions. In other words, an institutional framework which is more characteristic of an industry exists inside a national institutional configuration. Therefore, if innovation has a sectoral character, an analysis of a national system of innovation has only limited interests : a national system of innovation can be successful for a given industry and at the same time inadequate for others. So, it should be preferable to reason in terms of sectoral systems of innovation. But, in this case appears a new problem. What will be the space relevant to apprehend innovation : the sectoral space, the national space ? Should it not be necessary to reason in terms of national sectoral systems of innovation ? should it not be possible to have a sectoral system of innovation which is transnational?

1.1.2 Which frontiers for innovation?

The concept of national systems of innovation, implies that the nation is the most appropriated frame to understand the innovation phenomenon. Nevertheless, it would be proper to ask :

1) if, in the context of a raising internationalisation of economies and firms, National States will constitute the only significant frame for analysing the behaviour of the firms. Thus, concerning multinational firms, the question is about the national system of innovation to be considered. So, as underlined by M. Mac Kelvey[14], economical frontiers do not necessary coincide with national frontiers. So, a firm implemented in different national territories will be confronted to different national systems of innovation. Furthermore, a firm implemented in a country can, in its innovation projects, establish relations with firms implemented in other countries. Which

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new paradigms can not be studied independently of the dialectic rupture – filiation : they break with the past while born from it , cf. M. Delaplace 1994, p. 168.

[11] Cf. J. L. Gaffard 1990, R. Nelson et Winter 1982, R. Landau et N. Rosenberg 1986, G. Dosi 1988b, K. Pavitt 1984, O.C.D.E 1992.

[12] K. Pavitt distinguishes four kinds of sectors, the supplier dominated firms, the scale intensive firms, specialised equipment supplier, science based firms.

[13] R. R. Nelson, 1987.

[14] M. Mac Kelvey, 1991.

will then be the relevant national system of innovation ? Will the success of such a project not depend of the compatibility of the two systems of innovation ? should we then have a multinational system of innovation?

2) If there is not another context, a more local one, which will influence the behaviour of the firms ? Thus as pointed out by M. Mac Kelvey, we have " *regional imbalances in innovation and growth performances*"[15]. Thus the concept of national systems of innovation masks the existing differentiations inside a given State. So, B. Amable, R. Barré and R. Boyer[16] prefer to opt for a concept in terms of social system of innovation, to avoid putting a priori borders for such a system.

So the question is to know

1) What should be the respective part of these three geographical levels of analysis (multinational, national, intranational) in the study of the innovating behaviour of the firms.

2) Will this part always be identical, whatever kind of innovation, whatever industry and whatever kind of firm to be considered. In other words, we should identify :

i) the determinants of different kinds of innovation
ii) the spatial character of these determinants ; are they present in an undifferentiated way in the space or are they only present in one space or several spaces and if this will be the case, in what kind of space (national, local, peculiar to the firm or to a group of firms) ?
iii) the articulation between the eventual spatial character of these determinants and the other characters (sectoral….)

1.1.2 The system, what kind of system?

Beside the problems described above, it should be asked what will make the system. The reasoning, in terms of national systems of innovation, amounts to advance the existence of cultural, linguistic and institutional barriers, which further information and knowledge flows inside the system, i.e. the nation. In other terms, as advanced by J. Niosi, B. Bellon, P. Saviotti and M. Crow[17], the national system of innovation distinguishes itself from its environment by the fact that it facilitates intra-systemic interactions which will occur in a more important way than the interactions between the system and its environment. The systemic notion of the concept of national systems of innovation implies that the latter will have its own particularity corresponding to a kind of identity since the importance of an element results also from its interactions with other elements[18]. So, it matters to identify at the same time the elements constituting the system and what makes that these elements will make a system, i.e. that what constitutes the link, the "glue" of the system. Then, three kinds of questions should be asked :

1) Are the elements which constitute the system identical, whatever the systems ? In fact, even if nations will be equivalent in terms of technological performances, the elements which are

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[15] L. Mac Kelvey, 1991, p. 118.

[16] B. Amable, R. Barré and R. Boyer, 1997.

[17] J. Niosi, B. Bellon, P. Saviotti, M. Crow, 1992.

[18] R. Leoncini, M. A. Maggioni, S. Montresor, 1996.

characteristic of their national system of innovation will have an own and specific character. The concept if national systems of innovation should be analysed in terms of multistability of systems[19].

2) What is the minimal intensity of interactions and interdependencies between these elements which will justify an approach in terms of systems. In other terms "*what degree of relation and coherence between the elements will be necessary for a system of innovation to exist*"[20].

3) Among these elements, will there be elements essential to the system and are these elements always identical ? Can we identify the elements which constitute the link of the system ? Is it culture, public institutions…? Is this link always identical whatever the system ?

Furthermore, even if we would be able to resolve the problem of what will make the system, it remains that, as the innovation can only be analysed in dynamics, we can not stop by analysing a national system of innovation at a given moment. Reasoning in dynamics generates two kinds of problems :

1) The question about the borders of the system should be raised. In dynamics, the system can not favour innovation only if it is itself opened to other networks or systems which will allow it to renew itself. In other words, the system can promote innovation in dynamics only if it is opened onto the outside.

2) The system and its ability to generate innovations evolve and a successful national system of innovation (in the sense that it authorises the production of innovations which give a comparative advantage to the firm) at a time t, should not be successful at a time t+1, if it generates rigidities which hamper innovation. For example, a national system of innovation can favour at an instant t the creation of new firms likely to develop radical innovations and hamper the development and the diffusion of these same innovations. In the same way, a national system of innovation can favour the development of certain industries at a time t and hamper at t+1 the emerging of new industries which will compete with the former. So, the national system must be flexible enough to permit changes and rigid enough to trace guidelines for agents[21].

So, reasoning in terms of national systems of innovation needs to articulate the determinants of the different kinds of innovation, the spatial character of these determinants, what gives the systemic character to the system and the reproduction in time and in space of a given system and its ability to generate innovations.

But beside these problems, the concept of national systems of innovation needs to be completed to be used in a concrete case.

1.2 … to the limits met when studying an emerging technology

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[19] J. Niosi, B. Bellon, P. Saviotti, M. Crow, 1992

[20] J. Niosi, B. Bellon, P. Saviotti, M. Crow, 1992

[21] H. Kabouya, 1998

The conception in terms of national systems of innovation sets down a certain number of operational difficulties relative to the identification of the elements which constitute such a system and which are relevant in the case of a problematic in terms of an emerging technology (1.2.1.), to the weighting of these elements (1.2.2.) and to the interactions between these elements (1.2.3.).

1.2.1 The relevant elements

It should be asked if it is possible to identify in an exhaustive manner the elements that are likely to describe a national system of innovation and relevant in the case of a problematic in terms of an emerging technology.
If the Swedish school suggests two possible definitions of the elements constituting a national system of innovation[22], they are principally based on an "*empirical work* " which is "*ad hoc and lacking in clear and adequate theoretical explanation of the mechanisms involved*"[23]. They do not permit to delimit in a precise way the whole relevant elements. As for the study of Nelson and others[24], it deduces the elements of empirical studies from which it is difficult to theorise. So in the two cases, no methodology is established to apprehend the relevant elements in the case of an emerging technology.
On the other hand, the analysis of Porter[25]opens a track of thought. It can be admitted that the relevant elements are those which will directly or indirectly act on the four parameters describing his "*diamond*"[26] (factor and input conditions, demand conditions, related and supporting industries, context for firm strategy and rivalry). Thus, these four parameters can more easily characterise a sectoral configuration.

1.2.2. The question of the weighting

Moreover, even if it should be possible to extricate an exhaustive list of the elements acting on an emerging technology, it should be asked how to evaluate the degree of importance of these elements, i.e. how to establish a weighting between the different elements. Indeed, it can be supposed that :

1) the relevant elements have not the same importance in relation of technological performance. The presence of certain elements should not be sufficient on itself to assure the development of a given technology if other more important elements are absent. For example the presence of risk-capital, of consumers and of a favourable regulatory framework for innovation should not be enough for the development of a technology, if certain technological competencies on which it is based are absent. So the advantage due to the presence of one element can be partially (or totally) compensated be the disadvantage related to the absence of another important element.
2) The presence of an element should not be sufficient, it should need to be sufficiently significant. In the opposite case, the element should not have a positive effect on innovation[27].

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[22] B.-A. Lundvall, 1992.
[23] M. Mac Kelvey, 1991, p. 131.
[24] R. R. Nelson, 1993.
[25] M.E. Porter, 1993.
[26] see also M.E. Porter, 1997.
[27] F.H.A. Janszen and G. H. Degenaars, 1998.

So, for example, if an offer of risk-capital exists in Germany, it is not sufficient to have a positive impact on the development of biotechnology.

1.2.3. The interaction between these elements

The idea of the notion of innovation systems implies that it won't be sufficient to identify the elements which constitute the system, but that it is also important to identify the links between these elements. Thus, how should one measure the links in the concrete case of emerging technology?
Moreover, if it would be possible to measure the links, how should one evaluate the relation between these links and the performance of the system. In others terms, what is the critical mass[28] necessary for the deployment of an emerging technology. For example what is the minimal intensity of contacts between a producer and his users which are likely to affect the development of a technology.

If the concept of national systems of innovation presents a certain number of critical points, the studies which refer to this concept furnish an orientation for analysing the perspectives of development and diffusion of an emerging technology inside a nation.

II National system of innovation and emerging technology : the case of biodegradable materials in Germany

We will propose a methodology (2.1.) which should permit to analyse the elements and interactions which are characteristic for a national system of innovation in relation to an emerging technology, the biodegradable materials in Germany (2.2).

2.1 Proposition and methodology

These methodology is based on three sets of elements. These are : the institutional framework (2.1.1), the demand (2.1.2) and the competencies existing inside the nation (2.1.3).

2.1.1 The importance of the institutional framework

In his lecture of the national systems of innovation, Freeman[29] emphases on the importance of the adjustment between the institutional framework and an emerging technology. If this approach concerns essentially such innovations which are likely to constitute a "techno-economical" paradigm, it can also be applied to an innovation which do not in its nature correspond to such a paradigm[30]. So, it can be supposed that the interactions between institutions and technical change follow an analogous logic than the one characterising the "*complementary sequences*" which describe the dynamics of a "development bloc" as defined by Dahmèn[31]. In other terms, if "*economic success at certain stages…requires the realization of one or more specific complementary stages*" describing then "*structural tensions*"[32], the

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[28] B. Carlsson and S. Jacobsson, 1992.
[29] C. Freeman, 1994.
[30] B.-A. Lundvall, 1997.
[31] E. Dahmèn, 1989.
[32] E. Dahmèn, 1989, p. 111.

resolution of these tensions requires adjustments which are as technical as institutional. Consequently, it is necessary to proceed to the analysis of the interactions between the institutional framework an the emerging technology.

2.1.2. The importance of the local demand

The importance of the local demand for the success of the innovation has made the object matter of several analyses[33]. So, at the one side, innovation is necessarily the reflect of a local demand ; the needs in the vicinity are easier to perceive and less costly to analyse. On the other side, the proximity of a demand contributes to facilitate the access to information about the using conditions of an innovation. This point is particularly important in the period of trial and error inherent to the development of a new technology. Therefore, it is advisable to proceed to the analysis of the demand inside a nation which is likely to act favourably on the development and the diffusion of an emerging technology.

2.1.3. The competencies necessary to the development of a new technology

If the national system of innovation presents favourable institutional context and demand for an emerging technology, it must be also able to favour the development of knowledge and competencies necessary to this technology. So it remains important to analyse the sectors and industries inside the nation which are likely to proceed (by continuation of technological trajectories or on the base of paradigmatic constraints which characterise them) to the development of that technology[34]. Nevertheless, the bases of knowledge and competencies are not only stemming from the industry, they are also coming from universities and research institutions which must also be considered in the analysis. Last but not least, the government has also a role on the development of knowledge and competencies which are likely to permit the development and the diffusion of an emerging technology.

2.2 The case of biodegradable materials in Germany

The development of biodegradable materials (principally renewable resources-based as maize, cereals, potatoes, beets…) has started by the end of the seventies. The objective was to develop materials, endowed, on the one hand, with technical features analogous to conventional synthetic materials and, on the other hand, able to be rotted by micro-organisms. The research and development efforts relative to these materials have been intensified since the end of the eighties, because of the rising problems related to waste elimination. The resolution of these problems appears to be particularly difficult for scraps of synthetic materials (problems of recycling, illegal exportations of waste, emission of dioxin by incineration. Therefore, biodegradable materials are principally assigned to be substituted for synthetic materials destined for the fabrication of products with a short using duration and are likely to be rapidly transformed into waste. So, the packaging domain will probably constitute the principal domain of application for these materials.
Moreover, the Common agricultural Policy has confronted the farmers with serious outlet problems for their products, inducing them, with the help of the authorities, to support the development of non-food application for agricultural resources. This is notably the case of researches aiming to develop biodegradable materials.

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[33] M.E. Porter, 1993, S.B. Linder, 1961.

[34] B.-A. Lundvall, 1992, M. Bell and K. Pavitt, 1993, M.E. Porter 1993.

Using the methodology presented above and in order to analyse the emerging of the technologies related to biodegradable materials in Germany, it is intended to study the institutional framework and particularly the regulatory one (2.2.1), the demand for packaging (2.2.2) and the competencies related to these technologies (2.2.3). To conclude, we will try to characterise the impact of this national system on the development of biodegradable materials (2.2.4).

2.2.1 The regulatory context relative to waste management

Confronted with raising problems concerning waste management, the German government, has applied, from the beginning of the nineties, a policy aiming to reduce and to promote the recycling of waste. Because they are rapidly transformed into waste, packaging materials are situated at the core of this policy. The packaging decree of 1991 and it's amendment of 1998 have imposed to the producers and distributors of packaging the joining of a system[35] (the *Duales System Deutschland* company, DSD) of collection, sorting out and carriage of packaging waste to the recycling plants, which has to cover the whole German territory. The joining of this system, conditioned by the payment of a fee[36], has led to an internalisation of the costs related to the collection, sorting out and carriage of packaging waste to the recycling plants. Nevertheless, biodegradable packages do not have access to this system because the DSD imposes a fee to them identical to the one imposed to synthetic packages. Under such conditions, biodegradable packages can not benefit from the competitive advantages inherent to the facility of disposal.

The resolution of this problem for biodegradable packages requires the building of another system of collection, sorting out and carriage of packaging waste to the sewage plants.
Thus, the German government, by adopting "the technical instruction relative to town waste" of 1993, has promoted the disposal of biological waste by composting. This instruction plans a separated sorting of biological waste and a considerable increase of composting infrastructures before (the year) 2000. It will lead to a covering of 60% of the German territory by a system of disposal of biological waste.
The perspectives of an insertion of biodegradable packages in this system have been improved by two decrees adopted in 1998. On the one hand the decree relative to biological waste recognises their character of biological waste. On the other hand, the amendment of the decree relative to packaging, introduces an escape clause for biodegradable packages which exempts the system in which they may be inserted from covering the whole German territory. Consequently, the integration into the actually existing system of disposal of biological waste is sufficient. Under such conditions, the costs of collection, sorting out and carriage of biodegradable packaging waste would be three to six times less than the same costs concerning synthetic packages[37]. In other terms, this will lead to a rapprochement between costs of biodegradable packages and costs of synthetic packages, while the unit costs of the latter remain actually lower.

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[35] Distributors which do not join this system have to take by used packages at the selling point.

[36] multiplying by three the costs (per kilo) of synthetic packages.

[37] A. Schütte, 1998 and U. Witt et al. 1997.

If, today, the legislative situation in Germany seems favourable to the development and the diffusion of biodegradable materials, the producers of these materials have rapidly recognised the importance of parallel institutional steps. Notably, the integration of biodegradable packages requires the support of all implicated actors. This is particularly the case of the managers of composting plants, which are submitted to competitive pressure concerning the quality of their compost, and which are, under such conditions, not greatly inclined to integrate biodegradable packages in the masses to be composted. That's why manufacturers involved in the development of biodegradable materials got organised in an interest group (the Interest group biodegradable materials, *Interessengemeinschaft Biologisch Abbaubare Werkstoffe* IBAW). This institution was strongly involved in the achievement of a norm (DIN 54900) which has permitted the realisation of a certification to attest the ability to be composted of biodegradable materials and products using them. These certification is attested by a logo which has been developed by the Interest group.

2.2.2 The context of demand

The study of the demand requires to analyse three elements, the consumer (a), the big commercial chains (b) and the manufactures of packages (c)

a) The role of the consumer

Even if packaging does not constitute the main buying criterion, some studies[38] have revealed that 1) half of German consumers attach importance to package when buying and that 2) the replacement of synthetic packages constitutes a top priority for the consumers. In other terms, the packaging sector is constrained to fit the needs and claims of the consumers. Consequently, this should mean a rising utilization of packages more propitious to environment, i.e. perceived as easier to recycle. Thus, behind their, “easiness of disposal”, biodegradable packages based on renewable resources appear to be more ecological. As a matter of fact, they contribute to the reduction of the greenhouse effect and to the economy of resources, thus satisfying to the principle of sustainable development. However, the “ecological” behaviour of the consumer depends on the information relative to the ecological character of the product[39]; hence the importance of a logo of composting (which presupposes, as we have seen, a norm and a certification), which informs the consumer about the biodegradability of the package.

b) the role of the commercial companies

As they dispose of a manipulation power of the producers and consumers thanks to their ability to open or close the way to the different products they commercialise[40], the big commercial chains remain inescapable actors.

[38] Arbeitsgemeinschaft Verpackung und Umwelt, 1989.

[39] Umweltbundesamt, 1997.

[40] D. Pflaum and H. Eisenmann, 1988.

The behaviour of the German commercial chains presents a trade-off concerning the development of biodegradable packages. Indeed, on the one hand, concerned by the functioning of the dual system of the DSD, that allows them to be exempted from taking back used packages, as imposed by the packaging decree, they committed themselves to promote packages integrated in this system. This did not incite the adoption of biodegradable packages which are, as pointed above, excluded from this system.
However, on the other hand, they are not satisfied with the fact that a package is integrated in this system. They also pay attention to the ecological character of the package in question. In other terms, behind the easiness of disposal, a package has to present a satisfactory ecological profile. This selective policy of the commercial chains is likely to favour biodegradable packages because of their ecological characteristics mentioned above. However, to take advantage of such a policy, biodegradable packages should be integrated in a waste disposal system recognised by the legislator. Thus, as emphased before, the actual regulatory context facilitate this integration.

c) The role of the packaging manufacturers

Packaging manufacturers are potential users of biodegradable materials for the packaging production. By equal quality, it can be supposed that the decisive criterion for adoption or not of biodegradable materials would be the price[41]. Thus, without taking into account the costs of disposal, the prices of biodegradable materials are actually four to twenty times higher than prices for synthetic materials. Consequently, it could be supposed that packaging manufactures will not be ready to adopt biodegradable materials.

However, a certain number of considerations are likely to favour such an adoption.

1) the integration of biodegradable packages in a disposal system for biological waste (and Germany tends to offer this opportunity), will contribute to a rapprochement between the prices of biodegradable packages and prices of synthetic packages. Thus, it can be supposed that this rapprochement will lead to a rising of the production volumes and to the realisation of scale economies likely to contribute to a reduction of production costs and prices.

2) Confronted with a stagnation of consumption and with a rising competitive pressure coming from abroad, the German packaging sector tries to react by developing innovations[42] (new packages, more resistant packages at the same time lighter…). Thus, the biodegradable character of a product may constitute such an innovating reaction, since, as mentioned above, the consumer exerts pressure in this sense.

3) The R&D efforts of the producers of biodegradable products are likely to lead to a drop of the prices[43] of these products.

4) Among the four relevant criterions set out by the German association of packaging engineers to characterise the development of the packaging markets, two play in account of

[41] B. Ehlers and al. , 1997.

[42] H. Emminger, 1997.

[43] R. N. Foster, 1986 has theorised that the performance of a technology are an increasing function of the R&D efforts.

biodegradable packages[44]. Indeed, behind the determinants *costs and performance* and *reduction and avoiding of packaging*, the association cites the parameters *saving of resources et packages integrated in a circular economy*[45]and *protection of the atmosphere*.

2.2.3 The context of supply of competencies

The question here will be to identify the existing competencies, inside the German industrial structure, for the development of biodegradable materials (2.2.3.2) and to emphasize on the role of the government policy, universities and research institutions (2.2.3.3). However, it should be first necessary to illustrate the different technological trajectories which characterise these materials (2.2.3.1)

2.2.3.1 The technological trajectories characterising biodegradable materials

The development of biodegradable materials comes in a variety of categories of technological trajectories. These are the trajectory relative to materials based on native starch (a), the one relative to biodegradable plastics on the base of starch (b), the one relative to biodegradable materials obtained by fermentation (c) and finally the one relative to synthetic biodegradable materials (d).

a) Materials and products based on native starch

Starch is a substance extracted from certain resources (as maize, cereals, potatoes). Two kinds of products are manufactured from native starch :

1) loose-fill materials

The manufacturing of these materials consists of using vegetable starch or a mixture of starch and used papers as input. The biodegradable materials are obtained through an extrusion process of these inputs, and correspond in their characteristics to polystyrene chips traditionally used as loose-fill materials.

2) Pieces moulded according to the principle of cooking food waffles

The manufacturing of these pieces is proceeded installations similar to those used for cooking waffles. Nevertheless, the installations have been modified for the proceeding of the starch based mixture. If, the principal application field for these products is the catering field, the market for frozen food and for meat packaging offers interesting perspectives.

b) The starch based biodegradable thermoplastics

Thermoplastic materials are constructions based on polymer chains able to be deformed in a reversible manner from a certain temperature onwards. Through particular processes, starch is transformed into a mass with thermoplastic characteristics. However, when the obtained material is exclusively starch based, it shows itself to be particularly sensitive to water and to temperature both during its transformation in machine and its utilization. This is the reason

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[44] D. Berndt, 1997.

[45] The concept of a circular economy is written down in the German legislation. It implies that the first supplier will be the last user. So, if farmers are supplier of renewable resources used to manufacture biodegradable materials, they are the last users because they use the compost obtained from these materials after disposal.

why starch based materials are generally constituted of a mix of starch and synthetic biodegradable materials. These mixes permit to improve the technical characteristics of the biodegradable material; bringing them closer to those of synthetic materials (polypropylene, polyethylene, polystyrene..).

c) biodegradable materials obtained by fermentation

These materials are biopolymers obtained by microbial fermentation based on starch or sugar. The development of fermentation technologies is related to the realised advances in biotechnology. Two products and processes can be distinguished :

1) PHB is an aliphatic polyester obtained from sugar and/or starch and synthesised by a bacterial process with a carbonated substratum. The commercial perspectives of this product are promising because of its biodegradability and its technical characteristics close to the ones of polypropylene.

2) Polylactid acid (PLA) is produced by chemical polycondensation of lactid acid obtained by bacterial fermentation of carbohydrate. Contrary to the case of PHB, the process of fermentation leads to the obtaining of a monomer. This will permit the obtaining of a synthesised polymer through the traditional procedures of organic chemistry. PLA is used to manufacture a yoghurt pot distributed by Danone.

d) synthetic biodegradable materials

Biodegradable materials based on fossil resources are known since a long time. They are often used as copolymers complexed with thermoplastic starch In this manner, they allow an improvement of the characteristics of biodegradable materials based on renewable resources while conserving their biodegradability.

So, excepted for materials based on native starch mixtures and for materials obtained by fermentation, the majority of starch based materials contain biodegradable synthetic materials[46]. The latter, by enlarging the field of application of the former, play an important role concerning the commercial ability of starch based biodegradable thermoplastics.

2.2.3.2 The competencies inside the German industrial structure necessary to the development of biodegradable materials

The different technologies involved in the development of biodegradable materials are characterised by different competencies profiles. Therefore, it is necessary to analyse in a differentiated manner the competencies which are likely to participate to their development.

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[46] U. Witt, 1997.

1) The technologies based on native starch are characterised by competencies principally based on the mastery of the manufacturing processes of which Germany is richly endowed. The technique of processes (*Verfahrenstechnik*) is one of the most widespread training programs in Germany[47]. Furthermore, this discipline is intimately related to another discipline, the machine construction (*Maschinenbau*) for which the German reputation is recognised. These two disciplines contribute to a favourable development context for technologies based on native starch.

2) For the three other technologies, the German national system of innovation is characterised by the existence of competencies in organic chemistry. In this manner, Bayer and Basf, using their competence and knowledge base, could develop the synthetic biodegradable materials Bak and Ecoflex. The German innovation system is also characterised by an important paper industry[48]. As the biggest non-food user of starch, this industry possesses competencies in manufacturing and machining this material. It is therefore likely to develop biodegradable materials[49]. Moreover, Germany has also competencies related to the mastering of the biodegradation processes because of its early implication in the disposal of biological waste. They allow the analysis of the links between the polymer structure (biodegradable materials) and degradation. They play an important role for the development of biodegradable materials and have allowed the realisation of the norm DIN 54900 mentioned above.

However, if the mastering of the polymerisation processes (organic chemistery) is inescapable for the three technologies in question, it is not sufficient for the development of renewable resources based materials[50]. Other competencies are necessary : this is especially the case with competencies in the biotechnological field which are particularly relevant concerning the technologies based on fermentation.
Thus the German national system of innovation shows weaknesses in this domain. Indeed, the recourse by the German chemistry to biotechnological processes, as the fermentation processes, remains an exception[51]. This situation can be explained by a separation in the development of chemistry an biology. Although, the ground of what could have been biochemistry was prepared by the end of the last century[52], organic chemistry began the 20th century with an advance of seventy years[53] and imposed itself as a paradigmatic constraint for the chemical industry which concentrated its efforts on the utilization of fossil resources. In the same time, biology remained a descriptive discipline without any influence on the chemical industry practice. So, path dependencies, unfavourable to the mastering of processes based on biotechnology are perceptible concerning the German chemical industry which recognizes however, the importance of this technology for the protection of its competitive positions in the future.

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[47] more than 50 universities have training programs in this field.

[48] Germany is the first paper producer in Europe, CEPI, 1998.

[49] Biotec, one of the most involved firms in the development of biodegradable materials belongs to the group Mellita which belongs itself to the paper industry.

[50] The study of the firms which develop biodegradable materials furnishes interesting results : the examples of Novamont, Echochem and of Cargill Dow polymers show the association of competencies in organic chemistry and competencies in the farm produce industry.

[51] S. Werwel, 1997.

[52] by the enzymatical reaction realised by Emil Fischer and based on the foundations of biological chemistry.

[53] the first synthesis of an organic material by Wölhers, Friedrich in 1928.

Nevertheless, the pharmaceutical industry, as the principal user of technologies aimed to obtain PLA, masters the technologies based on fermentation. Thus, the opportunities, today offered by the fermentation technologies based on lactic acid, have leaded Boehringer Ingelheim[54] to search for new non pharmaceutical applications for its product : Resomer.

Finally, thanks to its consensual logic, the German industry appears to have a long tradition of inter-firm relations[55] favourable to interactive learning between users and producers with positive effects on innovation[56]. Biodegradable materials have also benefited by this tradition with several corporations between users and producers of these materials[57].

2.2.3.3 The role of public policy, universities and research institutions

In order to offer to farmers alternatives in terms of production (reduction of agricultural surplus) and to promote the realisation of industries likely to contribute to the protection of the environment and of the climate and to the saving of resources, the German government has adopted the "program of promotion of renewable resources. This program has been applied for a duration of five years from 1990 and was renewed in 1995[58]. The aim of this program is to finance the basic research in the field of vegetable cultures and the development of technologies which lead to the manufacturing of renewable resources. It mobilizes annually an amount if 50 million DEM for all the projects. From this amount, 15 million DEM are allocated to starch based industrial development projects with as principal application biodegradable materials[59].

If it remains difficult to estimate the effects of a government program to promote a technology[60], it is important to notice that the "program of promotion of renewable resources rises :

1) the means and efforts devoted to the development of industries on the base of renewable resources an so the potential technological performance in the domain[61],

2) the stock of knowledge available for the industry and the technological opportunities,

3) the financing opportunities for R&D activities. So it contributes to direct a part of the R&D activities toward the industrial development based on renewable resources and, concerning starch and sugar, toward the development of biodegradable materials.

Moreover, the governmental policy is supported by the involvement of 19 universities and 18 research institutions in research programs related to the development of biodegradable materials.

2.2.4 the German national system of innovation : what impact on the development of biodegradable materials?

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54 a company in the pharmaceutical industry.

55 D. Soskice, 1996.

56 B.-A. Lundvall, 1988 and 1992.

57 in the case of biodegradable materials, these cooperations concerned essentially diffusion projects (ICI and Wella, ICI and Siemens & Co, Novamont and the municipality of Furstenfeldbruck…).

58 Bundesministerium fürrnährung, Landwirtschaft und Forsten, 1995.

59 Fachagenture Nachwachssende Rohstoffe, 1997.

60 R.R. Nelson, 1989.

61 R. N. Foster, 1986.

The analysis of the German context relative to the development of biodegradable materials has shown that :

1) from an institutional point of view, the actually regulatory framework relative to waste management offers favourable conditions to the diffusion of biodegradable materials.
2) From the demand's, point of view, we are witnessing to favourable pressures to these material both from the point view of the consumers and the commercial chains. Nevertheless, the decisions of the German packaging manufacturers about adoption of these materials are strongly dependent on price considerations.
3) Biodegradable materials in Germany are supported by the public policy and by the existence inside the industrial structure of competencies necessary to their development. Nevertheless, the country shows a certain number of weaknesses concerning the mastering of biotechnology.

But we remain confronted to the operational difficulties mentioned above (1.2). The analysis of the German context relative to the technologies involved in the development of biodegradable materials has allowed to identify a certain number of relevant elements as well as a certain number of interactions between these elements bringing out the systemic character of this context. Nevertheless, we are not able to claim the identification of the whole relevant elements.
Moreover, it matters to ask oneself about the weighting of these identified elements as to their impact on biodegradable materials. If we could observe that certain elements present an important weight (the integration of biodegradable packaging in a disposal system for biological waste), it remains impossible to estimate its scale. Moreover, we have not the weighting of the whole elements identified.

Finally, the studies performed about the patents taken out[62] and about the potential volumes of demand[63] show that Germany 1) occupies actually an European leader position in the development of biodegradable materials and 2) represents not less than the fourth of the whole European market for these materials. So, if these studies confirm the positive impact of the German national system of innovation on biodegradable materials, it is difficult to relate this positive impact on the elements and interactions identified. In other terms, if we could identify the elements and interactions which characterise the system, it remains difficult to measure the direct impact of these elements and interactions on the development of biodegradable materials.

Conclusion

The confrontation of the national systems of innovation concept to the study of a specific emerging technology supposes to lighten a certain number of points (development of tools which should permit to identify and to balance the elements which constitute the system, measures of the internal interactions of the system, measure of the impact of that system…).
Moreover, this confrontation questions different concepts of the evolutionary theory (the nature itself of the technology, the question of the emerging of a paradigm).

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[62] These studies have been performed by J. Clad, M. A. de Looze and M. Nieddu and of the group ESSAI, in the frame of the research project mentioned above. Cf. Bascourret et alii. 1998.

[63] C.A.R.M.E.N., 1998 mentions the studies of the Frost & Sullivan Agency.

Indeed, to perform an analysis of the impact of the national system of innovation on an emerging technology, it is necessary to establish a representation of this technology. Thus, every technology can traditionally be apprehended by the deployment of technological trajectories inside a clearly identified paradigm (G. Dosi 1982) which concerns principally the knowledge and competencies incorporated in the organisations, individuals…

If we adhere to this representation, it is suitable to define the paradigm in which the technological trajectories are inserted and so the knowledge and competencies, inside the system, characterising this paradigm and likely to allow the development of the emerging technology.

Nevertheless, the study relative to the development of biodegradable materials in Germany suggests a representation of the technology which is not necessarily only founded on one single paradigm. In the case of the fermentation technology to obtain PLA, knowledge and competencies about microbiology, enzymology, biochemistry, which allow the obtaining of a natural monomer by a fermentation process are mobilised. Also mobilised are competencies and knowledge in the field of polymer chemistry mastered by the traditional chemical industry. In this way, PLA constitutes an artefact which is based on different technologies founded on different paradigms :

1) The technology of genetic engineering (which constitute an emerging paradigm),
2) The technology of fermentation founded on an existing paradigm in the farm-produce industry,
3) The technology of synthesising polymers based on the traditional paradigm of polymer chemistry.

So, this example suggests a multidimensional representation of the technology in the form of a vector which includes several paradigms allowing the obtaining of the artefact in question. But if it could be considered that this vector takes on paradigmatic aspects, the question then, is to know in what conditions the meeting of several paradigms can lead to the birth of a new paradigm.

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