TOWARDS LEAP-FROG INNOVATIONS IN A COATINGS CHAIN: A back-casting study in Portugal and the Netherlands

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ABSTRACT

The paint industry has been innovating towards more sustainable production processes, application, and end of life practices over the last couple of years. Driving forces were increasing government regulations as well as market pressures for better performances in the product chain. However, environmental pressures still exist, and new types of innovations (function and system innovations) are required in order to come closer to factor 20 sustainability challenges. This paper describes a research project applied on a supply chain involving metal polymeric coatings, with a particular focus on the automobile industry. It builds upon the experience obtained within the Dutch Sustainable Technological Development Programme, and an adapted version of the EU SusHouse R&D project methodology has been developed and applied within an industrial context in two countries, Portugal and the Netherlands. In a first stage of the project, current unsustainabilities have been identified in the polymeric coatings chain, and stakeholders have been brought together in creativity workshops, aiming at the generation of new socio-technical innovative ideas. From theses ideas three scenarios have been constructed, each with completely different characteristics, having been named: SusCoats (maximised ecoefficiency on coatings); Ever Lasting Surfaces (no coatings at all); and Going Incrementally. These scenarios have been developed in leap-frogs back from 2050, where for each three time horizons have been constructed. They are being discussed with experts and stakeholders both in individual workshops and in two back-casting sessions (November 2000; February 2001). The scenarios and the first results of the back-casting sessions will be presented at the Conference. Moreover, an adapted environmental life cycle assessment tool is being developed and will be presented, in order to estimate semi-quantitatively the environmental, and socio-economic effects of each scenario. Business opportunities for steps towards implementation, as well as necessary government incentives will be discussed.

Key words: system innovation, long-term planning, backcasting, scenarios, paint chain, stakeholders involvement.

1. INTRODUCTION

Companies are key actors in the shaping of technological transitions whenever market niche opportunities are identifiable. However, looking forward more sustainable production and consumption patterns, if innovation has to evolve by a factor of ten to twenty towards higher eco-efficiency levels, how do companies get involved in such levels of innovation ?

Industrial competitiveness is depending increasingly on players' learning capabilities and ability to innovate regarding: processes, products, structure organisation of activities and infrastructures. No prosperity will be possible without sustainability, therefore environmental and socio-economical issues are drivers to motivate a better performance. When addressing to Sustainable Development (SD), the innovation process is particularly complex and uncertain. Looking forward in particular to a more environmentally sustainable technology development, and the on-going increasing environmental pressure over industrial manufacturing systems requires changes in industrial production and consumption patterns that will require new pathways to be found out if industry is taking seriously the responsibility for the whole life cycle of their products. This changes should consist in effective answers through an eco-efficient supply, production and application of products, moving beyond current practices, to focus particularly on function innovations (same system concept, but performing better the same function) and system innovations (changing system concept design). However, this task can be a long and resource consuming process.

An important question currently formulated concerns the ways how to achieve SD. It is a process rather than a tangible outcome. Problem definition in the context of SD goes beyond the present regulatory process and, therefore, for most of the companies still is an indirect pressure today. Sustainability is basically a question of balance maintained over time. Definition of sustainability, as a concept, is widely related to the boundaries of the system (global, transboundary, regional, national, or local scale) or to a target economic activity (energy, industry, transport, agriculture, forestry, tourism). Sector specific approaches contribute to the overall effort. Basic assumption in this research deals with the unsustainability of current production and consumption of paints.

In general, product design is threatening to exceed the limits of the ecocapacity of the Earth. Based on a long-term view of more sustainable paths through function fulfilment by systems, say in 40 to 50 years from now, research activities and technological trajectories should be designed to direct innovations towards that long-term vision. Assuming the complexity and the requirements of the innovation process (most probably R&D intensive) to attain levels of ecoefficiency as high as 20, interim steps regarding short and middle-term activities within more evolutionary-like process should not be neglected.

This issue has a multi-criteria and multi-stakeholder nature, which is necessarily influencing the formulation of a range of operational challenges and implications, in particular within the design process. Long-term planning, scenario building making leaps in time, and participatory approaches, may be useful tools for planners to define and support a specific trend that should be shared by different stakeholder groups. It is useful as well to accelerate the process of systems design that fit to customers' needs. Moreover, assuming a life-cycle basis, this approach enables a reduction on production and environmental costs if a more sustainable design for environment will be used during planning and R&D stages. Finally, it should be stressed that this study has its basis on experimentative research, consisting into a learning process while being continuously implemented.

System innovations, because they involve complex changes, are more difficult to implement than incremental innovations. Moreover, scientific knowledge on systems innovation is limited. Technological change is performed by players within a defined S&T system.

However, existing knowledge on system innovations complemented by each national system of innovation (NSI) characteristics is hardly put into practice by actual stimuli from policy and decision-makers.

In fact, when considering a system design approach, the focus of interest has to centre in a wide array of needs and contexts of production and use, moving from single specific contexts. In current research, this means defining contexts of production and use within a more sustainable production and consumption of polymeric coatings for automotive equipment, which embraces several different specific contexts, either on the polymer or the application surface: i) Involving different materials (e.g. steel, aluminium, magnesium and plastics); and ii) Different car parts and components. Therefore, this action research methodology aims to contribute to make sustainability more tangible and, within a case study approach, looks forward breaking the boundaries of traditional coatings design approach.

2. FOCUS OF RESEARCH

Environmental issues are frequently complex in nature and, within a company context, they become gradually more technical, environmental and economical uncertain as the time horizon increases. It is also a fact that companies gauge their performance according to the ability of their investments to generate profits, so for SD goals it is necessary to question not only *what* should be done to solve long term problems (that will be structurally requiring), but also *who* (actors) should take action to prepare problem solving. Concerning the ‘who’ question within a company’s approach, there are two main perspectives: i) Horizontally covering common perceived problems in activities of various competing firms, promoting complementarity innovation potential; and ii) Vertically covering, regarding co-operation with suppliers and companies down the production chain, which could be promoted in one of two ways: 1) diverging environmental strategies, or 2) searching of particular high degrees of complementarity, that would result in the integration of problem solving activities within each cluster of firms involved.

The production of a methodological instrument focusing on long-term innovation issues, and having environmental sustainability as a driver, strongly impacts product design approaches and calls for the prioritisation of objectives in order to reduce uncertainty. As technological change is performed by players within a defined scientific and technological (S&T) system, the promotion of new pathways concerns then to motivations and barriers these players face in the system to innovate in certain directions.

Thus, this action research framework requires developments at different levels based on an interactive design process supported by a participatory methodology, including scenario construction and stakeholders involvement. The working method is characterised by three main elements:

(i) Addressing to long term pathways determine that short-term steps have to be taken;
(ii) Technological solutions form the approach starting point, but are viewed within the context of cultural and structural factors;
(iii) Solutions are agreed upon in consultation and co-operation with directly and indirectly involved parties.

In this context, within an integrated chain scope, current research aims to analyse conditions to stimulate and achieve the start up and implementation of strategic technology shifts to more sustainable technologies in industrial production and consumption, through a case oriented approach. The particular case of paint industry, like all scale-intensive sectors in general, manages environmental issues mainly by incremental approaches. However, it is crucial that products and processes are able to address to more sustainable patterns, in order to achieve significantly lower environmental impacts.

New problem definitions and new contexts of production and use, within a more environmentally sustainable production and consumption of polymeric coatings, offer key elements in the built up of new innovation networks and technological trajectories. It is important, therefore, to understand conditions that will enable and support long-term innovation, in order to stimulate the role of social networks to overcome such problem, clarifying subsequent uncertainties, values, knowledge, information needs in order to answer to interim pathways, that may lead to common platforms of support, identifying key actors and building their and other stakeholders commitment. Main hypothesis assumed in current research are the following: (i) Functions and systems have to be addressed in a more sustainable way, based on a strategic problem orientation, focusing on factor 20 eco-efficiency improvements on a time horizon of 50 years; (ii) A methodology for strategic innovation planning, integrating back-casting and scenario building, is an useful tool to be used in industrial contexts dealing with long-term innovation; (iii) Achieving a network of innovators (e.g. experts, researchers and non-researchers, scientists, engineers and non-engineers, financing people, government,…) sharing a problem definition is a key condition in designing shared action plans focusing on the shape of new innovative trajectories and flexible and result oriented co-operative ventures, to stimulate new research and development (R&D) settings, and demonstration/ pilot-scale projects.

This paper is addressing in particular to the following research questions:

- How to stimulate innovation in a scale intensive sector, to answer to SD goals on production and consumption ?
- Which areas in the product chain require changes on current trends, considering that co-operation and multidisciplinary approaches are needed with high risk of investments in long-term transitions ?
- Is it possible to enrol key actors in those predefined long-term issues ?
- Is the approach in redesign different between the two countries, and why ?

3. METHODOLOGY

The overall research goal on this subject is to understand in an industrial context, and for two national innovation systems (Portugal - PT; the Netherlands - NL), how to support the built up of new innovation networks and alternative technological trajectories addressing to a more environmental sustainable production and consumption of polymeric coatings. This exploratory research builds upon the experience obtained within the Dutch Sustainable Technology Development program (Vergragt & Jansen, 1993) and the EU SusHouse R&D project (Vergragt, 2000). It is being carried out in the particular industrial context of polymeric coating industry, which manages thousands of products covering different market segments. Due to research focus needs, it addresses in particular to the surface protection of industrial metal products like car (re)finishing. In 1998, this industrial sub-branch included 12 paint manufacturers in both countries, though currently it is reduced to 8 companies, as a result of merges and acquisitions. This selection was due to the relevance of car (re) finishing product, and process, related environmental stresses along the paint lifecycle.

In order to address the main research questions, the working methodology consisted, first in having insights about that selected product chain and main interested parties involved in the process, through interviews, empirical data, press releases and web pages. Afterwards, a conceptual model has been developed, based on target-oriented interviews with industrial stakeholders mainly (including the branch associations), and further elaborated by grounding on the following main concepts: strategic planning, scenario building, social networking, interaction and iteration between key actors, and national systems of innovation.

The model and its subsequent results are being tested in participatory approaches (meetings and workshops) – stage where we stand currently, and which is the goal of this paper.

After branch characterisation in each country, focusing on local industrial production capabilities, research problem orientation, goals definition and stakeholder identification/ enrolment were established. Product chain boundaries, environmental problems and main players were described in Partidário & Vergragt (2000A; 2000B). A survey addressed to the polymeric coating industry enabled to have the first insights on recent innovations, prevailing driving-forces, and existing motivations and barriers to improvement (Partidário & Vergragt, 1999). On a later stage, creativity workshops were performed, using different brainstorming levels, aiming at generating ideas for a sustainable function fulfilment in 2050. Based on those results (Partidário, 1999), future-images have been developed, that enabled afterwards to construct scenarios of new solution directions. Three scenarios are considered: *SusCoats* (environmental sustainability of paints and coatings), *EverLasting Surfaces* (no polymeric coatings at all), and *Going Incrementally* (business as usual), as firstly described in Partidário & Vergragt (2000B).

In a lifecycle perspective, considering different uncertainty sources (long-term addressed systems, technological mismatch, data availability), a streamlined 3D matrix methodology was developed to assess environmental and socio-economically the scenarios constructed, to gain insights and stimulate their discussion on possible environmental impacts, stakeholders acceptance, and economic consequences. Therefore, scenarios description and assessment results, are input material for a new workshop stage, where a second round of interaction and iteration with all stakeholders groups is performed. The main aim of this step is to develop an action plan and implementation streams. In a stepwise process, firstly a discussion and validation of scenarios' contents is promoted, followed by different discussion levels on their potential and possible improvements. That discussion enables to identify strong and weak points of each scenario, and possible improvement directions. Afterwards, a reflection is done about concrete strategies and projects by reasoning backwards from the future 'sketches' to the current situation. Finally, concrete shorter-term steps are defined and the required conditions characterised to implement the action plan.

4. RESULTS

4.1 Innovation patterns in the product chain

Interactions in the chain depend from the existing types of activities, in particular:

- Production of raw materials and resources (e.g. resins, solvents and pigments) by the chemical industry (e.g. Shell, Akzo, DSM, DuPont, ICI, Hoescht, BASF); Paint is made up of five groups of components: (i) binding agents (resins, cross linkers) for binding pigments and fillers, surface adhesion, hardness, gloss and elasticity, and resistance to external influences; (ii) solvents to dissolve binding agents, making it possible to actually work with the paint (the choice of solvent also has an effect on viscosity, vapour pressure and flow); (iii) Pigments (for the coating properties and colour); (iv) fillers as auxiliary pigment (they also help achieve the right degree of hardness, and thickness of the paint layer); (v) additives, such as drying accelerators, anti-foam agents, anti-crater agents, rheology enhancers and inhibitors.

- Paint production of intermediate and final goods performed in the same installations. Production processes consist basically on storing and mixing of resins, pigments and other substances (e.g. filler, biocides, drying agents, softeners, etc.) with organic solvents or other vehicles (which enable to fix properties like density, viscosity and vapour pressure), including dispersion or pre-dispersion operations, viscosity and tone adjustments, as well as the conditioning/ packaging of finished products; Each company has its own recipes that determine the special qualities of its product, although it is hardly possible to protect them from imitation. Services and direct contact with clients contribute to the creation of unique selling points.
- Applicators/ Users of coating processes. Paint shops and professional painters are the main users of paints. The most important industrial oriented market segments are steel construction companies, machine construction firms, the furniture industry, the car industry, the car refinishing business and the foodstuffs packaging industry. Automobile oriented, consists on any processes where there is the application of one or more layers of a continuous pelicule of coating on new vehicles, or finishing processes (repair, maintenance or decoration). Prior to coating application, also surface cleaning, at the applicator, should be referred because of its technical and environmental importance, being a processes based on different steps used to remove dirty materials from surfaces, namely oils and fats, or to remove used paint within re-coating activities.
- (Ultimate) Customers. In many cases have little to say in the choice of the paint to be used. However, the people that commission the work have the greatest influence on the kind of paint used.
- Final Consumers. They buy products that have been coated in one way or another. Therefore, the environmental aspects of the coating are mostly mixed up with other considerations concerning product quality. That is not the case, however, regarding the DIY sector, by obvious reasons, where they are directly involved with choices. Moreover, increasingly, consumers may want products that have certain properties that include less environmental impacts.
- Other parties involved. Other parties playing a part in the chain are wholesalers, transport companies, waste collectors, and waste processing companies.

Focusing on the innovation process at a company level, Utterback (1994) provided insights on the complex interaction of product and production technologies. It was supported on the recognition of need and on the means and encouragement to fulfil that need, not just considering technological innovation but considering as well the important interconnections between core competencies and organisational learning at changing rates, as the company moves within different development stages. In fact, innovations are social driven processes that depend from multiple conditions not only technical, but also cultural and structural. It is always the result of choices as a result of social processes inside and around the company (Vergragt *et al*,1992) by individuals and organisations. Cultural factors are strong determinants and difficult to influence. They concern perceptions and attitudes, lifestyles and believes. Structural factors concern economic (e.g. taxes) and organisational (e.g. establishment) aspects.

The shaping of innovation in the paint industry, and the ways technology is taken up, involve different roles and contributions along the chain due to different types of actors involved. Irwin *et al* (1994) emphasise how important is to technology dynamics the enrolment of key actors, within particular social networks, and niches, having shared problem definitions. Schot (1992) defines technological niche as a space (i.e. selection environment) where an innovation is temporarily protected. Thus, in social niches proactive actors test new technologies in practical situations. In a specific niche, the technology and its users have opportunity to adapt designs to users requirements and to learn about implementation and usage processes while users have opportunity to adapt their behaviours to the opportunities and limitations of the design (Vergragt & Noort, 1996).

Determining the attitude to innovate, each company is dependent on three main dimensions: (i) Internal and external motivations (regulations, costs reduction, image, market demands, strategy, stakeholders pressure e.g. government, pressure groups, other production chains, business networks, S&T network); (ii) Knowledge (learning effects on the organisation); and (iii) Interaction and power in the chain, within existing networks (vertical and horizontal relationships). Moreover, regarding enviromental oriented innovations, Cramer (1997) points out three important variables, when a company looks forward increasing eco-efficiency rates: (i)The coincidence of increased eco-efficiency and market opportunities; (ii) The internal structure and culture of the company (including the influence of a number of important actors in it); (iii) The pressure from the immediate and wider social environment to take environmental measures.

According to Pavitt's (1984) taxonomy of sectoral patterns of innovations, which defines the different types of innovative companies mainly in terms of its individual characteristics, the paint manufacturers are included in the scale-intensive sector, while suppliers of raw materials, strategic resources and equipment are science-based firms. On the other hand, paint applicators are supplier-dominated firms. Being supply chain specific, characteristics of the different innovating company types reveal interdependency and role-relations between the different actors. Table 1 represents an overview of the different groups involved.

Table 1 – Typical innovation patterns in the coatings chain

Type of Firm	**Type/ Role**					**Innovation Pattern**
	Suppliers	**Researchers**	**Users/ Applicators**	**Final Consumers**	**Regulators**	
Scale – intensive	Innovative	Supportive/ Innovative	Auto Industry and (re)Painters as clients	Customised niches	Passive	Supplier dependent
Science-based	Supportive	Innovative	Mixed	Anonymous	Passive	R&D dependent
Supplier dominated	Innovative	Supportive	Professional/ Anonymous consumers	Customised niches	Passive	Supplier dependent
Specialised Suppliers	Supportive	Supportive/ Innovative	Professional consumers	Anonymous	Passive	User-driven

Scale-intensive firms are usually market mature and have large-scale production facilities, and their customers are price-sensitive. Having in-house R&D focusing mainly on product applications and production troubleshooting, their main sources of innovation (product, process) depend from science-based suppliers, and the competitive relative advantages result mainly from achieving economies of scale, exploiting process secrecy and know-how from developing own process and product application technology, technical lags and patents.

Science-based firms are usually multinational firms that develop their competitive advantages on know-how and applied research, through an important R&D effort (in-house, university, government institutes) focusing on effective and potential developments of the underlying basic sciences. Process secrecy and know-how, patents and also the exploitation of economies of scale are important means as well to obtain competitive advantages.

Supplier-dominated firms are generally of small size and their in-house R&D and engineering capabilities are weak or unexistant, while own professional skills prevail. Users of painted equipment and material are price-sensitive. Competitive advantages of paint applicators is thus based on low technological diversification, on professional skills or issues like: aesthetic, design, trademarks and advertising.

Technological change in scale-intensive sectors, however, has been demonstrated (Pavitt, 1984; Tidd *et al*, 1997) to be increasingly difficult as production processes become more stable, due to incremental upgrading and higher investments. As such, answering to shifts needs, but requiring comparative modest change in the large and organised production systems, there is a request for evolutionary changes through add-on technology to incrementally extend, under short-term paybacks, the current life cycle of the production system. Following a typical technology life-cycle, at a certain stage and under certain conditions, process redesign becomes slower. Those conditions are in particular (i) technology improvements (e.g. scale advantages; costs reduction; better performance and application), and (ii) new market requirements, that are supported by the existing dynamic effects of scale, and by the accumulated competencies along the learning curve (particularly through learning by doing) within the existing production system. This behaviour will occur until enough adequate technical and cultural conditions may exist, to radically innovate in order to answer to new identified social needs. Therefore, very often the embedment of a technology, within a mature production system, hinders the implementation of breakthrough innovation.

At a micro-economic level, Ashford (1993) suggested four key organisational barriers to innovation, in order to explain a lack to improve environmental performance even where it may lead to economic benefit: i) Lack of information on the costs and benefits of environmental management; ii) Lack of confidence in the performance of new technologies and techniques; iii) Lack of managerial capacity and financial capital to deal with the transition costs of reorganising the production process; and iv) Lack of awareness of the long run benefits of environmental management resulting in low priority being assigned to environmental issues. As far as technical barriers are concerned, there is a range of technical barriers which limit the potential of environmental management initiatives over time. In fact, emphasis of environmental management initiatives that have been implemented in industry mainly addressed incrementally to process management. Thus, in this changing process, gradual adaptations on the existing production systems have prevailed.

Taking for instance cleaner production pathways in small and mid-sized companies (SMEs), they rarely promote revolutionary changes in the eco-efficiency of companies involved. Most cleaner production options reported are incremental innovations that can be classified as optimisations or redesign. Optimisation focuses on improving existing processes and does not essentially modify the system of production, but rather increases the efficiency of the system by making slight modifications (e.g. reducing heat losses, by better insulation). Redesign partly changes actual design of the existing processes, e.g. choosing to use materials that can be made suitable for reuse in the disposal stage, or that are less toxic. The system concept, thus remains basically unchanged.

Regarding design of new product specifications in SMEs is a highly limited process. It depends on company's degree of integration within the entire production chain, once companies with such size control only a small part of the product life cycle. A closer look at the motivations that are leading companies to currently implement cleaner technologies reveals several interesting factors. Costs are of primary importance, and cleaner technologies can be cost saving, once they can promote reductions e.g. on the consumption of resources, reductions on costs for safety, cleaning and on the replacement of remediation. Besides costs, companies concerned and committed to more environmentally friend practices emphasise their social responsibility, managing their public image as well.

Performance of polymeric coatings is highly dependent from their composition. General design criteria has different aspects. Regarding protection include: durability and protection against water, UV radiation, scratches and spots. Regarding decorative purposes include: colour, gloss and permanence. Concerning applicability include: flow, spread-ability, drying time, elasticity and hiding power. Finally, focusing increasingly on eco-efficiency issues, design criteria addresses in particular to reduction on pollution and resource use issues, within the main following areas:

- Consumption of non-renewable raw materials;
- Emissions from the production processes;
- Emissions from the application processes ;
- Waste management in all stages of paint life-cycle.

During the *application phase*, depending on the applicator system, paints release VOC to the atmosphere. Regarding a coated product, at the end of paint life-cycle, it is dumped or incinerated. Basically, the final result is that fossil hydrocarbons are transformed (completely or partially) in CO_2 and heavy metals (in pigments) are dragged with ashes (air and waste). Due to the fact that the type of paint most widely applied in metals coating has been the conventional wet paint with high organic solvent content, the paint shops are already aware of the pressure on the paint chain regarding the decrease of volatile organic solvents in paints. Development of product substitutes, such as water-based medium- and high-solid coatings, or powder coatings is not being reflected in the rate of adoption, which has been very slow. Most promising is the improved powder coating technology and the electrophoretic application of water-based paints which consequently require new investments.

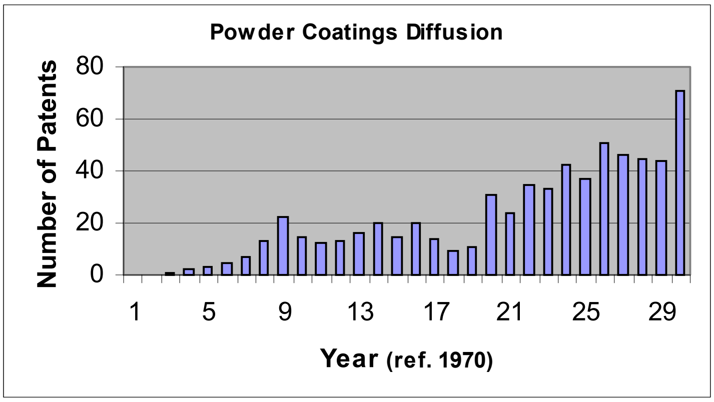


Fig. 1 – Powder coatings diffusion, based on a world wide patent research in Esp@ceNet database.

Powder coatings were introduced some 30 years ago, where the first patent registered dates from July 11st, 1972. Since then, this environmental friendly solvent-free technology exhibits an world wide annual growth as shown in Fig.1. This slow growth has been accompanied by a continuous development of raw materials, formulations and curing methods. Processing characteristics, application conditions and coating performance of powder coatings are most exclusively depending on the resin (Verkholantsev, 1998), i.e. on its composition, rheological, surface etc. properties in the form of resin melt, and on thermo-mechanical, adhesive, and other technical properties in the form of cured coating.

Another main issue in paint development is the reduction of heavy metals in pigments, including copper and zinc. Pigments with heavy metals are now excluded from the consumer markets. A ban has been issued only for cadmium, while the change over from other heavy metal pigments to organic pigments (in most cases) takes place on a voluntary basis. Main environmental measures addressed to Paint Shops concern: (i) Improvement of paint efficiency; (ii) Prevention of losses (pigments, paint, other chemicals e.g. heavy metals, and energy); (iii) Reduction of organic solvents; (iv) Cleaning of wastewater; (v) Cleaning of waste gases from furnaces.

Environmental sustainability is in fact an innovation driver. Moreover, taking into account the past experience regarding the dynamics of regulation e.g. EU Directive on Integrated Pollution Prevention and Control – IPPC (96/61/EC, from Sept. 24th), and proposed EU Directive on the Limitation of VOC emissions from certain industries which use organic solvents (97/C 99/02, from Feb. 18th), then product and process related environmental issues still can be expected to emerge as new drivers within the regulatory process. That perspective increases subsequently the emphasis on product-oriented holistic approaches, at function and system level, that might probably be supported by technology pathways that are not yet available.

On the other hand, the automotive industry is the largest industry in the world, and a powerful stakeholder in the paint chain. There is an estimate of 523000 million cars on Earth, and it is expected to achieve about 1 billion units by 2020-2030 (Champagne, 1998). Car creativity cycle (from the 1st idea, till serial production) is reducing from 4 to 2 years (also the car is being designed to have a shorter average life-time, though car buyers take performance and reliability for granted). Due to current cuts on production costs, and market saturation in the industrialised countries, the major global automotive companies are expanding into emerging economies. In fact, 85% of direct foreign investment in Asia, East/Central Europe, and Latin America comes from European, Japanese, USA and South Korean car manufacturers. The trend in the car chain has few suppliers providing systems or modules, instead of many suppliers furnishing components. Thus for car manufacturers, this means a transfer of responsibility and change of focus, obtaining services on a global scale.

Contrasting with the small amount of paint involved in an average car (4-5 L), which accounts after application for only about 3-4% on the overall cost of a new manufactured car, the painting function in car manufacturing is recognised to consume disproportionate energy. Depending on car size, it is ca 16% of total primary energy consumed in the overall car production process (Harsch *et al*, 1999). It also produces considerable pollution levels e.g. solvent emissions often exceed 10 Kg per car. This situation is still more absurd if we take into account that: (i) A paint facility, within a new automotive production plant, accounts for more than a third of the overall plant costs (Ryntz, 1999); (ii) Still more downstream the product chain, for individual mobility, there is a rather inefficient use of a private owned car in western societies, e.g. cars in NL are used daily only for about 72 minutes on average, therefore having not an intensive use, and occupying a lot of space in highways and parking places which are becoming increasingly scarce in crowded urban and suburban places (Meijkamp, 1998).

Trends in powder coatings exhibit in general a slow diffusion rate, as shown in figure 1, and in car industry it is not an exception. Tests with powder top coats are known since the early 1970s in US, epoxy based powder primer-surfaces in mid 1970s, epoxy-polyester based primer-surfacer, powder primer-surfacer at a (semi)industrial scale since 1982, or anti-chipping layers since early 1990's. Currently, research priorities for car industry are e.g. to replace car clear top coats with water based or powder coating based clear top coats, or low emission clear top coat on car bodies, and to define common specifications for powder anti-chip, primer-surfacer and black-out coatings.

4.2 Generating new solution directions

After problem orientation, and stakeholder identification/ enrolment, two stakeholder creativity workshops have been organised, in the Netherlands (April'99) and Portugal (Nov'99) respectively, aiming at generating ideas for a sustainable function fulfilment in 2050. Running a workshop, along a full day agenda, was useful within a process start up to identify ways for co-operation between key actors in each country. Moreover, the enrolment of stakeholders in networking, and subsequent shared solution directions, is an useful working basis for the construction and testing of normative scenarios. In the Netherlands, there was a medium level of stakeholder attendance to the workshop, where 18 people participated in the creativity sessions (>20 would be considered a good level), having a good distribution over the main stakeholders' groups coming from resins production, paint manufacturing, paint application and consumer's organisation, consultancy, research and government. In Portugal there was a low level of stakeholder attendance (8 people), with a moderate distribution once one stakeholder group (consumers) were not represented.

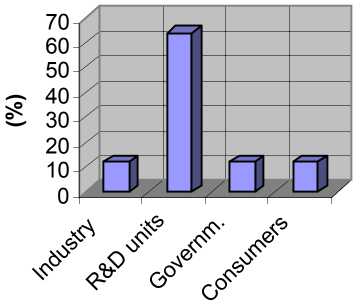


Fig. 2 – Composition, and level of attendance, in creativity workshop performed in NL.

In both NL and PT workshops, R&D groups were represented respectively by 61% and 50% of attendees, a slight unbalanced composition that was not just acceptable but desired, due to the need of achieving high technical content in the creativity process. A R&D oriented group composition, in the creative workshop session, is in fact an important condition towards credible long-term addressed ideas. Besides being particularly important to motivate each working group, due to the uncertainty of long-term focusing, it is also relevant when specifically concerns Portuguese NSI, where industrial innovation is typically characterised by incremental improvements mainly production process addressed. Another important condition for workshop success is the use of different levels of brainstorming, diverging and converging afterwards, where interaction and iteration is promoted both in plenary and subgroup formats. This proved as well to motivate and keep the stakeholders enrolled in the process regarding further activities.

At the end of the day, participants were asked to assess motivation within the process, and workshop usefulness. 99% of Dutch stakeholders wished to be kept involved in the networking (the only negative answer obtained regards a different business focus – truck oriented), whereas 100% of positive intentions were obtained from Portuguese stakeholders. In terms of workshop opportunities, the following issues were addressed: (i) Strategic information and dialogue; (ii) Networking; and (iii) Creation of new visions on future need fulfilment. Table 2 summarises stakeholders' evaluation of the creativity workshop performed in each country.

Table 2 - Stakeholders' evaluation of workshop opportunity (brief summary)

	Strategic information and dialogue		**Networking**		**Creation of new visions on future need fulfilment**		
	Useful	Not useful	Relevant	Neutral	Useful	Not useful	Neutral
Portugal	100	-	75	25	100	-	-
The Netherlands	85	15	92	8	62	23	15

From a more diverging brainstorming session, a main stream of ideas was registered and future directions identified e.g. foil technology; overprotection of surfaces and fitness of purpose; renewable materials on coatings production; thinner coat thickness; multifunction layers; no coatings by basic changes on surface materials; city without roads.

The filtering of those ideas generated resulted in the structuring of nine most inspiring clusters, with insights in-/out-side the product chain e.g. foil protection systems versus 'cities without roads'. Foils were considered having considerable priority on surface protection. Moreover, it is easier to focus on a foil than on the protected surface itself. Foil technology enable recycling, is flexible following fashion characteristics, and it is also easy to repair. On the other hand it will require consumer support, new designs and adequate logistics at body-shops, e.g. quick-fit stocks. The cluster 'city without roads', on the other hand, is addressing to a more holistic solution direction, requiring less individual transportation and mono-functional sources of traffic flows, but requiring new approaches to land use planning, transport policy and more sustainable urban development.

4.3 Scenario building

Scenarios should be ambitious but coherent sketches about the future, and particularly about the role the paint chain is expected to play in it. In this sense, they may contribute for a framework on promising system/ function design strategies. They may also contribute for niches having a long term potential to develop into key useful innovative technologies, products and more efficient and economic practices.

Clustered solution directions were derived from filtered ideas, which in turn resulted from the multi-actor interaction process. They enabled to develop three long-term oriented scenarios whose main characteristics are described on Table 3.

Those scenarios describe general atmospheres of future images, and each one focus on a set of changes, related products and services, that together enable to approach a more sustainable production and consumption of coatings though limiting the focus to automotive parts and components. The three long-term scenarios considered are the following: *SusCoats* (environmental sustainability of paints and coatings), *EverLasting Surfaces* (no polymeric coatings at all), and *Going Incrementally* (business as usual). Taking each long-

term scenario as a starting point, and moving backwards from 2050, three interim leap-frog jumps were also performed, though not fully represented here due to length limitations.
Finally, looking forward an evaluation stage, more insights about each narrative form are obtained through an environmental and socio-economically assessment process. Three main dimensions are used: environmental, economical and societal. Assessment results are then used as input starting points for further discussion about: (i) shared long-term goals, and subsequent backwards-like planning process; (ii) insights about interim development stages and operational conditions to be fulfilled, in order to achieve them.

Table 3 - Brief insights of constructed scenarios

1.Core idea: “SusCoats” scenario focus on the environmental sustainability of polymeric coatings for industrial products (e.g. cars), and on its functions as protection, aesthetics and/ or information carriers.
Main highlights (i) Breakthroughs are assumed; (ii) Highly consumer oriented production; (iii) Sustainable production and consumption of coatings; (iv) Full recyclability of coatings (e.g. foil systems); (v) Fitness for purpose; (vi) Product-Service integration; (vii) Reducing surface coating outside the chain; (viii) Changes on ownership concept and on consumption patterns.
Brief insights Y 2050 – 2025 : Highly customised services context, depending largely from internet with a 4-fold effect: The product life-cycle shortened; Production & liabilities costs reduced; Quick access to information (decision-taking); One-to-one marketing. In the automotive sector, cars are fully recyclable, and manufacturing and assembly processes have an higher level of integration within product chain. Transportation functions are service integrated and sold instead of cars. Car producers manage the all product life-cycle. In polymeric coatings industry, car coatings life time is designed to adjust to an easier application/ repairness, and the changing values outside the production chain, regarding product ownership and use, resulted in a deep shift from individual car use to public/shared transportation and non-polluting alternatives. Function and product developments enabled to achieve factor 20 in ecoefficiency (95% reduction, referred to 1998 levels). Reductions focused on components, structure, and system levels. Modifications on the coating life cycle are ecodesign based, from raw material supply (from C to Si based resins) to the coat end-of-life processing (recycling separately from the metal phase).

2. Core idea: “Ever Lasting Surfaces” scenario focus on the environmentally sustainable fitness for purpose of surfaces regarding industrial products (e.g. cars), with minimum needs (no polymeric coatings at all).
Main highlights: (i) Breakthroughs are assumed; (ii) Highly consumer oriented production; (iii) The minimalist fully recyclable metallic car; (iv) The plastic car 100% recyclable with flexible colouring; (v) Highly complementary intermodal transportation; (vi) The city without cars; (vii) Changes on ownership concept and on consumption patterns.
Brief insights Y 2050 – 2025 : Main context is a de-materialised society, highly internet based and new product-system requirements defining emerging market niches. There is a functional orientation near the consumer, instead of a delivered product. In-built energy and material efficiency in products are important items throughout product lifecycle. Car producers control car life cycle (100% recyclable, highly customised, based on metal/non-metal structures on the chassis and body, being not painted at all, but coloured with pigmented thermoplastic panels easily removable/ replaceable), and have a business portfolio where a hard product orientation is increasingly being replaced by transportation services. Transportation is based on cars being leased or rented; taxis (individually; shared) and multimodal public transport systems. The pattern of demand from car consumers looks for comfort, and to the easiest way to move from one place to another. Manufacturing have a higher level of integration with suppliers. Main existing strategies are the following: (a) The improved metallic car with minimum needs and no paints necessary (assumed a life-cycle duration of 8-10 years). (b) The plastic car based on advanced polymer application and built-in aesthetics. (c) The city without cars as an alternative for new transportation systems and reduction of traffic/space congestion. Factor 20 improvements on ecoefficiency were achieved (95% reduction, ref. 1998 levels) .

3. Core idea: “Going incrementally ... as usual !” scenario is trend following (business as usual), defining a base-line system where improvements addressing to industrial products (e.g. cars) are being achieved just by incremental innovation. So there is no room for radical innovation.
Main highlights: (i) Stepwise incremental changes are assumed; (ii) Increasing mass production; (iii) Enhancing SHE in coatings production; (iv) Pollution reduction at the source; (v) Increasing ecoefficiency in coatings production through the selection of low impact materials, and lower intensity on material/ energy

content on products; (vi) Introducing fitness for purpose; (vii) Reduce impacts during use; (viii) Optimisation of product end-of-life, and design for recycling.

Brief insights Y 2050 – 2025 : Higher functionality (use efficiency) of personalised products, supported quick manufacturing to customer specifications. For car industry, once this is a daily reallity, the challenge is to find ways of delivering niche products at affordable prices. This is requiring, on the other hand, a high level of integration with suppliers. De-materialisation initiatives are largely addressing to lower fuel consumption, and better process and cost reductions on recycling (product life cycle control) to control valuable materials/modules, but also a chain of higher value services on individual transportation (still increasing) where product-service integration is exhibiting barriers on values of ownership, or translating from hard product to service producers. In the paint industry, main strategies identified are: (a) Coatings fitness, and their use on metallic substrates (redesign on purpose). (b) Eco-efficiency improvements (powder and rad-cure coatings based), considering: b1) Use of low impact materials e.g. no solvents use; renewable materials; less colouring; b2) Reduce material intensity e.g. reduction of complexity on colours; de-complex coating systems; thinner layers on coatings (electrophoresis; plasma); fewer number and function integration on layers (nanotechnology); adding more functions to adhesives (information); coating before processing/ assembly; b3) Optimisation of production techniques; b4) Optimisation of distribution systems; b5) Reduction of impact during use e.g. lower consumption, few additional materials; b6) Optimisation of initial life-time e.g. increasing durability, reliability, adaptability, service repair, enable metal-based products not to require organic coatings any more (e.g. non-ferrous space frame constructions). b7) Optimisation of end-of-life system (e.g. reduce the amount of materials dispersed or lost by final dispersion, increasing the proportion of materials recovered, reused, re-manufacturing, and/ or recycled).

4.4 Scenario assessment

Methodology - An abridged 3D assessment methodology was developed on the basis of a matrix method as proposed by Graedel et al (1995), and Graedel (1998). It encompasses all stages of product life-cycle and uses experts' judgement, drawn from the integrated chain. It provides a relative numerical end point, supported by a numerical scale of relative judgement, supporting the building of an overall rating to measure (expected) improvements, enabling direct comparisons among related rated systems. It aims to give insights in strong and weak points of each scenario, and possible improvement directions. On the other hand, it avoids confidential information disclosure to external sources, and overspending resources, when compared with conventional LCA.

For each assessment dimension (environmental, economical, societal), impacts are assessed in five broad categories, representing comprehensive relevant concerns arrayed on a correspondent matrix, and a set of indicators and their structuring elements were also selected.

On the basis of a square array of elements, the matrix enables to array the five main life cycle stages on a vertical set (pre-manufacturing; manufacturing; product delivery; product use; waste management), against the five selected categories of concern on a horizontal set representing 5 indicators of that relevant assessment dimension, towards a more sustainable product performance. It results a 5x5 matrix representation, for a total of 25 elements, for each assessment dimension, that is used by the assessment panel group that has to assign scores for each category, at each life-cycle stage. In order to guide the assessment throughout the process, and reduce subjectivity, this process is supported by general guidelines that include rating criteria and a check list of 5 categories of indicators, used in each assessment dimension.

This 'participatory' analysis involves the calculation of a 'total value' index for each option (r_i), according to a multi-criterion assessment. The calculation results on a cumulative options' index score, where each matrix will have an overall rating of:

$$r_i = \Sigma S_{i,c} . W_c \quad ,$$

where the calculated score may vary : $0 \leq r_i$ (%) ≤ 100, if each element rating will have a score from the assessor to express the relative significance of one alternative over another, according to his judgement. That score is a value chosen from a scale varying between 0 (the worst, indicating highest impact) and 4 (the best, indicating lowest impact. Then, if the matrix score would increase, it would suggest a greater benefit having been achieved. This is a simple additive weighting model, summing the products of the scores $S_{i,c}$ of the performance of option i, under criterion c, and W_c the importance weighting of criterion c (e.g. 0-99%). This current approach, however, assumes that all selected criteria have the same weight.

The need for a broad functional unit should also be discussed. The functional unit, describing the function of the product under focus, and usually containing an amount/ time indication, is a key characteristic to enable comparisons between products, and to what extent/ proportion that is possible. While in a traditional life-cycle assessment of a product it is usual to know approximately how much product is used to fulfil a certain function, and the characteristics of the products, at a system level (and particularly focusing in mid-,long-term innovation) information about products or product-service systems have a high level of uncertainty (e.g. changes in consumers' behaviour), so a way to overcome this within each scenario is based on a broader functional unit that may be just a final product (e.g. a car; a coating) or a product-service (e.g. leasing, car sharing).

The set of indicators used was developed by analysing relevant sources available in this particular field of sustainability evaluation (Porter *et al*, 1980; Fiksel et al, 1999; Bennett & James, 1999). Selected indicators were grouped according to the three main sustainable technology development dimensions used in the assessment:

- *Environmental*: a) Materials use, and b) Energy consumption (those indicators track resource inputs, distinguishing the different life cycle stages); c) Solid wastes (tracks non-product outputs that may be submitted to recycling, treatment or disposal, differentiating the life cycle stages); d) Liquid emissions (tracks liquid pollutant releases, distinguishing the different life cycle stages); e) Gaseous emissions (tracks gas pollutant releases, including regional and global impacting agents, respectively e.g. acid rain, or ozone depletion, precursors).
- *Economical*: a) Direct (costs/ revenues; intangible assets); b) Potentially hidden (costs/ revenues); c) Contingencies (liabilities); d) Relationship (stakeholder, customer, public); e) Externalities (resources/ habitat).
- *Societal*: a) Community & Labour relations; b) Employment practices; c) Health & Safety; d) Ethical sourcing; e) Social impact of technology.

Results - Within this life cycle approach, a broad view of assessment outputs is represented in figure 3 (a-d), considering the case of a polymeric coating applied to generic average cars, as a functional unit. Scenario 0 (fig. 3d) was introduced, representing current situation. Scenario 1& 2 refer to breakthrough innovations, and Scenario 3 is trend-following.

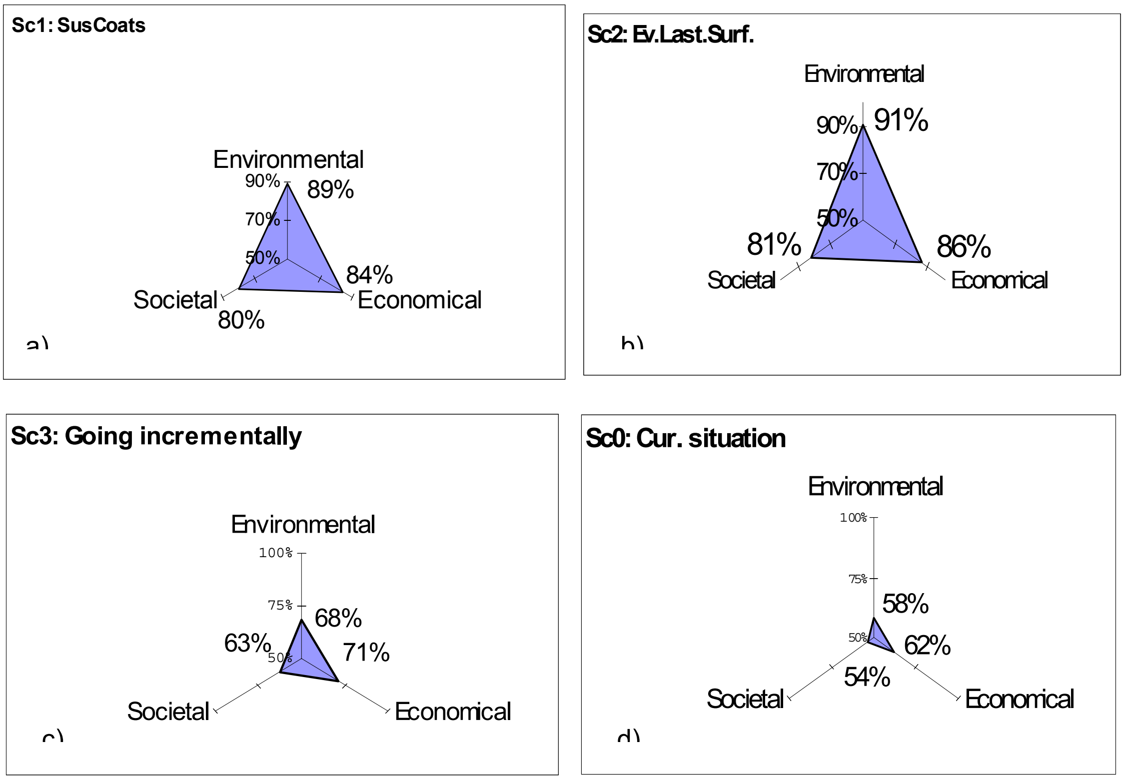
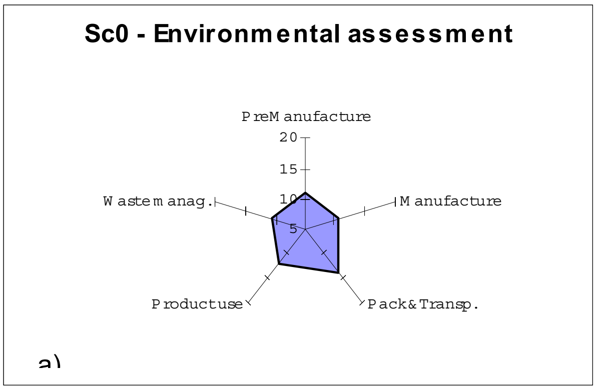


Fig. 3 – Environmental and socio-economic assessments for different innovation scenarios, addressing to a polymeric coating in average generic cars.

Considering e.g. current situation (scenario Sc0), the environmental and socio-economic assessments enable as well a comparative analysis of the relative relevance of the different life cycle stages on the specified assessment dimension, as represented in fig. 4. That analysis may also be performed to compare similar stages between scenarios. In each axe, the difference to full scale reflects the opportunity to perform new ecoefficiency improvements. If a comparative assessment is performed stressing on a specific environmental indicator along a life-cycle stage, it is also possible to compare eco-efficiency oriented improvements already implemented (or expected on Scenarios 1,2 & 3) on the basis of a full score of 20 in each column, and its relevance for each stage.



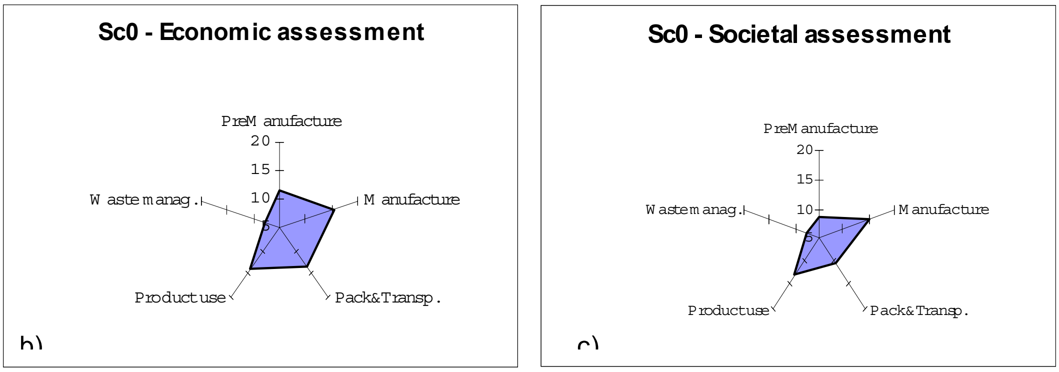


Fig. 4 – Scenario assessments from a) to c) with emphasis on the different lifecycle stages.

4.5 Long-term oriented action plan - Scenario Validation and Implementation

Finally, scenarios' description and assessment results, are inputs for a new workshop stage where a second round of interaction and iteration with all stakeholders groups is performed. The aim is to discuss and validate scenarios' contents, their potential and possible improvements, and finally to reflect about concrete strategies and projects by reasoning backwards from the future 'sketches' to the current situation, and finally defining necessary shorter-term steps and conditions for implementation.

Co-operation is used as a key issue, and back-casting as an approach to stimulate working backwards iteratively. First results obtained in one workshop already performed in the Netherlands (Nov. 10th, 2000) are reported during this paper presentation, referring the finds on how can it be possible to perform an identified plan, and which tools would be required. Within this series, another workshop is being prepared to be performed (Feb.12, 2001) in Portugal.

4.6 The national systems of innovation

An useful platform for the application of this study is the concept of national system of innovation (NSI). It enables to have insights at a country level, about the systems' ability to support and improve the efficient functioning of procedures for distribution and utilisation of knowledge (i.e. by improving transfer, transformation and access to the stock of existing knowledge - not necessarily limited to flows of scientific and technological knowledge). Therefore the broad concept of NSI pays attention at the network of innovations in the countries. In this concept, elements of a system of innovation are described on a meso- and macro-level e.g. economic, social, institutional sub-systems. This is in line with the level of aggregation required to make the analysis of function and system innovations, particularly within the analysis for conditions to support the innovation diffusion stage.

The concept of 'national system of innovation' was introduced by Freeman (1987) as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies...". Freeman's approach centres around the actors involved in the NSI. These could include a wide variety of organisations such as companies, research centres, government innovation bodies, intermediaries, etcetera. This NSI approach is subsequently used as a frame work for analysis in the comparison of nations, so in the frame of current research it is used to structure and interpret empirical findings and have insights to clarify how differences of approach in the two countries (policies; regional and cultural conditions) can be explained.

The importance companies give in Portugal to broaden product portfolio, or product replacement, is lower than the EU average. This conclusion is also in line with the basic characteristic of Portuguese companies to address mainly to incremental innovation. Also, the larger the company is, the higher is the chance of involvement in innovation activities, specially if performing in a high-, mid-level technological intensity branch (e.g. electric & electronic equipment, optics, chemical industry, rubber and plastic industries). Analysing the ratio between innovation expenditure (% business volume) and innovation performance (% innovative companies), it is possible to comparatively conclude regarding resources application efficiency that the Netherlands has three times more innovation in business activity than Portugal, having twice as the Portuguese investment level on innovation.

Considering the environmentally oriented framework, the first Dutch Environmental Policy Plan (NEPP) dates from 1989, while $NEPP_4$ is expected at end 2000. The Dutch approach gives a great emphasis on collective action. Continuing evolution of the environmental regulatory system from a traditional command and control system to a hybrid system, eventually driving to a predominantly voluntary agreement system, can be seen as a long-term integrated regulatory reform goal. It is a comprehensive strategy for sustainable development that explores the economics and social concerns of maintaining an adequate balance with environmental and resource issues.

In Portugal, a National Plan for Environmental Policy recognises since 1995 the need to accomplish both economic growth and a more sustainable use of environment and resources, assuming different levels of approach: local, regional and global. A relevant transition is currently under way from a command-and-control approach, to cleaner production/ ecoefficiency, voluntary instruments implementation, like environmental agreements (with direct involvement of branch associations), EMAS and eco-labelling. Examples of that transition can be illustrated in Portugal through: a) Programs sponsored by the Portuguese Ministry of Economic Affairs (MEcon), e.g. POE – Programa Operacional para a Economia, that adopts ecoefficiency as a concept on business excellency; b) PROSET regional project "Towards Sustainable Production in Setúbal Region", promoted by Portuguese MEcon (Pedip II, 2000); c) Participating on the European Eco-Efficiency Initiative (EEEI) recently created, also promoted by Portuguese MEcon; d) National surveys on wastes, and industrial wastes, promoted by the Portuguese Ministry of Environment, and focusing particularly on prevention and recycling.

5. CONCLUSIONS

Basic assumption for this research is the non-sustainability of current production and consumption practices regarding paints. Different actors were successfully enrolled from the universe of stakeholders, within the product chain, contributing for the generation of filtered ideas that were used afterwards in scenario building. New solution directions were designed and assessed, and are currently being tested about their coherence and social acceptance. From the existing empirical findings, the following main conclusions may be drawn:

- It is possible to enrol key actors in predefined long-term issues, but attention must be given to the structuring of (sub)networks in the action plan, due to differences of strategies and culture of involved parties;
- Redesign approaches should have the same technical basis in both countries, though business acceptance is strongly conditioned by individual strategies at a NSI level, and by availability of resources, not to compromise companies competitiveness particularly from scale intensive sectors;
- Implementation conditions are still complex to define due to multiple factors; conditions for implementation will be under research in the next working stage;
- Different areas were already identified to perform an action plan; however, according to the methodology, one more workshop has to be performed before focusing on conditions for an implementation stage.

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