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Economic foresight study on industrial trends and the research needed to support the competitiveness of European industry around 2025

Final report

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EXECUTIVE SUMMARY

Nanosciences, nanotechnologies, materials and new production technologies (NMP) have the potential to contribute significantly to the move of Europe from a resource-intensive economy to a knowledge-intensive economy. They will lead to new applications, new business models, new products, new production patterns, new services, new processes, substitution of resources, higher material and energy efficiency and changes in technological competitiveness. These effects may bring along significant growth of value added, employment or trade balance in the European industry. E.g. new job opportunities will be provided, existing jobs will be protected, but also some may disappear through substitution.

While there are high expectations in positive economic impacts of NMP technologies, only few information about the concrete potential drivers, impact mechanisms, quantitative effects on growth and potential differences between sectors is available. Hence, the main goal of the study is to provide insights to the potential impact of NMP and related industrial trends on the competitiveness of the European industry as well as the related current and prospective drivers which shape these impacts. Therefore, the study aims to elaborate and present qualitative and quantitative prospective scenarios considering the expected positioning and potential of the European industry in those areas where research in NMP is expected to make an impact. The key objectives of the study are:

- to identify the key factors which influenced positively or negatively economic competitiveness during the last 20 years (past trends),
- to analyse the influence of key factors and trends on crucial economic and NMP-specific aspects to assess the role of NMP under this framework around 2025 (future trends),[1]
- to elaborate and use a quantitative model based on the main past quantitative and qualitative key factors and derive different future scenarios around 2025 (economic model),
- and to assess the European position and critical parameters likely to affect the competitiveness of the European industry around 2025 in order to derive recommendations on technologies, research and policies needed to maintain or improve the European position (recommendations based on qualitative analyses and quantitative model).

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1 Please note, that the economic analysis is not focused directly on the impact of European FP7 research theme “Nanosciences, Nanotechnologies, Materials and New Production Technologies" but to general deployment of NMP products and applications.

Past and future NMP trends and signals

A wide range of factors determine the competitiveness of the European industry today. They embrace productive use and availability of resources, technological progress and innovation, commercialisation, demand, framework conditions and regulation. The importance of these factors will probably continue in the future, but the underlying challenges for society and policy may change, e.g. driven by a growing instability or uncertainty of resource prices and availability, more intensive global competition in high-tech industries and for high-skilled personnel through the rise of emerging countries. Similarly innovation and deployment of NMP in the European industry is affected by related factors. In this study, trends and signals for NMP as mostly generic technologies are discussed on an overall level and in more-depth for six industrial sectors being impacted by NMP (chemicals, pharmaceuticals, electronics, photonics/optics/instruments, automotive and machinery). Past and future NMP trends and key factors for competitiveness can be identified in the following fields or categories:

Resources: There has been an exploitive use of natural resources in the past and shortages, more difficult access and/or increasing materials as well as energy prices are expected in the future. NMP has the potential to increase resource efficiency by reducing the use of (critical) resources (e.g. by nano), substitute (critical) material (e.g. limited, toxic) and re-use strategic relevant resources e.g. by means of closed-loop production (life cycle, recycling) in the future. Especially high value materials are needed in particular in the chemicals sector. Also, the electronics and photonics sectors make use of strategic materials like Indium (e.g. as ITO in display technology or thin film CIGS in photovoltaics). Especially, if there is a need for a large amount of resources and the access to them might be critical (e.g. rare earth elements in China, Cobalt for lithium-ion batteries in the Congo, etc.), alternative technologies with substitute materials will gain importance (e.g. graphene to substitute the ITO conductive coating). According to expert assessments NMP may also contribute significantly to an increase in energy efficiency in some energy intensive sectors in the future (e.g. chemicals). With respect to human resources, in the past there has been a decline of researchers specialising in key areas directly linked to NMP. Therefore, human capital could be a restricting factor to the NMP development in the future and will likely gain importance.

Innovation: International competitiveness in NMP-technologies is decisive to gain the related economic benefits. This requires a strong research base fuelling the innovative ideas of tomorrow. Europe has been strong in NMP-funding, built-up of R&D networks clusters, and platforms in the past. In terms of NMP patents, Europe has a global share of around 40%. These shares are varying from sector to sector, in machinery, photonics/instruments and automotive they reach even around 50%. The patent analyses over time indicate that, whereas in all analysed sectors the number of NMP patents has increased since the late 1990s, there has been a world wide stagnation and downturn in recent years. For all sectors a peak can be observed in the dynamics with a decline in strength of patent applications beginning with 2000 or later (depending on the specific sector). The overall interpretation is, that there is a cyclical long-term behaviour of

NMP as has been observed, for example, for the case of nanotechnology already (Schmoch/Thielmann 2012). For the future, a new increase of patent activities would be expected, related to maturing NMP technologies and accompanied commercialisation of NMP-products in the different sectors.

Commercialisation: However, for early NMP applications there is still a gap in Europe between basic knowledge generation, innovative R&D and the subsequent production and commercialisation of the knowledge in marketable and requested products across sectors. This is reflected by often still moderate firm creation (e.g. compared to the USA), underdeveloped NMP production infrastructures like pilot lines or production facilities for upscaling from laboratory levels to the industrial scale. Moreover, there is a need for stronger integration of related (partly new or still unformed) value chains. Regarding economic impact, NMP applications and products may substitute existing products and value chains but also new markets may be created, which extend the total demand in the economy. Unsurprisingly, there is a great variation between the various NMP applications. Altogether, there is potential for Europe especially in high-tech-related and high-knowledge intensive production processes in the future.

Demand: There is an increasing demand of the consumer and society for safe and environmental friendly technologies, which often correlates with the need for substitution of (critical or toxic) materials in chemicals as well as electronics and photonics. This finally impacts the machinery and automotive sectors. However, potential impacts of nanotechnology on environment, health, safety (EHS) have been discussed widely, since there is a wide-spread concern of potential negative effects from nanotechnology. In some sectors (e.g. chemicals or the bio and pharma sector) there is a more pronounced sensibility, when using the term nanotechnology, as an early mishap associated with nanotechnology could eventually terminate technology funding and demand abruptly.

Quantitative results for economic impact of NMP

In order to assess the economic impact related to NMP technologies quantitatively, we elaborate an econometric model for the last 15-25 years. We use the estimated structural equations based on quantitative data for the past 15-25 years (by separate countries as well as by separate sectors and the whole manufacturing sector) to simulate the potential future developments in three different scenarios (optimistic, neutral, pessimistic) regarding the deployment of NMP on value added, export shares and employment. The scenario assumptions are based on expert assessments and proved consistence with the qualitative NMP trends.

In all sectors considered the employment and value added would increase in the optimistic scenario compared to the business-as-usual scenario, only the net effects on export shares are less clear. However, the overall notion of considerable economic impact of NMP does not provide directly a justification for policy intervention (as e.g. it may very well be the case that private actors might be able to realise this potential alone) and neither an indication of which policy instruments should be preferred, as innovation policy may take a broad variety of different forms (such as taxes, subsidies, intellectual property rights, education). Such specific types of policy usually cannot be captured explicitly in simulation models. However, we derive some key results and messages out of our econometric results for the past, the scenario simulations and the sensitivity analyses, which provide some hints for the direction of possible policy interventions. It has to be emphasised that positive results for NMP patents and capital stocks should not be interpreted in a way that these are the main aspects to concentrate on, but they are proxy indicators in our model for innovation (e.g. innovative R&D), commercialisation and production (linked to industrial competitiveness) related to NMP. On this basis, the following results can be interpreted as following:

- NMP technologies affect the economy **via a number of impact mechanisms** and may have significant positive impact **across many industrial sectors** in the future. These results point to the importance of actions, which take into account the whole innovation system across sectors and do not focus on single sectors or single activities only (such as R&D).

- **NMP patents** affect the majority of sectors and countries **positively**, partially also a positive impact of international spillovers[2] can be observed. As patents can be interpreted as a proxy indicator for output of applied research and development activities, these results may imply that keeping and even increasing the level of NMP-related R&D activities and related support measures would be beneficial also from an economic perspective.

[2] International spillovers indicate that the exploitation of the global knowledge base is important for the domestic economic development. This highlights the need for close links to the global knowledge base.

- The increase of **capital stock is the most important factor** to realise the economic potential of NMP. Hence, activities to raise capital investments in Europe are decisive. The determinants for investments in a given country are usually manifold. Respective policy measures should address the specific weakness of the innovation system.
- **Increasing material and energy efficiency** tends to result in economic growth and jobs. Hence, efforts to improve resource efficiency via NMP technologies are not only positive for the environment, but may most likely also for the economy. An efficient use of resources will be more and more important for industrial competitiveness.

While some of these conclusions may appear intuitively, the potential merit of this study is that they have been derived on a well-founded quantitative empirical basis. Moreover, the findings of the qualitative analyses on NMP trends and signals are in line and fit very good with the outcomes of the economic model: There is an increasing need for material and energy efficient technologies, for better commercialisation and built up of production in critical industries as well as for demand-oriented “green” products for the society/consumers within Europe. In particular, the indications of a cyclical long-term behaviour of NMP patents with a double boom calls for further support of innovation policy, despite the decline of patenting. The focus may shift to overcome potentials valley-of-deaths and backing commercialisation activities. Similarly, in the economic model, especially capital investments (e.g. for production infrastructures) but also material and energy efficiency in industrial sectors have been shown by the model to positively influence employment, value added and hence the European competitiveness.

This provides additional justification for policy actions and even points out more concretely the system weaknesses, on which policy should concentrate. Among others, key issues are the capabilities and the needed focus to commercially exploit technological knowledge in NMP, the lack of demand for innovative (sometimes more costly) NMP products, or the uncertainty of stable access to resources. Hence, to realise the economic potential of NMP and to contribute to other societal needs (“Grand Challenges”), strategic actions of the stakeholders across the innovation chain are needed.

Recommendations

While international competitiveness can only be achieved by industry itself, policy may provide adequate support. It is these support measures, where we particularly focus on. These actions are not all directly linked to the Common Strategic Framework (CSF) but address a wider set of policies. We propose a mixed policy approach with mostly cross-cutting issues for NMP and some measures, which are specified on a sectoral or value chain level. The proposed policy measures encompass issues of availability of resources, innovative capabilities, commercialisation of innovation, demand for innovative products and regulation and are in line and consistent with our findings in the quantitative and qualitative analyses:

Natural resources policy: A comprehensive natural resources policy is crucial to open up new application fields for NMP and to ensure a stable supply of NMP products and processes. Such policy would comprise e.g. ensuring the access to raw materials and energy at international level, fostering sustainable supply from European sources and boosting overall resource efficiency and promoting recycling.

Ensure availability of adequate skills in NMP: A continuous monitoring of the pace and size of extra demand for skilled personnel depending on new developments in industrial technologies should be conducted (Gelderblom et al. 2012). In addition, companies should further develop this role by a well-developed personnel policy in terms of internal function mobility, specific training and regular feedback, interest in S&T should be stimulated at a young age; and the interaction between companies and educational institutions should be improved.

Rebalance R&D-programmes to "innovation funding": The dominant funding model for R&D in the CSF and EU Member States is challenged from different directions. On the one hand, there is a strong plea to align research more directly to industry needs. On the other hand solely industry focused research programmes would lead to a decline of basic research projects as their direct present value is much smaller than the long-term value. Both rationales are well founded and appropriate. Thus a rebalance of R&D-programmes to a more integrative innovation funding would be adequate in such way that one part clearly addresses frontier science and blue sky research and the other part uses modified R&D definitions to support crossing the valley-of-death on the basis of the three pillar bridge model (see below).

Redefinition of R&D on the basis of new criteria: Concerning the funding of more applied innovation activities, the High Level Expert Group on Key Enabling Technologies (KETs)[3] proposes a three pillar bridge model to support crossing the so-called 'valley of death'[4] between research, technologies and marketable products. The

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3 N, M and P are three of the six defined KETs by the European Commission.

4 The notion "Valley of Death" is connected to road between the discoveries from basic research to market products and describes the funding gap at the intermediary stage.

role of policy would be to fund not just research, but also pilot lines, demonstration plants and support globally competitive manufacturing capabilities. This would imply an adjustment of R&D definitions in funding programmes which support the full and simultaneous implementation of the three pillar bridge model along the innovation chain

Feedback loops between R&D and demand/societal challenges: The innovation process in NMP is non-linear and the demand side needs to be integrated adequately. For that purpose a stronger alignment of R&D to market demand and societal needs is crucial. One issue might be to address the KETs (including NMP) explicitly in the Grand Challenges of the CSF in the Horizon 2020 programme, which is not obvious in the current plans. Another issue is the closer exchange between R&D results and market needs. Experts express a strong need for a study aiming at mapping the readiness of NMP R&D activities with respect to the market and also with respect to their integration into production processes.

Stronger integration of value chains: Stronger integrative value chains considering the key stakeholders are very important. Value chains are getting more complex and diverse and especially SMEs do not have the capacities to run projects for all value chains and to keep an overview of compatible research by possible partners. For a building-up of integrated value chains oriented towards a specific challenge, Public Private Partnerships (PPPs) are considered to be a promising approach. In the FP7 three PPPs (Factories of the future; Energy efficient buildings; Green cars) have been launched with a significant part of NMP-budget. In overall, this approach is appreciated by the stakeholders and further initiatives are requested. However, the adequate participation of enabling technologies and the respective industries (e.g. materials industry using NMP technologies) has to be ensured. One suggestion might be to enrich such initiatives by horizontal activities focussing on enabling technologies.

Exploitation of research results within the EU**:** In order to realise most of the economic benefits resulting from emerging technologies domestically, activities to exploit the results of R&D projects in commercial products and manufacturing within the EU should be intensified. There is no easy solution for this challenge but there are different starting points such as fostering the absorptive capabilities of the European industry by funding programmes for small and (in particular) medium-sized companies. One proposition by the High-Level Expert Group for Key Enabling Technologies is to adjust criteria and rules for participation in the CSF (e.g. concerning licensing, clear IP-plans). However, one should not push this idea to far.

Participation in global value chains**:** A funding system, which focuses intensively on those value chains which are still mostly located in Europe, might have a too narrow focus and miss the opportunities of successful participation in global value chains. Hence, policy should also adapt strategies for those activities, in which Europe is present only in niches or some steps in global value chains. Related measures may include the international collaboration in research as well as concerning foreign direct investment.

Redefinition of state aid*:* A related aspect to the rebalance of government support across the innovation chain is the adaption of adapt state aid regulations to facilitate RDI activities and large-scale investment. Presently, the European state aid control highly limits and regulates possible government support in Member States for technologies and industries. There are different proposition for adaptations, e.g. the introduction of a matching clause for investment incentives, higher maximum aid intensities in connection with additional criteria in the balance test or an increased funding from EU budgets. But, all of these options to adapt state aid control should be conducted very carefully and not hollow out the principle aims of the control, which can be considered as useful for competition and innovation.

Foster regional clusters**:** For the deployment of NMP across Europe the regional perspective may be fruitful, as geographic proximity still matters for innovation and commercialisation. A major step is taken forward in the new regulations of DG Regio concerning smart specialisation, which is prioritising KETs. An additional step could be to implement mechanisms supporting innovative regional structures along the innovation chain in a limited number of excellence centres in Europe by integrating all available European Commission mechanisms on a regional level (structural funds, general infrastructure, research facilities, etc.) (Oxford Research 2012).

Foster demand-side policies**:** While some challenges and hindrances to implement demand-side innovation policy exist (e.g. difficulties in inter-departmental co-ordination, some scepticism towards certain type of measures) it can still be considered as useful and powerful to foster market entry and diffusion of emerging technologies. NMP may benefit indirectly from such measures, as its applications are used in many different innovative value chains, which may be subject to demand-side policies (e.g. green public procurement, supports for the use of electric vehicles).

Dialogue about chances and risks of nanotechnology-based applications and products**:** Despite the partly negative acceptance of nanotechnology, there is a (strong) plea for keeping the term nanotechnology alive. Rather, an open and proactive attitude should be adopted in order to communicate and discuss nanotechnology with the public. The actions should include a balanced and factual dialogue on opportunities and risks of nanotechnology-based applications and products, the integration of EHS issues into product design, an understandable bundling of existing research results for stakeholders and identification of sectoral specificities and key EHS risks.

1 INTRODUCTION

Background

Nanosciences, nanotechnologies, materials and new production technologies (NMP) have the potential to contribute significantly to the move of Europe from a resource-intensive economy to a knowledge-intensive economy. They will lead to new applications, new business models, new products, new production patterns, new services, new processes, substitution of resources, higher material efficiency and changes in technological competitiveness. Products based on NMP often serve as inputs of great value added that are integrated into more complex products. Consequently, new sectors may emerge and traditional sectors are transformed. This may result in significant impact of NMP on the trade balance, growth or employment of a country. E.g. new job opportunities will be provided, existing jobs will be protected, but also that some may disappear through substitution. Of course the deployment of these industrial technologies and the resulting economic impact differs from sector to sector.

It is the core objective of the European FP7 research theme “Nanosciences, Nanotechnologies, Materials and New Production Technologies" (also referred to as ‘industrial technologies’) are to improve the competitiveness of European industry and generate the knowledge needed to transform it from a resource-intensive to a knowledge-intensive industry.[5] Strengthening this competitiveness is aimed for by generating ‘step changes’ in a wide range of sectors that can profit from these technologies and by implementing decisive knowledge into new product and process innovations.

But while NMP technologies are considered to have a positive impact on competiveness, growth and jobs, hardly any information about the concrete potential drivers, impact mechanisms, magnitude of effects and potential differences between sectors is available. Mostly the information consists only in form of very general statements of the importance of NMP or some indications concerning gross employment related to nanotechnology. A detailed analysis of impact mechanisms and in particular quantitative analysis of the economic impact of NMP, which considers the positive and potential negative impacts via substitution of existing jobs by emerging technologies, is missing yet. However, such an analysis is challenging as it has to integrate information about the heterogeneous, rapidly changing NMP technologies in an economic model. Such a model has to consider main economic interdependencies combined with a forward looking perspective by catching mayor economic trends as well as trends, signals and bottlenecks for NMP to provide policy relevant conclusions.

Objectives of the study

The main goal of the study is to provide insights about the potential impact of NMP on the competitiveness of the European industry as well as the related current and

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[5] http://cordis.europa.eu/fp7/co-operation/nanotechnology_en.html.

prospective drivers which shape these impacts. Therefore, the study aims to elaborate and present qualitative and quantitative prospective scenarios considering the expected positioning and potential of the European industry in those areas where research in nanotechnologies, materials and new production technologies (NMP) is expected to make an impact. The key objectives of the study are:

- to identify the key factors which influenced positively or negatively economic competitiveness during the last 20 years,
- to analyse the influence of key factors and trends on crucial economic and NMP-specific aspects to assess the role of NMP under this framework around 2025,[6]
- to elaborate and use a quantitative model based on the main past quantitative and qualitative key factors and derive different future scenarios around 2025,
- and to assess the European position and critical parameters likely to affect the competitiveness of EU industry around 2025 in order to derive recommendations on technologies, research and policies needed to maintain or improve the European position.

As these objectives cover broad and high-ambitious issues, it is important to stress also the boundaries of this study. While this study has a clear forward-looking character, it is not aim of the study to build up a strategic vision for the NMP-related industry in 2025; e.g. to analyse all needed actions to transform to a sustainable manufacturing.

These boundaries have some major implications for our study. The elaborated scenarios concentrate on some key issues regarding the deployment and impact of NMP, since the focus of the related model simulations is in particular the difference in economic development (closely) related to NMP. However, as from the foresight perspective they do not reflect general alternative futures (e.g. in terms of globalisation). Similarly, the recommendations are not focused not an explicitly-formulated vision for the manufacturing sector. Rather, we take the goals/vision of Europe 2020 as given and analyse the adjustment of the common policy tools in order to improve industrial competitiveness.

Methodology of study

Our study approach consists of two pillars, which are closely combined to ensure consistency.

On the one hand our approach has a rather qualitative character to assess the key economic and NMP-related drivers for competitiveness in the past and future. We assess the main potential paths and bottlenecks for NMP and its effects via different impact mechanisms. This analysis serves as input for the scenario and to draw well-founded recommendations for policy and other stakeholders.

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6 Please note, that the economic analysis is not focused directly on the impact of European FP7 research theme "Nanosciences, Nanotechnologies, Materials and New Production Technologies" but to general deployment of NMP products and applications.

On the other hand we conduct a quantitative analysis regarding the economic impacts of NMP. For that purpose, a specific econometric model is elaborated for this study. This model allows incorporating specific technological impact transmission channels of NMP as well as economic interdependencies. We estimate and calibrate the model with data of the past. Then we elaborate three scenarios regarding the deployment and impact of NMP and conduct model simulations and sensitivity analysis. The chosen model variables for the model and the scenario parameters are derived on the basis of our qualitative analysis. The resulting model simulations allow drawing general conclusions and are closely related to our concrete policy recommendations.

The analysis level in this study is twofold. We analyse the total manufacturing sector to derive general results but also conduct a more in depth review for key industries (chemicals, etc.), as such a level of granularity is the most appropriate for the economic impact analysis.

Structure of Report

The report is structured as follows:

Chapter 2 focuses on past and future trends concerning overall drivers for the economic competitiveness of the European industry and more specifically for the field of NMP. A short delineation of NMP and a critical synthesis of the main literature and expert opinions in workshops and interviews regarding trends, signals and main bottlenecks for NMP are provided.

Chapter 3 describes the main economic impact mechanisms of NMP and assesses the respective relevance for key industrial sectors.

Chapter 4 presents the quantitative results for the socio-economic impact related to NMP. A brief characterisation of the econometric model is provided and key results of the model regressions of the past are presented. Then, the elaboration of three scenarios regarding the deployment and impact of NMP as well as the scenario simulations with this model are presented.

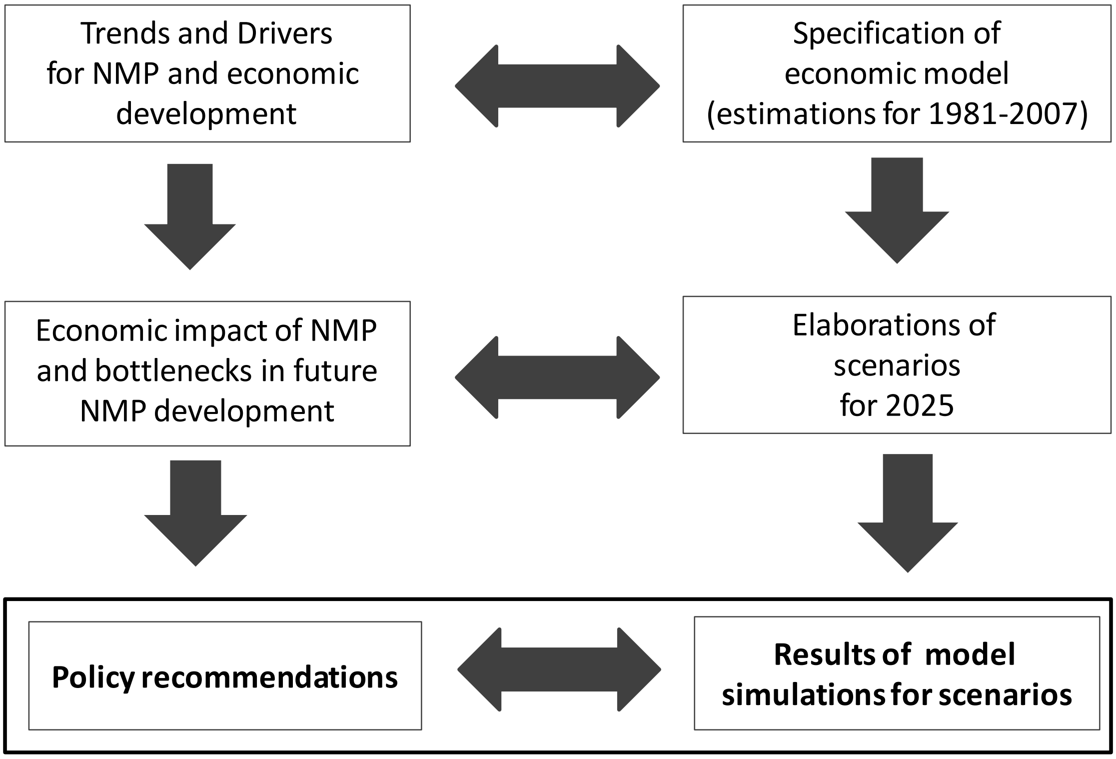
Chapter 5 comprises a brief conclusion concerning the economic relevance of NMP and need for action. A number of recommendations in order to foster the economic competiveness of the European industry related to NMP are given.

Annex 1 contains some additional results and sensitivity analyses of the scenario simulations with the economic model.

Annex 2 contains a detailed a description of the methodology. It also addresses problems encountered, solutions implemented and its impact on final results.

Figure 1-1 summarises the approach. The detailed methodology is presented in Annex 2.

Figure 1-1: Steps in the analysis



Source: Fraunhofer ISI

2 NMP TRENDS AND SIGNALS

2.1 Factors for economic competitiveness

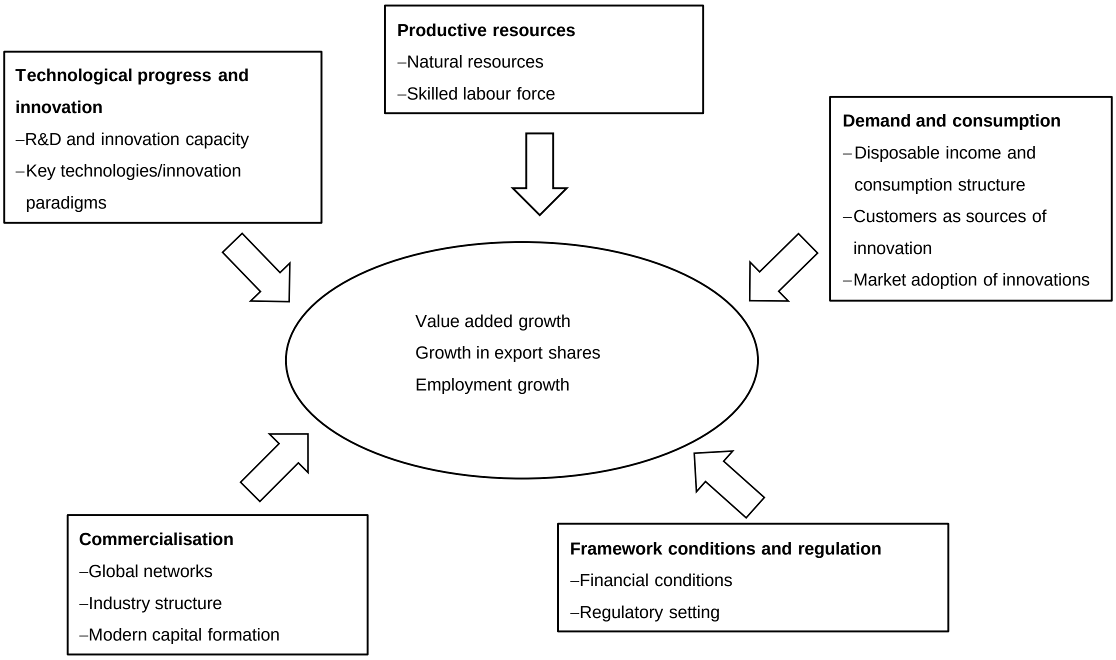
It is not possible to predict the contribution of specific technologies to economic development, as the outcome is highly dependent on the interplay of technologies with other factors. Consequently the impact of NMP on industrial competiveness cannot be analysed independently, but has to consider other factors as well. Hence, in this chapter, firstly a short discussion of main trends in the past and future, which are decisive for competitiveness, are presented. As it is not possible to study the entire corpus of literature relating to the economic impacts and determinants of technology, we point out the most important aspects in relation to NMP.

The objective of this chapter is to provide a critical synthesis of the main literature on past trends as well as foresight literature, like prospective views on economic and industrial trends. The survey should serve as background for the economic model and capture the relevant framework conditions for the development of NMP and for realising its economic potential. The following questions are addressed:

- Which are the important drivers for competitiveness to be considered in the economic model?
- What are potential developments/trends that are crucial for the scenarios?
- Is it to be expected that crucial trend breaks take place in the future compared to the past (e.g. is the economic impact of future technologies expected to be very different from the past impact of the information economy)?
- Are there key differences between the NMP-relevant sectors?

Existing literature identifies a wide range of determinants of competitiveness of EU industry. In this study, we use a modified framework and differentiate between 12 different factors in five categories (Figure 2-1).

Figure 2-1: Competitiveness factors



Source: Fraunhofer ISI (modifications based on EC 2009a)

For all these factors the respective impact of competiveness as well as the main past and future trends have been analysed. This survey serves as basis for the choice of scenario parameters and variables for the econometric model. While it would be to extensive to explain all trends in detail in this report,[7] this section presents four drivers[8] (natural resources, R&D and innovations activities, modern capital formation, demand and consumption), which have mostly direct relevance for the future evolution of NMP in Europe and illustrate the analyses in this study. All identified key past and future trends are shortly described in table Table 2-3 at the end of this section. In addition some overall findings concerning the stability of trends etc. are summarised in boxes.

Natural resources

No industrial production process is thinkable without the use of raw materials. All industrial activity starts by extracting natural resources and then assembles them in different ways to add economic value, while using energy and generating waste along the chain (JRC 2010). Many resources are affected by potential supply problems, which

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7 A detailed analysis has been presented in the first deliverable of the project.

8 For the following illustration demand and consumption as well as modern capital formation aspects of several drivers are combined.

could increase costs and limit production possibilities (Faroult 2009).[9] Estimating future changes in availability and supply at least of non-energy resources is extremely difficult due to the wide variety of products, which vary strongly in potential supply, regulation and so on. Hence, the scarcity of non-energy resources is controversially debated among experts. The discussion has been going on for several decades, starting with the 'limits to growth' debate, and remains without conclusion (Montalvo et al. 2006). One potential important factor for Europe is the feared increase of protectionism of resource-based countries, like the export restriction of China on rare-earth metals (OECD 2010a).

Whatever the prices will be in the future, the uncertainty about prices and stability of supply will increase efforts to raise resource productivity. In the past, growth in productivity of material resources and energy in the EU was significantly slower than growth in the productivity of labour energy productivity. While labour productivity rose by more than 150% between 1970 and 2006, material productivity rose by 100% and energy efficiency by 50%. Probably, a main driving force has been the relative pricing of these three inputs and the prevailing tax regimes, which make labour more expensive and has led to a focus on labour costs (Bleischwitz 2010). This could change in future, as the pressure on higher efficiency will rise,[10] due to the increasing costs share of materials and uncertainty of stable supply. Moreover, according to Bleischwitz (2010) the traditional assumption that restricted supply of natural resources has negative impacts on growth could be reversed. Instead, particular resource-poor regions may benefit from increasing resource productivity, as import dependencies and costs to purchase commodities will decrease and probably also innovation activities will rise (Bleischwitz 2010). But still, several barriers for material efficiency have to be overcome (Rennings/Rammer 2009), like the relatively low awareness among companies to pursue material efficiency. This low awareness partly relates to the lack of detection or attribution of the material costs to processes and workflows. Moreover, at an international level material leakage and advanced process innovation in order to close the loops in global chains remain challenges especially for end-of-life stages of consumer goods (Bleischwitz 2010).

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9 Already in the past decade prices soared well above inflation, although the related turbulences on the commodity market are less caused by the exhaustion of natural resources, but resulted from an imbalance between supply and demand in the short-term (Angerer et al. 2009). The misjudgement of the market goes back to a stormy on the development of Chinese economy and it triggered boom in commodity demand, which was unexpected for many market participants. Second, the misconception is due to anticipated technical developments in time (Angerer et al. 2009).

10 E.g. in German manufacturing the share of material costs at the gross production value rose to 46% in 2008 from 38% in 1993, while the share of labour costs declined from about 24% to 19%.

Box 1: Is there empirical evidence for the importance of the selected factors?

A wide range of studies have analysed the importance of the various factors on economic growth or competitiveness (e.g. OECD 2003, 2004, 2011, EC 2009a, Fagerberg 2007, Hämäläinen 2003). The studies differ widely in their input variables (e.g. capital, ICT-related variables, demand variables, institutional factors) and output variables (TFP growth, value added, exports, etc.) and model specifications. Important for this study is a general agreement that innovation and technological change appear to have strong and pervasive effects on virtually every aspect of the economy (Cave et al. 2009). In most studies, variables that do not rely on a specific technology, but variables like R&D expenditure, (technology neutral) patenting or indicators from innovation survey (e.g. share of firms with product innovation in a sector) have been used. In studies with technology-specific results, the focus has been mostly on ICT. For other cross-sectional technologies like biotechnology, nanotechnology or environmental technologies far fewer empirical results exist. These technologies have mostly been addressed in model simulations similar to the current study. These studies point out, that a range of different economic impact mechanisms of technologies have to be considered. All in all net production and employment effects of emerging technologies are rather limited e.g. Walz 2011, Wydra 2011a, Nusser et al. 2007, IPTS 2002). Complementing qualitative assessments show, that the impact may mainly arise from the protection of existing jobs and value added in manufacturing sectors.

R&D and innovation activities

R&D and innovation capacity are key determinants of technological innovation and hence for growth and productivity. While the role of R&D for innovation and competitiveness has been appreciated for a long time, the emphasis of the importance of innovation capacity has risen especially in the last two decades. The varying degrees of capacity to distribute knowledge have been identified as one factor for country differences in respect to innovation and growth (OECD 2009b).

However, total R&D intensity in the EU stagnated in the last years and reached the level of 1.85% in 2009 (OECD 2010b) and is significantly lacking behind the sustained commitment to R&D in Japan and the United States. Similar results can be observed in surveys with a wider range of innovation indicators, e.g. in the European Scoreboard a significant gap remains between the EU27 and these two other countries. In addition, East Asian countries are catching up, with China at the forefront. Not only grew Chinese government expenditure on R&D from 0.65% to 1.54% of GDP between 1998 and 2008, but also the business expenditure on R&D. It almost rose by the ten-fold in the same period (OECD 2010b).

It can be expected that the world wide distribution of R&D and innovation activities will continue. Hence, on the one hand the world wide innovation potential will rise, by creating opportunities for developing new or improved, products or processes. But on the other hand from a European perspective the importance of R&D locations will shift more and more in an easterly direction. Moreover, the need for broader fiscal consolidation may put pressure on the ability of some European governments to maintain their investment in R&D and innovation in the medium-term. Some countries have cut already cut their annual budget provisions for R&D and tertiary education (OECD 2010c). This reduces resources for public research and private R&D activities in the short term, and could lead to declines in the human resources being available for innovation in the long-term. However, some other countries (e.g. Austria, Germany, Korea, United States) have recently increased investment in public research and human resources, in order to improve future innovation and growth prospects.

In regard to the structure of R&D and innovation activities much effort is put into addressing the societal challenges. A number of complex, intertwined challenges put pressure on policy makers and societies to change established patterns of production, consumption and interaction. There are different definitions for the so-called grand challenges, the current list of the European Commission contains:

- health, demographic change and wellbeing;
- food security, sustainable agriculture, marine and maritime research and the bio-economy;
- secure, clean and efficient energy;
- smart, green and integrated transport;
- climate action, resource efficiency and raw materials;
- inclusive, innovative and secure societies.

A review of the OECD (2010b) concerning priorities in research and innovation policy in various countries highlights the increasing focus on societal challenges. Related R&D policies have become increasingly articulated (JRC 2009).

Box 2: Can it be expected that crucial trend breaks take place in the future compared to the past?

Taken as a whole the importance of factors like resources, R&D, demand or regulations will probably continue in the future. Also the underlying megatrends like globalisation, climate change, demographical change have begun in the past and will continue (partly more intensive). But of course the framework conditions in Europe and other parts of the world may change. The rising state debts will it make more difficult to provide the necessary infrastructure and continue R&D promotion at the same or higher level. Moreover, the underlying challenges for society and policy may change. One example might be the supply and demand of high-skilled workers. While the overall causations of demand and supply of workers are expected to continue in the future, such as international competition, trade or demographics, the consequences may differ. E.g. an increasing pressure on high skill jobs in the future due to globalisation and international trade is thinkable.

These trends have several important implications in the context of our study. First, the structural equations for the variables (e.g. capital) in our econometric model tested with past data might be a fair approximation for the future, as e.g. the importance of the factors probably persists. But, secondly, the challenges behind may significantly differ from the past and have to be reflected in the policy recommendations. Thirdly, the high uncertainty for many factors implies a high variety of parameter values in the scenarios.

Modern capital formation

Capital formation increases production capacity and contribute to the competitiveness of firms and sectors by improving labour productivity (EC 2009a). Capital goods usually incorporate new technology knowledge, innovation and intangibles (e.g. software) into the production process and hence facilitate change and reorganisation. Especially in capital intensive industries the diffusion of new materials and technologies is dependent on new investments. The respective sectoral speed of diffusion depends on the length of investment and product cycles in the industries. In sectors with long investment and product cycles amortisation periods are usually long. This importance of capital formation does not apply only for private investment, but also for investments in infrastructure (e.g. telecommunication, energy, traffic). They are increasingly assessed to have positive productive effect on the economy (OECD 2010b).

Trends in investment can be described by the investment ratio that is defined as the ratio of gross fixed capital formation (GFCF) to value added. The main sectoral aggregates show a slowdown in investment since the end of the 1990s. This trend appears to have stabilised for the most sectors. However recent data for 2006-2009 on a slightly different country basis indicate again a decline (EC 2011a).

Table 2–1: EU-21 investment ratio in 1995-2006

Sector	1995	2000	2006
Agriculture and forestry	0.29	0.27	0.38
Fishing	0.20	0.18	0.19
Mining and quarrying	0.26	0.15	0.23
Manufacturing	0.19	0.18	0.15
Food, drinks and tobacco	0.23	0.19	0.16
Textiles and clothing	0.16	0.14	0.13
Leather and footwear	0.11	0.12	0.10
Wood and wood products	0.19	0.21	0.17
Pulp, paper and publishing	0.19	0.18	0.18
Refined petroleum	0.34	0.24	0.28
Chemicals	0.20	0.19	0.16
Rubber and plastics	0.21	0.20	0.18
Non-metallic mineral products	0.23	0.20	0.21
Basic metals and metal products	0.17	0.17	0.15
Machinery n.e.c.	0.14	0.12	0.11
Electrical and optical equipment	0.16	0.18	0.15
Transport equipment	0.27	0.23	0.19
Other manufacturing	0.15	0.14	0.13
Electricity, gas and water supply	0.48	0.39	0.35
Construction	0.09	0.09	0.09
Wholesale and retail trade	0.14	0.13	0.11

Hotels and restaurants	0.16	0.15	0.14
Transport and communication	0.36	0.37	0.34
Financial intermediation	0.16	0.17	0.12
Real estate and business activities	0.54	0.41	0.42
Public administration	0.32	0.24	0.23
Education	0.12	0.09	0.08
Health and social work	0.14	0.11	0.12
Other services	0.32	0.27	0.26
Total	0.24	0.23	0.23

Source: EC 2009b

For the future, a continuation of the high pressure for the EU as location for private investments is likely due to fierce international competition and related industrial policies. There are frequent concerns, that the EU may have certain disadvantages compared to emerging countries, like more stagnant markets, lower returns on investments due to a combination of relatively high production costs because of regulation, changing regional balance in manufacturing in customers sectors, and the absence of advantaged feedstock (EAG 2009). Moreover, a recent "global revival of industrial policy" (Economist 2010) can be observed. Reasons for this revival are the weak state of the world economy, the aim of some countries (e.g. US, UK) to rebalance their economies towards a higher share of manufacturing, the prospects of generating value added and employment with leadership in emerging technologies (like clean technologies, etc.) and the response of the western countries to the apparently successful policies of fast-growing economies, like China and South Korea (Economist 2010). How successful these interventions will actually be, is an open question, as there were a lot of negative examples of such policies in the past (Lerner 2010).

Box 3: Are there key differences between the NMP-relevant sectors?

Unsurprisingly, factors such as resources, innovation, demand, commercialisation as well as macroeconomic conditions and regulation are of high importance for all sectors.[11] However, some characteristics differ:

- NMP is connected with different technological paradigms and technologies in the various sectors (e.g. electric mobility in the automotive sector);
- the main types of demand (intermediates, investment, final consumption) differ considerably between the sectors; while e.g. automotive is at the end of the value chain and close to private consumption, investments are a main demand driver for machinery;
- relevant types of regulations significantly differ (e.g. importance of standards, regulation of prices, environmental regulations).

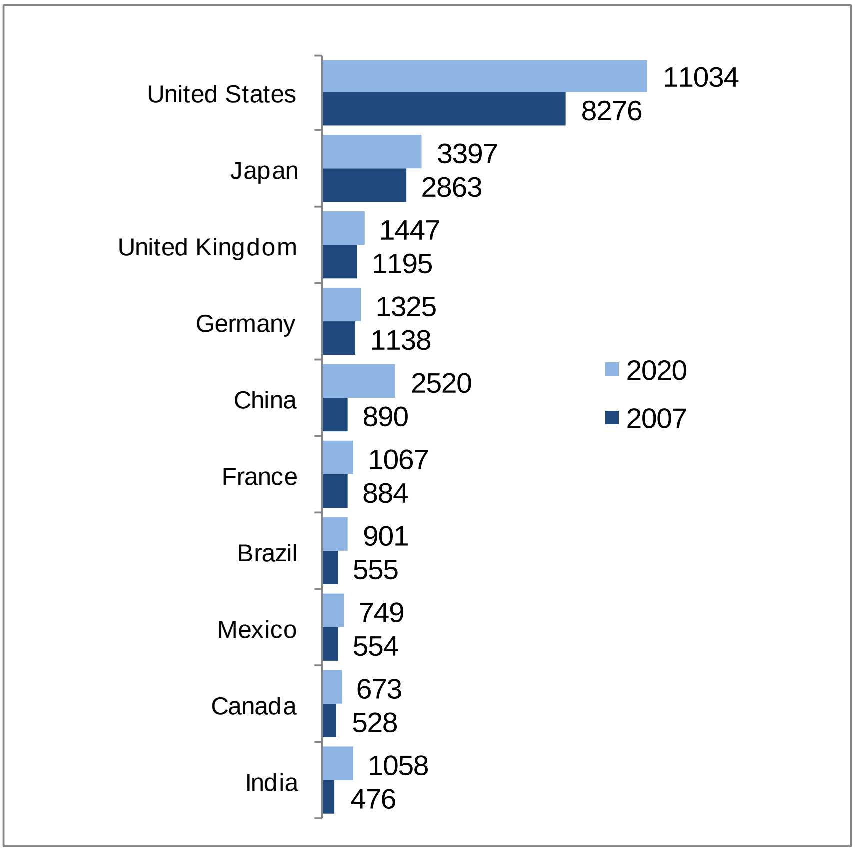
Demand and consumption

Demand side factors profoundly influence the magnitude of output and profit generated by enterprises. Even most efficiently produced goods and services will fail, if there is no adequate demand. The total possible end-market for a given sector consists of consumer expenditures, investment spending, government spending, and net exports, as well as the demand for intermediate goods (EC 2009a). As consumption expenditures have the highest share of end demand in overall terms and are a main component on structural change we will especially focus on this category.

Consumption trends are strongly related to income and growth level (Montalvo et al. 2006). Concerning the shares of worldwide final consumption Europe and USA still dominate, but some countries like China are steadily gaining more significance (Figure 2-2).

[11] Also on a more detailed level, there are very few exceptions, such as the minor importance of the availability of natural resources for the pharmaceutical industry.

Figure 2-2: Private consumption in 2007 and 2020 (in bn US$)



Source: McKinsey (2010)

With a further expected population increase over 1 billion in 2025 the world will face unprecedented challenges during the next two decades (Faroult 2009). While 97% of the increase will take place in developing countries, the active population of many developed countries will decrease. Therefore new regions will progressively represent sources of dynamism and growth (Faroult 2009). One implication might be that the rich world loses its leadership in terms of breakthrough ideas that transform industries. The continuing growth of consumption in emerging-markets not only challenges companies to adapt products to different preferences and budget constraints; it also challenges them to develop products designed specifically for emerging-market needs and to market them in new ways (OECD 2010c, The Economist 2010). Moreover, the ability of the emerging countries to offer established products for dramatically lower costs grows: examples are US$3,000 cars and US$300 laptops which promise to change people's lives (Economist 2010). This sort of advance is sometimes named “frugal innovation”. It is not only a matter of exploiting cheap labour, but relies on redesigning products and entire business processes to cut out unnecessary costs.

Table 2-2: Summary of past and future economic trends

Category	Factors	Past trends	Future trends and drivers
Resources	Natural resources	Energy prices have increased significantly in the past; material prices have been stable for a long time, but have been increasing in the last 10 years; growth in the productivity of material resources in the EU has been significantly slower than labour productivity growth	For energy and for some materials supply shortages as well as prices are expected to rise and resource productivity will gain importance. Uncertain drivers that could enforce this trends are growth in demand in developing countries, protectionism of supply and energy taxation
	Skilled labour force	Continuous improvement in the share of high skilled workers in the EU and a widening in wage differentials and unemployment among unskilled workers	Overall causations (attractiveness for migrants, demographics, globalisation, new job opportunities) are expected to continue, but the consequences may differ
Technological progress and innovation	R&D and innovation capacity	Stagnation of EU R&D intensity in the last years	Efforts to increase R&D in Europe will probably be kept up, but faced with various challenges as catching-up of emerging countries continues, difficult macroeconomic conditions arise and the aim of addressing societal challenges
	Key technologies/innovation paradigms	ICT Revolution, gradual evolution of bio, nano, etc.	Various emerging and maturing technologies, but respective developments are uncertain and economic impact will largely depend on technological leadership
Commercialisation	Modern capital formation	Slowdown in investment ratio since the end of the 1990s	High pressure for EU as location for private investments due to fierce international competition and related industrial policies. Sufficiency of public

Category	Factors	Past trends	Future trends and drivers
			investments in infrastructure are uncertain due to financial constraints
	Global networks	Internationalisation of R&D and manufacturing with partly changing objectives	Likely continuity of trends, but also possible scenarios of stagnation of globalisation
	Industry structure	Renewed role of SMEs and entrepreneurship	Further development is largely influenced by institutional setting (e.g. recognition of entrepreneurship, policy support, regulation)
Demand and consumption	Market adoption of innovations	Highly different adoption rates between innovations; multiple barriers for diffusion (regulation etc.)	Diffusion of many innovations increasingly dependent on demand-side innovation policies, especially those related to grand challenges (no easy uptake in markets)
	Disposable income and consumption structure	Shares of worldwide final consumption have changed significantly; EU consumption is growing fastest in less essential categories of goods and services	The worldwide and European consumption structure will depend heavily on the large increase of the world-wide middle class, developments in inequality, demographic change, future preferences and kind of consumption
	Customers as sources of innovation	User-centric innovation become more important through new possibilities; emerging importance of Lead-Markets concept	Continuity of trend is likely, challenges to cope with innovation in emerging markets or individualisation of consumption arise
Framework conditions and regulation	Financial conditions	Increasing liberalisation until financial crisis; increasing imbalances in mid-term; increased government intervention in short-term	Future arrangement of international regulations for financing are of crucial importance; diverse scenarios concerning multilarism/ nationalisation are possible

Category	Factors	Past trends	Future trends and drivers
	Regulatory setting	Significant reforms in product markets	Future arrangement of international regulations are of crucial importance; diverse scenarios concerning multilarism/nationalisation are possible

In European Member States and other developed countries ageing will influence the level and structure of individual consumption behaviour (OECD 2005). Although, OECD research concludes that ageing-induced changes in consumption shares are not expected to generate major structural changes in the economy in the next decades, the expected shifts can have at least moderate consequences for sectoral consumption (OECD 2005). Other possible trends may concern the changing kind of consumption and requirements concerning the products. For example, TNO (2007) summarises that in future there will be more demand for time-saving and convenient products, and that the products and services have to be entertained in a variety of ways and need to reflect self-identity of individuals and groups (e.g. by branding, labelling). One way to cope with these challenges might be to integrate design as an important building block in innovation. "Design is seen as a way of identifying and solving user problems by, for example, studying users or by involving them through visualisation and participatory design techniques such as co-creation" (EC 2009c, p.18). One example for an instrument that becomes increasingly popular and helps to involve the user at all stages of the research, development and innovation process are Living labs (EC 2009c).

2.2 Overall NMP trends

2.2.1 Definition and description of NMP

The NMP area is delineated as follows[12]:

- **Nanosciences and nanotechnologies** – studying phenomena and manipulation of matter at the nanoscale and developing nanotechnologies leading to the manufacturing of new products and services.
- **(Advanced) Materials** – using the knowledge of nanotechnologies and biotechnologies for new products and processes.
- **New production** – creating conditions for continuous innovation and for developing generic production "assets" (technologies, organisation and production facilities as well as human resources), while meeting safety and environmental requirements.

12 http://cordis.europa.eu/fp7/co-operation/nanotechnology_en.html.

- **Integration of (NMP) technologies** for industrial applications – focussing on new technologies, materials and applications to address the needs identified by the different European technology platforms.

Advanced industrial technologies refer to those industrial processes, from design to production, requiring a high level of applied scientific knowledge. This is generally the case with industries dealing with new products or inputs (such as nanotechnology, new materials, biotechnologies or new sources of energy) or with innovative ways of production. NMPs are part of advanced industrial technologies. The focus of this study is on NMP technologies however, and not on advanced industrial technologies as a whole. Accordingly, information and communication technologies, biotechnology, optics/ photonics and other advanced technologies not covered by NMP will and cannot be considered.

NMP includes areas of science, research and industry concerned with nanosciences and nanotechnologies, materials and manufacturing and production. These may cover not only new industrial sectors but also traditional sectors of activity as long as new materials and production techniques or nanosciences and nanotechnologies are applied. In the following we will give a brief overview on these fields.

Nanotechnology and nanosciences are often referred to as "key" or "enabling" since they can pervade almost all technological sectors and accordingly are expected to influence almost all industries in the 21st century. Examples include medical applications (e.g. miniaturised diagnostics or drug delivery devices), information technology (e.g. data storage media), energy production and storage (e.g. novel fuel cells), manufacturing (e.g. new concepts for bottom-up constructing based on self assembly), instrumentation (e.g. new tools such as the Scanning Tunnelling Microscope for atom-scale analyses), and environmental applications (e.g. new remediation approaches based on photo-catalytic techniques). Accordingly, nanotechnology is seen as one of the most important fields of innovation and technology today.

Applications in nanotechnologies typically build upon the new and special features and functions of nanomaterials and -structures, in particular due to the enhanced surface to volume ratio, which can lead to products, methods or tools in the electronics, information and communication, optics, medical techniques or many other sectors. Thus, nanotechnology does not constitute a product per se but is typically present and integrated in a large variety of different applications in a large number of industrial sectors. It therefore rather has to be understood as enabler of innovative technologies and applications by substituting and improving existing products or leading to fundamentally new products.

Advances in nanotechnologies are expected to develop into mass markets in the coming years, with new products and services capable of enhancing human health, while also conserving resources and protecting the environment.[13]

However, focused European-level research and technological innovation is essential to master the properties of matter that can only be understood and controlled at the nano-scale and make the assembly of nano-elements possible that could lead to new functional, mechanical and other characteristics. New attitudes, world-class infrastructures and interdisciplinary skills are essential to underpin the potential nanotechnology revolution.[14]

New or advanced materials play a key role for the further development of a number of important industrial sectors including the chemical industry, automotive, metals and others. Accordingly, the number of employees directly or indirectly concerned with the results of materials research is large. In general, materials are used at various sides of the value chain for different purposes. Therefore, materials research is faced with a broad spectrum of different problems calling for solutions, which among others lead to rather long development times for new materials. Not surprisingly, there is a strong interest in future trends in materials research.

Materials can enable industrial and commercial success for both existing and not-yet existing products and processes: they may introduce new functionalities and improved properties adding value to existing products and processes, thus representing an invisible revolution; at the same time, the engineered production of materials by design might allow the development of products and processes under a really sustainable systemic approach.[15]

Materials research can be presented starting from the materials themselves (e.g. biomaterials, metals, polymers) or the industrial sector (e.g. metallurgy, chemistry) or their applications (e.g. energy, health, transport) as well through other approaches. Materials profit from a wide range of scientific disciplines, such as chemistry, physics, biology and engineering, as well as from all available technologies and multidisciplinary approaches, like nanotechnology and biotechnology. This is why several European funding initiatives support materials research within the structure of the EU 7th Framework Programme (e.g. research on materials for specific applications in energy can be also funded under Theme 4 ENERGY, according to the public call for proposals)

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13 http://ec.europa.eu/research/industrial_technologies/nanoscience-and-technologies_en.html.

14 http://ec.europa.eu/research/industrial_technologies/nanoscience-and-technologies_en.html.

15 http://ec.europa.eu/research/industrial_technologies/materials_en.html.

as well as with other EU funding schemes (see Innovation: Beyond Research and Research Funding Bodies)[16]

Current trends in materials research include smart materials which are able to sense their environment and react actively to changes in specific environmental conditions, materials for applications in the health care sector and materials for the energy sector. New materials for energy storage, coating materials for harvesting solar energy or high-temperature stable materials are expected to play a crucial role for the energy sector in the future. Materials for health care play an important role in the context of regenerative medicines where bioactive and biodegenerative materials are used for restoring or replacing human tissues. Nanotechnology and biotechnology are expected to play an important role for the development and production of future materials. These include, for example, materials based on renewable resources made by biotechnological processes or using nanoscale production and analyses technologies for materials research. The expected trends in materials research will most likely call for new or modified skills of the workforce. In particular, interdisciplinary skills might play an important role when it comes to the convergence of materials research, biotechnology, ICT and nanotechnology.

Mastering the design, research and development of new and improved materials will remain key factor for achieving the goals of the European innovation policy, in agreement with the European strategy for a smart, sustainable and inclusive growth EUROPE 2020. Research should respond to people's needs and concerns with integrated solutions that tie energy, natural resources and human health.[17]

Production and manufacturing industries are still of major importance for the future welfare, value adding and jobs in Europe. While the manufacturing sector itself has been slightly declining in recent years, new jobs and value added has been created by outsourcing activities of manufacturing companies to business services. Manufacturing represents approximately 21% of EU’s GDP and combined with the directly induced value added in the service sector, manufacturing industries are (still) responsible for one third to one half of the GDP in European countries.

Additionally, the manufacturing sector is exceedingly important for the creation of future innovation, knowledge and skills in Europe. Around 80 to 90% of R&D expenditures in European countries and a similar share of their exports are performed by manufacturing companies. The core of industries serving as provider of innovative production technologies, particularly the mechanical engineering sector, but also significant parts of metal, electronics and instruments manufacturers as component suppliers, are characterised by R&D intensity and innovation expenditures well above the average of all service and manufacturing industries. Additionally, these companies are crucial “providers of productivity increase” for their customers using these

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16 http://ec.europa.eu/research/industrial_technologies/materials_en.html.

17 http://ec.europa.eu/research/industrial_technologies/materials_en.html.

innovative production technologies to realise more effective and efficient production and value adding processes. This underlines the superior importance of production technologies and industries for the future competitiveness, skills, knowledge base and welfare of the European economy.

Apart from manufacturing, the construction sector (also linked to the NMP technologies) is Europe's largest industrial employer, a major source of revenue from exports and an evident contributor to the quality of life for all citizens. Continued research and development is vital to provide a sound basis for recovery from the effects of economic downturn and to address the global problems of climate change and population growth.[18]

Today, European manufacturing is a dominant element in international trade, leading the world in areas such as automotive, machinery and agricultural engineering. Already threatened by both the lower-wage economies and other high-tech rivals, the situation of EU companies was made even more difficult by the downturn. Restoring growth and achieving sustainability require a strategic shift in Europe from cost-based competition to an approach based on the creation of high added value. There is also an increasing demand for greener, more customised and higher quality products. Manufacturing needs to address the challenge of producing more, while consuming less material, using less energy and creating less waste.[19]

Despite growing globalisation and challenges from low-wage economies, manufacturing has a bright future in Europe in a sustainable, knowledge-based society. There is a strong indication of the re-emergence of the EU manufacturing sector as part of the new sustainable economy – in technical, environmental and social terms. But it is clear that such sustainable development requires continuing innovation in the underpinning products and processes, with a need for consistent and effective research over the next decade based on a clear and long-term vision.[20]

2.2.2 Past and future NMP trends by competitiveness factors

Quantitative data can provide interesting insights on general past and future NMP trends and may even provide a feeling, if there is consensus or not with respect to a given competitiveness or key factor. However, the data has to be critically assessed and taken with care, since NMP technologies and their subfields may be differently defined and hence, granularities of the technologies, their general cross-disciplinary character (e.g. their distribution over several disciplines, applications, sectors), and uncertain information on validity, reliability of the data sources have to be taken into account. In contrast, qualitative arguments and trends providing a relatively clear picture on

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18 http://ec.europa.eu/research/industrial_technologies/innovation-in-construction_en.html.

19 http://ec.europa.eu/research/industrial_technologies/innovation-in-manufacturing_en.html.

20 http://ec.europa.eu/research/industrial_technologies/production_en.html.

potentials and risks seem to be quite reliable and robust. Thus, a semi-quantitative approach has been used in this study, based on a qualitative description of past and future NMP as well as economic trends and scenarios that feed into and help to interprete quantitative developments of the econometric model. The main findings on all over past and future NMP trends for different competitiveness or key factors are summarised below.

Resources

There has been an exploitive use of ***natural resources*** on industrial level in the past. Today, there is widespread recognition of the need to adopt cleaner, sustainable practices by switching from a resource-intensive to a knowledge-based economy. NMP has the potential to reduce the use of critical resources (e.g. by nano), substitute critical (e.g. limited, toxic) materials and re-use strategic relevant resources by means of closed-loop production (life cycle, recycling) in the future.

Industrial players consider the lack of appropriate ***human resources or skilled workforce*** one of the major obstacles to innovation. Chemistry, physics and most branches of engineering have shown a relative decline in researchers specialising in key areas directly impacting on NMP in the past. Human capital could be a restricting factor to NMP development in the future. At the same time interdisciplinary researchers or workers being specialised as well as generalists are needed for NMP. The most important trend analysed in studies is, that both skill shortages and skill gaps will increase (Gelderblom et al. 2012). The EC Study “Assessment of impacts of NMP technologies and changing industrial patterns on skills and human resources” indicates that employment increases related to technological developments are expected in companies involved in NMP. Expected growth is highest in companies that indicate that they are involved in a combination of N, M and/or P technologies, compared to companies involved in just one of these new technologies (Gelderblom et al. 2012).

Technological progress and innovation

With respect to nanotechnology ***funding***, the EU is quite strong and comparable to other world regions like USA and Asia. Available data on public funding and regional centres of nanotechnology activity suggests that the EU and its Member States are competitive overall, even though there were time lags in the provision of public funds in the early years of this decade (EURONANO 2009). However, Europe does not provide private funding to the same extent as other regions like the US or Japan, which may hint to a worse performance in terms of commercialisation of nanotechnology.

There has not been the same effort in funding materials and manufacturing (compared to nanotechnology). However, the FP7s NMP Programme is assessed to be unique. The PPPs enhance NMP’s industrial focus, its contribution to the grand challenges and its connectivity to ICT, energy, environment and transport directorates in ways that could help shape future framework programmes. The NMP programme in FP7 has proved to be robust to harsh economic changes and demonstrated both leadership and innovation in RTD policy creation and implementation. The EU has earmarked a total of €3.5 bn for funding this theme over the duration of FP7.

Science and technology indicators remain the most reliable source of information for assessing the competitive position of world regions and countries. The EU Member States perform well in terms of R&D, especially with respect to scientific activity measured by ***publications***. In terms of technology development measured by ***patents***, the EU performance is solid yet not as strong as on the science side.

The global distribution of publications and patents indicate that NMP-related research and development activities are concentrated in a few countries and regions of the world (North America, Asia and Europe). Nonetheless, some smaller countries also show up as being very active considering size differences across countries.

Over the past 15 years, nanotechnology has had the highest growth in patent output. Advance materials show rather slow increases in generating new technological knowledge. The strong growth in nanotechnology patenting helped Europe to maintain its market share in global patent output. Europe's position is strongest in advanced manufacturing technologies with a market share of almost 50%. This could be sustained over the past 15 years. A look at the subfields of NMP shows, that there is at least one subfield in each technology, where Europe performs particularly well, but there are also several subfields with weak performance. As a consequence, one should be aware of the wide variety of individual technologies within each area and that competitiveness differs by subfields (ZEW/TNO 2010).

However, the rapid entry of "newcomer" countries such as the BRIC and the South-East Asian countries should also be highlighted. All of these countries are characterised by rapid growth rates in the number of publications and patents although from low starting levels. These results suggest that the thrust of NMP R&D may partly be shifting away from traditional countries which have had a longer history of involvement in nanotechnology.

Commercialisation

Research ***infrastructures*** are excellent developed and strongly supported in the EU, technology platforms and cluster activities are visible but could be co-ordinated and complement better with other activities and stakeholders for sake of defragmentation and improved synergies. The EU is among the leading regions providing access to large scale research infrastructures (e.g. synchrotron sources as well as thematic clusters). NMP production infrastructures however, have to be maintained, further supported and expanded, in particular if nanotechnology and advanced materials innovations have to be up-scaled from laboratory levels to industrial scale for commercialisation. Especially production facilities on industrial scale are rather limited in Europe. Large semiconductor nanoelectronics production facilities, advanced battery production and other industries are located mainly in Asia or some other world regions. The built up of demonstrators, pilot lines and small to volume production are subsequent necessary tasks and investments after the R&D phase. They are principally costly and therefore a critical mass of actors (e.g. by joint ventures, alliances) or high investments by one company are needed. Although, the European research infrastructure is believed to be competitive, the production infrastructure for NMP products is often still missing, leading to unclosed value chains and a too weak commercialisation of NMP.

Europe has strong ***international collaboration and global networks*** in research projects, mainly focused on global challenges. Co-operation among the EU Member States as well as with third countries has been established in the past but will be more important in areas of joint global thematic and strategic interest and will have to be further developed (e.g. for regulation, standardisation, risk assessment, etc.).

European industry is modern and competitive in many areas. A long-lasting industrial culture exists, with large ***industrial networks*** linking suppliers, manufacturers, services and user companies. Advanced materials is a rather traditional technology driven by large companies with longstanding R&D and market experience. A main barrier for the rapid diffusion of advanced materials is long product cycles and often high investment needed to adopt new materials. In advanced manufacturing technologies, the situation is quite similar, though barriers to adoption are different. As many users of more advanced process technology are small manufacturing firms, specific barriers to technology adoption by SMEs (lack of external capital, lack of specific skills, uncertainty of price-cost advantages over the life cycle of new technologies) matter (ZEW/TNO 2010). With respect to firm/***company*** creation the US are leading world wide (for nanotechnology), however Europe as a further player with substantial activity on the level of individual Member States.

For the future, an increasing and more efficient ***transfer*** and co-operation of universities, applied research organisations and industry is of importance, in particular to cover the whole value chains.

Demand

Typically for an emerging field, the level of uncertainty is high and there is considerable variety in ***market*** estimates. While these factors are not restricted to NMP, they must be taken into consideration when interpreting data. The potential socio-economic impacts of NMP are considered very large especially in terms of forecast market size, particularly for nanotechnology-related ***products***, the multiplicity of applications and their potential to contribute addressing global challenges. The USA is the strongest actor bringing nanotechnology products into the market, followed by Asia and the EU.

For nanotechnology estimates of current ***market size*** vary a lot, ranging from US$12 to US$150 bn, depending if the materials market or also the enabled products and applications are counted (see also chapter 3). This range indicates the difficulties in determining the borderlines of this emerging industry. Though one cannot simply add market size of individual technologies and subfields to get a total volume of demand as several subfields and technologies overlap to some extent. But, more importantly, demand for NMP is expected to increase at rates above the average expansion rate of world markets for most technologies. Expected annual growth rates are particularly high for nanotechnology (ranging from 16% compound annual growth to an extreme of 46%) and rather moderate for advanced materials and advanced manufacturing technologies (5 to 6%, which is about the expected medium-term growth of global demand for goods and services) (ZEW/TNO 2010).[21]

The user integration in the innovation process is crucial for the ***acceptance*** and economic success of future NMP applications and products. There is a growing future demand towards environmental friendly, further technologically improved (e.g. new functions, extreme, new conditions), individualised, etc. and also always cheaper products. These products will enjoy public acceptance only if the regulations adequately address the new challenges from the technologies, if manufacturers can demonstrate their safety and if consumers perceive them as safe. NMP has the potential to meet these demands with nano-improved techniques, materials enabling new functionalities or individualised, adaptive and flexible production systems.

Regulation

Governments' role in advancing NMP differs with respect to the role of public funding for conducting R&D, the role of public policy for stimulating demand (e.g. through public procurement, taxes or regulation), and the role of environment, health and safety issues (EHS). Governments tend to be important players in nanotechnology since public funding and ***regulation*** are important for commercialising new research results. In materials and manufacturing, governments tend to be less directly involved in advancing technology. Their role tends to be more focused on providing a favourable

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21 It has to be reminded that this statement only refers to M and P in total. E.g., the various markets for advanced materials differ considerable in their dynamics (Oxford Research 2012a).

environment for industry, including to maintain a strong industrial base as a key starting point for developing and commercialising new technologies (ZEW/TNO 2010).

The EU is active in risk assessment, EHS, standardisation, regulation, legislation, dialogue with public, etc. However, the EU Scientific Committees have stressed the need for further research on safety for human health and the environment. There is a major concern, that nanotechnology could get a negative image. An essential element of the integrated, safe and responsible approach is to integrate EHS aspects in the development of nanotechnology, and to establish an effective dialogue with all stakeholders (public awareness, trust, code of conduct). To obtain relevant data, currently available methods for risk assessment need to be adjusted, validated and harmonised for nanomaterials. A continued commitment to regulatory and standardisation activities is important in this and also a wider context. Investments in nanomaterials EHS risk research should be maintained or even increased to US levels, which is three times that of the EU. Especially environmental aspects need long-term sustainable funding of R&D.

The main results and observations for past and future NMP trends with respect to the competitiveness factors are summarised in Table 2-3.

Table 2-3: Summary of NMP past and future trends

Category	Factors	Past trends	Future trends and drivers
Resources	Natural resources	Exploitive use of natural resources on industrial level. No significant effects of nano-/materials-technologies	NMP has the potential to reduce the use of critical resources (e.g. by nano), substitute critical (e.g. limited, toxic) materials and re-use strategic relevant resources by means of closed-loop production (life cycle, recycling)
	Human resources (skilled labour force)	Chemistry, physics and most branches of engineering have shown a relative decline in researchers specialising in key areas directly impacting NMP	Human capital could be a restricting factor to NMP development. Interdisciplinary researchers/workers being specialised and generalists are needed for NMP
Technological progress and innovation	R&D funding	The EU has been leading in overall funding in nanotechnology (most strongly in public funding). The USA and Asia have been stronger in private funding. There has not been particular funding in materials and manufacturing (compared to nanotechnology)	NMP is unique to the EU in this constellation. The funding should be maintained, private investment should be increased to compete with other regions commercialisation; new players are arising (e.g. China)
	Key technologies & innovation paradigms	The EU is strong in NMP research. The USA has been leading in nanotechnology. All regions are active in materials (Asia is specialised e.g. in nanomaterials). The EU is leading in advanced production	"Newcomer" countries such BRIC and the South-East Asian countries are serious competitors in NMP in the future. In particular, China is developing extraordinary rapidly. NMP have to be understood as a part of further KETs (photonics, biotech, etc.) within a multi-KETs innovation development and should not be regarded independently

Category	Factors	Past trends	Future trends and drivers
Commercialisation	Modern capital formation	The EU has established excellent research infrastructures, platforms and clusters for NMP. However, NMP production infrastructures, e.g. pilot lines, production facilities for upscale onto industrial levels, are underdeveloped and result in a missing or unsatisfactory commercialisation.	The gap between R&D and production as well as deployment has to be filled in the future.
	Global networks	The EU has established co-operation with third countries for NMP in the past (e.g. under NMP)	Co-operations have to be continued and even further strengthened in the future
	Industry structure	The EU is still moderate in firm creation (e.g. compared to the US). There are more SMEs in nano compared to materials and manufacturing (more traditional technologies)	There is a need for clear market drivers, for example, industrial problems, global challenges that can be solved by the application of NMP, to exploit commercialisation
Demand	Market adoption of innovations	Market estimates for nanotechnology vary strongly from 12 to US$150 bn (uncertain, problem of definition). Markets for advanced materials are expected to be US$100 bn and for advanced manufacturing US$150 bn	Expected annual growth rates are particularly high for nano-technology (16 to 46%) and rather moderate for advanced materials and advanced manufacturing technologies (5 to 6%)
	Customers as sources of innovation	The user or market demand is crucial for the acceptance and economic success of future NMP applications and products	There is a growing future demand towards environmental friendly, further technologically improved, etc. products
Framework conditions and regulations	Regulatory setting	The emerging need of regulatory settings for NMP has become clear (e.g. in the context of setting standards, environmental regulations – e.g. on CO_2, etc.)	Environmental, health and safety (EHS) concerns (in particular in context of nanotechnology, nanoparticles) are particular for NMP and will have to be addressed seriously (risk assessment, dialogue with public, etc.)

2.3 Sector-specific NMP trends

2.3.1 Definition and description of sectors

Besides the overall view on NMP trends, there are specific differences and unique characteristics to different sectors, in which NMP play an important role or might do so in the future. We chose those industrial sectors, which have a special relevance to NMP, are relevant because of many promising NMP applications and are most adequate, representative and best linked to the NMP field in terms of coverage of the technologies behind:

- Chemicals (covering chemical nanomaterials, advanced materials, etc. within the chemical industries),
- Pharmaceuticals (as part of the nanomedicine and nanobiotechnology innovations in the pharma industry),
- Electronics (covering nanoelectronics with a focus on the semiconductor industry),
- Photonics (Optics)/Instruments (covering the optics/photonics industry as well as instruments and equipment, where NMP is contributing to);
- Automotive/Vehicles (where NMP enters via new functionalities and improved characteristics due to nanostructured devices and components, advanced materials and production technologies for new designs and efficient manufacturing),
- Machinery for advanced manufacturing (covering the improvement of machines via NMP as well as advanced processes for manufacturing via NMP).

On the level of each of these sectors, there are specific key drivers and barriers for NMP. E.g. the issue of public acceptance is more relevant to the chemical and pharmaceutical sector, where e.g. nano-based particles may be released to the environment or enter the human body, but it is not so relevant for the other sectors, which relate to equipment technologies or components integrated in other products and applications. In some cases the attribution of aspects to the drivers and barriers is complex, as the future evolution of the factors is highly uncertain. E.g. it is uncertain how fast and to which extent international standards and norms for electric mobility will evolve. If standardisation is successful it will support the deployment and impact of NMP significantly. If not, the uncertainty about compatibility will be an important barrier. Also, there may be further disruptive and unforeseeable developments, which may be due to changing frame conditions (e.g. changes in regulation, governmental targets) or depend on the technology development (e.g. breakthroughs in NMP, alternative or competing technologies).

2.3.2 Key drivers and barriers

2.3.2.1 Chemicals

One main **key driver** of NMP in the field of chemistry will be the development of the **oil price**, which if strongly increasing will lead to the demand for energy-efficient NMP applications. The need for **substitution** of rare elements e.g. by using nanotechnology (metamaterials; novel chemistries) can also be a big driver for fundamental new possibilities to generate material functionalities. Moreover, the need for advanced (nano)-materials for renewable energies and e-mobility (batteries, light-weight composites) will foster the development (Serrano et al. 2009). A global warming policy for CO_2-free or a low carbon economy is another general driver for NMP technologies in the chemical sector.

There are however also many **barriers** (see Table 2-4). If substantial **R&D investment** stays low as indicated in the SusChem paper (SusChem 2005), Europe will loose its position especially against Asia. If **regulation** issues for nanomaterials (e.g. safe handling protocols) are not solved or a high imbalance between European and Asian markets evolve, nanotechnology cannot contribute significantly. There are severe problems to find free space for new **nanopatents**. This could hamper the industrial use of nanotechnology. Concerning the **resource efficiency of nanomaterials,** the results of total-life-cycle analysis (LCA) (cradle to grave) so far give very different results (Eckerlmann et al. 2008). In some cases the overall LCA gives advantages compared to the use of classical materials in other cases e.g. structural automotive parts the use of classical structural materials like aluminium or steel gives much lower overall energy impact compared to e.g. CNT-reinforced polymers. With respect to **costs**, even in the case of up-scaling costs for nanomaterials stay high: Nanotechnology stays for most of the parts functional not structural. Furthermore, there are **underdeveloped value chains** for nanomaterials especially for nano-bio-ict applications. The improper use (especially free nanomaterials) can lead to severe damages of workers or customers. Even the use of bound nanomaterials or nanocoatings might be negatively affected and could be problematic with respect to **public acceptance of nanotechnology**. Due to political reasons supply of or access to rare elements could be limited and used as a means to try to transfer high-tech industries e.g. to China. Finally, there could also be barriers with **technological developments in related areas.** E.g. biopolymers based on renewable feedstocks are often high in price and low in performance. This however could also be a chance for nanoenhancement of these materials.

Table 2-4: Main drivers and barriers in chemicals

Factors	Drivers/Opportunities	Barriers/Challenges
Resources	Substitution and efficient use of fossil resources; need for substitute of rare elements	Rare element supply restrictions from other countries due to political reasons
Technological progress and innovation capacity	Nanomaterials; Biofeedstocks; Complex and smart materials	Substantial R&D investment need; production costs for nanomaterials may stay high, even in case of up-scaling processes
Demand	Megatrends: Smart cities, environmental consciousness, renewable energies, e-mobility	Cost-sensitive demand; public acceptance of nano-technology, if communication is successful
Commercialisation		Costs
Framework conditions and regulations	Need for alternative materials can foster development (REACH etc.)	Regulatory issues for nanomaterials have to be solved

Source: Fraunhofer ISI

2.3.2.2 Pharmaceuticals

The future development and **commercialisation** of NMP in healthcare is regarded positively, as the pharmaceuticals sector is expected to grow significantly in the next years. Nanomedicine – and NMP in pharmaceuticals in overall – will partly be technology push and partly demand pull driven (Wagner et al. 2008). The crossover of medical needs with novel nanomaterials serving these needs will be the starting points for commercialising products. But also some crucial challenges exist, especially regarding regulation and the commercialisation. Overall, following **key drivers** for NMP in pharmaceuticals can be identified (see also Table 2-):

The **technology progress** in genomics and proteomics has led to a much improved knowledge of molecular processes linked to diseases and this has led to a redefinition of many diseases. Advances in nanotechnology now allow manufacturing and manipulating materials on nanoscale. That means the scale of proteins and DNA that make the body work. At the point where nanomaterials meet with a molecular understanding of cell function and disease development, nanomedicine emerges. Using nanomaterials allows targeting cancerous tissue, transporting drugs and imaging agents into cells or stimulating cell responses that support the healing process. For these applications nanomaterials are unique as their scale corresponds to the scale of biomolecules and it is intuitively understandable that nanomaterials could potentially be of great value for medical applications (Ferrari 2005).

On the **demand** side, important drivers are the **demographic change** and **medical needs** that need to be met to increase the efficacy of disease treatment: The development of novel nanotechnology-based drugs and therapies is driven by the need to develop therapies that have fewer side effects and that are more cost-effective than traditional therapies, in particular for cancer. Moreover, the trend of **personalised medicine** may bring forward innovations in nanomedicine. Much of the improvement for the patients’ healthcare, that will be brought by nanodrugs and contrast agents, will be related to their ability to target diseases more patient specific and to deliver more specific diagnostic information. However, this implies smaller patient populations and smaller markets for nanomedicines. The smaller the targeted markets, the larger the share of costs for obtaining regulatory approval in the total development costs, which may make a development economically unattractive (Wagner et al., 2008, ETEPS 2008).

Among the main **barriers** for NMP in pharmaceuticals r**egulatory issues** have to be mentioned. Regulation has ambiguous implications for nanotechnology and is much discussed: Presently, no specific regulations exist in Europe which refer specifically to the production and use of nanoparticles neither for workers', consumers' or patients' safety nor for environmental protection. Thus, current regulations and operational practices are applied for nanotechnology (JRC 2008). But according to experts, this may change and specific regulations will be introduced. Nanoparticles and their potential health and environmental risks are currently the focus of discussions at European and international level. Moreover, the regulatory framework implies the following consequences:

Firstly, regulation is an issue in relation to tissue and bone regeneration. For example, stem cell delivery by nano-capsules could be covered by existing regulatory systems for pharmaceuticals or medical devices or both (EAG 2009, ETEPS 2008). Secondly, regulation is also a key issue regarding production efficiency. When a new drug application is approved, it provides little or no flexibility to the manufacturer to make changes without resubmission and pre-approval. In the US, the Food and Drug Administration (FDA) has tried to relieve this situation through the concept of “Design Space”, which allows manufacturers to operate in certain predefined ranges of process variables as long as they can prove that the critical product attributes lie within satisfactory levels (Suresh/Basu 2008). There is no similar regulation in Europe. Thirdly, the cost pressure for European health systems will rise further in future. Hence, health innovations will not only be assessed by efficiency and improved quality of life of patients, but also with respect to the costs at which the improvements come (JRC 2008). The need of nanomedicine products to show cost-effectiveness in comparison to conventional alternatives may be a potential hurdle to commercialisation. Moreover, as each Member State in Europe applies different reimbursement rules, the lack of data and economic models will hamper the development of nanomedicine in Europe (EU Nanomed 2010, ETEPS 2008).

A further barrier is the remaining **difficulty for start-ups** to find major pharmaceutical companies that licence their technology or to find a partner with whom to bring their novel nanomedicine or diagnostic methods through the regulatory approval process (ETEPS 2008). Patents are crucial for nanomedicine start-ups to protect their technology but also to attract investors. Patent experts anticipate that **intellectual property (IP) protection** will have a great impact on the success of companies in commercialising their technologies. The IP landscape for nanomaterials is seen as complex and fragmented as these materials are of multidisciplinary nature, situated at the borderline between physics, chemistry and biology, which makes categorisation particularly difficult.

Table 2-5: Main drivers and barriers in pharmaceuticals

Factors	Drivers/Opportunities	Barriers/Challenges
Resources		
Technological progress and Innovation capacity	Strong R&D position; unique technological possibilities to target cancerous tissue, to transport drugs and imaging agents into cells, etc.; personalised medicine	Uncertain cost-effectiveness
Demand	Unmet medical needs; hope for new treatments; ageing population	Smaller patient populations and smaller markets for nanomedicines
Commercialisation		Difficulties for Start-ups to find partners for commercialising products; access to capital for start-ups during the long development phase (clinical trials etc.); lack in commercialisation efforts compared to US
Framework Conditions and Regulations		Complex IP-landscape; cost regulation of European pharmaceutical markets; uncertainty about future regulations

Source: Fraunhofer ISI

Nanomaterials, such as quantum dots, dendrimers or carbon nanotubes, can potentially be used for a broad range of medical applications just by modifying the core nanoscale component (JRC 2008).

2.3.2.3 Electronics

One **key driver** for NMP in electronics is an ongoing potential of **technologies for new products and markets.** The toolbox of applications beyond Moore's law is rising and there exist many more possibilities to replace analogue by digital applications. Another key driver is the **demand for environmental friendly products**. While the potential for NMP to contribute to environmental friendly products is relevant for all sectors, it may by especially likely that it is further increased here by corresponding regulations in the electronics sector.

A **key barrier** is the fact, that there are only a **few global players in Europe.** In the semiconductor market the introduction of a further scaling step towards smaller structure size or larger silicon waver diameters requires huge financial investments for lithographic systems and other production line elements, which can be carried only by very few globally active players. In other parts of electronic Europe often has only one of the worldwide leading firms as well, which can lead to a bottleneck in the sectoral development, if those players are not successful in the market.

It is widely acknowledged that public policy has a high importance for the semiconductor industry. There is a fierce international competition between the US, Europe and Asia and in all of the leading countries high government support can be observed. However concerning investments for large production sites, the European **state aid control** regulate ceilings to government incentives. While there are of course important reasons against large state aids (e.g. government failures, subsidy races etc.) the state aid control in its present form is suspected to limit the competitiveness of the European semiconductor industry (Wydra et al. 2010).

During the last decades the rapid and foreseeable advances in semiconductor technology allowed to depict and to follow a concise roadmap of semiconductor development. Clear predictions on a very limited class of main parameters (memory and calculation power) enabled many actors to synchronise their activities. However, a similar virtuous circle is unlikely to develop for technologies in the “More than Moore” domain: There is an abundance of various scientific ideas that lead to a large set of combinatorial possibilities for further applications. Thus, predictions on finally influential technologies and successful products are more difficult and coherence among the various players or might not even be achievable to the same extent. As a result, there are high **uncertainties for new paths in micro- and nanoelectronics**.

Table 2-6: Main drivers and barriers in electronics

Factors	Drivers/Opportunities	Barriers/Challenges
Resources		Unpredictability/Instability of availability and price of critical material
Technological progress and Innovation capacity	Toolbox of applications beyond Moore’s law; Possibilities to replace analogue by digital applications; Printing electronics	"Rising costs for existing More-Moore path”; High uncertainty for new paths in micro-/ nanoelectronics

Demand	Needs like higher safety, more environmental friendly	
Commercialisation		High firm concentration in semiconductors with key firms from non-European countries
Framework Conditions and Regulations	Regulations for environmental friendly products	Global distortion by state aids

Source: Fraunhofer ISI

2.3.2.4 Photonics

There are just a few specific important sectoral NMP drivers and barriers. Especially regarding the drivers, environmental challenges and efficient use of resources are **key drivers** in this industry.

Concerning **barriers** some specific aspects can be mentioned. Many of the nanophotonics applications are **competing against established technologies**, like LCD displays, crystalline silicon solar cells etc. The competing technologies improve in performance and manufacturing costs as well. Hence, **commercialisation** of nanophotonic technologies can be a very difficult task. Governmental policy is an important factor in this sector. Massive efforts have been undertaken in the US and in Asia with respect to research funding and investment incentives (ZEW/TNO 2010). Instead, European research policy faces the challenge to effectively link and co-ordinate the national R&D activities and programmes in the Member States of the European Union. Moreover, as the financial position of many governments is under pressure, the **supporting policies** in particular for implementation of photonic energy systems are expected to be reduced. As a result, the demand for these systems would significantly decline. Finally, while the overall European photonics industry has a strong global character and shows limited interdependencies, the **vertical value chain** with research organisations is often more crucial. Here, the European industrial linkages are limited (Butter et al. 2011).

Table 2-7: Main drivers and barriers in photonics

Factors	Drivers/Opportunities	Barriers/Challenges
Resources	Substitution and efficient use of fossil resources as key driver	Potential limitations of access to strategic resources
Technological progress and innovation capacity	Reduction of environmental impact as major technological issue; multidisciplinary approach with non-photonics research is promising (nanomaterials, nano-bio, manufacturing etc.)	High competition against established technologies
Demand	Environmental friendly demand; Renewable energy (solar etc.)	
Commercialisation	Innovative SME in Europe	Low availability of financial capital as key bottleneck for SMEs; weak value chain linkages in Europe's photonics industry;
Framework Conditions and Regulations	Possibility of funding "from lab-to-fab" (see machinery/advanced manufacturing)	Potentially reduced government spending may affect photonics-related industries

Source: Fraunhofer ISI

2.3.2.5 Automotive

As it was shown above, NMP technologies can contribute to nearly every major part or technology built in or embedded in passenger cars and other vehicles. Nevertheless, there are key drivers and barriers that may result in the quicker or slower propagation of the new innovations, and in order to make NMP technologies a success story for every stakeholder, they have to be examined well.

There are some general **key drivers** for NMP technologies. Worldwide, governments started to crack down on **CO_2-emissions**, with OEMs finding themselves left with the urge to lower their products' emissions. In the short term, this results in more efficient petrol consumption through lighter cars and better engines. In the long run, the turn to electric mobility may be necessary to face this regulation. The automotive sector is highly competitive and the market is largely customer-driven. They only buy cars that fulfil their highest **customer requirements** regarding safety or comfort, two areas that are heavily influenced by NMP technologies. Technological advances by NMP can also be a selling argument for products of competitive companies. In a competitive industry, car manufacturers need to deliver on innovative technologies or can achieve an advantage through offering their customers the new features if they do not want to be outrun by their competitors. The setting of **norms and standards for (inter-) national NMP product application** will be crucial to reduce uncertainty for providers and customers. Although the role and necessity of **public procurement or market regulations** for electric mobility is highly disputed, it can be a powerful instrument to foster market realisation of R&D. As an example one can take China were electric motorbikes were pushed heavily by forbidding other types of motorbikes in some large cities.

Possible barriers for NMP technologies are that the **production prices remain high** and thus, many NMP technologies today are still far too expensive in order to be introduced in car markets on a broad scale. Experts say that this will change once production will reach significant numbers as the costs will go down through the up-scaling – the problem is that production materials and processes are not ready to deliver in broad scales yet. Also, there is a challenge with respect to a **possible low progress in research** (e.g. for batteries for electric vehicles or light-weight components). As of today, the landscape of scientific institutions and projects aimed at solving nanotechnology challenges is not only widespread in geographical terms but also rather complex when it comes to understanding its structure. While the danger of producing same results twice through parallel efforts is real, a comprehensive approach to solve the grand challenges through NMP technology seems not have been found yet.

Table 2-8: Main drivers and barriers in automotive/vehicles

Factors	Drivers/Opportunities	Barriers/Challenges
Resources	Oil price increases need/demand for alternatives	Potential shortages of critical raw materials
Technological progress and innovation capacity	NMP enables electric mobility with progress in batteries; coatings for improvement/development of light-weight engines	Costs for nanomaterials may stay high, even in case of up-scaling processes
Demand	Needs like higher safety, more environmental friendliness or more comfort; megatrend electric mobility	Cost-sensitive demand; sceptics about nanotechnology (term is avoided by industry)
Commercialisation		Acceptance of higher prices (e.g. electric vehicles)

Framework conditions and regulations	Environmental regulation results in the need for more efficient petrol consumption; norms and standards for (inter-) national product application; public procurement of high importance

Source: Fraunhofer ISI

The scenario of an early mishap mentioned above and the high challenges in research, lead to **companies investing carefully**. Although it is possible that entrepreneurs "want to do things right" and tend to invest more on NMP technology research than they would do in other technology areas which could lead to good solutions, barriers for NMP technology are high.

2.3.2.6 Advanced manufacturing/machinery

Advanced manufacturing technologies (AMT) have some **strength** due to a top class engineering tradition and related expertise and know-how, the broad technology basis, availability of a sound structure, existing technological and manufacturing clusters, as well as the cultural diversity in Europe.

There are **opportunities** for the EU to enhance the technological leadership, to tap the potential of new (e.g. green) industries for growth and jobs creation, to provide top class education, and to pioneer the development for the whole industry.

Weaknesses are due to a costly research, complex and bureaucratic R&D support structures, high investment risks for individual private partners, a growing deficit of skilled staff, the costly up-scaling of processes, public innovation policies that are focused on the end of the value chains, barriers to commercialisation, a limited access to finance in capital markets, the fragmented EU markets, and a low labour mobility.

Among the **threats** one has to mention the globalisation, the application of the precautionary principle when faced with new technologies, the state-supported rise of new industries, asymmetric conditions for trade in spite of the WTO framework, the ageing society, a lack of skilled workforce, a non-smart regulation, as well as investments in R&D in other regions that brings the leading edge of manufacturing to other regions e.g. 450 mm (HLEG 2010).

A more NMP-specific characterisation of AMT is shown in Table 2-. Since AMT is on the other end or at a later stage of the industrial value chain – compared to advanced or nanomaterials (chemistry) – every trend (and related barriers) like resource efficiency, lack of strategic resources, the use of renewable energies etc. will at some stage also influence AMT. Therefore these drivers and barriers will not be repeated here. Instead, some more specific aspects for the machinery sector shall be mentioned. Important specific drivers are, for example, the **competitiveness und funding possibilities in this field**. Europe has a leading position in machinery, which is an important basis for innovation and commercialisation of NMP technologies and applications. A potential driver would be the possibility for funding prototype factories (from lab-to-fab), if introduced. This would address bottlenecks in the commercialisation of products.

Among the specific barriers the **policy focus** has to be mentioned. Innovation policies focus on other stages of the value chain but often neglect the specific needs of the machinery actors. Many firms are small and do not perform formal R&D but other kinds of innovation activities, which are not addressed by must funding programmes. According to experts, also the ***cross-sectoral collaboration*** of machinery actors in R&D is insufficient, which often leads to a late introduction of new materials in machinery.

Table 2-9: Main drivers and barriers in advanced manufacturing/machinery

Factors	Drivers/Opportunities	Barriers/Challenges
Resources		Potential limitations of access to strategic resources
Technological progress and innovation capacity	Technological development and implementation of advanced ICT e.g. for robotics	No cross-sectoral collaboration in R&D (=> late introduction of new materials in machinery)
Demand	Need for advanced manufacturing technologies for energy systems like solar cells, batteries or polymer electronics etc.; “Production at home” (higher product flexibility, individuality, 3D-printing)	
Commercialisation	Leading position of Europe in machinery	Higher labour costs in Europe compared e.g. to Asia
Framework Conditions and Regulations	Possibility for funding prototype factories (from lab-to-fab), if introduced	Innovation policies focus on other stages of the value chain

Source: Fraunhofer ISI

2.3.3 Comparison of sectoral challenges along the value chain

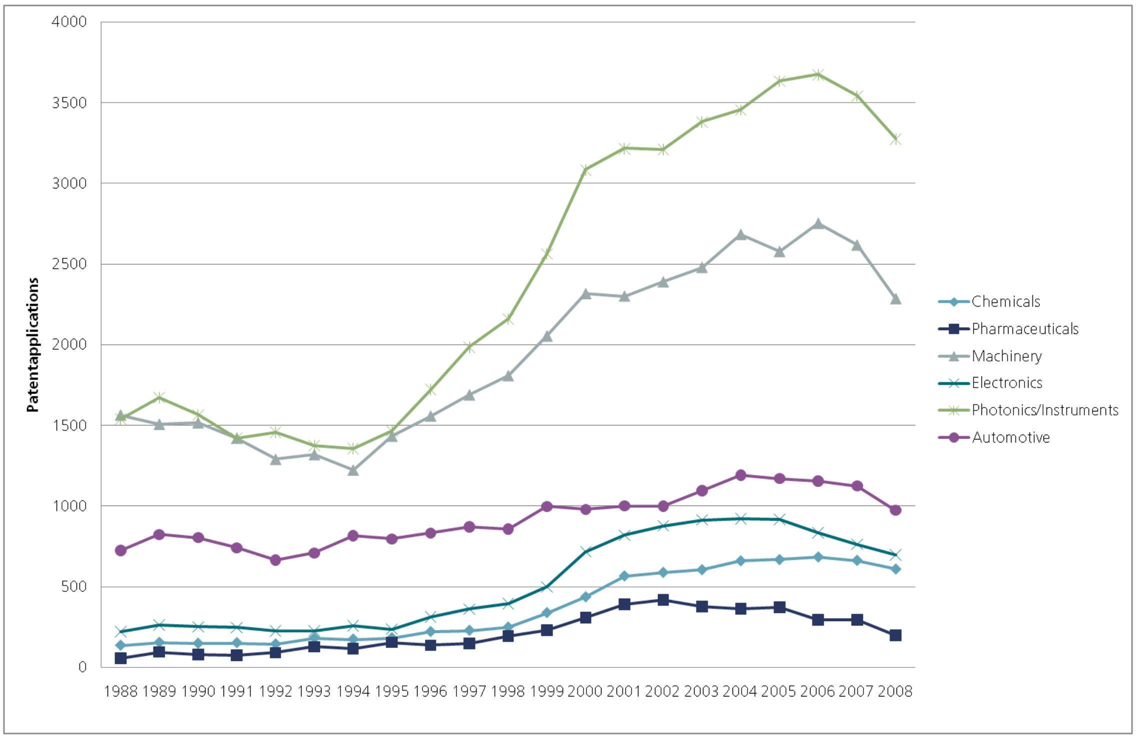
Whereas nanotechnologies and advanced materials enter the value chain typically and most strongly at early stages, advanced processes and manufacturing are relevant, when it comes to the production of components and finally their integration into new and innovative products.

Resources, especially high value materials are needed in particular in the chemicals sector. Also, the electronics and photonics sectors make use of strategic materials like Indium (e.g. as ITO in display technology or thin film CIGS in photovoltaics). Especially, if there is a need for a large amount of resources and the access to them might be critical (e.g. rare earth elements in China, Cobalt for lithium-ion batteries in the Congo, etc.), alternative technologies with substitute materials will gain importance (e.g. graphene to substitute the ITO conductive coating). Since electronic or photonics components, new chemical coatings or light-weight materials are to be integrated to a larger extent in future automobiles and will help improving machines, instruments and processes, also these sectors, which become relevant later in the value chain would be affected by shortages of strategic resources and hence increasing prices. Only in the pharmaceutical sector this has no equivalent importance.

There is an increasing demand of the consumer and society for safe and environmental friendly technologies, which often correlates with the need for substitution of (critical or toxic) materials in chemicals as well as electronics and photonics. Again this finally impacts the machinery and automotive sectors, but not the pharmaceutical sector. However, at the same time, there is a still ongoing demand for cost-effective and achievable products on the demand side.

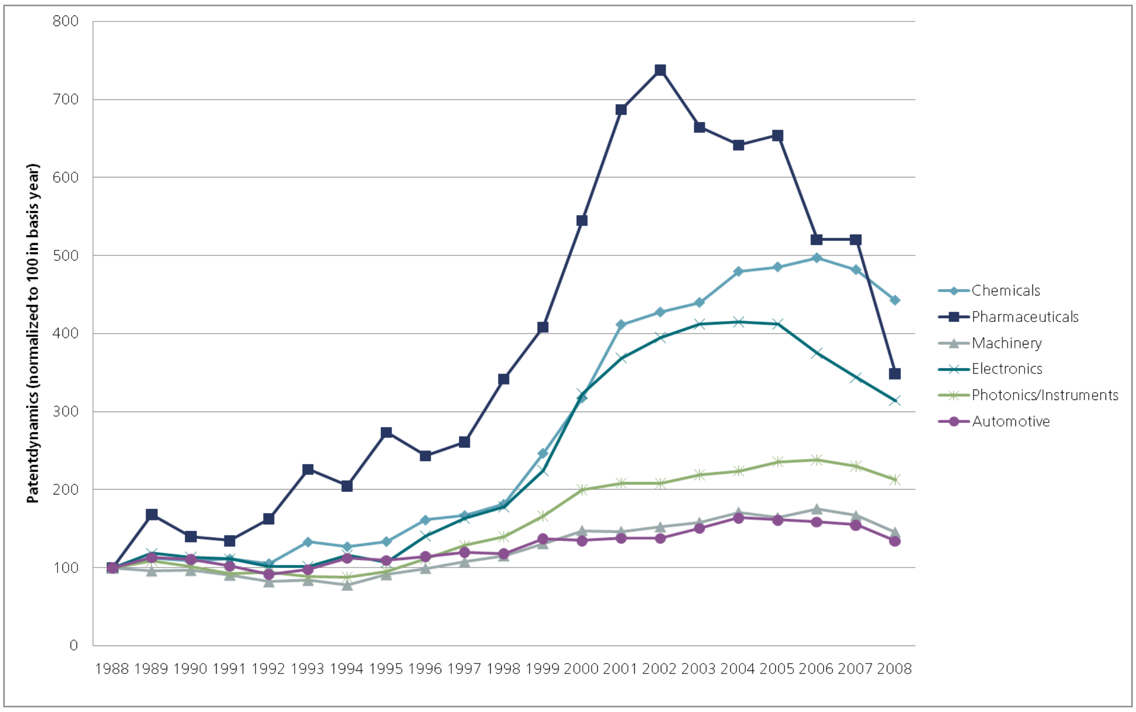
Technology developments are therefore increasingly challenged by the improvement of technology parameters and functionalities and at the same time should maintain or even reduce costs. NMP developments can help facing these challenges in the future. However, NMP are still in the development stage in most sectors and therefore have to mature in the next years. In order to obtain an overview of major technology trends in the sectors under consideration a patent analysis was carried out. This analysis shows that, whereas in all analysed sectors the number of NMP patents has increased since the late 1990s, there has been a stagnation and downturn in recent years. Figure 2-3 shows the absolute number of patent applications in the different sectors between 1988 and 2008 for NMP as defined in this study. NMP patents in machinery and photonics/ instruments have been on a highest level in the past due to a strong number of engineering improvements. Furthermore, in the automotive sector NMP has contributed to engineering solutions in the past and advanced components and automotive parts based on nanostructures and advanced materials still wait for their broad exploitation in the future. Looking at the dynamics of these three sectors as shown in Figure 2-4, only a smaller increase can be observed, as the sectors start on a higher level. For NMP in the chemicals, pharmaceuticals, and electronics sectors in contrast, nanotechnology and advanced materials developments have been realised within chemistry, nano-biotechnology and/or nanomedicine as well as in physics in the last years.

Figure 2-3: Absolute NMP patent numbers in sectors 1988-2008



Source: Patstat, own calculations

Figure 2-4: NMP patent dynamics in sectors 1988-2008



Source: Patstat, own calculations

Starting at a small level, also in these sectors there has been a strong increase starting around the late 1990s.

For all sectors a peak can be observed in the dynamics with a decline in strength of patent applications beginning with 2000 or later (depending on the specific sector). The overall interpretation is, that there is a cyclical long-term behaviour of NMP, as has been observed, for example, for the case of nanotechnology already (Schmoch and Thielmann 2012). Here, a broader mix of also more mature NMP technologies shows up in somewhat earlier stagnation behaviour. A further increase would be expected within the next years, when the different technologies in the considered sectors might mature and overcome the stage of basic research and development.

However, also for early NMP applications there is a gap in Europe between basic knowledge generation and the subsequent ***commercialisation*** of this knowledge in marketable and requested products across sectors. This gap has been identified by the High level expert group (HLG 2011) across the KETs, of which NMP are a part of, and is known in broad terms as the "valley of death" issue. The crossing of the “valley of death” in the KETs can be imagined in constructing a European bridge comprising three pillars: the technological research pillar based on technological facilities supported by research technology organisation (with the aim e.g. to show proof of concepts and be proprietary, i.e. to apply for patents), the product development pillar based on pilot lines and demonstrator supported by industrial consortia (with the aim to result in competitive process and product prototypes and their validation), and the competitive manufacturing pillar based on globally competitive manufacturing facilities supported by anchor companies (with the aim to built up production volumes and to be cost competitive).

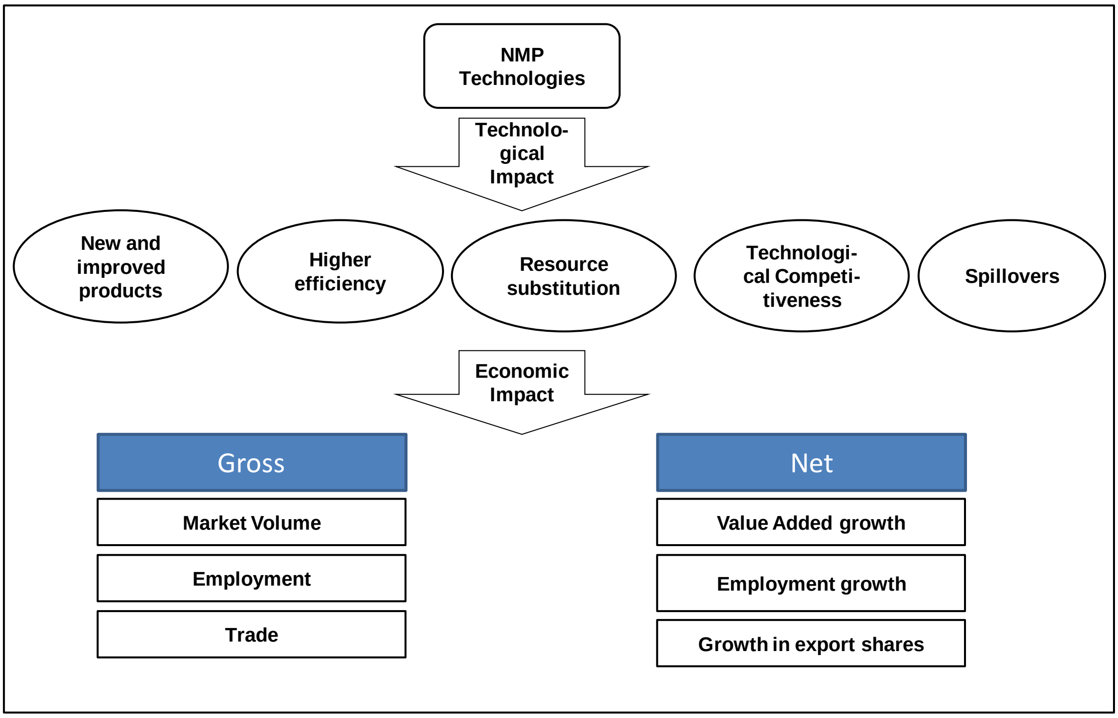
To achieve this, appropriate ***framework conditions*** have to be adopted and a complete political and regulatory environment needs to be put in place. E.g. current EC financial, legal and commercial support measures should be adapted in order to develop, deploy and protect European technologies successfully, so as to enterprises and especially SMEs could develop, that local innovation ecosystems could be born and grow, that the products could benefit from standardisation activities, that emerging markets could be privileged and that the rules of international commercial engagement could guarantee a fair competition between producing nations at world level (HLG 2011).

3 ECONOMIC IMPACT OF NMP

The socio-economic impact of NMP technologies is manifold. NMP technologies may lead to new products and processes, price changes, substitution of resources, higher material efficiency, changes in technological competitiveness, changes in consumer demand, etc. In addition, products based on NMP technologies often serve as inputs of great value added that are integrated into more complex products. It is these subsequent applications that drive major economic growth and competitiveness.
As a result, NMP technologies may have significant impact on the trade balance, growth or employment of a country. E.g. new job opportunities will be provided, existing jobs will be protected, but also some jobs may disappear through substitution.

Unfortunately, there is no common understanding of impacts of technologies. Sometimes just the market size is issued to assess economic impacts, while others focus more on indicators of changes in an economy, as pure substitution effects are of no relevance from a macroeconomic point of view. As no indicator or perspective is able to grasp the whole picture of economic impact of technologies, we include several indicators in our analysis, which are classified as gross and net effects (Figure 3–1; see also Annex 2).

Figure 3–1: Economic impact of technological innovation



Source: Fraunhofer ISI

In this section we will first present estimations of market volumes, as no data for serious calculation of employment or trade exist yet. In the next step we discuss the impact mechanisms (higher efficiency, etc.). The resulting net effects cannot be assessed directly, but are estimated by the econometric model and related scenarios in chapter 4 and 5.

3.1 Market volumes and growth

Various market studies for nanotechnology and – in some cases – for advanced materials and advanced production technology have been made in the past. Table 3–1 provides an updated overview of an earlier meta-study by the EU Commission for markets of key enabling technologies[22] and highlights three aspects:[23] Firstly, NMP technologies have already penetrated markets significantly with an estimated overall volume above US$250 mio. Secondly, studies differ enormously in their estimated market volume. And thirdly, all of the studies expect considerable growth rates for NMP, in particular for nanotechnology. In principle the same problem could be expected for advanced materials and advanced production methods, but hardly any estimation for the total technology exists.

Table 3–1: Market potential of NMPs

	Current market size (~ 2006/08) USD	Expected size in 2015 (~2012/15) USD	Expected compound annual growth rate
Nanotechnology	12-150 bn	30-3,100 bn	16-46%
Advanced materials	100 bn	150 bn	6%
Advanced manufacturing systems.	150 bn	200 bn	5%

Source: HLEG (2011), BCC (2010)

The main critical issue for the large differences in market studies is the definition of nanotechnology products. It is either defined along the specific subset of

22 N, M and P are three of the six defined Key Enabling Technologies by the European Commission (EC 2009d).

23 Table 3–1 reflects an updated version of the assessment of the key enabling technologies background study. It was checked, if the used numbers to estimate upper and lower bounds have been revised by the respective consultancies in their underlying market study.

nanotechnology raw materials (e.g. carbon nanotubes, quantum dots, fullerenes), components (e.g. nanocoatings or composites, electronic devices etc.), and other types of intermediaries. Or it is referred to the whole set of products along the value chain that are believed to become, in some way, affected by nanotechnology. The most optimistic market forecasts refer to the total market value of all end products that embody a nanotechnology component, rather than the value of end-products that can be directly attributed to this component. The idea behind is that innovation impacts can be manifold and are not limited to technology producers. For example, a recent study for photonics estimates that next to 300,000 direct jobs more than 2 mio employees in the EU manufacturing sector depend indirectly on photonics products (Butter et al. 2011).

However, the inclusion of the total market value of all end products may lead to significant overstatements. Some parts of the total market value may be equally attributed to other technologies (ICT, biotechnology etc.) or factors (e.g. demand), which affect these value chains as well. Moreover, level and growth in market volumes for a particular technology have little explanatory power for macroeconomic net effects. Although key enabling technologies make it possible to develop entirely new applications in many fields of manufacturing and help to establish new markets, many of the new applications may result in demand shifts between sectors and markets and cause declining demand in sectors less affected by such technologies (Butter et al. 2011).

In a nutshell, the market volume and expected growth rates highlight the penetration of NMP technologies and provide an imagination about its impact across the economy. However market volume or related employment can be hardly measured in an objective and comparative way. In addition, standing alone, they do not provide enough explanatory power for setting policy priorities.

3.2 Impact mechanisms

In the following we analyse the potential contribution of NMP via different impact channels and estimate its impact in key industrial sectors. As for other technologies, the impact of NMP can be supposed to be unequal across sectors. The sectors are affected differently by the penetration of NMP, related productivity effects, substitution effects or demand reactions. We choose six industrial sectors[24] for an in depth analysis and conducted literature, expert workshop and interviews.

Resource productivity

Resource productivity has gained increasing attention in the last years. While efficiency increases in material and energy lagged behind e.g. labour productivity growth in the past, this may change in future. The pressure for higher efficiency will rise, due to the increasing scarcity and costs of many materials and energy (Bleischwitz 2010). But, it has to be reminded that demand and supply of material resources are extremely difficult

[24] See Annex 1 for the selection of the industrial sectors.

to forecast, due to the wide variety of products, which vary strongly in potential supply, regulation or strategic policies of supplier countries. Main impact of NMP refers to:

- ***Reduction of materials used:*** Nanotechnology may improve conductivity in electronic structures (e.g. in photovoltaics), reactivity in electrochemical systems (e.g. lithium-ion batteries) etc., due to the enhanced surface to volume ratio of the nanoscale structures and materials used. In terms of upscale of emerging technologies from laboratory to industrial scales (e.g. electric cars with lithium-ion batteries), nanotechnology has the potential to quantitatively reduce the materials needed.
- ***Substitution of critical materials:*** Advanced materials technologies have the potential to lead to new materials classes providing the same or even better functionalities. Critical materials (in terms of limited resources but also toxicity) could be substituted and the technology could become independent of the resource. Thus, advanced materials technologies lead both to new substitutes with reduced costs in comparison to existing materials and to new higher added-value products and services. One example is the use of cobalt in first generation cobalt cathodes for lithium-ion batteries. Today, there are alternative cathode materials like iron-phosphates, and new materials are under development. Other examples are transport-related innovations (e.g. development of safer, greener and lighter vehicles), medical applications (e.g. new diagnostics, drug delivery systems, novel biomaterials for tissue regeneration), etc.
- **Life cycle of resources:** By moving from a linear life cycle (extract-consume-waste) to closed-loop processes such as cradle-to-grave or cradle-to-cradle resource management, resource efficiency rises and carbon intensity of products decreases. The creation of such closed-loop production systems is only partly a technological challenge, but also a strategy and management issues, but still future NMP enabled products and processes may contribute significantly to such development.
-

Unfortunately, only little information about the magnitude of the impact von NMP is available. The results of an impressive study of the estimated impact of nanomaterials in the chemical industry are shown below (Table 3–2). Especially catalysts and coatings/membranes can lead to drastic savings in energy and costs (Los Alamos National Laboratory 2006).

Table 3–2: Energy saving impacts through the use of nanotechnology in chemical industry

	Cost Savings Billion US$/Year	Energy Savings Trillion BTU/year	Nanomaterial Application
Chemicals	2.5-4.0	200-400	Catalysts
Petroleum	0.2-0.8	80-200	Catalysts
Automobile	0.2-1.1		Catalysts

Shipping	2.5-3.4	150	Coatings
Manufacturing	1.8-3.5		Coatings
Natural Gas	1.0-2.7		Membranes
Overall *(for this limited set of chemical industry applications)*	• Energy Savings = 0.5 to 1.1 quads/yr • Value Creation = US$10-30 B/yr		

Source: Los Alamos National Laboratory 2006

The increase in energy efficiency will probably be uneven across sectors:

- In some energy intensive sectors considerable improvements of efficiency through NMP are achievable. E.g. for the chemical sector experts assess a 25% increase of energy efficiency as plausible.
- Some sectors are less energy intensive (e.g. pharmaceutical), so effects are more negligible.
- In some of the sectors the impact may not arise in the production of their own sector, but in downstream sectors using NMP applications or final consumption (e.g. automotive).

A less visible impact will probably be the case for material efficiency. Material efficiency is less science based but more complex as application-specific. So far, the results of total-life-cycle analysis (cradle-to-grave) for nanomaterials have given very different results (Eckerlmann et al. 2008). In addition, the substitution of material may lead less to a cost decline or visible efficiency increases but to higher quality of downstream products.

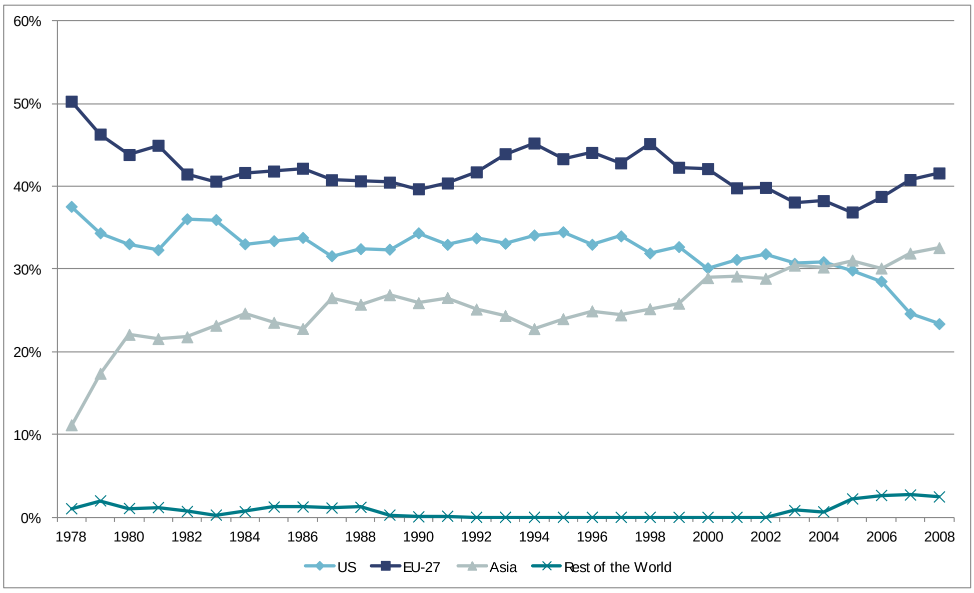
International competitiveness in NMP

International competitiveness in NMP-technologies is decisive to gain the related economic benefits. Value chains of certain high-tech products are often concentrated in few clusters and countries and intense competition between locations arises.

One important factor for Europe is technological competitiveness in NMPs. The concept of technological competitiveness "refers to the ability of knowledge producing actors (in a certain region or sector) to produce economically relevant new technological knowledge" (ZEW/TNO 2010, p.32). In order to provide an empirical assessment of the situation of international competitiveness in enabling technologies, patent data is often assessed to be the most relevant source.

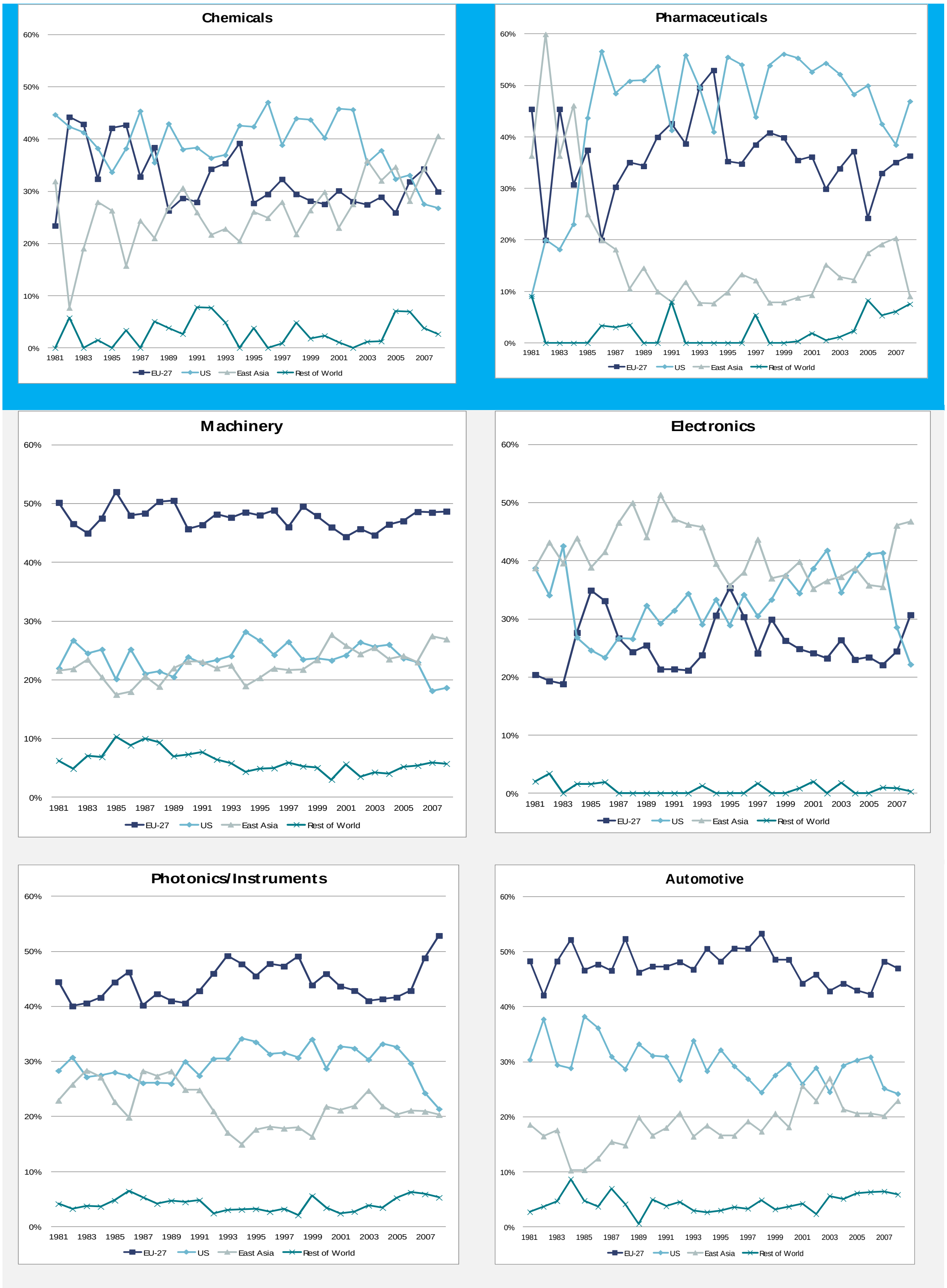
The figures showing the share of Europe's total NMP-related patents (Figure 3–2) as well as for the various sectors (Figure 3–3) give an idea of the strong research base in Europe. Europe's patent share for total NMP patents amounts to around 40%. For the future, experts expect a slight decline for the patent share of Europe for most sectors, as particularly countries from East Asia will probably be able to catch up further in the generation of knowledge. Europe's position in NMP-patenting in the various sectors is mixed. In some sectors Europe is significantly leading (e.g. machinery) in others not (e.g. pharmaceuticals). The trend in Europe's sectoral NMP patent share is rather constant and no significant loss to others (e.g. Asian countries) has been visible yet.

Figure 3–2: Market shares for NMP patents



Source: EPO: Patstat, own calculations

Figure 3–3: Market shares for NMP patents in sectors



Source: EPO: Patstat, own calculations

However, it has to be reminded, that the world market share for patents is just one factor for the success of a country in a certain technology. Frequently, reports and industry experts point out examples of technologies in which Europe is quite strong in patents but did not succeed on the market. In other words, there is a disconnection between the production of knowledge and the "use" of knowledge in manufacturing activities and marketable products (HLEG 2011). E.g. for lithium-ion batteries, micro-/nano-electronics, photovoltaic industry as well as for bioethanol a rather positive position in patent applications does not correspond to manufacturing capacities. However, it has to be reminded that not for all these fields the levels of aggregation for patents and production shares are identical. E.g. differences for bioethanol and PV-cells may be a consequence of the fact that patents correspond to whole technologies and production share to more specific technology fields.[25]

Table 3–3: Patent Shares and Production Shares in key technologies (in %)

		Europe	North America	Asia	Others
Lithium-Ion Battery	Patent share (2005-2008)	10	17	60	13
	Production share (2008)	0	1	87	12
	Market share (2008)	0	1	95	4
Bioethanol	Patent share (2005)*	36	34	23	7
	Production share (2009)	5	54	3	38
	Market share (2010)	6	62	5	27
Microelectronics	Patent share (2005)	22	30	46	2
	Production share (2010)	5	11	65	19
	Market share (2010)	13	18	69	0
PV-Cells	Patent share (2005)**	29	27	42	2
	Production share (2009)	13	12	57	18
	Market share (2011)	71	6	11	12

Source: HLEG (2011), Crean (2011), ZVEI (2011), EPIA (2011), Thielmann et al. 2010
* Patents for whole Industrial Biotechnology, ** patents for photonics.

Nevertheless the question arises, how meaningful patent indicators for the analysis of competitiveness are? All in all, it can be stated that the production of knowledge can be still considered as a necessary perquisite for Europe to be competitive in NMP fields.

[25] The patents for Lithium-Ion Battery are drawn from Thielmann et al. (2010). They show significant differences to the ones used by HLEG (2011), as the former analysis was carried out on a more specific level.

Moreover, our econometric analysis in chapter 4 will show that at least in the last 30 years, patents have been a crucial factor for the overall sectoral competitiveness.

But, patent activities reflect of course just one factor of competitiveness and are not a guarantee for gaining the related economic benefits. This is especially the case for technology fields,

- which are considered of high strategic importance and intensive government support can be observed (e.g. microelectronics, PV-cells) and/or
- where the market largely lies in other world regions (microelectronics, lithium-ion battery) and/or
- where the critical knowledge to produce new products and scale up processes is less codified in patents, but reflected in in-house competences (bioethanol, partly PV-cells).

Product Innovation and Demand

A powerful impact of technologies is the creation of new markets which extend the total demand. Concerning NMP, the question arises, if further technological advances may lead to new markets (not just new products for firms) or substitute existing products/ value chains. Unsurprisingly, there is a great variation between the various NMP applications within each sector. According to experts, there is hardly any statement possible on the sectoral level. There are slight tendencies between the sectors, mostly because of system issues. E.g. in the pharmaceutical sector incentives to invent products with new functionalities or for different types of diseases are set (with different success). Moreover, substances that should be substituted often don't leave the market but co-exist with the new ones. In contrast, in the automotive sector, the impact of NMP technologies comes from contributing to already existing parts, products or technologies. This will also be the case, if electric mobility becomes successful, as electric cars together with nano-enhanced batteries, nanolectronic components, light-weight parts, etc. would probably mainly substitute the traditional automotive market.

Moreover some arguments for rather additive effects across sectors are brought forward by experts:

- Some innovations may replace materials/chemicals which would be forbidden due to health and safety reasons or not be able to be produced, because of lack of raw materials.
- The potential of Europe is especially in high-tech-related and high-knowledge intensive production processes. Hence, markets where saturation is rather low and the highest potential for product innovation exist, would be addressed. Consequently an important part of NMP-related markets would probably have an additional character for chemicals compared with the counter situation of non-NMP-developments.

Other impact channels

Beside the mentioned direct effects, NMP technologies may have enormous indirect economic effects on economic activities via spillover effects across the economy and via addressing the grand challenges. It is not possible to provide a rating of their importance, but these effects are certainly crucial for the economy.

Spillover effects: Technological change in NMP facilitates other activities, innovation and competition in the whole economy. Hence, myriad spillover effects arise. In the analyses above, we tried to catch the impact of NMP via so called forward and backward linkages in other sectors along the value chain. In addition, more indirect impacts via technological spillovers have to be taken in mind. NMP technologies do not stand alone but overlap and interact with other technological developments. They enhance the improvement of other technologies (e.g. ICT, biotechnology) and create new opportunities for application.

*Grand challenges***:** NMP technologies contribute significantly to address the grand challenges. E.g. for health, nanomedicine offers substantial progress in true preventive medicine and precisely targeted intervention as well as regenerative therapy. Concerning the environment, NMP-technologies are important for developing recycling technologies; to substitute critical materials or provide powerful solutions for improving the future energy system. Consequently, fossil energy use and CO_2-emissions are reduced. If these global challenges are addressed successfully, positive feedback effects to the economy will arise since better environment and better health are – at least in the long run – itself crucial for a sustainable economic growth.

In conclusion, NMP technologies can be supposed to contribute tremendously to the economic and social development in Europe. However, due to the limited visibility and high heterogeneity of NMP and its applications, the assessment of the importance of each impact mechanism in the various sectors is difficult. Nevertheless, the findings indicate that there are considerable differences between sectors (Table 3-4). E.g. in the machinery and photonics/instruments/optics sector NMP will probably enable the rise of resource productivity efficiency and the high competitiveness may help to achieve/hold a significant market share in research and production. Subsequently, domestic value added will be generated. In other sectors the impact is more complex and unclear, as Table 3-4 shows.

Table 3-4: Economic impact of NMP in key industrial sectors

	Energy efficiency*	Material efficiency*	Additive vs. substitutive markets	Competitiveness situation of Europe	
				Technological (NMP patents)**	Commercial (Overall capital stock)
Pharmaceuticals	0 (not relevant, small use of energy)	+/-	Mostly additive	middle	middle
Chemicals	++	+	Partly additive, partly substitutive	middle	middle
Machinery	+	+	Mostly substitutive	high	middle
Electronics	0 (less in production, but more in use of product)	+/-	Partly additive, partly substitutive	low	low
Photonics/ Instruments/ Optics	+	+	Partly additive, partly substitutive	high	middle
Automotive/ Vehicles	0 (less in production, but more in use of product)	+	Mostly substitutive	high	middle

Source Fraunhofer ISI; legend: * ++ = strong increase; + = increase 0 = stable; +/- unclear; ** high > 35 patent market share 2005-2007; middle = between 25 to 35 patent market share 2005-2007; low < 25 patent market share 2005-2007

4 QUANTITATIVE RESULTS AND SCENARIO SIMULATIONS

In order to assess the impact related to NMP technologies quantitatively, we estimate an econometric model for the last 25 years and use the estimated structural equations to simulate the potential developments in three different scenarios regarding the deployment and impact of NMP. In this chapter we provide first a brief overview of the model. A more detailed description can be found in Annex 2. In chapter 4.2 the estimation and calibration of the model is presented. On this basis, we elaborate three scenarios regarding the deployment and impact of NMP and conduct scenario simulations with the model.

4.1 Model characterisation

For the quantitative analysis of the economic impact of NMP an appropriate model is needed. However, existing models and data sets are not entirely appropriate for this kind of analysis. They tend either to concentrate on highly specific individual technologies or market sectors or to take a broad approach to model technological change. Hence, a specific econometric model is elaborated for this study. This model allows incorporating specific technological impact transmission channels of NMP as well as economic interdependencies. Its flexibility allows us to explicitly consider key economic mechanisms of NMP and to investigate prospective scenarios. The model variables and the specification of the model are selected on the basis of the analysis of past and future socio-economic, technical, industrial trends.

In overall, the econometrical model assigns a prominent role to the supply side of the economy. This can be justified by the almost commonly accepted understanding in economics that long-term economic growth is mainly determined by supply side factors (development of the production factors labour, capital, knowledge and technical efficiency, while short-term fluctuations are mainly determined by the demand side (the exception are exogenous supply shocks) (e.g. cf. Mankiw (2010). Thus, from the for our purposes more suiting long-term view, sectoral growth is caused by changes in labour, capital, research output and progress in efficiency (e.g. in material, energy or autonomous technical progress). While the model incorporates a rather linear-view of innovation, it appears to be as most appropriate fur our purposes considering the limited data availability, which hampers a more-in-depth analysis of the complex relationship between NMP and the economy. Furthermore, it is well known from many econometric studies that even complex relationships can be well described – at least as a good approximation – by linear functions or nonlinear relationships and can be transformed into linear functions by adequate transformations of the model variables. The latter was done for the estimation of the production and employment functions for the sectors considered (cf. Annex 2: Methodology).

In the following we present important characteristics regarding the empirical model specification:

Level of analysis

The model is estimated and calibrated on a sectoral (industry) level. This level of granularity may be most appropriate to integrate both economic drivers as well as the impact specifics of NMP. We estimate and calibrate our model for the following sectors (NACE 1.1 sector classification in brackets):[26]

- **total manufacturing** (15-37),
- **chemicals, including pharmaceutical** (24 chemicals and chemical products),
- **machinery** (29 machinery, not elsewhere classified),
- **electronics, including instruments/optics** (30-33 electrical and optical equipment),
- **automotive** (34-35 transport equipment).

The integration of the whole manufacturing sector is a special case, as it includes the other sectors as well as some more (food and feed, petrochemicals, rubber, etc.). On the one hand many industries are covered on this analysis level and indications about the overall impact of NMP are provided. On the other hand, the impact of NMP had to be estimated more roughly and has to be interpreted with caution.

Variables

The economic model consists of several (independent) input and (dependent) outcome variables. As outcome indicators we use

- (sectoral) employment,[27]
- (sectoral) value added,
- (sectoral) export shares in the world market.

These indicators reflect key dimensions of the competiveness and development of the European industry.

The selection of the input variables in our model is challenging, as data for quantitative indicators related to NMP is hardly available. Emerging technologies, such as NMP, can hardly be captured adequately by existing sectoral classifications in national statistics and their applications are spread across many different classes.

In this study, we select the variables on the basis of the analysis of competiveness factors (chapter 2.1) and the analysis of the economic impact mechanisms of NMP

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[26] Due to shortages, we had to further aggregate the regarded industrial sectors in chapter 2 and 3, as can be seen in this listing.

[27] We originally intended to use foreign direct investments as a variable for competitiveness. However, this was not possible due to data shortages. Instead, we included employment as variable, as the experts of the 1st workshop recommended such an approach.

(chapter 3.1). Variables such as material efficiency, energy efficiency, patents and capital stock are considered (Figure 4–1). These variables are related to the NMP in the following way:

For the *past*, we are able to calculate sectoral NMP-patent stocks by a multi-step procedure. Concerning capital stocks[28] and other variables, we use overall sectoral figures, as it is definitely impossible to derive NMP-specific data.

For the *prospective scenarios*, the impact of NMP is incorporated in various input variables by the assessment of past trends and relying on expert judgements for prospective NMP-specific developments. This approach reflects that most of the economic
effects of NMP probably arise in the future.

For the interpretation of the model results it is important to remind that in particular NMP patents and capital stocks are only – in our belief the most appropriate – proxy indicators for innovation, commercialisation and production related to NMP. Of course, neither all R&D and especially non R&D-related innovation activities will result in patenting nor just the domestic knowledge stock is relevant for commercialisation of NMP, as patents from abroad may be licensed by domestic companies. Similarly, commercialisation and production of NMP-related goods and services is not always capital-intensive. In conclusion, a high economic impact of NMP patents or capital stocks in our model does not mean that industry and policy should not exclusively focus on increasing patents or capital stocks, but more generally on innovation, commercialisation and production activities related to NMP.

Figure 4–1 summarises the variables and interrelations in the model.[29]

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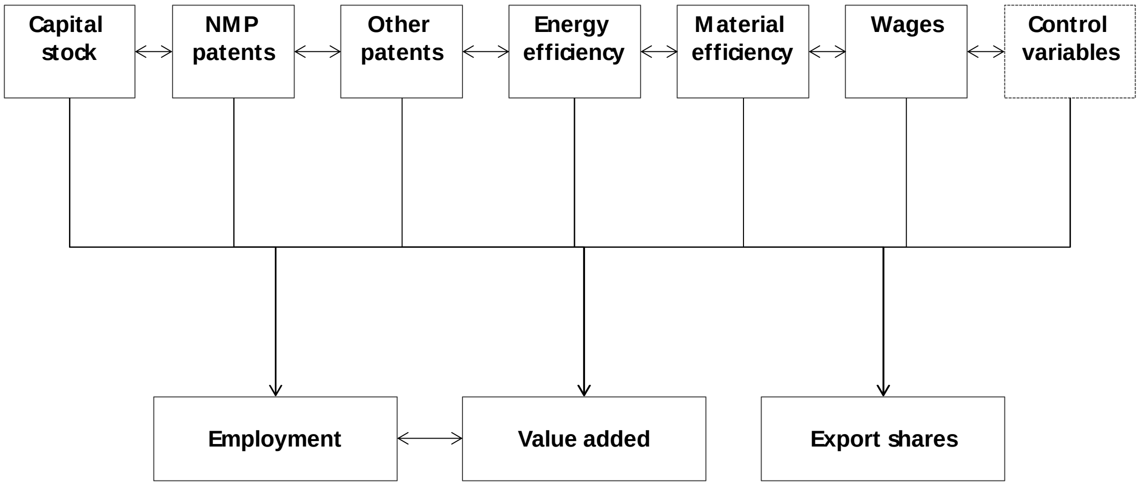
[28] The capital stock changes by annual gross investments minus deprecations.

[29] The concrete empirical specification of the model can be found in Annex 1.

Figure 4–1: Structure of the model



Source: Fraunhofer ISI

Time frame

We run and test the model for the last 25 years and use the estimated structural equations to simulate the potential developments in three different scenarios, regarding the deployment and impact of NMP. Due to the lack of data for some important variables (e.g. capital stocks) we can only cover the period between around 1980 and 2006/2007. While it would have been preferable to use data for the most recent years, the fact that we do not include the economic crisis can be regarded as less serious. The inclusion of these "exceptional years" would have probably limited the significance of each explanatory variable, due to the special effects of the financial crisis. While it is important to remind such potential impact of shocks, their consideration is not helpful regarding the boundaries of our model. In the model simulations from 2007 to 2025 the crisis is considered in respective assumptions for the capital stocks.

Geographical coverage

Concerning countries, we consider the following ones:

- European Countries: DEU; ITA; NL; ESP; AUT; FRA (only for exports); FIN, GBR; DNK; SWE,
- Non-European Countries: USA; CAN (only for exports); JPN; KOR; AUS.

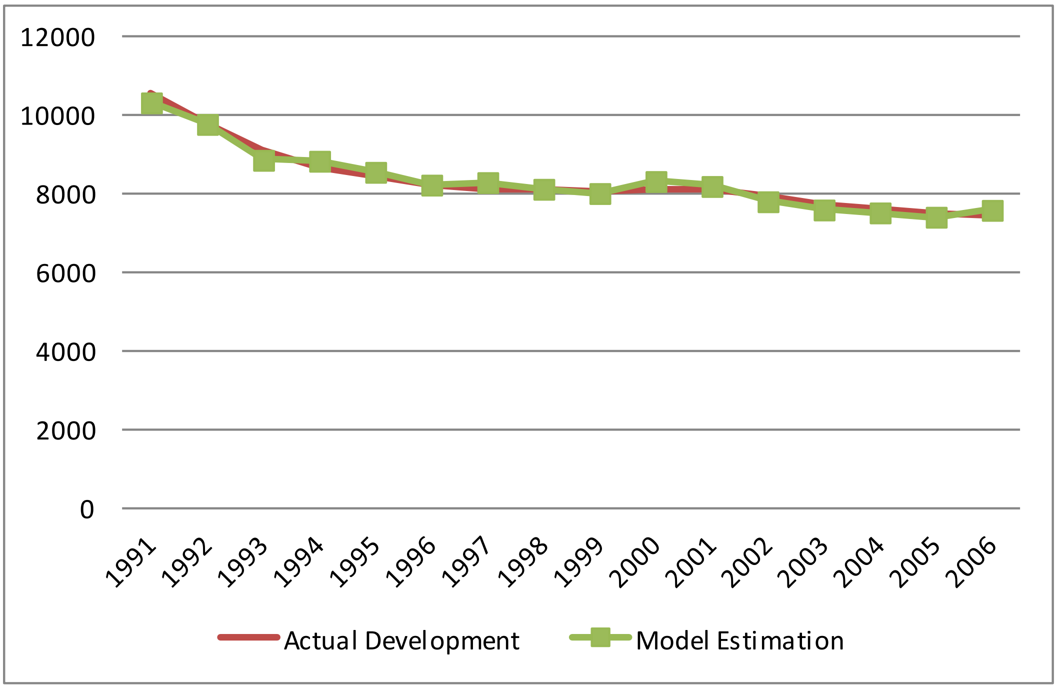
Due to data shortages, we were not able to include emerging countries from Eastern Europe or Asia. The comparison of our results to these potential dynamic countries would have been interesting. Nevertheless, we do not expect that the inclusion of such countries would change the results significantly. The estimated relationships between the variables are hardly concerned by the upcoming of those countries. E.g. the impact of each Euro capital stock on value added is still the same and will probably remain in the future (chapter 2, box 2). So, the fact that in some sectors significant parts of production has been relocated outside Europe does not change the relationship between the variables, but is reflected in declining or stagnating total numbers for capital stocks, value added and jobs. For the prospective scenarios the challenge is to estimate the impact of the further rise of emerging countries. As described in chapter 4.3, we consider an increase explicitly or implicitly in our scenario variables. In a nutshell, while the model simulations are conducted only for a limited set of countries, we do not leave out the potential impact of other emerging countries in our analysis.

4.2 Results of the economic model regressions

We use appropriate econometric techniques to test structural relations of key factors on the outcome variables with two main objectives:

- to estimate and calibrate the equations to use it for scenario simulations;
- to analyse the impact of NMP patents in the past.

Figure 4–2: Comparison of the model estimates and actual development: Example of employment in total manufacturing in Germany



Source: Fraunhofer ISI

The economic model is estimated for all mentioned countries, sectors and outcome variables. In overall we estimate 205 equations simultaneously. In almost all equations the resulting r^2 is above 90%. This means that a high proportion of the variances can be explained by the model. This is illustrated by the example of employment in total manufacturing in Germany. Figure 4–2 shows that the actual values in the past and the estimations of the econometric model are almost identical. In other words, the model is capable of describing past developments quite accurately.

We derive the following key results for the impact of the various input variables.

NMP patents and total patents: The results for the effects of NMP patents and total patents in our model are rather mixed. There are several examples for significant positive results in our 205 equations, but we cannot derive a clear whole picture across all sectors and countries. Instead we observe some different patterns for the various sectors:

- In the chemical sector there is a tendency that NMP patents and total patents have a positive impact on the outcome variables;
- In the machinery sector NMP patents have mostly significant positive effects on export shares. However, there is no clear impact on value added and employment;
- In the electronics sector NMP patents and total patents have a slight positive effect on employment, but not on value added and export shares;
- In the automotive sector total patents have a positive impact on employment and NMP patents on value added. All other results are mixed;
- For total manufacturing the results are mixed. This is not surprising, as on this aggregated level many effects outside NMP-patenting (e.g. exchange rates, labour regulations) are of key relevance and effects in some application sectors do not reveal themselves on this aggregated level.

But despite the fact, that the results are rather mixed they fit in our general observations concerning the importance of the number of patents for industry employment, value added and exports. As stated in chapter 3 patents are just one factor of competitiveness and are not a guarantee for gaining the related economic benefits.

Capital formation is of key importance in all sectors and countries. The local enhancement of physical infrastructures is decisive for the production of NMP applications and the resulting value added activities and employment.

Material/energy efficiency: Material and energy efficiency do not have significant impact on the outcome variables in our model. But it has to be noted, that there is not sufficient data for longer time periods available for all 15 countries. In addition, while efficiency increases in material and energy lagged behind e.g. labour productivity growth in the past, this could change in future, as the pressure on higher efficiency will rise, due to the increasing costs share of materials (chapter 2.1).

While the last mentioned aspect sounds plausible, it is very speculative to which extent this will be the case. Consequently, these efficiency variables do not have impact in our scenario simulations. Nevertheless, we conducted a sensitivity analysis for Italy, where the most optimistic results for these variables were sustained in order to get an idea of the effects of potential changes (Annex 1).

4.3 Prospective scenarios for NMP

The objectives of the scenario analysis are to assess alternative paths regarding the **deployment and impact of NMP** in Europe within a time horizon to 2025. In consequence, the scenarios do not reflect general alternative futures (e.g. in terms of globalisation), which would undoubted interesting from a foresight perspective, but they concentrate only on differences in economic development (closely) related to NMP.

To develop the scenarios for 2025, we conduct the following steps which are described in more detail in Annex 2.

- Identify the key drivers for the competiveness of the European industry related to NMP technologies;
- Develop scenarios primarily based on coherent combinations of high impact and high uncertainty drivers;
- Transfer the scenario assumptions into reasonable values for the future development of the exogenous model variables;
- Quantify the economic impacts under each scenario by model simulations;
- Conduct sensitivity analysis on the parameters and assumptions.

In this chapter we summarise the elaborated scenarios and the derived settings for the scenario-specific model simulations.

Elaboration of scenarios

We derive three different scenarios around 2025, one "business as usual" (neutral) and two alternative scenarios with positive and negative developments regarding the **deployment and impact of NMP in Europe**. The scenarios contain overall key drivers for NMP – but not those, which are highly sector-specific – as well as key economic drivers (e.g. overall demand, financial conditions) with a time horizon to 2025. Table 4–1 summarises the results for our scenario parameters. Overall, a wide range of different factors is important for the competiveness of European industry related to NMP technologies.

Table 4–1: Main features of the scenario description

		Pessimistic scenario	Neutral scenario	Optimistic scenario
Resources	***Resource prices and relatively high availability****	Prices stagnating (*Oil price 130 US$/bbl*)	Prices growing *(Oil Price 150 US$/bbl)*	Prices high growth (*Oil price 170 US$/bbl)*
	Resource productivity	As today	Increase (~ 10% less energy+material	Strong increase (~ 15% less energy+material

		Pessimistic scenario	Neutral scenario	Optimistic scenario
			input per gross output)	input per gross output)
Technological progress and Innovation capacity	***Technological competitiveness in Europe***	Loss *(world patent share of EU-27: 30-32%)*	Constant *(world patent share of EU-27 as 2005-2007: 37%)*	Increase *(world patent for KETs: 42-44%)*
	R&D intensity in NMP-technologies (overall in % of GDP)	Stagnating *(overall 1.8%)*	Continuous increase like past 10 years (*overall* 2.1%)	Considerable increase (*overall* 3%)
Commercialisation	***Investments***	Negative *(decrease of EU 27 investment -5%-points)*	As today	Optimistic *(increase of EU 27 investment + 5%-points)*
	Market diffusion	Low	Middle	High
Demand	***Demand for environmentally friendly products***	Rather low	Medium	High
Framework Conditions and Regulations	***Environmental health and safety (EHS) concerns for nanotechnology***	Rising concerns and regulation	Status quo/no critical incidents	Successful risk assessment and communication

Source: Fraunhofer ISI

In the next step, the scenario assumptions have to be translated into reasonable values for the future development of the exogenous model variables. We estimate values for these variables for each of the three scenarios by considering past trends, integrating results of another prospective model simulation with the ASTRA-model[30] as well as expert judgements in the interviews and workshop.

Table 4–2 gives an overview of the scenario-specific trends, the common characteristics of these scenarios are not shown.

30 The ASTRA-model is explained in Annex 2.

Table 4–2: Variations in developments between the scenarios in the economic model

	Pessimistic scenario	Neutral scenario	Optimistic scenario
Number of NMP patents	- 15%*	trend	+ 15%*
EU-share of NMP patents	~ - 5%-points *	trend	~ 5%-points *
World-wide capital stock	~ - 5%*	crisis-adjusted simulation	~ 5%*
EU-share of capital stock	~ - 3%-points*	trend	~ 3%-points*
Material and energy efficiency	constant	moderate improvements (sector-specific)	high improvements (sector-specific)

Source: Fraunhofer ISI (* compared to the neutral scenario)

Not all of the scenario factors from Table 4–1 are included directly in the scenario simulations because of the boundaries of the economic model. More specifically we do not explicitly model the demand side. But our implicit assumption that e.g. demand will evolve in line to the modelled movements on the supply side, corresponds well to our overall scenarios.

Of course each model and scenario elaboration has its own limitations. In **Error! Not a valid bookmark self-reference.** we discuss potential concerns about the methodology used in the current study and present some ideas for potential ways to expand the current approach for assessing the potential impact of NMP, which could be in principle mostly be realised on the basis of the elaborated model.

Table 4–3: Limitations and potential ways forward concerning the used methodology

Limitations	Impact on explanatory power of results	Potential ways forward
No geographical coverage of emerging countries (e.g. from Eastern Europe, China)	No mayor concern for model estimates, as structural equations would hardly be affected; For the scenarios worldwide developments are taken into	Calibration of the model for these countries thinkable; but on weaker empirical basis, because of data shortages

	account as much as possible, but uncertainty remains[31]	
Limited number of economic impact channels of NMP could be regarded	Results probably reflect lower limit of potential impact of NMP; partly only limited policy conclusions possible (e.g. no differentiation between public and private actors for patents)	Addition variables thinkable, e.g. differentiation between NMP patents from industry and from academia
Model based on past data, which cannot reflect trend breaks in the future (e.g. disruptive innovations, higher importance of resource efficiency)	Impact on results hardly to be determined; Sensitivity analysis: impact for resource efficiency shows considerable effect on outcome variables	Elaborations of additional explorative scenarios based on expert judgements or analogies of trend breaks in the past
No explicit modelling of the demand-side	No decisive impact on results, as incorporated indirectly in scenario assumptions; but e.g. potential demand shocks or direct impact of public procurement could not be regarded	Model extension in principle possible (additional data issues may arise)

Source: Fraunhofer ISI

31 E.g. we derive the scenario values for the NMP patent shares of the European countries by considering the worldwide NMP patents (including China, Eastern Europe etc.) and a potential catch-up by emerging countries. Mayor disruptions, such as a forging-ahead of emerging countries, can not be taken into account.

4.4 Quantitative economic impact in the scenarios

The analysis focuses on the net impacts of NMP deployment on value added, export shares and employment. Hence, the optimistic and pessimistic scenarios are each compared to the neutral scenario. The latter represents the most likely outcome, if all currently measured trends continue in the directions they are going. In other words, the relative variation of each scenario compared to the neutral scenario is of particular relevance for the study. These variations are connected to the net effects regarding the deployment and impact of NMP in Europe.[32]

However, to get an idea of the overall developments, we present the example of the past and scenario development of value added in the European manufacturing sector by indexation (2007=100). In all the scenarios (Figure 4–3) value added remains rather constant between 2006 and 2014 before the trajectory goes up to 2025.[33] In the optimistic scenario the value added path continually rises faster than in the neutral scenario and vice versa for the pessimistic scenario. These paths capture roughly the “until-now known” effects of the crisis. Of course, the actual volatility with current up and downs is higher. E.g. value added in manufacturing actually fell in most of the European countries between 2008 and 2010. However, we do not claim that these scenario paths are precise forecasts and contain all factors that may drive the absolute prospective development. Instead, the important aspect for this study is that the impacts of the variations in the scenarios are captured adequately by the model. We attempt this by creating plausible and consistent scenarios with a continuous trend in the variations of time and by the consideration of the main impact mechanisms of NMP in the model.

Figure 4–4 shows the net effects of value added between optimistic scenario vs. neutral scenario. The value added in total manufacturing in the optimistic scenario would be around 12% higher compared to the value added in the neutral scenario. In all sectors value added is expected to rise significantly, however, with different long-term perspectives. The strongest rise would occur in the machinery and the automative sector.

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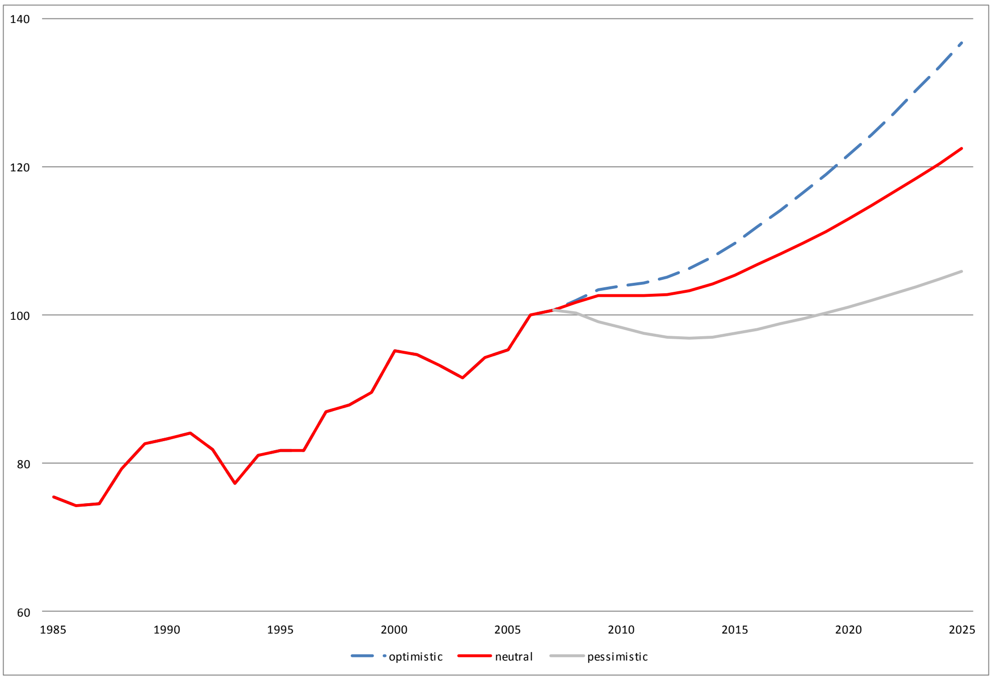
[32] Please note that these results do not indicate an employment growth compared to today. For example, an overall decline of total employment in some sectors can be expected due to further productivity gains. However in the optimistic scenario these declines would be at least partly compensated.

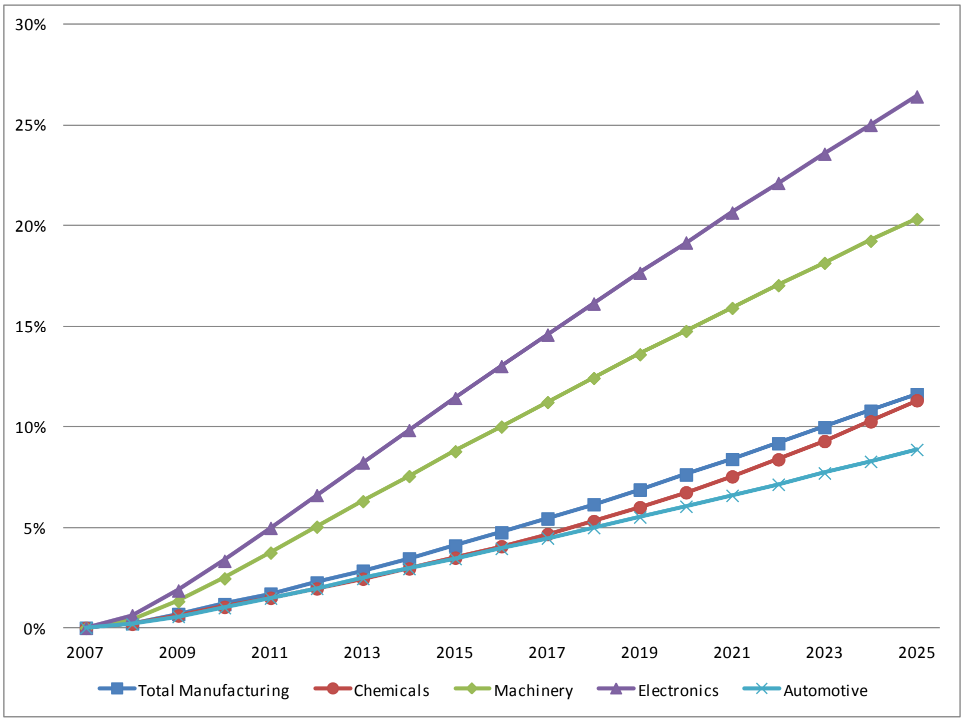
[33] One might imagine an even more negative trend in the pessimistic scenario. However, our main focus is not to cover the whole bandwidth of potential developments of the industry, but to focus on different paths for NMP.

Figure 4–3: Development of value added in the manufacturing sector in the past and in the scenarios in 9 European countries



Source: Fraunhofer ISI

Figure 4–4: Net value added effects in the optimistic scenario vs. neutral scenario for 9 European countries (in %)

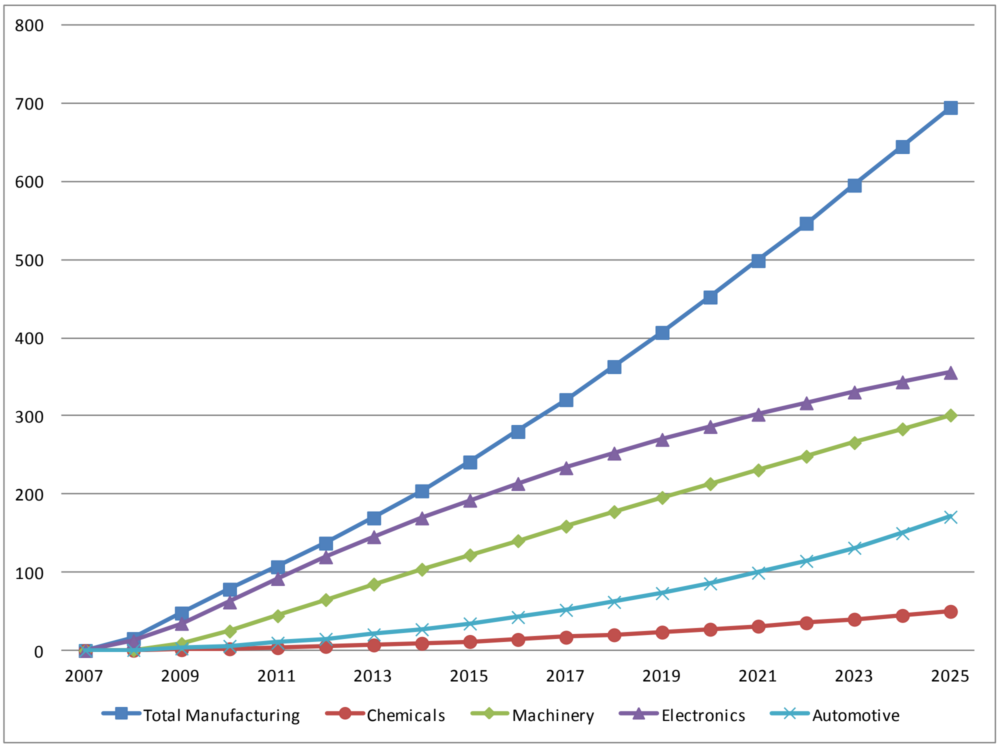


Source: Fraunhofer ISI

Regarding net *employment gains* in the European countries the picture is rather similar. In total manufacturing net employment impact would rise to around 700 thousand employees. Also in all sectors the employment would rise in the optimistic scenario. The highest gains occur in the electronics and machinery sector, where total employment would be around 300 thousand employees higher than in the neutral scenario.[34]

Overall, the sum of the potential employment gains in the four sectors is higher than for manufacturing in total. This implies a structural change towards these manufacturing sectors and a subsequent loss in other manufacturing sectors (e.g. food, textiles, etc.).

Figure 4–5: Net employment effects in the optimistic scenario vs. neutral scenario for 9 European countries (in thousand employees)



Source: Fraunhofer ISI

For the net effects on *export shares* the results are less clear. Figure 4–6 depicts the changes in cumulated export shares for the European countries in %-points. E.g. in the manufacturing sector the export shares of the modelled European countries sum up to 54.8% in the neutral scenario, but only to 56.8% in the optimistic scenario, the resulting difference amounts to 2%-points.

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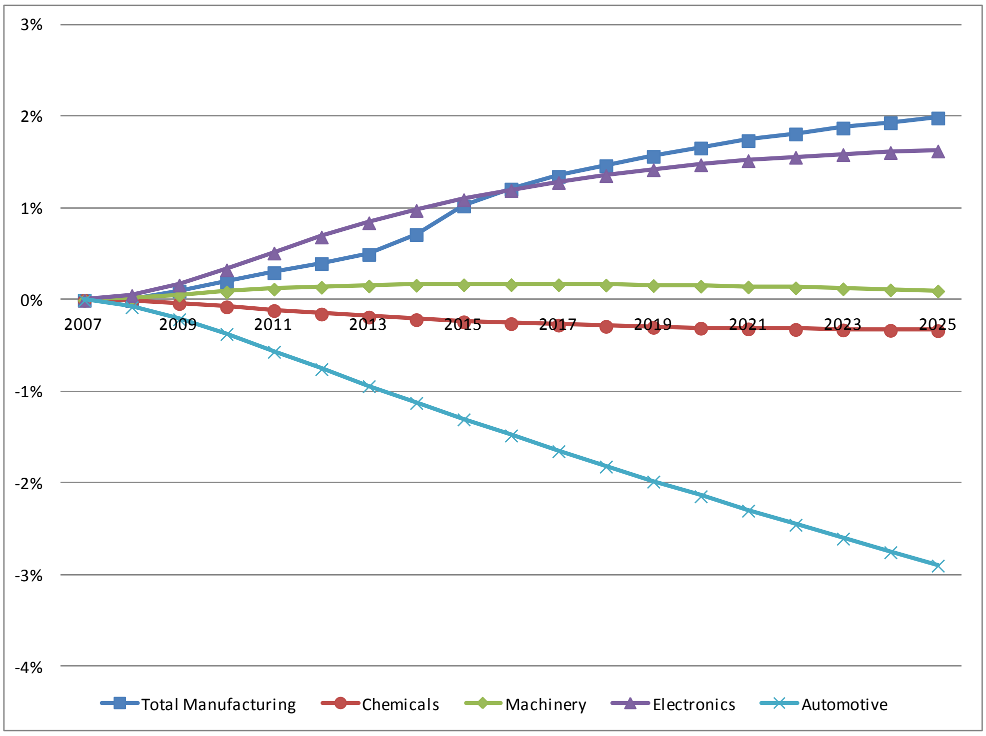
34 Please note, that differences in value added and employment in sectors arise not only due to changing labour intensities, but both variables are estimated simultaneously in our model.

Figure 4–6: Net changes in export shares in the optimistic scenario vs. neutral scenario for 10 European countries (in %-points)



Source: Fraunhofer ISI

The cumulated export shares in the European countries do not rise in all sectors in the optimistic scenario. Instead they fall slightly for automotive and chemicals. While these results are puzzling, as rising export shares would have been straighter forward, they are not automatically contradicting to employment and value added results. Some explanations might be:

- Unlike other indicators the world-wide export shares are limited to 100%. Hence one cannot expect high differences in cumulative values like for indicators in absolute values. Instead, in some European countries the export shares rise, while they fall in others;

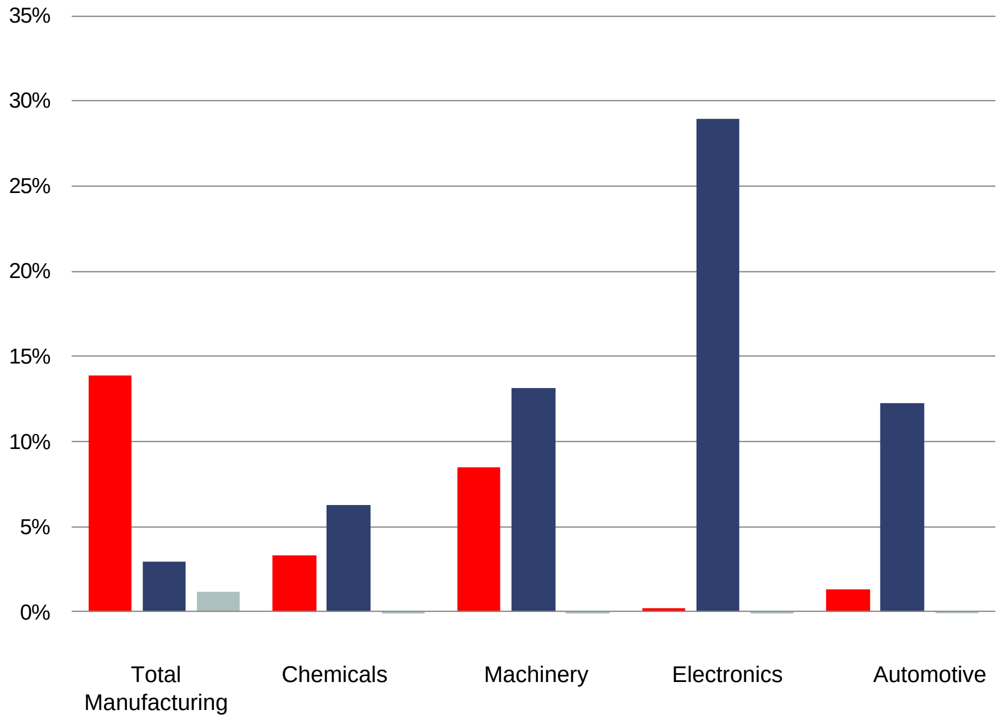
- The structural equations for export shares differ to employment and value added and exclude e.g. the capital stock and include others such as wages.[35] But while the inclusion of wages to explain export shares is plausible, one cannot assume differences between the scenarios for this variable due to developments in NMP (e.g. no variation for wages is assumed in the scenarios).

[35] The reason behind is to include France and Canada, for which no data for capital stock is available (at least for one outcome variable).

The net outcomes of employment etc. are not equally distributed between the European countries (Figure 4–7). E.g. for changes in employment (expressed in %-differences between the optimistic and neutral scenario for 2025) the effects significantly differ between large and small countries. There are no clear overall diverging developments to expect, but varying differences from sector to sector may arise.

For the non-European countries the variations between the scenarios are rather small. This is not surprising, as the scenarios mainly reflect positive NMP deployment effects in Europe. For instance, while the capital stock rises in the US, Japan or Korea as well as in Europe in the optimistic scenario, the assumed surplus is much smaller for the first than for Europe as an increasing world-wide share of the capital stock is assumed to shift towards Europe.

Figure 4–7: Net employment effects in the optimistic scenario vs. neutral scenario for country groups (in %) in 2025



Source: Fraunhofer ISI

Legend: red = small EU countries (AUT, DNK, FIN, NLD, SWE); blue = large countries (DEU, ITA, ESP, UK); grey = other countries (AUS, JPN, KOR, USA)

4.5 Sensitivity analysis

Additionally to the scenario simulations, sensitivity analyses for key input variables of the model has been carried out in order to illustrate the dependence of the results on main variables. This is especially interesting in the case of our study: As discussed below, the impact of the various factors may give some hints concerning valuable actions of policy and industry.

We conduct several sensitivity analyses to get a better understanding of the dependency of the results on the main impulses. We test the sensitivity of value added and employment on the variables NMP patents, capital stocks as well as material and energy efficiency. In these analyses only the differences in the respective variable between the optimistic and neutral scenario are considered. All other variables are simulated equally for both scenarios by using the values of the neutral scenario. We compare the variation between the “hypothetical” optimistic scenario and the neutral scenario to analyse the sensitivity.

The respective analyses are summarised in Figure 4–3, while the concrete results of the sensitivity analysis are presented in Annex 1. For reasons of clearness of the results, the aggregation level differ from chapter 4.4 and show the **cumulated number of employment and value-added impact for the four industrial sectors**. This can be interpreted as **net effects in these sectors**; they may be offset partially by losses in other industries in the total manufacturing sector. But according to the results presented in chapter 4.4 this is probably only the case to a limited extent.[36]

The results show a significant positive impact of each of the analysed input variables. A higher worldwide capital stock of about 5% compared to the neutral scenario in combination with a 3%-point higher share of the EU-countries results in around 690.000 more jobs. Similarly, a higher worldwide number of NMP patents of about 5% compared to the neutral scenario in combination with a 5%-point higher patent share of the EU-countries countries is related to around 215.000 more jobs. The potential material and energy efficiency increases in the optimistic scenario are sector-specific and only tested for Italy (see Annex 1 for more details); in overall they are related to around 4% higher employment in the four industrial sectors.

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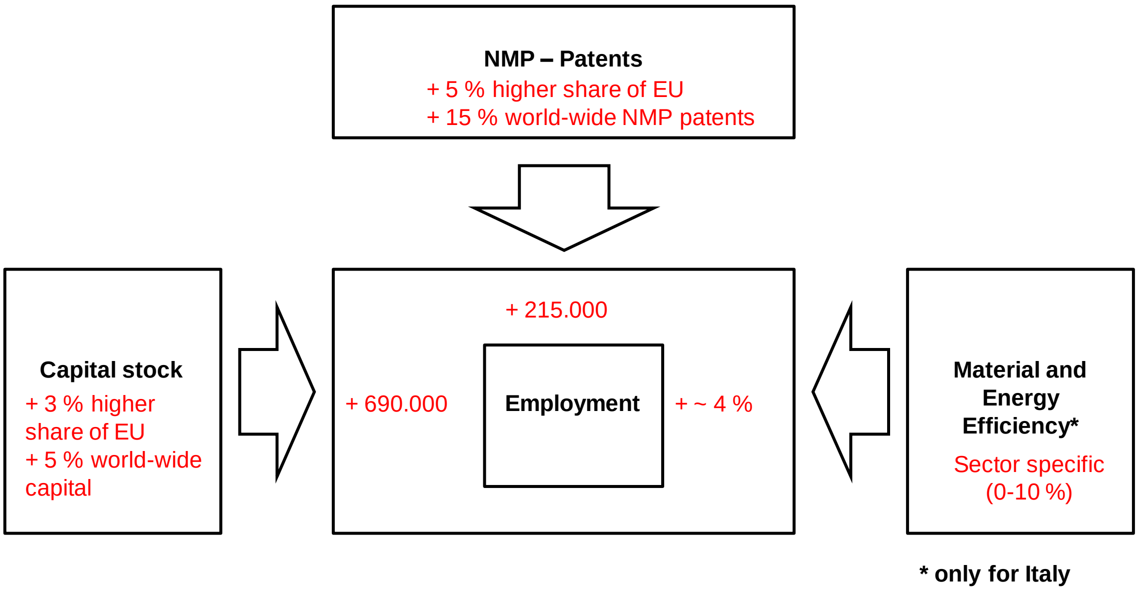
[36] Another option would have been to present the number for total manufacturing. However, as, like argued above total manufacturing is a special case in our model simulations. On this high aggregation level, it is rather likely that NMP has a less clear-defined impact, as some industries (e.g. food, rubber, petroleum) may be affected more indirectly and other variables (e.g. foreign-exchange rates, inflation etc.) may be more visible on this level. While our model in overall is also for total manufacturing robust and stable, this is not the case for each input-output variable combination in our model.

Figure 4–8: Sensitivity analysis for key model parameters (variation of single variables according optimistic scenario vs. neutral scenario)



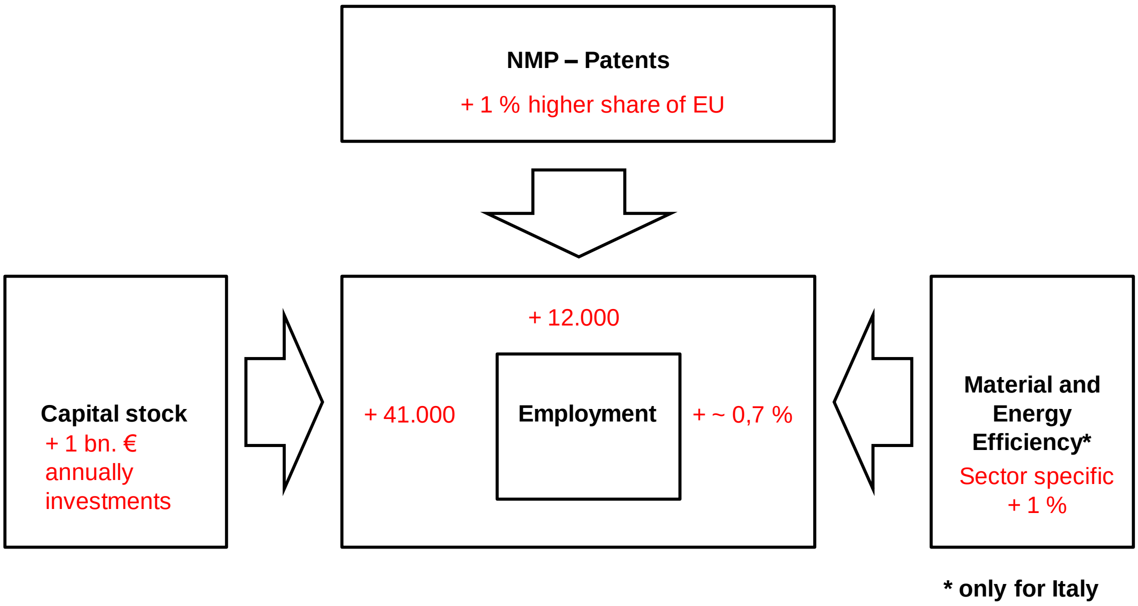
Source: Fraunhofer ISI

It is important to note that such high variations of single variables are hypothetical cases, as it is rather unlikely and less consistent that one variable reaches the value of the optimistic scenario, while the others remain constant. For example, one would at least expect some additional investment, if the number of NMP patents increases significantly and vice versa. Hence, another interesting related sensitivity analyses is to calculate the net effects of a "marginal increase" of these variables. More concretely we analysed which impact on employment would have

- a €1 bn increase in capital investment per year between 2007-2025,
- a 1% increase in patent share of the EU-countries,
- a 1% increase in material and energy efficiency by using NMP technologies.

Such an impact could arise as result of higher international competiveness of industry and/or related policy measures. The results show that slight increases of patents, capital stocks, material and energy efficiency have considerable positive effects on employment. For example, a higher annual investment of €1 bn per year between 2007 and 2025 would be related to a higher employment of around 41,000 persons compared to the neutral scenario.

Figure 4–9: Sensitivity analysis for key model parameters (marginal variation of single variables vs. neutral scenario) in 2025



Source: Fraunhofer ISI

4.6 Discussions of the results for the model and their policy implications

Before discussing the implications of the model results and drawing conclusions, the limitations of such an approach have to be considered:
Our scenario simulations were based on a number of premises, and their importance for actual policymaking and concrete actions for industry should not be exaggerated. The overall notion of considerable economic impact of NMP does not provide directly a justification for policy intervention (as e.g. it may very well be the case that private actors might be able to realise this potential alone) and neither an indication of which policy instruments or actions from industry should be preferred. For example, innovation policy may take a broad variety of different forms (such as taxes, subsidies, intellectual property rights, education). Such specific types of policy usually cannot be captured explicitly in simulation models. We therefore had to focus on some few input variables in our model, because of methodological reasons and restrictions in data availability. As stated above the positive results for NMP patents and capital stocks should not be interpreted in a way that these are the main aspects to concentrate on, but they are proxy indicators in our model for innovation (e.g. innovative R&D), commercialisation and production (linked to industrial competitiveness) related to NMP. Under the assumption that these variables are capable to represent these activities some generalisations are appropriate in our view.

Hence, our econometric results for the past, the scenario simulations as well as the sensitivity analyses, may provide some hints for the direction of possible actions from policy and industry. While some conclusions may appear intuitively, they have been derived on a well-founded quantitative empirical basis in this study. In the following, we summarise the main results and discuss their possible respective implications:

1. In all sectors employment and value added increase in the optimistic scenario compared to the business-as-usual scenario with the underlying model assumptions. Only the net effects on export shares are less clear for some of the sectors. In addition, various sensitivity analyses indicate that not one single variable related to NMP only, but rather several variables (e.g. capital stocks, NMP patents) together drive these positive results. Consequently, NMP technologies affect the economy **via a number of impact mechanisms** and may have significant positive impact **across many industrial sectors** in the future. These results point out **the importance of actions, which take into account the whole innovation system across sectors and do not focus on single sectors or single activities or functions (such as R&D)**.

2. The results for the effects of NMP patents and total patents for the past in our model are rather mixed. There are several examples for significant positive results in the 205 equations of the model, but no clear pattern across all sectors and countries can be derived. However, the sensitivity analyses for the industrial sectors show that the positive impacts overweigh. As patents can be interpreted as a proxy indicator for output of applied research and development activities, **these results may imply that keeping up and even increasing the level of NMP-related R&D activities and related support measures would be beneficial from an economic perspective**.

3. Regarding export shares, we assess also potential international sectoral spillover effects in NMP technologies, by including an additional variable with the total number of NMP patents on the world market (apart from domestic NMP patents). The idea behind this is that countries profit not just from exploiting their own patents, but also from patents which have been generated in other countries. But also the opposite effect is possible as higher worldwide patents could be a sign of less domestic technological competitiveness. Our results show that different patterns across sectors occur, but at least in some of them positive impacts of world-wide NMP-patents are observable, in particular in small EU-countries. International spillovers indicate that the exploitation of the global knowledge base is important for the domestic economic development. This highlights the need for close links to the global knowledge base. Hence, industry and policy should not only focus on exploiting domestic patents, but also to **build up absorptive capabilities to exploit knowledge from abroad and participate in global value chains**.

4. The capital stocks has a positive impact on employment and value-added in all sectors and countries and is the most important factor in our model. **The local enhancement of physical infrastructures is decisive for the domestic production of NMP products and applications.** Hence, activities to raise capital investments in Europe are required. As pointed out in the literature, the determinants for investments in a given country are usually manifold (OECD 2010, Thomas 2010). Although, the model results do not provide answers concerning which concrete measures are urgently needed in Europe, they clearly show, **that industry should invest more and policy should identify the main barriers for investment and address these with adequate support.**

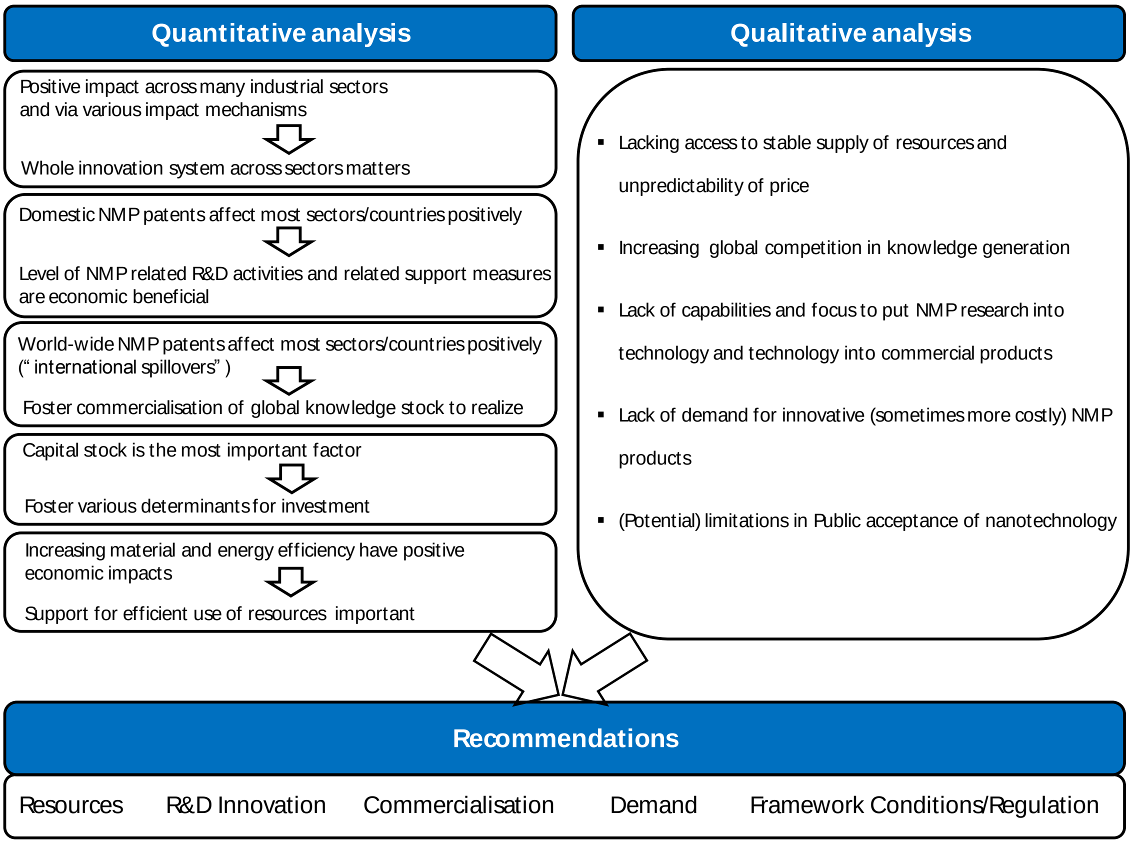
5. Material and energy efficiency mostly have no significant impact on the outcome variables in our model. However, we could only estimate the impact of these variables for some countries, due to data restrictions. In addition in a few countries, e.g. Italy, we could observe a positive impact. The sensitivity analysis for the potential economic impact of resource efficiency via NMP for Italy shows indeed a remarkable effect. In combination with the argumentation of rising economic pressure on higher efficiency in the future, due to the increasing costs share of materials**, this finding may indicate a need for more efforts from industry and policy to increase efficiency**.[37]

[37] Moreover, if it would be possible to could include factors in the model simulations, such as raw material and energy prices, regional laws/regulation and incentives/subsidies for “green/clean production“, more significant impacts might be observable.

5 CONCLUSION AND RECOMMENDATIONS

Combining the findings from the quantitative analysis with the econometric model and the qualitative analysis on trends and signals for NMP, very similar needs for actions can be identified. For example, the qualitative analysis highlights, among others, an increasing need for material and energy efficient technologies, for better commercialisation and built up of production in critical industries as well as for demand-oriented "green" products for the society/consumers within Europe. In particular, the indications of a cyclical long-term behaviour of NMP patents with a double boom calls for further support of innovation policy, despite the decline of patenting. We summarise the main findings in Figure 5–1. These findings point out that in order to overcome these bottlenecks and challenges, strategic actions of all stakeholders along the innovation chains as well as value chains are needed. The scope of actions has to encompass challenges in resources, R&D and innovation, commercialisation (including production), demand and framework regulations.

Figure 5–1: Key results for recommendations



Source: Fraunhofer ISI

While these findings point out the scope for actions, they have to be more concretised to provide clear implications for industry and policy. For this purpose we take up the findings of our intensive review of trends and signals for NMP (chapter 2), discussions with stakeholders in various workshops and interviews as well as recommendations of several recent other studies on similar issues, as far as they correspond to the findings of the study.[38]

According to our findings in chapter 2.3 many challenges occur across the various sectors. Hence, we propose a policy-mix with mostly cross-cutting issues for NMP and some measures, which are concretised on a sectoral or value chain level. While international competitiveness can only be achieved by industry itself, policy may provide adequate support. It is these support measures, where we particular focus on. These actions are not all directly linked to the Common Strategic Framework (CSF) but address a wider set of policies. However, it is out of the scope of this study to build up a strategic vision for the future manufacturing sector until 2025. Rather, we take the goals/vision of Europe 2020 as given[39] and analyse the adjustment of the common policy tools in order to improve industrial competitiveness.

The formulation of a consistent set of recommendations is a challenging task. While there seem to be less divergent opinions considering the challenges for European industry the perception of an adequate strategy differs. One main issue is whether policy support should focus intensively on industries, themes or value chains, in which the European industry possess strengths in the global competition. While there are proponents for such strategy and many possible options have been addressed by the Expert Group for Key Enabling Technologies, other experts hint to the probable disadvantages for (sub-)industries, which are already highly integrated in global value chains. But also the success and participation in global value chains matters for value added and jobs. As the different argumentations are plausible and it's not the objective of this report to formulate a detailed strategy but to propose options for action, we take up both argumentation lines by following the proposition of Castellacci (2008). He summarises the innovation policy implications from an evolutionary perspective as follows: "In those clusters of vertically integrated industries where the country is specialised, the interactions between producers, suppliers and users of new technologies should of course be strengthened. In those sectors where the economy has not a traditional stronghold, however, vertical linkages should be actively supported through co-operation schemes and, particularly in the case of small open economies, through incentives to build up these linkages by cooperating with foreign advanced firms." (Castellacci 2008, p. 1000). We transfer this idea into the context of our study, by

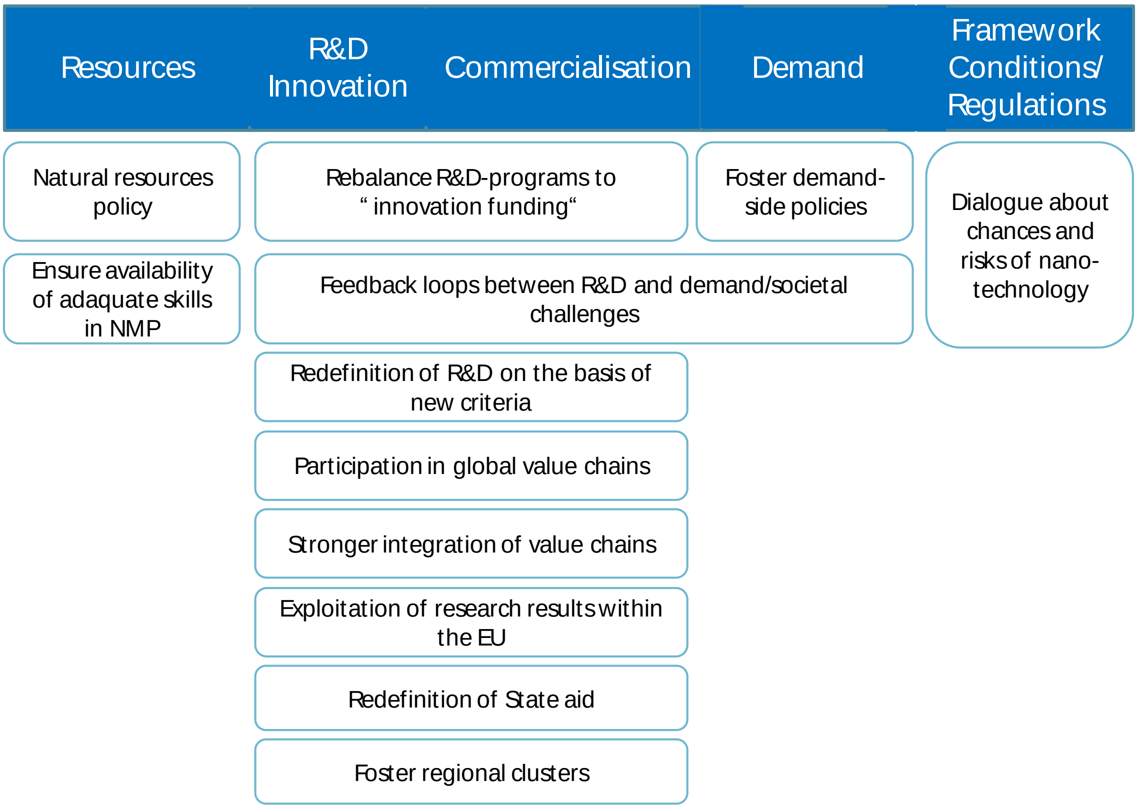
38 E.g. High-Level Expert Group for key enabling technologies, Horizon 2020 thematic workshops, parallel projects for policies regarding NMP (Oxford Research 2012, Gelderblom et al. 2012).

39 This approach was recommended by experts in workshop. The reasoning is not that necessarily each aspect of this strategy is highly appreciated, but because this strategy is already rather accepted and widespread in the community, and each new approach for a revised strategy would be very time consuming.

proposing on the one hand vertical measures to bring forward topics and support whole value chains, in which Europe possesses specific strengths. And on the other hand horizontal measures, which explicitly support activities in global value chains, where Europe only has partial strengths.

Figure 5–2 summarises the recommendations assigned to the competitiveness drivers. It has to be emphasised that despite the recommendations are attributed to certain steps in this innovation chain this does not mean that policy should have a linear view of innovation, but rather adopt a dynamic systemic perspective, with strong interactions and feedbacks between the various actors (supplier firms, user firms, end customers, ministries, etc.).

Figure 5–2: Overview of recommendations



Source: Fraunhofer ISI

Natural resources policy

As described in chapter 2, the relationship between NMP technologies and natural resources is twofold. On the one hand NMP has the potential to reduce the use of critical resources (e.g. by nano), substitute critical (e.g. limited, toxic) materials and re-use strategic relevant resources by means of closed-loop production (life cycle, recycling). On the other hand, NMP products rely on natural resources itself. As no general shortages in all kinds of materials and prices can be expected the impact of potential shortages will differ between the various NMP applications. But generally spoken, the availability of natural resources (including its predictability and stability) as well as the price of resources will be crucial for the deployment of NMP in various industries (electronics, automotive, chemicals).

Hence, a comprehensive natural resources policy is crucial to open up new application fields for NMP and to ensure a stable supply of NMP products and processes. Such policy would comprise e.g. ensuring the access to raw materials and energy at international level, fostering sustainable supply from European sources and boosting overall resource efficiency and promoting recycling.

Ensure availability of adequate skills in NMP

While skills and competencies are decisive for the competitiveness of the European industry, shortages and gaps related to NMP are expected to increase (OECD 2010, Gelderblom et al. 2012). These gaps encompass interdisciplinary competences of researchers and workers as well as the quantitative numbers of engineers and scientists (OECD 2010, HLEG 2011). However, future development of demand and supply is very uncertain as skills demands in both quantitative and qualitative terms differ depending on sector and type of technology applied (Gelderblom et al. 2012).

Recommendations in order to ensure the adequate supply of skilled researchers and workers comprise monitoring pace and size of extra demand depending on new developments in industrial technologies. In addition the recently published study about the "Assessment of impacts of NMP technologies and changing industrial patterns on skills and human resources" concludes that

- companies should further develop this role by a well-developed personnel policy in terms of internal function mobility, specific training and regular feedback;
- interest in S&T should be stimulated at a young age (preferably in primary schools);
- interaction between companies and educational institutions should be improved;
- vocational education and training institutions should pay more attention to the impact of new technologies for skills.

Rebalance R&D-programmes to "innovation funding"

The dominant funding model for R&D in the CSF and EU Member States is challenged from different directions. On the one hand, there is a strong plea to align research more directly to industry needs, since the focus of research on applications is currently too low. Moreover, the funding models do not take into account sufficiently the whole R&D process for key enabling technologies like N,M and P. "When the funding from the framework programmes come to an end, the outcomes of the specific projects are typically at a "technological readiness level", where the technological outcomes are not close to commercialisation" (DTI 2011, p.10).

On the other hand mainly industry focused research programmes would lead to a decline of basic research projects as the direct present value is much smaller than the long-term value. But as a strong research base is essential for innovation and competitiveness in the long run frontier science and blue sky research should be addressed intensively as well (Oxford Research 2012b).[40]

Both rationales are well founded and appropriate. Thus a rebalance of R&D-programmes to a more integrative innovation funding would be adequate in such way that

- one part clearly addresses frontier science and blue sky research,
- and the other part uses redefined R&D definitions to support to cross the valley-of-death on the basis of the three pillar bridge model (see below).

Hence a clearer alignment of the budgets to different kinds of research would be necessary. Some activities already reflect such approaches, such as the FET-Open programme for blue sky research on the one hand and industry focused initiatives with PPPs on the other hand. But more can be done as still a large part of budget is allocated to programmes which have the high ambiguity to address frontier science and a high applied focus at the same time. One discussed possibility is to design calls with different evaluation criteria and guidelines, e.g. with more emphasis on scientific excellence for calls for basic research and more emphasis on market impact for calls for applied research actions (EC 2011). However, also new challenges by such an adaption of the research system may emerge. According to experts, basic-researchers would have less incentives to conduct needs-driven research and the links between basic and applied research might be weakened, if they are less aligned to common goals. Hence, additional aspects have to be considered, such as incentives for further exploitation or the assurance of an adequate communication of the results. These aspects are discussed more in-depth below.

Redefinition of R&D on the basis of new criteria

Concerning more applied innovation activities, additional adjustments of measures have to be considered. The High Level Expert Group on Key Enabling Technologies proposes a three pillar bridge model to support to cross the so-called ‘valley of death’[41] between research, technologies and marketable products. They define three important pillars: “Technological Research”, “Product demonstration” and “Competitive Manufacturing”. To cross the valley-of-death a “European bridge comprising these pillars” should be constructed. The role of policy would be to support not just research, but also pilot lines, demonstration plants and the support of the globally competitive manufacturing capabilities. This would imply an adjustment of R&D definitions in its funding programmes which support the full and simultaneous implementation of the

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[40] Even in the cases of no direct use the knowledge of physical properties can help to save spending money, which might had been invested in technological paths that latter turn out as unpromising.

[41] The notion “Valley of Death” is connected to road between the discoveries from basic research to market products and describes the funding gap at the intermediary stage.

three pillar bridge model along the innovation chain, from basic research, through technological research, product development and prototyping up to globally competitive manufacturing**.**

Feedback loops between R&D and demand/societal challenges

However, according to experts, the pillar bridge model refers mostly to a linear process of innovation. The consumer is at the end of the process and it may become obvious only very late, that the product is not appropriate. To address the undisputed non-linearity of the innovation process in NMP, additional aspects have to be considered. First the stronger alignment of R&D to market demand and societal needs is crucial. One issue might be to address the KETs explicitly in the Grand Challenges of the CSF in the Horizon 2020 programme, which is not obvious in the current plans. A stronger connection between the KETs and societal needs may be fruitful for a stronger alignment of technological activities to societal needs. A second issue is the closer exchange between R&D results and market needs. The point is not only to intensify the knowledge transfer from research to industry but to assist the articulation of demand. This is not easy for the customers, since it is unclear, which technological possibilities exist and how far they have been developed. One proposition is to intensify specifically targeted dissemination activities towards industry and the broader public (Oxford Research 2011). In addition experts expressed a strong need for a study aiming at mapping the readiness of NMP R&D activities with respect to the market and also with respect to their integration into production processes. This could be done by using the so-called Technology Readiness Level (TRL) scale. The scale outlines the different research and deployment steps, which support the innovation and industrialisation process of technologies to transform ideas to the market (HLEG 2011). Thereby transparency and information about the midterm application potential of NMP are expected to increase.

Thirdly, a related issue to demand driven research funding may be to focus on certain issues, which are in line with the strengths of European Industry. In this study especially the following topics are identified, which could be included as additional criteria’s or eligible activities in certain calls:

- An important asset of Europe is its strength in design (EC 2009c). Moreover, the design issue would be another way to integrate much better the needs of applicants and users into the R&D activity. Accordingly, it should be better integrated into development and production activities. For example, recycling could already be integrated as a design feature. In terms of policy measures this could, for example, be implemented via the mandatory requirement for new products to include a recycling plan. R&D projects would not get any funding if such a plan would be missing.
- Industrial services would be an unique selling point of European activities in the context of NMP developments. New NMP solutions would require additional knowledge-based new services in order to make best use of them. At the same time a number of new services would also call for new NMP technologies (e.g. in the domain of sensors). Accordingly, there is a mutual positive relationship

between service and NMP development. Funding calls may encourage and support the development of industrial services.

A mayor concern of this study was to identify, to which extent sectoral specifics have to be taken into account for innovation and commercialisation measures. However, most issue are cross-cut and not specific. Only some additions have been proposed in expert workshops:

- some sectors only profit to a limited extent of the PPPs and the expansion of the idea to those sectors and value chains may be fruitful (e.g. chemicals, machinery). As discussed above such new PPPs should also integrate NMP technologies sufficiently;
- in pharmaceuticals more specific and diverse products will be produced in the future as the blockbuster model declines and trends such as personal medicine may result in a higher product diversity. This creates a challenge for pharmaceutical production as more flexible production lines are necessary. This is a promising topic for NMP, but it is not addressed in funding calls yet.

Stronger integration of value chains

Stronger integrative value chains considering the key stakeholders are very important. Value chains are getting more complex and diverse and especially SMEs do not have the capacities to run projects for all value chains and to keep an overview of compatible research by possible partners. In the CSF collaboration projects between different stakeholders are already one “of the key aspects. However, the current collaboration projects with multisectoral stakeholders may be not sufficient to address the societal challenges adequately. Often, direct competitors are in the same projects with different aims and there are no clear goals for applications set.

For a building-up of integrated value chains oriented towards a specific challenge, PPPs are considered to be a promising approach. They may enhance collaboration between the public and the private sectors as well as between private stakeholders. In addition, the immediate pressure on public sector budgets is usually reduced, as leverage private funding and risk-sharing allows the completion of private projects that would otherwise not have been undertaken.

In the FP7 three PPPs (Factories of the future, Energy efficient buildings; Green cars) have been launched with a significant part of NMP-budget. In overall, this approach is appreciated by the stakeholders and further initiatives are requested. However, there are some concerns that NMP technologies do not profit in all of these existing projects adequately. For example, the green car initiative is oriented in a vertical way, meaning that they are starting from established OEMs and going down the value chain from these starting points. An adequate participation of enabling technologies and the respective industries is missing (e.g. materials' industry using NMP technologies). Accordingly, one suggestion might be to enrich such initiatives by horizontal activities focussing on enabling technologies.

Exploitation of research results within the EU

In order to realise most of the economic benefits resulting from emerging technologies domestically, activities to exploit R&D project results in commercial products and manufacturing within the EU should be intensified. There are different options, which may be realised in combination:

First, policies should still focus on the absorptive capabilities of the European industry to exploit the R&D results. This should encompass entrepreneurial policies (e.g. venture capital) but also the large amount of small and (especially) medium-sized firms with middle or low R&D focus. The firms are part of NMP value chains as well. Good-practice examples to support a wider set of firms are the German programmes ZIM and "Gemeinschaftsforschung". These programmes are small, simple and quick in terms of bureaucracy. These measures would also be appropriate on the EU-level (the current SME programme is not adequate enough) and for other EU Member States.

Second, the High-Level Expert Group for Key enabling technologies proposes adjusted criteria and rules for participation in the CSF (HLEG 2011). The propositions include that

- "at the start of any project, consortium partners should have to demonstrate in their proposal that they have a clear IP plan for both the ownership and first exploitation of IP resulting from the project within the EU";
- "critical parts of the value chain sectors (upstream and/or downstream) have to be actively engaged in the governance of the programmes/projects to ensure engagement along the value chain";
- "at the end of any project, rules should be implemented to favour the EU exploitation of the results of projects. For example, the European Commission should have discretion over whether to allow a Public Research Organisation or an industrial company to licence such results to a non-EU party and to decide whether reimbursement of all or part of the funding received for the R&D project was required within a reasonable timeframe" (HLEG 2011, pp.34 f.).

While those measures may have some impact on domestic exploitation of research results, they would prioritise and leave few funding possibilities for others as many innovation and value chains are already highly globalised, and in many sectors European firms are not the key players (HLEG 2011). Hence, this strategy of strict within EU deployment may be only useful for some activities and sectors. The challenge is to identify the (sub-)industries and value chains for which a focus on European value chains and domestic exploitation is fruitful.

Participation in global value chains

Besides, policy should adapt strategies for those activities, in which Europe is present only in niches or some value chain steps. Also the success and participation in global value chains matters for value added and jobs. Related measures may include the international collaboration in research as well as concerning foreign direct investment.

Concerning research, Europe is still in a leading position in NMP. Hence, internationalisation is only urgent in some fields until now, but with further globalisation of value chains this might increase. The diversity of technology options and the related need to share knowledge across the globe can be successful only if it is based on extensive networking (EC KBE Expert Group 2009). European research policies will have to increasingly recognise the need to network, interact, and participate in the global research area. Links with other global centres of activity have to be forged in order to create synergies and access complementary expertise (EC KBE Expert Group 2009).

Attracting foreign direct investment, in particular for production facilities will be crucial to achieve the needed capital investment for the positive impacts in our optimistic scenario. Already today, many governments currently target international investments in high-technology industries by a mix of broader innovation policies, investment promotion complemented with direct government incentives (OECD 2011a). There is still no consensus about the cost-benefit of those measures. Recent experiences with such measures point out the need to design policy instruments (public private partnerships, collaboration in innovation, clusters, etc.) that foster this interaction and are maximally open to foreign enterprises, but at the same time optimise the benefits to the local economy (OECD 2011a). Another lesson might be that governments are better of providing performance-based incentives where the payment is conditioned on the realised performance of the multinational enterprises on specific criteria (employment, R&D investments, etc.), instead of ex-ante incentives.

Redefinition of State aid

A related aspect to the rebalance of government support across the innovation chain is the adaption of state aid regulations to facilitate R&D&I activities and large-scale investment.

While many countries around the globe support high-technology intensively, the government support in European Member States for technologies and industries is highly regulated and limited by the European state aid control. In principle the aims of the state aid regulations are regarded as useful, as competition and related policies are an important basis for innovation (Metcalfe 2008). However, reviews of the various Frameworks showed some missing flexibility and inadequate criteria from an innovation policy view.

The probable first-best solution would be a greater world-wide harmonisation of state aid rules in order to avoid distortion of international competition and the avoidment of subsidy races. But as various efforts have not been successful yet, there have been various propositions to some adaption of state aid control in the light of global competition and challenges like climate change (HLEG 2011, Aghion et al. 2011, Wydra et al. 2010). While the first proposition in the following addresses the limitation of support for large scale investments, the other propositions point to more generally redefine the frame of the allowance of support:

The most discussed change is the introduction of a ***matching clause for investment incentives*** to Regional Aid Guidelines – or in generally for state aid control – analogous to that contained in the EU Framework for State Aid for R&D&I (HLEG 2011, Wydra et al. 2010). It should allow Member States to match funding up to the maximum levels of support provided elsewhere for product development and manufacturing activities, if it is in line with WTO rules. Such measure would reduce distortion of international competition. However the practical usefulness for such measure is disputed even for the R&D&I Framework, as it is difficult to prove the aid bid of other states.
Additional efforts to clarify possibilities as well as supporting measures like the implementation of a state aid observatory might be necessary.

A second possibility is to allow ***higher maximum aid intensities*** (e.g. by lowering the scaling-down mechanism for large investments), but to ***connect the decision with additional criteria*** in the balance test, which ideally correspond to system failures. One important point would be the development of rules for investment aid that are primarily based on system failures and structural policy considerations, which could be addressed by other policy instruments such as the European Structural funds. The main challenge would be to set up adequate criteria's, which are somehow measurable and do not open possibilities of arbitrariness. Propositions for possible criteria's are the degree of skill-intensity and the degree of competition within the sector.

A third proposition is ***an increased funding from EU budgets***. EU spending is not classified as state aid in the EU Treaty and it would avoid two problems of individual Member States aid (Aghion et al. 2011): First, most countries are not be able to finance more than a few firms, particularly in capital-intensive sectors. Second, governments may have bias against production and entry by foreign-owned firms. However such changes are probably not easy to implement as they would also mean increased shift of competencies and budget from a regional or national to a supranational level.

Any of these options to adapt state aid control should be conducted very carefully and not hollow out the principle aims of the control.

Foster regional clusters

For deployment of NMP across Europe the regional perspective may be fruitful, as geographic proximity still matters for innovation and commercialisation. The specialisation at innovative clusters level may lead to the generation of first-class knowledge, which is directly used and targeted to develop innovative regions (Oxford Research 2012b). Innovations may more likely reach the commercialisation stage due to direct engagement of industry at local level. A major step is taken forward in the new regulations of DG Regio concerning smart specialisation. Each regions applying for regional funds has to satisfy the smart specialisation strategy, which is prioritising KETs.

An additional step could be to implement mechanisms supporting innovative regional structures along the innovation chain in a limited number of excellence centres in

Europe. The intervention can integrate all available European Commission mechanisms on a regional level as: structural funds general infrastructure, research facilities, SME support project (incubators), venture capital market, education facilities, educational programmes, labour market intervention, concentration of demonstration projects, cultural activities and other social and economic dimensions.

Of course, such implementation of excellence clusters is highly challenging and confronted with some obligations (Oxford Research 2012b). Most concern is how such cluster initiatives may fit to the manifold existing related strategies.

Foster demand-side policies

The interest in demand-side innovation policies has increasingly emerged as part of a greater awareness of the importance of feed-back linkages between supply and demand in the innovation process (DTI 2011). They are important policy instruments aiming to increase the demand for innovations, to improve the conditions for the uptake of innovations or to improve the articulation of demand (Izsak/Edler 2011, Edler 2007). Different policy tools can be used such as systemic policies, regulation, innovative public procurement and pre-commercial procurement, standardisation, support of private demand.

In a number of countries demand-side innovation policy has become an explicit part of recent innovation strategies. But still, the implementation of demand-side policies is in early stage and the majority of countries still largely focus on supply-side instruments (Izsak/Edler 2011, p. 37). One hindrance is the on-going debate and some scepticism towards certain type of demand side instruments (fear of picking winners problematic). The implementation faces various challenges, such as the needed inter-departmental co-ordination in countries for public procurement (OECD 2011b). Moreover EU-wide initiatives like the Lead-market-initiative face the difficulties of co-ordination between EU Member States. Hence, a current policy report expresses the fear that "… as always when new trends diffuse through European policy making, that demand-based measures are rolled out prematurely and with high transaction and learning costs" (Izsak/Edler 2011, p.41).

But, dedicated studies (e.g. OECD 2011b, Oxford Research 2011b, Izsak/Edler 2011) as well as the approached experts in this study still consider these tools as useful and powerful to foster market entry and diffusion of emerging technologies. Hence, demand-side policies, such as innovative public procurement and pre-commercial procurement, should be further developed and implement to foster market entry and diffusion of NMP. According to recent experiences they should implemented in form of more systemic policies, which

- focus on the specific context of challenges and sectors,
- combine different demand-based instruments or even demand and supply side approaches.

As NMP has a high cross-sectional character it's uptake can hardly be addressed directly and in a comprehensive way by demand side policies. But NMP may benefit indirectly as its applications are used in many different innovative value chains, which may be subject to such policies:

- for micro-/nanoelectronics, examples would be incentives for buying energy efficient electronic products or medical implants, which require innovative chips. In overall green public procurement or regulation concerning energy efficiency or materials may have an impact on many NMP technologies;
- for automotive, the use of electric vehicles could be supported by fiscal instruments or also by intangible infrastructural measures (e.g. permission to use bus lanes for electric vehicles);
- in the chemical sector, demand-side policies are mostly discussed for bio-based products; e.g. in the US a public procurement and a related voluntary labelling programme (BioPreffered) has been launched for bio-based products;
- in the health sector the reimbursement rules will highly impact the market uptake of nanomedicine. Key questions are the handling of rising cost pressure (e.g. higher focus on cost-effectiveness) and the co-ordination between the Member States.

Besides procurement or regulation with direct fiscal impact, "soft measures" activities as well as international harmonisation in norming, standardising and regulating to elaborate generally accepted guidelines ensuring planning certainty as well as the respective should be enhanced. This in particular is the case for new emerging industry fields (e.g. electric mobility), which are just evolving

This has been recognised in FP 7. NMP projects are systemically screened for standardisation potential and IPR issues, however this procedure is still evolving.

Dialogue about chances and risks of nanotechnology-based applications and products

The potential impacts of nanotechnology on environment, health, safety (EHS*)* have been discussed widely, since there is a wide-spread concern of potential negative effects from nanotechnology (ZEW/TNO 2010, chapter 2). In some sectors (e.g. chemicals or the bio and pharma sector) there is a more pronounced sensibility, when using the term nanotechnology, as an early mishap associated with nanotechnology could eventually terminate technology funding and demand abruptly. Studies showed, that the closer the technology comes to the human body (e.g. nanomedicine) or its environment (e.g. facades and paints at home), the more sensitivity and aversion can be observed and the acceptance of nanotechnology shrinks. But in overall, there is a (strong) plea among experts and literature for keeping the term nanotechnology alive. Rather, an open and proactive attitude should be adopted in order to communicate and discuss nanotechnology with the public. The actions should include (OECD 2010, Grimm et al. 2011),

- that sectoral specificities and key EHS risks should be identified and better understood in order to draw statements about both EHS risks and societal benefits on an accurate level of generalisation.
- a bundling of existing research results for the stakeholders in society, politics, government, business and science and preparing the results for the layman.
- a balanced and factual dialogue on opportunities and risks of nanotechnology-based applications and products. Already some actions are under way (e.g. “NanoSafetyDialogue for Success” of the European Commission). But additional efforts might still be useful (e.g. conferences about risk assessment for certain products, civic dialogue, more risk assessments).
- the integration of EHS issues into product design.

6 ANNEX 1: ADDITIONAL RESULTS AND SENSITIVITY ANALYSIS

In this Annex we present

- firstly, some additional results for our model estimates for the export shares:
- secondly, the results of the scenarios for employment and value added in table form for the variations between optimistic and neutral scenario as well as pessimistic and neutral scenario:
- thirdly, several sensitivity analyses for the scenarios.

Export Shares

Regarding export shares, we conduct a special specification of the model to assess potential international sectoral spillovers in NMP technologies: We include not only the number of own patents for a country in the equations, but also the total number of NMP patents on the world market. The idea behind this is that countries not just profit from exploiting their own patents, but also from patents which have been generated in other countries. This is particular likely for small countries. But also the opposite effect is possible as higher worldwide patents (minus domestic patents) could be a sign of less domestic technological competitiveness. The results indicate that these mechanisms are of considerable importance for export shares, as we got much more significant results than for other variables. The direction of impact is different between variables and sectors. In total manufacturing, machinery and automotive international spillover effects dominate for NMP patents, but not for other patents. In the opposite, for chemicals and electronics international spillover effects rise for other patents but not for NMP.

Table 6–1 lists the overall impact of the variables worldwide NMP patents and worldwide other patents (apart from NMP).

Table 6–1: Economic impact of NMP in key industrial sectors

	total manufacturing	chemicals	machinery	electronics	automotive
worldwide NMP patents	+	-	+	-	+
worldwide other patents (other than NMP)	-	+	-	+	-

Source: Fraunhofer ISI

Scenario results

In the following tables the respective variations between the scenarios are presented.

Table 6–2: Net value added effects in the optimistic and pessimistic scenario vs. neutral scenario for 9 European countries (in %)

Sector	Scenario variation	2010	2015	2020	2025
Total manufacturing	Optimistic vs. neutral	1,2%	4.1%	7.6%	11.6%
	Pessimistic vs. neutral	-4.2%	-7.5%	-10.5%	-13.5%
Chemicals	Optimistic vs. neutral	1.0%	3.5%	6.7%	11.3%
	Pessimistic vs. neutral	-4.1%	-7.4%	-10.7%	-14.4%
Machinery	Optimistic vs. neutral	2.5%	8.8%	14.8%	20.3%
	Pessimistic vs. neutral	-3.4%	-9.3%	-14.4%	-18.8%
Electronics	Optimistic vs. neutral	3.3%	11.4%	19.2%	26.4%
	Pessimistic vs. neutral	-5.7%	-13.0%	-18.9%	-24.4%
Automotive	Optimistic vs. neutral	1.0%	3.4%	6.0%	8.9%
	Pessimistic vs. neutral	-3.6%	-9.4%	-15.5%	-20.5%

Sensitivity analysis

We conduct several sensitivity analyses to get a better understanding of the dependency of the results on the main impulses. We test the sensitivity of value added and employment on NMP patents and capital stocks. Moreover we analyse the potential impact of material and energy efficiency, which is not included in our scenarios. As the results are mostly identical for employment and value added we just present those for value added.

Table 6–3: Net employment effects in the optimistic and pessimistic scenario vs. neutral scenario for 9 European countries (in thousand employees)

Sector	Scenario variation	2010	2015	2020	2025
Total manufacturing	Optimistic vs. neutral	78	241	452	695
	Pessimistic vs. neutral	-399	-805	-914	-997
Chemicals	Optimistic vs. neutral	2	12	27	50
	Pessimistic vs. neutral	-17	-44	-57	-72
Machinery	Optimistic vs. neutral	25	122	214	301
	Pessimistic vs. neutral	-36	-126	-192	-248
Electronics	Optimistic vs. neutral	62	192	287	356
	Pessimistic vs. neutral	-86	-207	-272	-314
Automotive	Optimistic vs. neutral	6	35	86	171
	Pessimistic vs. neutral	-38	-124	-209	-276

All other variables are simulated equally for both scenarios by using the values of the neutral scenario. Once again we regard the variation between the "hypothetical" optimistic scenario and the neutral scenario. In electronics, for example, employment would be for around 200,000 employees higher and value-added for about 10% than in the neutral scenario.

While the results cumulated for all four sectors are positive, this is not the case for each single sector. Positive results are obtained for electronics and machinery, while the results are negative for chemicals and partly for automotive.

This does not mean that NMP patents are a “bad thing” in the latter sectors. Instead the model estimations for the past highlighted positive impact at least some countries. But the larger countries dominate the results and not in all of them was a positive impact of NMP estimated empirically.

Table 6–4: Sensitivity analysis for impact of NMP patents on value added for the optimistic vs. neutral scenario

Scenario variation	2010	2015	2020	2025
Employment (in thousand employees)				
Chemicals	-1	-12	-27	-41
Machinery	10	45	57	48
Electronics	44	124	168	194
Automotive	0	2	5	15
Total 4 industrial sectors	**53**	**158**	**203**	**216**
Value Added (in %)				
Chemicals	0%	-1%	-3%	-6%
Machinery	1%	4%	6%	7%
Electronics	2%	6%	9%	11%
Automotive	0%	0%	-1%	-3%
Total 4 industrial sectors	**3%**	**9%**	**11%**	**10%**

Sensitivity analysis for capital stocks

Similar to the analysis for NMP patents we conduct the analysis of the sensitivity of value added and employment on the capital stocks by simulating a hypothetical scenario: in this scenario only the differences in capital stocks between the optimistic and neutral scenario are considered. All other variables are simulated equally for both scenarios by using the values of the neutral scenario. The variation between the “hypothetical” optimistic scenario and the neutral scenario reveals that the capital stocks have a large positive effect in each sector. Unsurprisingly, capital stocks can be considered the most important in our model to explain sectoral growth.

Table 6–5: Sensitivity analysis for impact of capital stocks on value added for the optimistic vs. neutral scenario

Scenario variation	2010	2015	2020	2025
Employment (in thousand employees)				
Chemicals	4	25	60	110
Machinery	14	74	147	240
Electronics	18	65	112	152
Automotive	6	33	85	185
Total 4 industrial sectors	**42**	**197**	**404**	**688**
Value Added (in %)				
Chemicals	1%	5%	10%	19%
Machinery	1%	5%	8%	12%
Electronics	2%	6%	10%	14%
Automotive	1%	3%	7%	14%
Total 4 industrial sectors	**5%**	**18%**	**35%**	**59%**

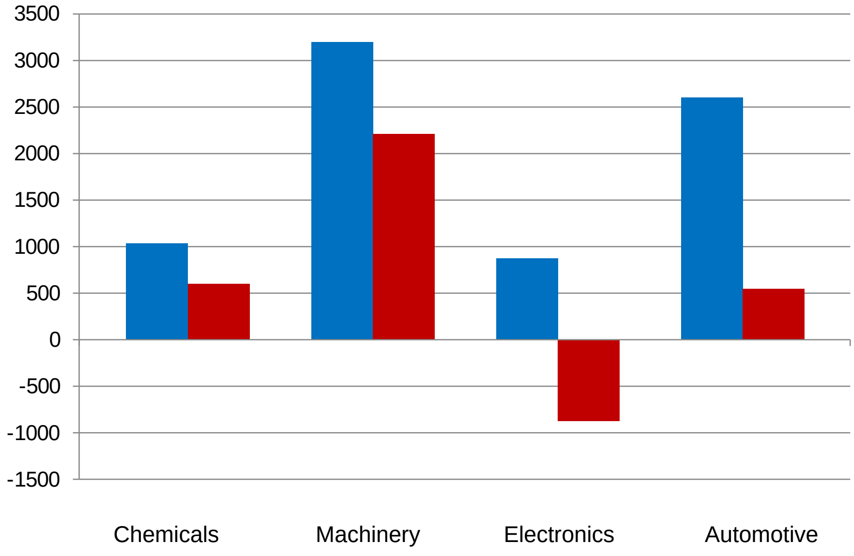
Sensitivity analysis for material and energy efficiency

As described in chapter 4, there are several arguments that the structural equations in the model still may have high explanatory power in the future. However, of course some things might change. This could be disruptive innovations which lead to new sectors or significantly transform existing ones. Another possibility might be the changing role of resource efficiency. Material and energy efficiency have no significant effects on the outcome variables in our model. This could change in future. Due to the increasing costs share of materials and energy, resource efficiency may be a requisite to be able to expand production and to be successful on the world market. To get an idea, what the impact of such changes might be, we conduct an example analysis, where we include resource efficiency in the model for the scenarios. Therefore we have to estimate additional structural equations. As it would be too speculative and too vague to define prospective structural relations for the energy/material efficiency we use the case of Italy. Here we could already find a rather high impact of resource efficiency in the past. Energy efficiency has been positively significant for all sectors, material efficiency has been significant for automotive. With the resulting adapted model we run our scenarios again, including our scenario parameters for material and energy efficiency, which have been derived on the basis of expert judgments and reports. We compare these results with the ones of the regular model, as the difference between both models indicates the impact of material and energy efficiency. Figure 6–1 and Figure 6–2 present the results for each sector with both model specifications. E.g., in chemicals, in the adapted model value added is about €1,000 mio higher in the optimistic scenario than in the neutral scenario. In the original model, the surplus has reached only about €500 mio.

In overall, the results for value added and employment show that the variations between the optimistic and neutral scenario are mostly higher for the adapted model compared to our regular scenario results. In the sectors the economic effects are more favourable in the adapted model, with exception of employment in chemicals and machinery. In other words, NMP will have considerable economic impact via higher resource efficiency in the sectors under the assumptions

- that a deployment of NMP products and processes connected to higher resource efficiency takes place and/or
- that resource efficiency will have a significant direct impact on growth and employment in the future.

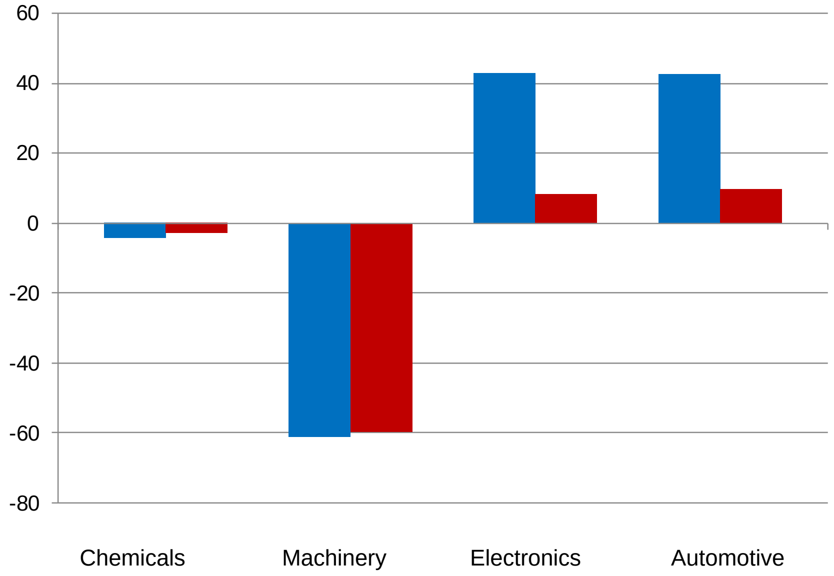
Figure 6–1: Sensitivity analysis for impact of material/energy efficiency on value added (in mio €) for the optimistic vs. neutral scenario in Italy (results for 2025)



Source: Fraunhofer ISI

legend: blue = adapted model for material/energy efficiency; red = original model

Figure 6–2: Sensitivity analysis for impact of material/energy efficiency on employment (in thousand employees) for the optimistic vs. neutral scenario in Italy (results for 2025)



Source: Fraunhofer ISI

legend: blue = adapted model for material/energy efficiency; red = original model

7 ANNEX 2: METHODOLOGY

This methodological overview consists of two parts. Firstly, we clarify our used definition for economic competitiveness and the conceptual design to operationalise the economic impact of NMP technologies. Secondly, we present our steps of analysis and explain our approach in detail. The qualitative assessment of the methodology and empirical challenges is part of chapter 3. However, this chapter necessarily contains already some of the methodological discussions and the qualitative assessment of the model, because choices in methods had to be made to cope with the challenges.

7.1 Definitions and conceptual design

7.1.1 Definition of competitiveness and economic impact

In order to identify relevant key factors and to map related past and potential future trends, it seems feasible to take up a framework for key competiveness factors. Unfortunately analysing competitiveness is not straightforward because the concept of competitiveness has always been controversial (Lall 2000). The controversies include the usefulness of the concept of competitiveness on a national level, the definition of competitiveness, the determinants and its measurement (Montalvo et al. 2006):

Definition: Numerous definitions for competitiveness evolved, focussing, for example, on productivity (Porter 1990), on ability of sell, on ability to create welfare etc. (see Aiginger 2007). While some are referring narrowly to export performance, others incorporate broader socio-economic goals.

Usefulness of the concept of competitiveness on a national level: While some regard the concept as useful to increase or secure welfare in an economy others are more sceptical of such concept. Especially if it is connected to trade performance the obsession on international competitiveness may cause wasteful spending of government money, inefficient allocation of resources, possibility of protectionism and trade wars as well as indirect impact on the quality of economic policy making in general (Krugman 1994). This sceptics regained attention with the growing imbalances in trade balances and the related discussion of prosperity of some countries (those with high export surpluses) on the expense of others.

Determinants of competitiveness: Various concepts with different conditions and factors exist (e.g. Montalvo et al. 2006, WEF 2010, EC 2009a). All of them appreciate that there are many determinants driving productivity and competitiveness but differ in the compilation of factors.

Measurement: The concepts to measure competitiveness ranging from one aggregated composite indicator to a multilevel framework are intensively discussed.

For this report we take up the following definition of competitiveness: We define competitiveness as the capability and performance of a firm, an industry, an industry cluster, a nation or region in selling and supplying goods and/or services to a market – local, regional, or global (Montalvo et al. 2006). In this definition, competitiveness is a multifaceted target without the existence of a single and fully comprehensive measure. As we have to limit the number of variables to be explained in our quantitative model, we concentrate on value added, employment and exports. These indicators are definitely considered as crucial for the European economy and reflect together some dimensions of the multifaceted goal of competiveness. They do not solely focus on the trade performance, but on the overall industrial economic development. Thus, its explanatory power is less affected from the above mentioned critics to the usefulness of the concept. In addition, the benefit of innovation and deployment of industrial technologies is much more than these purely economic indicators can reflect. Industrial technologies certainly have high potential to address the grand societal challenges. While we are not able to quantify such dimensions, we will consider them in the interpretation of our results, our qualitative assessment of trends and signals in NMP as well as in our recommendations.

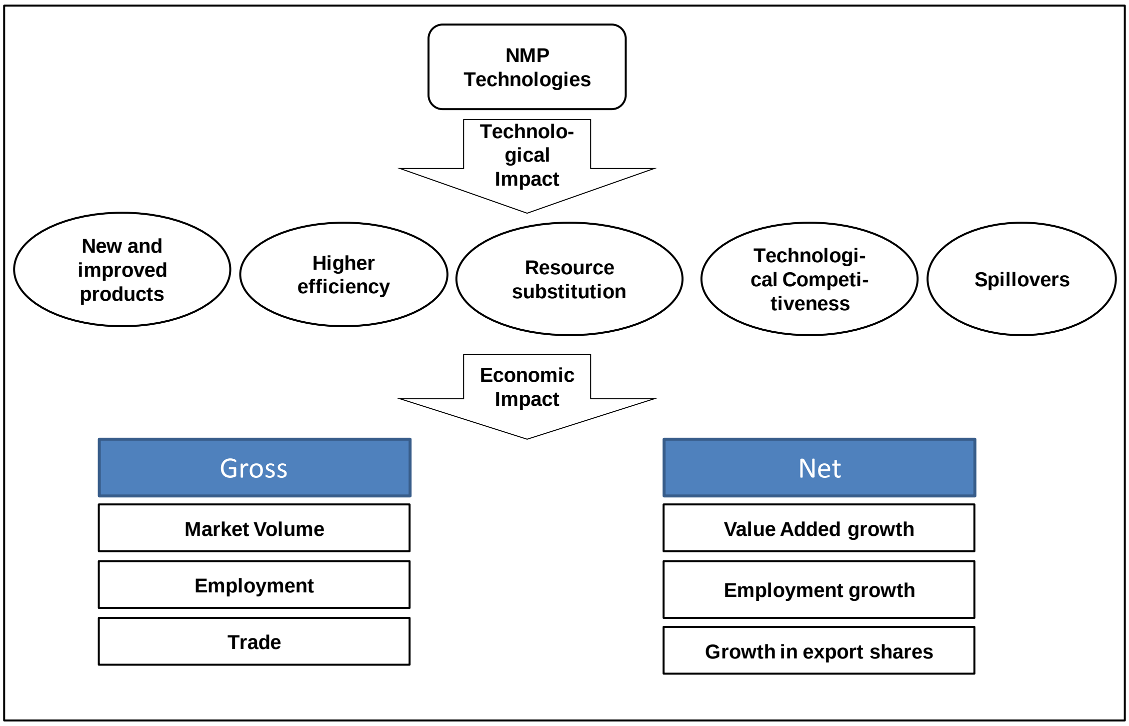
Concerning the determinants of competitiveness we use a rather broad approach and rely heavily on the Study “Sectoral growth drivers and competitiveness in the European Union” (EC 2009a). We adapt the concept slightly and precise some determinants more concretely to commercialisation issues of emerging technologies.

7.1.2 Approach to analyse economic impact

The socio-economic impact of NMP technologies is manifold. NMP technologies may lead to new products and processes, price changes, substitution of resources, higher material efficiency, changes in technological competitiveness, changes in consumer demand, etc. Such effects may have significant impact on the trade balance, growth or employment of a country. E.g. new job opportunities will be provided, existing jobs will be protected, but also that some may disappear through substitution. Unfortunately, there is usually no common understanding of impacts of technologies, due to this complexity. E.g. media or position papers highlight indicators like the overall number of jobs, value added or market volume, which are somehow related to technologies or activities. Instead, scientific literature is focusing more on indicators of changes in an economy, as pure substitution effects are of no relevance from a macroeconomic point of view.

As no indicator or perspective is able to grasp the whole picture of economic impact of technologies, we include several indicators in our analysis, which are classified as gross and net effects (Figure 7–1).

Figure 7–1: Economic impact of technological innovation



Source Fraunhofer ISI

Gross effects: Indicators like employment or value added are useful to highlight the pervasiveness or outcome (Rose/McNiven 2007) of emerging technologies or sectors and the related economic importance. Moreover, they can give a good idea of the magnitude of effects as those indicators are very familiar, albeit not directly comparable to figures of sectoral NACE classifications like the automotive industry etc. However, such indicators have main drawbacks for analysing the impact of emerging technologies: Indicators like market volume or associated jobs do not reflect the importance of the technology for those markets. Often they do not represent new markets, but redefinitions of long existing markets. Moreover, they assume the same importance of a certain technology for each application.[42] In addition, double counting would occur, if one summed up all markets or jobs for different applications of NMP. For example, NMP products in the chemical industry are often processed in the automotive or

[42] E.g. while biotechnology is often considered to have the highest impact on pharmaceuticals, the market volumes in other sectors like food are estimated to be higher, although biotechnology is often not decisive for the competitiveness in these applications. Such problems may be reduced by assessing the relative importance of a technology by expert assessments (e.g. Butter et al. 2011; see sectoral analysis for photonics) but not eliminated.

electronics industry. The market value of the NMP chemical product appears in the chemical industry and as part of the end product in the processing industry.

Net effects: Other indicators focus on the changes through a technology in an economy, through higher substitution of resources, higher material efficiency, changes in technological competitiveness, new products, changes in consumer demand and so on. These ‘impact mechanisms’ influence changes in macroeconomic indicators such as overall employment, GDP, trade balance, productivity growth etc. These interrelations are usually analysed in model simulations. Such approaches have been pursued in the past for various technologies (e.g. ICT, biotechnology, environmental technologies). Main drawbacks of such methods are the high complexity, gaps in necessary data and the problem of the subjectivity to set up a reference system or simulation, with which the different model simulations are compared. Moreover, the results are often difficult to compare to other data and also might be misunderstood. For example, net employment effects of emerging technologies are usually small, as emerging technologies often lead primarily to a renewal of existing sectors and supports the competitiveness of domestic production plants and less to totally new sectors.

In this study we use following approaches to analyse gross and net impact of NMP:

- We gather data for related market volumes or related employment to analyse the pervasiveness of NMP;
- The main aim of this project is to analyse the net effect of NMP, as hardly any results about this aspect exist yet. For that purpose, we conduct a model simulation, which incorporates specific impact channels of NMP.

7.2 Steps in the analysis

The steps involved in assessing the economic impacts are as follows:

1) Assessing the key drivers for the competiveness of the European industry related to NMP technologies;

2) Adapt and test an econometric model, which comprises main economic factors and impact channels of NMP;

3a) Setting up three scenarios;

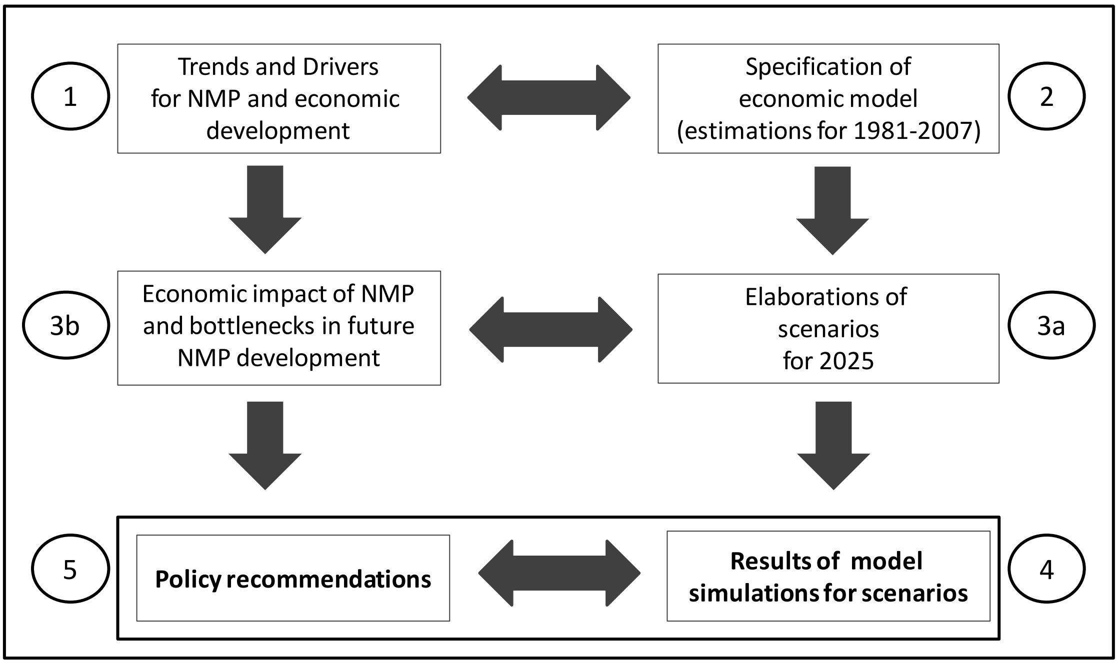
3b) Discussing and quantifying the contribution of NMP in the three scenarios;

4) Running the model for the three scenarios and conducting sensitivity analysis on the parameters and assumptions;

5) Assessing the pattern of impacts for each scenario and policy implications.

The approach is summarised in Figure 7–2:.

Figure 7–2: Steps in the analysis



Source: Fraunhofer ISI

7.2.1 Main factors

In this report we mostly follow the concept of the report "Sectoral gowth drivers" (EC 2009a). But in order to take more "qualitative" aspects into account, such as different types of technological change and various microeconomic business determinants of innovation, we complement the drivers list by some factors. As a result we get the following set of driver categories

- productive use and availability of resources,
- technological progress & innovation,
- commercialisation,
- demand,
- framework conditions.

For each driver category we differentiated between several competiveness factors. For each factor, we reviewed the relevant literature and data on past and future socio-economic trends (state of the art analysis) with the following questions:

- What is the justification for the factor to be relevant for the competitiveness of the European Industry?
- What have been the main past economic and industrial trends (past 15-20 years)?

- Which are the main trends in the development of economy, industry and industrial sectors for the coming 15-20 years? What are potential developments, which are uncertain, but may be critical for the competiveness determinant?

In addition, we analysed potential differences of these trends across sectors. Such differences are crucial for the build-up of our model and for the interpretation of the results.

7.2.2 Adapting and testing a model

In order to analyse the impact of NMP we built up a specified econometric model to assess the determinants for the following variables

- sectoral employment,[43]
- sectoral value added,
- sectoral export shares in the world-market.

Such a model allows incorporating specific technological impact transmission channels of NMP as well as economic interdependencies. We choose the model variables and the specification of the model on the basis of the analysis of past and future socio-economic, technical, industrial trends (see section 1). In the following, we issue more concretely the analysis level, some data issues (e.g. geographical coverage) and the model specification.

Analysis level

First, the concrete level or granularity of the analysis has to be determined. Neither a pure macroeconomic-level nor a NMP application-specific approach is feasible, as the first can hardly incorporate NMP specifics and heterogeneity while the latter is not able to comprise sufficiently the important economic drivers. Hence, a meso-level is required to integrate both economic drivers as well as the impact specifics of NMP. Our focus is on sectors, confined by the official NACE classification, for several reasons:

- First, the important ***key economic drivers*** vary significantly between sectors. E.g. there are major differences in the rate of technological change and in the organisation of innovation activities across industries. Even in case of rather similar factors for all sectors, like the overall financial conditions or oil prices, the relative intensity in factor use as well as the specific capabilities and

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[43] We originally intended to use foreign direct investments as a variable for competitiveness. However, this was not possible due to data shortages. Instead, we included employment as variable, as the experts of the 1st workshop recommended such approach.

incentives required for transforming them into successful business vary between sectors (EC 2009a).[44]

- Second, ***NMP*** processes and products are quite heterogeneous, as their usage and related impact significantly differs between applications and sectors. Therefore a sectoral approach is more appropriate to single out the impact of NMP.
- Third, we delineate the sectors by ***NACE classification*** – although it is difficult to match with NMP data on this level – in order to incorporate as many economic variables as possible, which usually exist on such industry level, but not in greater detail.

But also the limitations of such a sectoral approach have to be taken in mind. Emerging technologies cannot be captured adequately by existing sectoral classifications in national statistics and their applications are spread across many different classes. This difficulty will become even more crucial in the future as NMP, like other general purpose technologies, is characterised by rapid and significant scope for improvement and by a variety of uses and sectors of applications while developing. Consequently, with a focus on key sectors the cross-sectional character cannot be captured. Moreover, analyses on a sectoral level are sometimes too broad to describe the dynamics of important sub-segments. Some important applications cannot even be directly assigned to sectors. E.g. "molecular factory" or "innovative factories" or "photovoltaic" (EAG 2009) cannot be found within the NACE classification, neither be deduced from it. Another drawback may be the neglecting of important drivers in the respective (usually cross-sectoral) value chains. We attempt to reduce this problematic by integrating such aspects in our sectoral analysis of NMP.

Despite these limitations, the sector-level is the most promising starting point for our economic analysis. Other levels of analysis would either even be broader or not be capable to match with sufficient official economic data to build up an appropriate model and check hypotheses.

We are not able to conduct such analysis for all potential relevant sectors, as applications of NMP are spread across many sectors. So we have to focus on the very important ones from an economic point of view. We compare the analysed application fields of different studies, some quantitative figures of the “key enabling technologies” study from ZEW/TNO (2010) as well as the knowledge and experience of the project team in NMP to define six most significant sectors (chemicals, pharmaceuticals, electronics, machinery for advanced manufacturing, automotive/vehicles, photonics

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[44] This does not mean that all of our independent variables have to be necessarily sector-specific, as some variables/factors are equal for all sectors shape the general business environment, but their impact may differ.

(optics/instruments). This comparison also shows the different classifications of the studies, which may complicate our analysis.

Because of data issues, it seemed to be meaningful to further aggregate some of our selected sectors to a higher aggregation level. We calibrate our model for the following sectors:

- D total manufacturing,
- 24 chemicals and chemical products,
- 29 machinery, not elsewhere classified,
- 30-33 electrical and optical equipment,
- 34-35 transport equipment.

The integration of the whole manufacturing sector is a special case. On the one hand many industries covered on this analysis level and indications about the overall impact of NMP are provided. On the other hand, the impact of NMP had to be estimated more roughly and has to be interpreted with caution.

Data Issues I: Selected variables, time coverage and geographical coverage

We used different data sources (e.g. OECD, Eurostat) to create a database for the model specification. Unfortunately, for some variables the coverage of the various countries and sectors and needed time period is rather low. Hence, we do not have sufficient data for all preferred variables and countries for our model. Especially the critical variable capital stock is not available for some of our selected sectors. Hence, we include the following independent variables for our model: capital stocks,

- energy efficiency (gross output per energy input),
- material efficiency (gross output per material input),
- NMP patents,
- total patents,
- relative unit labour costs *(for sectoral export function)*,
- price indices for value added *(for sectoral export function).*

Concerning countries, we consider the following ones:

- European Countries: DEU; ITA; NL; ESP; AUT; FRA (only for exports); FIN, GBR; DNK; SWE;
- Non-European Countries: USA; CAN (only for exports); JPN; KOR; AUS.

Another issue is the *time period* for our model estimates. Due to the lack of data for some important variables (e.g. capital stocks) we can only cover the period between around 1980 and 2007. While it would have been preferable to use data for the most recent years, the fact that we do not include the economic crisis can be regarded as less serious. The inclusion of these “exceptional years” would have probably limited the significance of each explanatory variable, due to the special effects of the financial crisis. In the model simulations from 2007 to 2025 the crisis is considered in respective assumptions for the capital stock.

Data Issues II: Data and methodology for the patent analysis
In order to assess the technological evolution of NMP and the technological competitiveness in each of the mentioned industrial sectors[45], we conduct a patent analysis. For the analysis of NMP activities in terms of patent applications, the relevant documents have been extracted using the PATSTAT database. PATSTAT is the (EPO European Patent Office) Worldwide Patent Statistical Database developed and maintained by the EPO for government and intergovernmental organisations as well as academic institutions. PATSTAT covers the patent data of about 70 national and international patent offices. In order to compare the patent activities of the EU-27 Member States, the USA and Asian countries (Japan, China, Taiwan, Korea, India) transnational patents have been considered, i.e. no patent applications at national patent offices have been considered, which would imply a domestic bias. Transnational patents are patent families with at least one EPO or one PCT application.

In order to conduct this patent analysis we have to delineate NMP in terms of IPC classes and to link them to industrial sectors. The related approach is described in the following.

Delineation of NMP

In the following we will give a brief overview of the delineations for NMP which are used in this study and the used patent classes.

Nanotechnology is a cross-sectional field of technology that combines scientific approaches from physics, chemistry and biology to discover and develop processes and substances for a wide variety of applications, ranging from materials, electronics and chemicals to process engineering, transportation and medicine. Nanotechnology deals with methods for analysing, controlling and manufacturing structures on a molecular or atomic scale, i.e. of a size of 100 nanometers or less. Nanotechnology subfields are typically clustered into the following six groups: nanomaterials (and surface sciences), nanoelectronics (information processing, storage and transmission), nanoinstrumentation (-mechanics/-analytics, -tools), nanobiotechnology, nanomagnetics, and nanooptics (and -photonics).

Identifying nanotechnology is rather straightforward since patent offices have introduced separate classes to mark patent applications related to that field of technology. EPO uses the tag class Y01N which has been introduced in 2003 and is also

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45 Patent analysis is sometimes criticized as an indicator for competitiveness because it does not include important commercialisation patterns. Please note, that we use it here only as indicator for technological competitiveness, the “economic competitiveness” in terms of valued added etc. is derived as the result of our model which reflects and interplay of various factors.

used to classify patents applied prior to 2003. In addition, the IPC class B82B covers the manufacture of nanostructures.

There are different classifications of **advanced materials** in literature. We use a definition that puts emphasis on combining a structure-based view with application potentials of new materials (structural or functional classification, compare also ZEW/TNO 2010):

- nanomaterials (e.g. nanoparticles and crystals, nanocomposites, nanofibres and nanorods, nanotubes and nanofullerenes, thin films and spintronic materials),
- smart materials (i.e. complex materials that combine structure characteristics with specific physical and chemical properties, such as shape memory materials, functional fluids and gels, piezoelectric, ferroelectric and pyroelectric materials, magneto, electrostrictive materials, electroactive polymers, electro-, photo- and thermo-chromic materials, tuneable dielectrics),
- bioconceptual materials (i.e. materials based on biological technologies such as bio-inspired materials, biohybrids, bioactive materials, biodegradable materials and soft matter), and
- tailored macroscale materials for high performance applications (which comprise structural and functional materials for extreme environments, energy efficient materials, electromagnetic materials).

For the patent analysis, we adopted an approach of ZEW/TNO (2010), which classifies IPC-classes of layered materials, high-performance materials, tailored macroscale materials, new alloys, energy-efficient materials, magneto and piezo materials and nanomaterials.

Advanced manufacturing technologies (AMT) comprise all technologies that significantly increase speed, decrease costs or materials consumption, and improve operating precision as well as environmental aspects like waste and pollution of manufacturing processes. AMT are rather a combination of different technologies and practices that aim at improving processes of manufacturing goods. Material engineering technologies (including cutting, knitting, turning, forming, pressing, chipping), electronic and computing technologies, measuring technologies (including optical and chemical technologies), transportation technologies and other logistic technologies are some of the many technologies that come together to form advanced manufacturing technologies.

For the patent analysis, a classification (by means of IPC patent classes) into six subfields of AMT has been proposed by ZEW/TNO (2010), and has been adopted in this study: robotics, measuring of industrial processes, controlling industrial processes, regulating industrial processes, machine tools, and computer integrated manufacturing (CIM).

Table 7-1 summarises the used patent classes.

Table 7-1: IPC classes used to delineate NMP

Technology	***IPC***
Nanotechnology	Y01N, B82B
Advanced materials	B32B 9, B32B 15, B32B 17, B32B 18, B32B 19, B32B 25, B32B 27, C01B 31, C04B 35, C08F, C08J 5, C08L, C22C, D21H 17, H01B 3, H01F 1, H01F 1/12, H01F 1/34, H01F 1/44, Y01N 6
Advanced manufacturing technologies	a) robotics/automation: B03C, B06B 1/6, B06B 3/00, B07C, B23H, B23K, B23P, B23Q, B25J, G01D, G01F, G01H, G01L, G01M, G01P, G01Q, G05B, G05D, G05F, G05G, G06M, G07C, G08C; except for co-occurrence with sub-classes directly related to the manufacture of automobiles or electronics; b) computer-integrated manufacturing: co-occurrence of G06 and any of A21C, A22B, A22C, A23N, A24C, A41H, A42C, A43D, B01F, B02B, B02C, B03B, B03D, B05C, B05D, B07B, B08B, B21B, B21D, B21F, B21H, B21J, B22C, B23B, B23C, B23D, B23G, B24B, B24C, B25D, B26D, B26F, B27B, B27C, B27F, B27J, B28D, B30B, B31B, B31C, B31D, B31F, B41B, B41C, B41D, B41F, B41G, B41L, B41N, B42B, B42C, B44B, B65B, B65C, B65H, B67B, B67C, B68F, C13C, C13D, C13G, C13H, C14B, C23C, D01B, D01D, D01G, D01H, D02G, D02H, D02J, D03C, D03D, D03J, D04B, D04C, D05B, D05C, D06B, D06G, D06H, D21B, D21D, D21F, D21G, E01C, E02D, E02F, E21B, E21C, E21D, E21F, F04F, F16N, F26B, G01K, H05H

Source: ZEW/TNO (2010)

Linking NMP technologies to industrial sectors

A key issue in evaluating the role of NMP for competitiveness is the link between NMP and industrial sector. To assign NMP patents to industrial sectors, we rely on creating concordance tables. We use the approach of Schmoch et al. (2003) who developed the concordance between IPC classes on a four-digit level with economic sectors on a two- or three-digit NACE code level. In this approach each IPC four-digit class is assigned to a single industry sector based on NACE revision 1.1. All in all, this industry classification comprises 44 industrial sectors. The concordance table of Schmoch et al. is based on a large empirical analysis where more than 3000 large firms applying patents representing more than 150,000 patent applications were assigned to the manufacturing sector according to Dun&Bradstreet information. This concordance table can be used for international comparisons and provides a 1:1 mapping.

Of course, limitations of the patent indicator have to be taken in mind:

- NMP patents may only reflect the impact of NMP rudimentary, as application implementation is of higher importance.

- For the Nanotechnology of the NMP term the patents are measured clearly and concretely by patents, but for the “Material “and “Production” aspects of NMP the patents are not measured in such a concrete way.
- The absolute numbers of NMP-patens is not the most relevant factor. Instead the main issue is what kind of value added the different patents generate.

The calculation of patent stocks

The stocks of total patents as well as NMP Patents for the various sectors and countries were calculated from the patents applied by these countries at the European Patent Office. With regard to the calculation of patent stocks from patents applied or granted, two opposite opinions predominate in the literature. In the one vein of the literature, the view is taken that the economically relevant life time of a patent is much longer than its legal life. Thus Anderson and Walsh (1998), Cantwell and Anderson (1996) and Cantwell and Piscitello (2000) calculate patent stocks by accumulating patents over a thirty-year period and assume thereby a linear depreciation function as in vintage capital models, i.e. the current number of patents is weighted with 1, those of the previous periods with factors from 29/30 to 1/30. They justify their assumption with the hint that new technical knowledge is partly embodied in new equipment or devices, which have an average life span of 30 years. Zachariadis (2000), who calculates patent stocks using the perpetual inventory method with a depreciation rate of 7%, argues similarly by pointing out that his rate would correspond with this century’s average annual rate of technological obsolescence estimated by Caballero and Jaffe (1993).

In the other vein of the literature, the opinion is held that the economically relevant life span of a patent is much shorter than its legally possible life. As evidence for it, among other things, the analysis of Mansfield et al. (1981) is quoted, which shows that 60% of all patents are invented at most 4 years ago. Therefore many authors use a depreciation rate of 15% in their calculations of patent stocks by means of the perpetual inventory method, which implies a average life of 6.6 years (e.g. Chen et al. 2002, Gambardella and Torrisi 2000, Hall et al. 2001, Lach 1995). Other authors use even higher depreciation rates of 20% (e.g. Agrawal and Henderson 2001, Henderson and Cockburn 1996) or 30% (e.g. Blundell et al. 1998, Cockburn and Griliches 1988, Dushnitsky and Lenox 2002). We also assume a depreciation rate $\mu = 0.15$ for the calculation of patent stocks, but the problem of calculating an initial stock is avoided by following the suggestion of Heeley et al. (2000) to confine the depreciation of the patent stock to a period lasting only several years. Here, a four year period is used, such that a patent stock PST_{ijt} is given by

$$(1) \qquad PST_{ijt} = \sum_{\tau=t-3}^{t} (1-\mu)^{(t-\tau)} P_{ij\tau},$$

where P_{ijt} is the number of EPO patents related to sector i and applied by country j in year t.

Empirical specification of sector production functions

The starting point for the derivation of the empirical sector production functions is a Cobb-Douglas function, augmented by the stocks of NMP and other patents:

(2) $$Y_t = Ae^{\beta t} \cdot K_t^{\alpha} \cdot L_t^{1-\alpha} \cdot PSTOTH_t^{\gamma} \cdot PATNMP_t^{\delta},$$

where Y_t represents real value added of the considered sector in a certain country, K_t the sector capital stock, L_t labour input in the sector, $PSTOTH_t$ the sector stock of patents not related to NMP and $PSTNMP_t$ the sector stock of NMP patents. The parameters α and 1 - α (α < 1) represent the partial production elasticities of capital and labour. Furthermore, the interplay of $Ae^{\beta t}$, $PSTOTH_t$ and $PSTNMP_t$ can be interpreted as a technical progress function, explaining the increase of efficiency (cf. Jungmittag 2004, Blind/Jungmittag 2008). The expression $Ae^{\beta t}$ measures exogenous technical progress (technical efficiency), while the indicator variables $PSTOTH_t$ raised to the power γ and $PSTNMP_t$ raised to the power δ measure the degree of efficiency due to the stock of results from research and development activities (innovations) in the area of NMP as well as in other technique fields. In logarithmic form the production function can be written as

(3) $$y_t = a + \beta t + \alpha k_t + (1-\alpha) l_t + \gamma pstoth + \delta pstnmp$$

with lower case letters (with the exception of t) denoting logarithms. For estimation purposes, the production functions are supplemented by stochastic error terms u_t.

Empirical specification of sector employment functions

For the specification of the sector employment or labour demand functions, we use a standard formulation whereby the number of persons employed depends on real value added and a time trend (cf. e.g. Hansen 1992). It would be desirable to include real labour costs per person employed, but such data is not available or many sectors and countries. However, we include additionally the sector stocks of NMP patents and patents related to other technique fields in the employment functions. Adding again an error term u_t, the specification of the sector employment function in logarithmic form is:

(4) $$l_t = \beta_1 + \beta_2 y_t + \beta_3 t + \beta_4 pstoth_t + \beta_5 pstnmp_t + u_t.$$

Empirical specification of sector export functions

Sector Exports will be explained by conventional factors like the relevant world trade and relative price (or cost) levels as well as by the relative stocks of technology capital. More concretely, loosely inspired by the seminal “Almost Ideal Demand System” of Deaton/Muellbauer (1980), export market shares (EXS) of sector i and country j are specified in lin-log form as

(5)
$$EXS = \gamma_1 + \gamma_2 pstnmp_{ij} + \gamma_3 pstnmp_{i,row} + \gamma_4 pstoth_{ij} + \gamma_5 pstoth_{i,row} + \gamma_6 rp_{ij} + u_{ij},$$

with lower case letters denoting logarithms. Furthermore, *rp* are relative prices or relative unit costs of labour, and the index row denotes the rest of the world. In the case of a lin-log specification, the regression coefficients $\gamma_1,\ldots,\gamma_6$ indicate the absolute change of the dependent variable resulting from relative changes of an independent variables. More specifically, the coefficient γ_2 multiplied by 0.01 gives the absolute (%-point) change of the export share EXS resulting from a one % change of the stock of NMP-related patents.

7.2.3 Elaboration of scenarios

To elaborate our scenario we draw on the mayor trends identified in earlier working steps. The drivers identified in step 1 cover a broad set of potential factors:

- productive use and availability of resources,
- technological progress & innovation,
- commercialisation,
- demand,
- framework conditions.

After having selected major relevant uncertainties that may impact the European industry position, the potential values that might occur in the future are estimated. We derive three different scenarios around 2025, one "business as usual" (neutral) and two alternative scenarios with positive and negative developments regarding the deployment and impact of NMP. The scenarios contain overall key drivers for NMP – but not those, which are highly sector-specific – as well as key economic drivers (e.g. overall demand, financial conditions) with a time horizon to 2025. Our future scenarios for the European industry in NMP-technologies are not only qualitative, but also have a quantitative character. Hence, we conducted an economic outlook, which mainly builds on the system dynamics model ASTRA. This approach is described in the following:

Integrating of results from the ASTRA model

To our knowledge there are no widely accepted scenarios for the potential economic development in the EU. Whereas previously the long-term developments of production, income and employment were in the foreground of interest, now energy-economic implications and consequences for the environment are mainly attracting public attention. (Pollitt et al. 2010). Nevertheless, related simulations comprise an economic part, which is useful for our purpose. We use the so called ASTRA-model to get some key indicators for our later scenario simulations. This model-based approach enables us to get a consistent set of data as a basis for the baseline scenario (e.g. GDP-growth, CO_2-emissions) and the corresponding simulations in the elaborated econometric model. During the current project it became obvious that a completely new building of a business-as-usual scenario is not adequate, as tremendous assumptions would have to be drawn which are hardly related to the project objectives. Instead we generate simulations and additional unpublished results with an existing set of scenario assumptions in a comprehensive project. We rely on the scenarios of the project ITREN-2030 (Integrated TRansport and ENergy) (see Schade/Krail 2010). The main objective of ITREN-2030 is to design a powerful toolbox for European transport policy-making by creating an integrated model system of transport, economics, energy and the environment. Despite the focus of the overall project on transport, the simulations seem to be very suitable for our objectives, as the simulations with the model of ASTRA consider various important economic patterns for more or less the same time frame. For our business-as-usual scenario we adapt the “Integrated Scenario” of ITREN-2030 as important basis for our “Business-as-Usual” scenario, mostly because it considers the impact of the economic crisis. In this “Integrated Scenario” climate policy becomes an important policy goal (Schade et al. 2010). Every policy is checked against the criteria of how it contributes towards reducing the climate impact of energy and transport. Those policies that contradict climate mitigation would not be implemented. Furthermore, awareness on the part of industry and households of the need for climate mitigation actions and of the future continuous growth of fossil energy prices is increasing and supports behavioural change to increase climate efficiency and energy efficiency (Schade et al. 2010). Regarding economic development, this scenario integrates the impact of the economic crisis by considering pessimistic investments, downturn of GDP, increasing private savings, growth of short-time work and reduction of travelling (business and tourism). It reflects a return to the smooth growth path of the last

decades after 2010. It has to be reminded that the financial system still bears risks (e.g. a speculative bubble because of too much cheap money provided by the central banks, the high government debt in some major countries, the imbalance between the US and Chinese trade flows and currency values), which could cause the next financial and economic crisis within the coming decade. Such a successive crisis is not integrated in the model. But even with the model outcome that economic development over the next two decades returns to a smooth growth path, some longer term influences of the economic crisis from 2008/2009 can still be observed. First, from 2010 onwards, the first five-year period reveals the highest average annual growth of +2.3% in the EU27. Such high growth rates reflect the economic recovery after the crisis. For the subsequent five-year periods, growth rates decline in each period, so that in the period between 2025 and 2030, the average annual growth rate is down to +1%. This happens because in the longer run the dampening effects of high public debt and ageing with the resulting reduced labour force are enforced, whereas the stimulating effects of the global and European economic recovery disappear. Over the whole next two decades the average annual EU GDP growth rate is expected to be at +1.5%. The results of key indicators are presented in Table 7-2.

Table 7-2: Indicators of the ITREN-2030 integrated scenario until 2030

Variable	Unit	2005	2020 integrated scenario	2030 integrated scenario
GDP	Billion Euros 2005	10.537	12.926	14.445
Employment (E)	1000 persons	210.749	203.334	192.645
Labour force	1000 persons	314.100	315.545	304.261
Retired (>65)	1000 persons	76.582	88.609	103.376
Primary energy production	Million toe per year	905	953	890
Share of domestic energy production	%	50	56	54
Oil price	Euros 2005 per barrel	44	77	89
Gas price	Euros 2005 per boe	22	28	35
Gasoline price	Euros 2005 per litre	1.07	1.36	1.48
Share of renew-ables in electricity	%	15	37	44
Share of renew-ables in final energy demand	%	8	19	24

Source: Schade et al. (2010)

Furthermore we extracted sectoral data for several indicators for the time frame until 2025 of the scenarios fom the ASTRA simulations:

- production value,
- gross value added,

- exports,
- employment,
- intermediate inputs.

However, as most variables are the same which we explain in the econometric model they could not be used directly.

Furthermore, it would be interesting to compare the scenario data with our model simulations, in order to get an impression of the magnitude of the results. Unfortunately, it is difficult to compare these results with other quantitative model simulations, as the objective and necessary assumptions for the scenarios differ; the endogeneity and exogeneity of variables in the models vary; different schools of economic thought of models are implemented and different data is made publicly available (Pollitt et al. 2010). Only for some indicators and a limited number of studies comparable data is available (see Table 7-3).

Table 7-3: Comparison of ITREN-2030 scenario parameters to other studies

	Scenario	GDP (bn €)	Employment (mio)	Population (mio)
ITREN-2030 (EU27)	*Integrated Scenario*	2020: 12926 2030: 14445	2020: 203,3 2030: 192,6	2020: 496,3 2030: 494,3
	Reference Scenario (without crisis)	2020: 11188 2030: 13029	2020: 214,1 2030: 203,3	2020: 496,3 2030: 494,3
PRIMES (EU 27)	*Baseline 2009 Scenario*	2020: 14164.0 2025: 15503.7 2030: 16824.7		2020: 513.8 2025: 517.8 2030: 519.9
DEMETER (EU 27)	Baseline/ before Crisis Scenario	2025: 18448	2025: 262	
	Crisis /New Forecast Scenario	2025: 16592	2025: 221	
	Counter Cyclical Scenario	2025: 17323	2025: 225	

Source: Schade et al. (2010)

It gets obvious that the outlook in terms of GDP, employment and population of the ITREN-2030-scenarios lie somewhat beneath the other simulations. There is no right or wrong in these outlooks, but this comparison just helps us to see that our “Business-As-Usual“ is somewhat less optimistic than other “Business-As-Usual“-scenarios. Consequently, we will use the ITREN-2030-indicators for the “Integrated Scenario” for our “Business-As-Usual-scenario”-simulations; some figures are already integrated in the preliminary scenarios below.

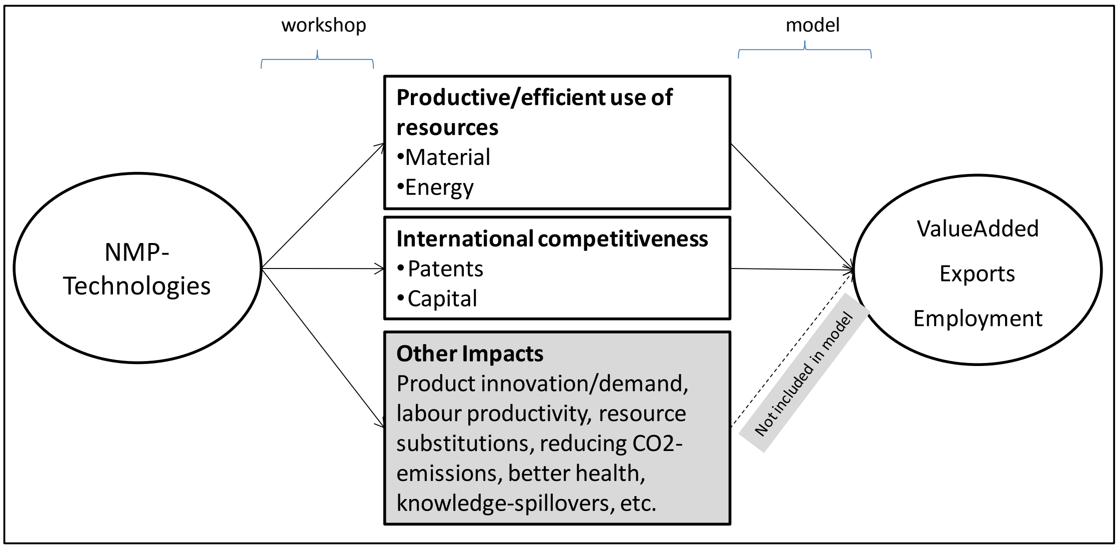
7.2.4 Assessment of the contribution of NMP in the three scenarios

In the next step, the scenario values have to be translated in parameters of the model variables. The estimation of the prospective impact of NMP is especially complicated, as

- future market development for NMP is very uncertain, since it depends on various factors (technological improvements, demand, regulation, etc.),
- there is a complex interplay between a wide range of factors, which influences the economic impact,
- products and services of NMP are very heterogeneous,
- the effects will change in time, by further developments and diffusion.

Hence, it is not possible to estimate all possible impacts, as there is hardly any useful information available. Moreover, no concepts of economic models exist, which can consider all impact channels. Figure 7-3 highlights the overall approach to assess the economic impact of NMP in the scenarios of each of the selected industrial sectors.

Figure 7-3: Analysis of impact of NMP on economic competitiveness



Source: Fraunhofer ISI

We aim to assess the impact of NMP on several variables like efficiency of material or energy, technological competiveness etc. and integrate them for the scenario simulations in our economic model. We chose those variables, for which 1) NMP can be expected to have a considerable impact and 2) an inclusion in the model is realistic. On the basis of past trends as well as expert judgements in the interviews and workshop, we estimate values for these variables for each of the three scenarios.

To conduct scenario simulation with our econometric model, we have to specify the scenario values for the exogenous model variables. While we could mostly use values for the parameter from the simulation with the ASTRA model and trend extrapolation for the neutral scenario, we had to adapt the values for the optimistic and pessimistic scenario. This is done by transferring the scenario assumptions to the parameters that have to be estimated. E.g. the sectoral developments of capital stocks or patents have been chosen in such way, that they have a high congruency to the scenario assumptions for total capital stock or total NMP patent share. The time trends to the year of 2025 have been estimated by combination of the value for 2025 and linear trends.

While this overall approach appeared to be the most adequate way to assess the economic of NMP, some limitations have to be taken in mind.

First, in the model regressions for the past periods, we only have one NMP-specific variable with NMP patents. Concerning capital stock and other variables, we use overall sectoral figures, as it is definitely impossible to derive NMP-specific data. For the prospective scenarios, the impact of NMP is incorporated in various input variables by the assessment of past trends and relying on expert judgements for prospective NMP-specific developments. This approach reflects that most of the economic effects of NMP probably arise in the future.
Second, our scenario model simulations cannot quantify some economic impact mechanism for NMP. In particular, intersectoral effects such as knowledge spillovers between sectors or environmental effects, which may have a feedback on the economy (e.g. CO2-emissions), cannot be considered. Nevertheless we analyse these effects qualitatively by desk research and expert judgements and include these aspects in our interpretation.

7.2.5 Scenario simulations

We use the following inputs from the steps above to transfer the different scenarios around 2025 into the econometric model

- the econometrical model with structural relations from the tested model,
- the estimated values for the exogenous variables in the scenarios (see Table 4–2).

Then, we assess the differences between the scenarios concerning our explained variables in our model (export shares, value added and employment).

7.2.6 Policy conclusions

We derive our policy conclusions from the scenario analysis in combination with desk research concerning the development of NMP as well as from expert consultation. Concerning the relationship between the scenarios and our policy conclusion the following aspects have to be regarded:

Although each scenario presents a holistic picture that involves a specific policy stance, the scenarios do not correspond directly to policy choices. However, our working steps to derive concrete policy conclusion go closely together with the scenario simulations: the scenario parameters are the basis for both, for the model and the qualitative assessment. Then, the scenario values had to be more qualitatively specified to give appropriate recommendations and to be more quantitatively specified to fit in the economic model.

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The purpose of this study was to develop qualitative and quantitative prospective scenarios of the positioning and potential of European industry in those sectors, where research in nanotechnologies, materials and production technologies (NMP) is expected to make an impact. The study identified the key factors which influenced economic competitiveness and employment in the past, and subsequently used a quantitative model to assess different scenarios around 2025. Despite the limitations of the model in quantifying all relevant factors, the study used additional inputs such as validation workshops with experts, and confirmed the key factors in R&D for industrial competitiveness: a shift of focus towards innovation; the importance of skills and resources; and responding to market needs, by developing integrated value chains and demand-side actions.

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