

# THE LEVERAGE EFFECT

## of Photonics Technologies: the European Perspective

Study prepared for the European Commission,  
DG Information Society and Media under reference  
SMART 2009/0066

**Final Report**

March 2011

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 PHOTONICS<sup>21</sup>



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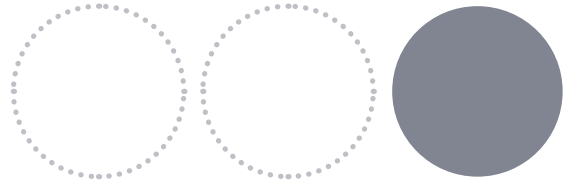
# Contents

- Executive Summary ..... 5
- 1 Introduction to the study ..... 9**
  - 1.1 Backgrounds to the study ..... 10
  - 1.2 Objectives of the study ..... 11
  - 1.3 Approach to the study ..... 12
- 2 The photonics industry ..... 17**
  - 2.1 Introduction ..... 18
  - 2.2 The Photonics industry is substantial and still in its early industrial stage ..... 19
  - 2.3 Strengths of the EU photonics industry ..... 22
  - 2.4 Implications for EU policy ..... 25
  - 2.5 Conclusions for the assessment of the photonics industry ..... 29
- 3 Looking at the value chains ..... 31**
  - 3.1 Introduction ..... 32
  - 3.2 Scanning, sensing and imaging ..... 33
  - 3.3 Information, communication and networks ..... 46
  - 3.4 Screens and displays ..... 58
  - 3.5 Advanced lighting ..... 69
  - 3.6 Photonic energy systems ..... 79
  - 3.7 Laser systems ..... 89
  - 3.8 Conclusions for the value chain analysis ..... 100
- 4 Leverage of photonics ..... 103**
  - 4.1 Introduction ..... 104
  - 4.2 Leverage assessment on markets and employment ..... 105
  - 4.3 Trends in industries 2010-2020 ..... 108
  - 4.4 Trends in leverage from photonic technologies ..... 111
  - 4.5 Conclusion on the leverage assessment ..... 118
- 5 Main drivers for change ..... 119**
  - 5.1 Introduction ..... 120
  - 5.2 Demographic drivers ..... 121
  - 5.3 Economic drivers ..... 124
  - 5.4 Social drivers ..... 128
  - 5.5 Technological drivers ..... 130

5.6	Ecological drivers .....	133
5.7	Political drivers .....	135
5.8	Conclusions for the drivers of change .....	137
<b>6</b>	<b>Scenario analysis .....</b>	<b>139</b>
6.1	Introduction .....	140
6.2	Gadget world .....	141
6.3	Green innovation .....	142
6.4	Budget society .....	144
6.5	Emergency .....	145
6.6	Conclusions .....	147
<b>7</b>	<b>Final conclusions .....</b>	<b>151</b>
7.1	Introduction .....	152
7.2	The European photonics research and industry base is globally significant .....	152
7.3	The field of photonics is growing fast and creating vast opportunities .....	154
7.4	Also focus on large sectors where photonics has the potential to enhance competitiveness .....	155
7.5	Establish a specific policy to support SMEs .....	155
7.6	Support the vertical connection between research and industry .....	156
7.7	Participate actively in photonics as government .....	157
7.8	Create an active policy to ensure the availability of highly skilled personnel .....	158
7.9	Focal areas: Non-consumer markets, with exceptions .....	159
	References .....	162

## Annexes:

- A Overview of photonics technologies in application domains
- B Backgrounds on leverage assessment
- C Four future scenarios of Photonics
- D Overview of experts consulted in the interviews and the workshop
- E Overview of sources used in the economic assessment
- F Overview of connections made between the leveraged industries and markets and the NACE sectors



# Executive Summary



# Executive Summary

The objective of this study was to understand and quantify the importance of photonics as key enabling technology for the European economy, by investigating the leverage effect of photonics technologies on photonics-enabled applications, markets and related value chains, and by assessing the potential socioeconomic and environmental impact of photonics technology take-up. A central element of the study was the analysis of the structure and dynamics of the European value chains in key photonics technologies, and of how these value chains may develop in the future.

**To understand better the European position, a full analysis of six distinct photonics value chains was conducted considering a number of drivers for change drawn from social to economic, demographic to political and technological to environmental factors. The six value chains are:**

- Scanning, sensing and imaging systems
- Data transmission, storage, communication and networks
- Screens and displays
- Advanced lighting (confined to solid state lighting alone)
- Photonic energy systems
- Laser systems

In all value chains Europe was found to have a strong research and development position, although in many cases R&D in more consumer oriented areas was not well represented. Volume manufacturing was absent in most value chains with the clearest gaps in displays and low value imaging components. This results in poor linkages in some value chains between early stage development and volume production that make it difficult for Europe to gain full economic benefit of successful mass market products. However, Europe was found to be strong in high value, high performance products, including the production of manufacturing equipment, giving it some economic gain from increases and improvements in volume production. The value chain in laser systems, in particular, was found to contain many significant global players and the links between the value chain elements were strong. Several value chains were also found to be threatened by a dependency on Rare Earth materials available as raw materials from only a few global locations.



The economic impact of all value chains was seen as positive with substantial potential for growth in some areas such as photonic energy system (i.e. photovoltaics). In general their environmental impact was less certain, with photonics technologies mostly offering greater efficiencies and more effective ways of working, but often creating greater demand (e.g. for displays) in the process. In general photonics is built into complex systems resulting in difficult end of life recycling. However, both advanced lighting and photovoltaic technology offer the potential for major impact on energy consumption/generation, although future scenarios where subsidies or economic prosperity are reduced would significantly impact developments in these areas.

Social impacts are slightly more diverse with the scanning, imaging and sensing value chain having positive impacts on healthcare and security. Other value chains such as displays and communications have positive social impact by enabling more informed decisions, but there is the risk of social exclusion for those that are not able to access the latest technology in these areas.

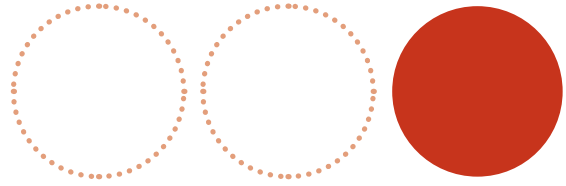
The 'leverage' of photonics was defined as the contribution photonics makes to the value of an end product, or service, either by enhancing the productivity of the manufacturing process, or by providing/enhancing the functionality in the end device. A method was devised to quantify leverage, by combining the size of main markets impacted by photonics, with an assessment of how critical photonics was to those markets based on an expert survey. The results indicated that as an order of magnitude estimate **photonics impacts around 10% of the European economy. This leverage is generated by a European photonics market worth €58.5billion (21% of the world market) and a European photonics industry employing 290,000 people.**

**Photonics leverage was seen in multiple markets as diverse as retail, medical and healthcare, manufacture of electronics and vehicles, transport, and telecommunications.** The size and diversity of this impact and the large ratio (>50) between the total leveraged market and the photonics market illustrates how crucial photonics technologies are to many very significant products and processes. Furthermore, **the photonics market has consistently grown at ~10% in real terms - faster than industry in general and therefore its influence is likely to further increase in the future.** In particular, the study concludes that **photonics leverage**

**will increase significantly in the areas of construction** (based on photovoltaic and lighting technologies), **retail** (based on displays and lighting), **transport** (based on scanning, imaging and lighting) and **medical and healthcare** (based on almost all photonics technologies). With Europe comprising over 20% of the global photonics market, having some 5,000 companies active in the field and well over 1,000 research organisations extending knowledge in the area, Europe has a considerable photonics capability.

A number of **future scenarios differing on the rate of economic growth and the role of government in the economy** were used to provide **further insights into the robustness and vulnerabilities of European photonics**. The global nature of the photonics market, and the high concentration of active Small and Medium-sized Enterprises (SMEs) are seen to make European photonics both more adaptable to change, and more sensitive to international market fluctuations. The focus on the high end markets requires a strong research, design and development base to be maintained. Public investments in photonics research play a crucial role in this regard, and thus have a significant impact on European competitiveness. In all future scenarios energy efficiency becomes an increasingly important parameter and one where photonics should have a significant role.

Overall it is concluded that the European photonics market is significant on a global scale and has very high leverage on other industries and markets. The future of photonics is bright, as leverage on most markets and industries is set to increase in the coming decade with very substantial gains in some areas. However, the photonics industry is by no means homogeneous, technically or structurally, and its many variations enhance products and processes in many different ways, requiring a heterogeneous policy approach. Photonics is still at the early stages of its development and thus its impact will continue to grow in new and unforeseen ways.



# Introduction to the study

## 1.1

# Background to the study

Photonics can be seen as one of the major enabling technologies of the last decades, leading to new products and services with significant economic benefits. The huge diversity of products with photonic components demonstrates the positive impact to our economy of this pervasive technology. However in the field of photonics production there is a strong competition with companies in the US and the Far East. Photonics is a high-tech field, being at the forefront of R&D and innovation. For the future European policy on research and innovation in this area, more insight is needed into the actual impact of and the benefits generated by the photonics industry (**leverage**) for European industry at large, both to legitimize policy as well as helping setting priorities in the field.

To analyse this and provide information for future policies, this study was conducted for the European Commission's Directorate General for Information Society and Media to address these issues. The study results will contribute to the process regarding future orientation and structuring of European photonics research for the latter stages of FP7 and future FP8. It will give guidance for future investments in photonics research by providing qualitative and quantitative information about the leverage the photonics industry has on the industries that use photonics technologies (the 'photonics enabled' industries).

The study was carried out by a consortium of three partners. The main contractor was TNO, where both the methodological expertise in the field of photonics was provided, as well as technological knowledge of photonics. The Electronics Sensor and Photonics Knowledge Network (ESP KTN) provided access to the European Photonics network, as well as their in depth expertise in the field. Technologia was responsible for the quantitative economic data analysis, where the input of the European photonics networks was also crucial.

## 1.2

# Objectives of the study

The overall aim of the study was to investigate the leverage effect of photonics technologies on photonics-enabled applications, markets and related industrial value chains, particularly as applied to the European situation, to illustrate the degree to which this affects the development of new markets and to assess the potential socioeconomic and environmental impact of photonics technology take-up.

Another element of the study focused on the future. The major trends that could change the size and structure of photonics research and industry were assessed, including the identification of major photonic technology trends.

This information on the future trends and related driving factors of change were integrated into four scenarios. These scenarios formed the basis for the analysis of emerging and new markets for photonics-enabled technologies, processes, applications and devices. Part of this was the assessment of the **Strengths, Weaknesses, Opportunities and Threats (SWOT)** of the various value chains of the photonics industry, as well as an assessment of the major social, environmental and economic impacts.

The specific objectives of the study were:

1. Overview of today's size and structure of the photonics market.
2. Survey of today's markets of photonics-enabled technologies, processes, applications and devices and the relative position of Europe in the value chain and key European market players.
3. Qualitative and quantitative analysis of major trends and drivers for the development of new markets for photonics-enabled technologies, processes, applications and devices.
4. An analysis of emerging and new markets for photonics-enabled technologies, processes, applications and devices
5. Assessment of the potential socio-economic and environmental impact of photonics technology today and in the future.

## 1.3 Approach to the study

These different parts of the study were performed using different methods, but connected to each other. In the following overview the links are illustrated.

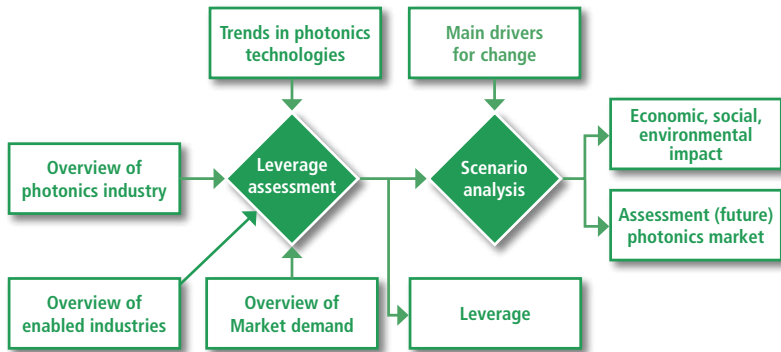


Figure 1: Methodological overview of the project

In the first stage of the study, the main aim was to assess the present situation. A quantitative industrial and market analysis was conducted, based on readily available information, using input from the European photonics networks. The assessment of leverage was based on a combination of the quantitative industrial and market analysis with the outcomes of an expert survey on the leverage of photonic technologies on manufacturing and consumer markets. The results were evaluated by a group of experts during a workshop. The analysis of trends in photonic technologies was based on desk research. The final outcomes of the desk research and workshops were integrated in a detailed description of six photonics value chains, including SWOT analyses for each one. The Photonics21 database<sup>1</sup> was used as an important source of information.

The second stage of the work focused on future developments. The drivers of change to the photonics (enabled) industry were identified

<sup>1</sup> See Section 2.1

by desk research and individual expert interviews. Based on the drivers, four scenarios were developed in order to assess future trends and changing SWOTs. The results of the project were strategically analysed using a scenario analysis, including a second expert workshop. This provided a future-oriented SWOT analysis.

*The study distinguishes between six photonics technologies, which are also considered the core of the value chains in Europe:*

- 1. Scanning, sensing and imaging*
- 2. Information, communication and networks*
- 3. Screens and displays*
- 4. Advanced lighting*
- 5. Photonic energy systems*
- 6. Laser systems*

To enable a more specific assessment of impact, a distinction is made within the analysis between six photonic technology clusters, based on technological and economic linkages:

### **1. Scanning, sensing and imaging systems**

This cluster includes sensory devices for the measurement of physical properties and conversion to a signal that can be read by observers or other instruments. It deals with the capturing of 1, 2 and 3 dimensional images. Examples vary from small sensors for measuring temperature or distance, to infrared imaging for defence and security to large systems used for medical scanning and semiconductor production.

### **2. Information, communication and networks**

At the core of this cluster are the many photonics technologies behind the high speed data transmission of data that form the backbone of the modern information/knowledge society. The Internet and modern global telecommunications have been revolutionized by fibre optics and associated photonics technology. This cluster includes both the fibre infrastructure, as well as the many photonics devices for routing, transmitting and receiving data. It also extends to storage devices such as DVDs and Blu-ray players and may in the future extend to optical computing.

### 3. Screens and displays

Displays are critical for the presentation and visualization of information both for leisure and business. The technologies behind 2 and 3 dimensional displays of all sizes are at the core of this cluster which focuses mainly on the flat screen displays, but also includes devices such as head mounted displays and projection displays. The applications are numerous, from use in mobile phones, television, computing, to large screen advertisement and professional entertainment.

### 4. Advanced lighting

The shift from traditional light bulbs to LED based solid state lighting is at the core of this cluster. Applications extend from basic domestic, retail and industrial lighting, to automotive and street lighting as well as advanced adaptive lighting, specialist lighting (e.g. surgical theatre lighting and photo-dynamic therapy). To focus on emerging developments this cluster specifically excludes traditional incandescent lighting and fluorescent lighting and focuses on light sources based on organic and inorganic semiconductors i.e. OLEDs and LEDs.

### 5. Photonic energy systems

Photovoltaic technology has been available for niche electricity generation applications for many years but in recent years interest in photovoltaic technologies has exploded as it is now seen as a more widely applicable long term sustainable energy source. This cluster includes the technologies for the use of solar energy to produce electricity including the many new technologies in development. However additional photonic energy technologies are also relevant such as laser driven fusion. Solar thermal systems e.g. applied to water heating, are excluded, since although they still rely on the interaction of solar light they have minimal dependence on photonics technology development.

### 6. Laser systems

Laser systems prove to be a core enabling technology for many applications. Lasers vary widely from the very low power lasers used in bar code scanning to the very high power used in cutting and welding and this clusters includes all lasers types notable both diode and non-diode systems. Lasers are available in many formats with very different properties dependent on a wide range of technologies making this cluster very heterogeneous. Applications are equally varied from systems for manufacturing (e.g. welding and marking), lasers for surgery, lasers in



defence (e.g. ranging and weaponry) and lasers used in scientific research and development.

To inform the assessment of leverage within the economic analysis a distinction is made between the following three entities:

1. the **photonics industry** itself, manufacturing photonics components and sub-systems, like lasers, LEDs, PV panels, screens and optical devices,
2. the **'photonics enabled' industries**, which use those components and sub-systems both in their products and as part of their manufacturing processes. The automotive industry, the telecoms industry, the lighting industry and the medical equipment industry are all examples of these enabled manufacturing industries.
3. The final end use or **consumer markets** where photonics based products are used in transport, healthcare, retail, science and construction for example.

An overview of the enabled manufacturing industries and final markets distinguished within the study is included in the following table.

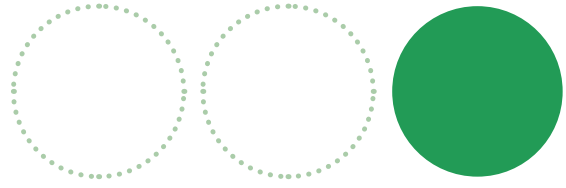
Enabled manufacturing industries	Final Markets
Manufacture of Electronics and Optical Equipment	Medicine & Healthcare Activities
Manufacture of Vehicles and Large Machinery	Defence and Security Activities
Manufacturing of Fine Chemicals and Pharmaceuticals	Aviation and Space Infrastructure
Manufacturing of Textiles and Clothing	Road & Rail Transport and Logistics Infrastructure
Media Production and Broadcasting	Telecommunications Infrastructure
Food and Beverage Production	Science, Research & Development
Printing & Publishing Activities	Electricity Generation & Supply
Oil and Gas Exploration	Construction and Built Environment
	Environmental Monitoring and Protection
	Recreation, Culture and Education
	Retail & Services

Table 1: Overview of the main enabled manufacturing industries and final markets in which photonics technologies are significantly relevant, based on the study results (see Annex B).

An overview of possible photonics based technologies and products for the enabled manufacturing industries and final markets can be found in the Annex A.

*Within the study, three basic perspectives for the economic and technological assessment are distinguished:*

- 1. The **photonics industry**, where manufacturing of photonic components is core.*
- 2. **Enabled manufacturing industries**, where these components are used in the production process.*
- 3. **Final markets**, in which the photonics-enabled products are used as end products.*



# The photonics industry

## 2.1 Introduction

The photonics industry has been assessed several times in recent years. Therefore this study did not include additional fieldwork, but rather undertook the systematic analysis and representation of the data that are already available in the various sources. An overview of those sources is provided in Annex E. Alongside these sources, information was also used from individual experts in the ESP KTN, TNO and several other European photonics networks.

### Photonics21 as data source

The data used for the analysis of the various value chains are largely based on the Photonics21 database provided by the EU funded 'Phorce21' project. Phorce21 has been assessing the Photonics industry and research infrastructure for the last few years, within the framework of the Photonics21 European technology platform. The partners involved in the Phorce21 project are: VDI Technologiezentrum GmbH (GER), OpticsValley (FR), Enterprise Ireland, IMEC (BE), EOS and TNO (NL). A vast amount of data is collected in the Dynamo database, hosted by TNO. It includes 774 European research organizations involved in photonics and 2609 European companies involved in photonics.

The photonics industry is defined as those sectors that produce photonic technologies: photonic components and systems that are used in end user products, processes and services.

This chapter of the report is structured around the key conclusions that were drawn from our analysis of the data collected during the study.

## 2.2

# The Photonics industry is substantial and still in its early industrial stage

The world market for civil photonics products in 2008 was worth €256bn, the defence market adding an additional €21bn - leading to an overall total of €277bn [Optech Consulting, April 2010]. The two largest civil sectors were flat panel displays and information technology. They accounted for €71.8bn and €49.0bn respectively and together made up nearly half the total market volume (44%). The remaining seven non-defence sectors accounted for between €15bn and €27bn each.

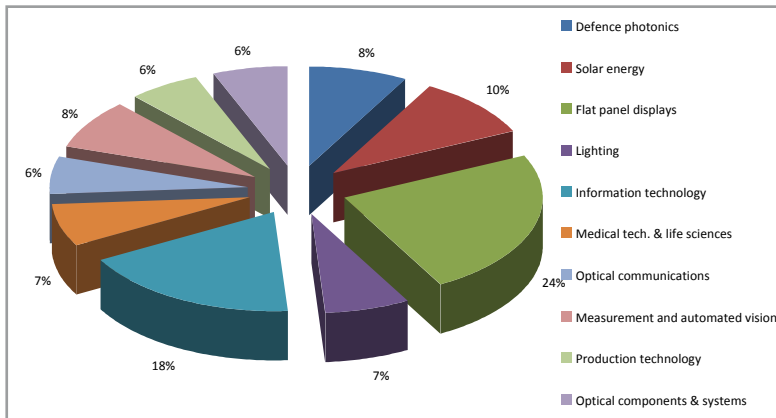


Figure 2: World photonics production by sector (2008). Total: €277B, redrawn with modifications from [Optech Consulting, April 2010].

The total of €277bn can be put in perspective by comparing this with other important industries. In total, the overall worldwide GDP is around €60trillion (2008), where the EU GDP is around €12trillion (2008). The overall production of defence related photonics in 2008 was around €22bn, which can be compared to defence procurement of €44bn in Europe and \$154bn in the USA in 2009 (EDA<sup>2</sup>). Compared to technol-

<sup>2</sup> European Defence Agency

ogy focused sectors, the world pharmaceutical market, which is around €500bn, is about twice as large as the total photonics market. The conclusion is that the photonics market is significant relative to other technology sectors although it may appear more limited relative to major end markets such as food or automotive.

From 2005-2008, the global civil photonics market grew by 21.2% on a Euro basis, equivalent to a median annual growth rate of 6.6%. However, photonics supply and demand is highly global, with some 30% share within the Euro zone, and with the appreciation of the Euro relative to other relevant currencies, it is useful also to measure the photonics world market in US dollar terms. On this basis, the global civil photonics market grew even by a total of 42%, or at a median annual growth rate of 12.4% between 2005 and 2008<sup>3</sup>. Taking into account a core inflation rate of approx. 2% for this period, this growth equates to a real annual growth rate of 10%. By comparison worldwide gross national income (GNI) growth was approximately 4.4% over the same period and the GDP increase of OECD countries on average was around 2.5%. Other sectors in general showed significantly less increase (Food: 2%; Automotive: 3-5%). Overall, the employment within the photonics industry is around 290,000 people.

Although consistent updated information for the EU is not generally available, the world market as given in [Southern European Cluster in Photonics and Optics, 2010] can be compared for 2008 with the information from 2005 in [Optech Consulting, 2007] to extract some indicative trends. Most sectors have roughly the same proportion of world production in both years. The exceptions are information technology (down from 21% to 18%) and solar energy (markedly increased from 4% to 10%). It can be concluded that the major recent change to be expected in the composition of the EU photonics sector is the growth of solar energy, since information technology is not very significant as a proportion of EU production. This is consistent with [Optech Consulting, April 2010], which found that in Germany, the solar PV sector represented 23% of production (the largest proportion of any sector) in 2008 having grown at an annual rate of 45.5%, compared to 6.8% for the other sectors. While a complete and consistent data set for all major EU producers is not available, based on all the available indicators, the

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<sup>3</sup> Differences between the annual growth in euros and dollars are due to the disproportionate changes in exchange rates over this period.

### Kondratiev waves of economic growth

In the 1920-ties, the economist Nikolai Kondratiev discovered the existence of 60 year long waves of macro economic growth [Kondratiev, 1984]. Based on important enabling technologies, historically the economy shows expansions that lead to restructuring of our economy. Examples are the steam engine in the 18th century, electrical and chemical engineering, as well as petrochemicals in the 19th century. Today, we experience the long wave based on ICT, which is believed to have started in the 1970s.

best estimate of the size of EU photonics production in 2008 is €58.5bn. The evaluation workshop and recent growth figures of e.g. ASML indicate that production and markets in 2010 are back to their 2008 growth path, following the impact of the credit crunch. This is confirmed by recent market analysis on laser markets and other markets [Anderson, 2010; Solarbuzz, 2010].

Whilst the overall size of the photonics industry is not vast relative to other industries, the growth rate of the photonics industry is strong compared to industry in general. Growth is far above average and new markets are constantly emerging. The conclusion can therefore be drawn that the sector shows characteristics of an industry still in its early phases of evolution. As discussed in Chapter 4, the impact of photonics on other industrial sectors is strong, e.g. on automotive, building & construction, science and consumer electronics. New photonics-enabled products and connected services are expected to emerge and their enabling characteristics will have strong impacts on industrial activities. Two clear examples are the enabling characteristics of the flat screen displays and the ever growing use of photonics enabled high speed internet. This not only offers the potential for economic growth, but the potential impact of photonics on the rest of the industry and society requires attention to ensure optimal usage of its changing impulse. Based on its high economic growth and leverage to the rest of the industry (see chapter 4), it can be said that photonics is a key enabling technology of the ICT Kondratiev wave now fully emerging. Support of research and development is also crucial for an industry that is still in its development stage.

*The photonics industry is highly globalized industry with an estimated production level of €277bn (2008). The sector shows a rapid overall growth and even further **increases** can be expected for the coming decade. But within the sector, strong differences can be seen and its character is **heterogeneous**. The EU is a **significant player** in this field, with an annual production of about €58bn (2008), which is about **20-25%** of the total global production. However, the heterogeneous character also applies for Europe, as it is **world leader** in certain fields and only has a **marginal** position in others.*

## 2.3

# Strengths of the EU photonics industry

Although recent (2009-2010) consistent information about the EU photonics industry is not readily found, within the study the different Photonics Networks were consulted and additional national information has been provided. Also the Photonics21 database provided valuable insights in the economic structure of the European photonics industry.

Within the EU around 5,000 companies are presently active in the field of photonics technologies and a raw estimate of research is that some 1,000-2,000 organisational units work in the field of photonics (institutes, labs, university groups).



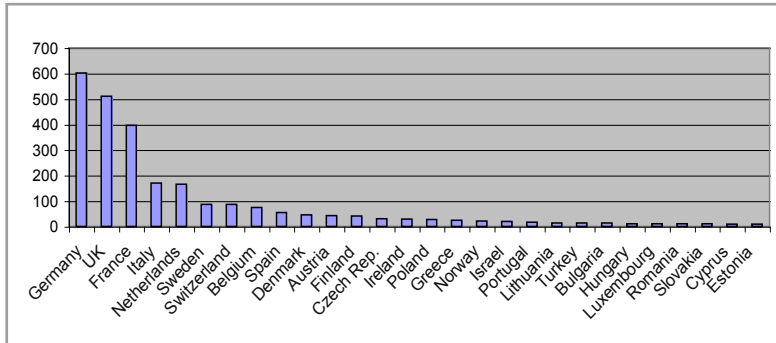


Figure 3: Overview of the company distribution mapped in the Photonics21 database (total 2,600 companies).

Looking at the Photonics21 database, the strongest industrial participation can be seen in Germany and the relative number of large companies in Germany is significantly higher than in the other countries. UK, France, Italy and the Netherlands are also important for photonics activities with a significant number of large companies (>10). What is important to see is that many of the other EU countries also show a representation by photonics companies. The conclusion is that although most of the activities are based in a small number of countries, also other EU countries show a critical mass.

Some highlights from the updates from individual national photonics networks have also been collected during the study. Germany's photonics production reached a volume of €23.1bn in 2008, with an export rate of 65%. Over the period 2005-2008, output rose by 41.4%, at an average annual rate of well over 10%. Following these positive trends in revenues, 27,000 new jobs were created in the sector across Germany between 2005 and 2008. The employment growth rate was 8.8% in the same time period, nearly as strong as real production growth in the sector (10.2% p.a.). A 2009 survey by the UK ESP KTN indicated that the value of the UK Photonics market had grown to €7 billion and indications showed the sector attaining strong growth again in 2010. The output of the Spanish photonics industry was worth an estimated ~ €1.5bn in 2008, not including the photovoltaic sector, whose output alone was worth €16.3bn in 2008. An average compound annual sector growth of 18% was reported between 2000 and 2006, according to a study carried out by the trade association SECPhO. Production value of the Swiss

photonics sector in 2008 was 2.97bn Swiss Francs (CHF), a 4 % reduction compared to 2007. The biggest decline in production was in the laser material processing sector (which fell CHF150 million). Measurement technology & image processing also suffered – together these sub-sectors made up over 65% of Swiss production. The estimated production volume of the photonics industry in Sweden in 2007 was €2.5bn. A 2007 survey found that Sweden has the second highest number of photonics companies/per capita in Europe.

The strengths of the EU research community are slightly different as illustrated in the following figure. Although the same strong countries can be seen, Poland is also an important country for photonics research.

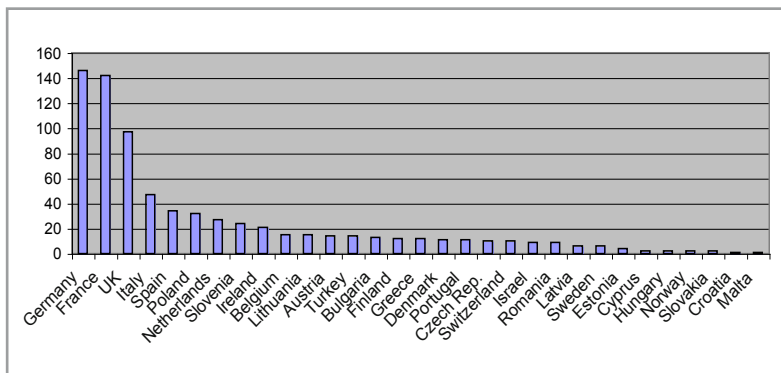


Figure 4: Distribution of the research activities mapped in the Photonics21 database to the countries (total: 774 mapped).

As in production, photonics research activities are present in almost all countries leading to the conclusion that there is a broad critical mass for photonics research across Europe. Additionally the 1000-2000 research institutes, labs and, university groups active in photonics are distributed among ~ 400 universities and large research & technology organisations present across Europe [EARTO<sup>4</sup>]. The relatively large average of ~5 underlying departments working in photonics per organisation reinforces the broad ranging influence of photonics across multiple disciplines es-

<sup>4</sup> EARTO: is the trade association of Europe’s specialised research and technology organisations. EARTO represents RTOs with a total staff of some 150,000 scientists, engineers and technicians and an annual turnover of €15 billion.

pecially at the research level. The conclusion can be drawn that photonics research is well represented within the European research community.

The following research areas are highly represented within the EU:

- Laser technology
- Thin film
- Photonics related design research
- Nanophotonics

*The European photonics research and industry is represented **in most of the EU27 countries**, but most of the research and industrial activities take place in Germany, France and the UK (over 50%). Overall, it is estimated that around **5,000 companies** are involved in photonics related industrial activities, employing about **290,000 people**. Some **1,000-2,000 research organisations** are estimated to be present in Europe. The photonics industry includes a relative **high proportion of SMEs**, but also a significant number of **multinational companies** have their main office in Europe.*

## 2.4

# Implications for EU policy

### 2.4.1 A heterogeneous industrial sector, demanding heterogeneous policies

The photonics industry includes various subsectors, from energy oriented products, to imaging, medical and information technologies (Figure 5). The various subsectors are often based on different technologies, and not all subsectors grew at the same rate between 2005-2008.

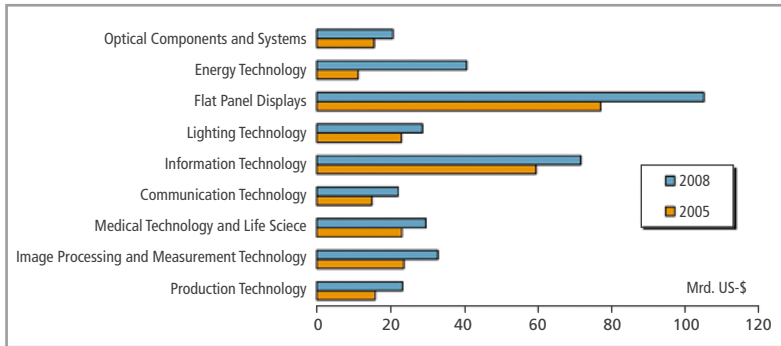


Figure 5: Overview of the world civil photonics market sectors on a US\$ basis in 2005 and 2008, adapted from [Optech Consulting, April 2010].

As has previously been said, the overall growth rate of the photonics sector was around 10% in the period 2005-2008. However, some subsectors have shown more growth than others. The largest subsector is flat panel displays (over \$100bn in 2008), which also shows a strong growth (almost 30%). But perhaps the most important relative growth can be seen in energy, where growth was over 250%. This finds its origin in the further political attention to the energy challenge, but is combined with the improvement in technological efficiency and cost reduction. However, it can be expected that growth may be slowed in an environment where governmental funding for renewable energy may be under pressure as part of measures to reduce overall state spending and associated debt. However there are also several other subsectors of importance that show a highly dynamic future trend. Information and communication technologies can expect further growth, as the demand for high speed data communication continues to increase exponentially. Solid state lighting will also see substantial growth as LED lighting becomes cost effective and offers higher efficiency than traditional lighting with equivalent or improved user experiences. It can also be expected that the market for medical technologies will become increasingly important because of the pressure on the healthcare system demanding more efficient and effective healthcare. Also photonics enabled production technologies can be expected to grow, as a consequence of their impact for improving the efficiency of many manufacturing processes (e.g. production of chips, and materials processing).

An analysis of the impact of the 'credit crunch' shows that although the impact on the overall photonics industry was limited, situations vary along the different subsectors, with some sectors, such as materials processing, hit harder than others such as medical and biophotonics. An example is given by [Optech Consulting, 2009], which indicates that the German photonics production and markets in 2010 should be back to their 2008 levels – thus we would broadly expect the future pattern of growth to revert close to the trends forecast in 2005. [Southern European Cluster in Photonics and Optics, May 2010] and [Optech Consulting, 2009] track aggregate revenues of leading publicly quoted laser and photonics firms. [Optech Consulting, 2009] shows that these fell from Q2 to Q3 2008 slightly, then markedly in each of the next two quarters, finally stabilising in Q2 2009 before starting to grow again. Sales were down 26% in 2009, with materials processing down 35%. Laser revenues worldwide fell to 2003 levels in 2009. Further evidence comes from the underlying semiconductor base. [Southern European Cluster in Photonics and Optics, 2010] shows a 'devastating' decline from 2008 to 2009 in EU optoelectronic component revenues – a 25% drop with all product types suffering. The same estimate for world revenues shows an 8% decline, with displays (up 31%), LEDs (12%) and 'other' (9%) showing positive growth globally but not in the EU.

Although various elements of the photonics industry are linked to economic cycles, the conclusion to be drawn from this overview is that the photonics industry is a highly dynamic and heterogeneous industry and a supportive policy on the subsectors should not be homogenous. Supporting existing subsectors and related networks should be looked at with intelligence, as new and upcoming markets could be more interesting. Within the support, this dynamic nature should be addressed by allowing significant changes in participation, activities and focal themes, including a forward looking component. Continuous anticipation on future developments is crucial.

#### **2.4.2 Focus on the winners, but do not neglect new markets**

The EU is not strong in every subsector of the photonics industry. It is commonly accepted that, in general, the EU position in large volume consumer products is weak. However, more tailor made high end and high tech products and manufacturing systems are strong in Europe. As innovation and new product developments are an important aspect of the photonics industry, research is crucial to optimally benefit from the opportunities

of photonics in an economical way. However, there are barriers to entry, as the workshops conducted within the scope of this study showed that the connection between universities and business is crucial for the future position of companies. Research needs full public and private support in order to keep the innovative capacity strong enough. But to support all possible research fields would limit its effectiveness. Support of weak areas of research should be limited and strong research communities should be further strengthened, but with future developments in mind.

However, the dynamic character of the industry and stage of evolution also leads to the conclusion that policy should support small and upcoming areas of research and innovation. As described before, the photonics industry is highly characterized by new and emerging (sub) markets. These new markets will have some connections to existing strengths in research, but need support to grow out of infancy. As the photonics industry has strong presentation of SMEs<sup>5</sup>, adjacent policy needs to be developed that supports SMEs to connect to research and develop new innovations in new markets (more radical innovations).

*Looking at the assessment of the photonics industry in Europe, two policy implications can be drawn:*

- 1. The photonics industry is highly heterogeneous, including several subsectors with fundamentally different characteristics. A general policy will be suboptimal and a thematic **policy is needed**.*
- 2. The industry shows many growth markets with critical mass, but also several new emerging markets can be identified. So next to a policy of "backing the winners", also **support is needed for newcomers and for innovative SMEs**.*

<sup>5</sup> Within the Photonics21 database some 2,600 companies are collected. Over 90% is SMEs, and less than 10% have over 500 employees. It is estimated that some 200,000 people work in the SMEs within the EU photonics industry.

## 2.5

# Conclusions for the assessment of the photonics industry

The assessment of the photonics industry shows that it is a significant industry, about half the size of the pharmaceutical industry. The estimated world production is €277bn (2008), of which Europe contributes about €58bn (2008). This is about 20-25% of the total global production and it can be said that the EU is a significant world player. However, although Europe is considered a world leader in certain fields it only has a marginal position in others. It can be concluded that the photonics industry is significant for Europe, but not in all fields (see chapter 3 for more information).

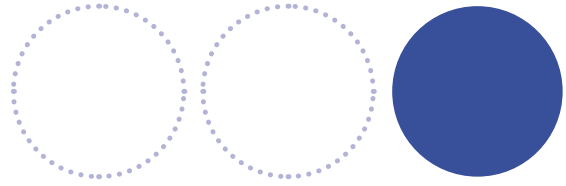
In the last decade, the photonics industry has shown a growth rate that is significantly higher than average and it can be said that the industry is still in its early phase of economic life (this is supported by the leverage assessment). Although the credit crunch has had a large impact on the industry, already in 2010 the growth paths have shown it to be back to the level before the credit crunch. Even further increases can be expected for the coming decade, but within the sector, strong differences can be seen and its character is heterogeneous.

The European photonics research and industry is broadly addressed by most of the 27 EU countries. However, over 50% of research and industrial activities take place in Germany, France and the UK. Some other countries like Spain, the Netherlands, Poland, Sweden and Italy are also considered substantial players in the field of photonics, but focal areas of the individual countries vary significantly. Overall, it is estimated that around 5,000 companies are involved in photonics related industrial activities, employing about 290,000 people and some 1,000-2,000 research organisations are present in Europe. The photonics industry includes a relative high proportion of SMEs, but also a significant number of multinational companies have their main office in Europe.

The assessment of the photonics industry in Europe, lead to some policy implications:

1. As the photonics industry is highly heterogeneous, the policy to support the industry needs to address this. The existence of having several subsectors with fundamentally different market, innovation and research dynamics, asks for a thematic approach.
2. The industry shows many growth markets where already a critical mass exists. Networks are present (industrial and research), as well as a sound economic position in global markets. But the industry also shows a dynamic emergence of new economic activities in new markets. So next to a policy of “backing the winners”, also support is to be provided to newcomers and to innovative SMEs enabling them to create critical mass for both research and industrial activities.





# Looking at the value chains

### 3.1

# Introduction

The previous chapter assessed the European photonics industry at large and did not draw conclusions on specific clusters/networks within the Europe. As one of the objectives of the study is to create a better insight into the research and industrial base in Europe, a further systematic breaking up of the photonics related research and industrial activities is needed. The concept of value chains is used.

In the value chain approach, the main element is the assessment of the added value that different activities contribute to the full production chain. The value chain can be seen as ‘economic clusters’, wherein economic activities are connected and add value through economic links (including also research). In the value chain, specific activities are identified that can be analyzed on the basis of their added value.

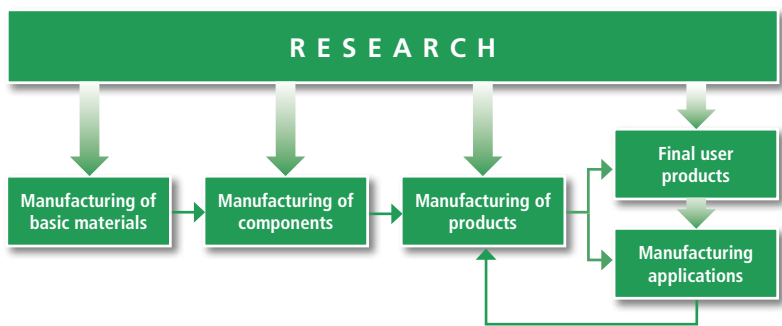


Figure 6: Methodological framework for the value chain analysis of the photonics and photonics enabled industry.

Looking at the photonics industry, technology is an important linkage through the value chain. The photonics technology areas are set in the centre of the identified chains and therefore this view focuses on the key questions on the nature of the life cycle of specific photonics-based technologies:

1. Scanning, sensing & imaging
2. Information, communication & networks
3. Screens & displays

4. Advanced lighting
5. Photonic energy systems
6. Laser systems

In this chapter, the following sections will discuss each value chain:

- After a short introduction, **the emphasis** will be given to the main characteristics of the various elements of the value chain, focusing on the European position.
- The second part of the analysis will use the Leverage survey results and provide a more detailed analysis of the **present and future perspective** of both enabled manufacturing industries and final markets on their dependency to photonics for their competitiveness.
- The third element of the assessment focuses on the **Strengths, Weaknesses, Opportunities and Threats** of the European economy in regard to the value chain.
- An assessment of the **economic, environmental and social impacts** of the products and services core to the value chain.

The chapter will finish with a short overview of the main conclusions.

## 3.2

# Scanning, sensing and imaging

### 3.2.1 Introduction

Scanning and sensory devices are used in several application areas, usually to measure physical quantities and convert them to signals that can be read by observers and/or other instruments. They deal with the capturing of 1, 2 and 3 dimensional images and the processing of information. Examples vary from small sensors for temperature, chemical composition, to large systems that are used for medical scanning, lithographic production systems and astronomy.

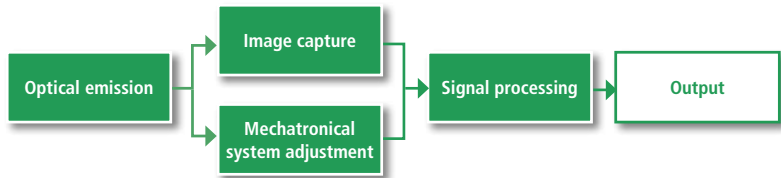


Figure 7: Functionalities in scanning and imaging.

Within manufacturing, scanning and sensing are often crucial elements to the production process especially in quality control, marking and positioning. Examples are the imaging systems for robotized manufacturing and scanning systems for detection of production errors. These systems are used both in high tech manufacturing industries such as microelectronics production and increasingly in traditionally lower technology areas such as food production. The use in final markets is diverse. Within Medical & healthcare activities scanning & imaging is a critical component of diagnostics in locating diseased areas. Within Defence & security, remote threat identification is just one of the examples of the use of these devices and systems. Within Transport many imaging devices are used with the infrastructure to e.g. enhance safety with speed and traffic monitoring cameras as well as automatic toll and congesting charging. Sensing devices are also increasingly deployed in cars to monitor the surrounding environment to increase safety and comfort. Also the use of sensors in Science has become crucial to conducting research, especially to make the invisible visible (e.g. microscopy and astronomy) and to assess material and process characteristics. Last, but not least, scanning and sensing is increasingly important in ICT based consumer devices such as camera's, mobile phones and home automation.

### 3.2.2 The European value chain

**Research** in this value chain includes research on the further miniaturization of sensors, higher quality, broadening the spectral response, as well as on signal processing and imaging. The European **research infrastructure** in this field is diverse. Based on the Photonics21 database, it can be concluded that this area is overall highly addressed in Europe, with over 50% of all organisations conduct research in some area of Scanning, sensing and imaging. Optical measurement, adaptive optics, biophotonics, spectroscopy, microscopy, astronomy and (parts of) imaging are well represented in Europe. The geographic distribution from Photonics21 indicates that countries that are generally highly active in

photonics research show high participation in this field; the database shows also representation by numerous other EU countries.

The second key element in the sensing and imaging value chain is the manufacturing of **basic materials**. This area is of limited specificity to this particular area as the basic materials used are the common materials for the production of electronics and sensors, although there is increased use of non-silicon semiconductor materials such as GaAs and III-V semiconductors.

The production of **basic components** mainly includes the actual production of sensors, light sources, as well as imaging software. Europe is underrepresented in this field, especially in high volume camera components, as most of the production is low cost and positioned in e.g. Asia. However, for some very high performance components Europe shows a significant position, especially those used in defence & security, astronomy and healthcare. General imaging design is considered a European strength and Europe has a significant position in the emerging high growth area of advanced image processing (e.g. augmented reality, automate camera monitoring).

The production of photonics based equipment used in **manufacturing** includes e.g. the measurement & testing, support for automation (e.g. imaging for robotics) and the use of other sensors in manufacturing. Europe is generally strong in the production of sensing and imaging equipment as it is generally in the use of photonics in manufacturing tools. An example is the production of photonics based testing measurement equipment, in which about 20% of the companies in the Photonics<sup>21</sup> database are active. A particular strength is the use of scanning and sensors in the production of high capital cost low volume production systems (e.g. wafer steppers, robotized slaughtering).

Scanning, sensing and imaging is used in several **final markets**, of which Medical & healthcare activities and Defence & Security are perhaps the most prominent. But also Transport and Science are important. In the application area of *Science*, Europe can be considered a highly significant player making vital photonics based tools for scientific research in all disciplines, but especially relevant to Physics and the life sciences. The industry is mostly served by SMEs, although there is an important number of large multinationals. Europe also has a strong overall pres-

ence in the production of systems for *Medical & Healthcare* equipment using photonics. Europe (especially Germany but also the UK and the Netherlands) is particularly strong in the area of advanced microscopy and other emerging tools used in medical and life science research as well as increasingly being utilised in healthcare. In *Defence & Security*, infrared imaging is a major application, along with security monitoring cameras. Especially in *Defence & Security* companies are usually large multinationals, although some SMEs are involved. Biometrics and surveillance cameras are considered of high importance and have strong European representation. Also in safety Europe is a significant player, overlapping with the application area *Transport* where Europe also has a significant presence especially in traffic monitoring and congestion charging systems. The last application areas are *Consumer products*. In this area European presence is limited and this market is mostly dominated by Asian companies, although the design rather than the production of low cost CMOS cameras is regarded to be an EU strength.

Looking at the connections between the different elements of the value chain, in general the connections are limited. For several high volume components especially imaging chips, production is based in Asia although some specialised high performance production is based in Europe. The high volume products are essentially commodities usually purchased on cost and then integrated in systems. However, the linkages between research and manufacturing are relatively strong and essential. Particularly with specialised systems, the pipeline of research and manufacturing is crucial for survival of a business. But the actual situation highly depends on the concrete product groups, where less complex systems have limited linkages.

### ***Scanning, sensing and imaging***

*The following conclusions can be drawn from this assessment:*

- *EU research in this area is **diverse and well represented**. Several areas are broadly covered and of world class*
- *Europe in general is **underrepresented as manufacturer of components** in this chain, although on certain components it is strong (e.g. lenses, low cost CMOS)*
- *The application of **scanning/sensing/imaging in manufacturing industries is significant** in Europe, with even some exceptional world players.*
- *Especially the **non consumer markets**, like healthcare, defence and science are important final markets for European industries, although some activities are of importance, like design of products.*

### **3.2.3 Present versus future**

Main technology development activities in the imaging field are aimed at the realization of imaging devices with improved performance, e.g. spatial resolution, sensitivity, dynamic range, speed, compactness; extended wavelength response (UV, infrared, terahertz region); development of technology for 3d imaging and hyperspectral imaging, and development of advanced data processing and analysis techniques. Developments also include combinations of optical and acoustic imaging. Further on, miniaturization of camera systems is an important technology driver. Overall developments in this are focused on increasing the information content of images i.e. more pixels and more data per pixel and the automated processing of images. Along with rapid cost reduction, driven by some consumer applications, the impact of imaging technology is continuing to grow. Many photonics technologies based on imaging and sensing systems have also been developed with continued development in sensitivity and selectivity.

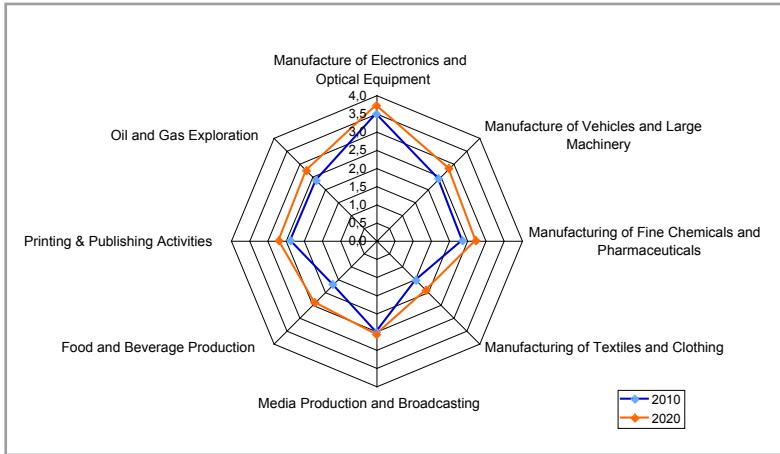


Figure 8: Overview of added value to competitiveness of scanning and imaging devices to enabled manufacturing industries based on Photonics survey.

The results of the survey show that the importance of scanning and imaging for manufacturing industries is of high importance and it is expected to increase in the coming decade. It is clear that the highest dependency can be seen in the manufacturing of electronics and optical equipment. As its importance is already high in 2010, the increase is limited. Another interesting assessment is that although the use of scanning and imaging in Food and beverage is currently limited, it is expected to significantly increase in the coming decade. Expected developments in automation and quality control/verification in this industry using photonics technologies can explain this outcome. This is also the case in textiles and clothing, although the impact will be less.

The survey shows that looking at final markets, scanning and imaging will also increase in the coming decade.



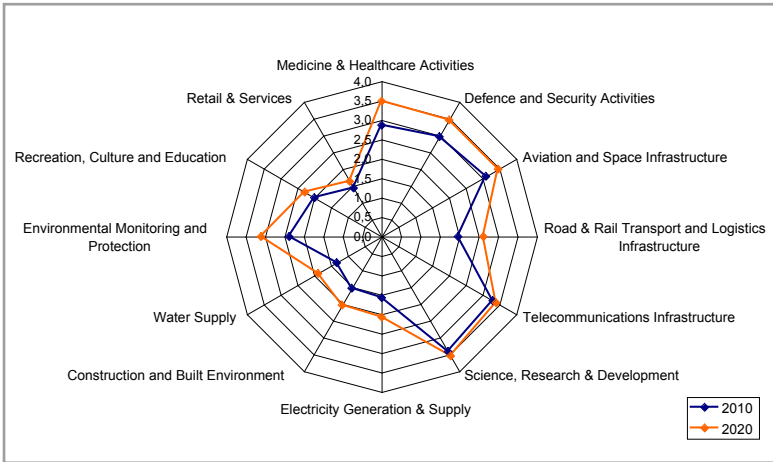


Figure 9: Overview of added value to competitiveness of scanning and imaging technologies to final markets based on Photonics survey.

In most of the markets, scanning and imaging technologies are crucial to their further development. In some, dependencies are limited, for example, retail, water supply, construction and energy generation. However, based on the analysis presented in previous chapters, even there the importance of photonics is significant. Future developments in the coming decade show a slight potential growth.

### Scanning, sensing and imaging

The assessment of present versus future for this value chain shows:

- In all enabled manufacturing industries and final markets an increase in importance of this value chain is to be expected.
- Application of the technologies in enabled manufacturing industries is crucial for certain industries and significantly applicable in most other industries.
- Application in final markets shows even more dominance in a selected number of markets, with even higher dependencies.
- Some final markets, now of less importance, show a significant increase in importance in the coming decade, like construction, water supply and environmental protection.

### 3.2.4 Strengths, Weaknesses, Opportunities, Threats

In the *present* situation, the following conclusions can be drawn on what the **present European strengths** are:

- Research and development in Europe is strong in this area, especially optical measurement, adaptive optics, biophotonics, spectroscopy, microscopy, astronomy and (parts of) imaging are well represented in Europe.
- The connection between research and industry in several subsectors is closely connected, allowing research based innovation.
- The production of photonics enabled manufacturing systems is in Europe well represented, especially in the field of “low volume, high cost” tailor made production systems.
- For some high value submarkets Europe is leading including e.g. medical diagnostics systems (especially biophotonics based), design of low cost CMOS cameras, light microscopes, biometrics and surveillance cameras, safety systems, scanning systems for science.
- Europe shows strong capacities in system integration, where different components are integrated into new complex products.

The **European weaknesses** identified are the following:

- In general, Europe is not the world leader in the production for final markets, especially in consumer areas.
- Consumer oriented production is almost not present in Europe and therefore is not an important market.
- The European imaging components manufacturing industry in general is not strong, but there are some markets where Europe is a global player, like (advanced) imaging, lenses and some high performance components.

The **opportunities** for the European industry, created by external trends and factors mainly based on the assessment that the contribution of the area to the grand societal challenges identified by both the European Commission as well as several national governments are:

- The pressure on the healthcare system, in combination with ageing lead to a further demand for efficient (cost reduction) and effective (high quality) healthcare. Scanning, sensing & imaging can facilitate both, and a significant increase in the market demand is to

be expected, further augmented by growth in the photonics tools used extensively in health and pharmaceutical research and development.

- Increased political attention to take preventive measures against physical and intentional attacks will lead to an increase in demand for efficient and effective security measures, e.g. by using advanced surveillance systems. Increasing safety by enhanced danger detection systems for transport and scanning systems for goods and people include many scanning & sensing technologies.
- Enhanced industrial competitiveness by improving quality of goods and services, as well as cost reduction often depend on improved automated production systems, as well as innovative testing and measurement systems.
- Environment and food safety are still important political issues driving further demand for sensing systems.

The external **threats** to the European industry are:

- Due to the economic credit crunch, governmental funding for research and innovation in the field of the grand challenges might be reduced. This can lead to limitation of public research and innovation in general, but more specifically in healthcare and security (lead markets).
- Due to further globalisation and strong governmental funding support to research and industry, the Asian research and innovation might quickly catch up with the level of knowledge in Europe. This can undermine the present strengths of the European industry, especially when the pipeline between research and industry is put under pressure by reduced governmental funding in Europe. Although this is generally true for all value chains, it is highly relevant for scanning, sensing & imaging due to the strong connection between research and industry in this area.

### Scanning, sensing and imaging: a SWOT analysis for Europe

Strengths	Weaknesses
<ul style="list-style-type: none"> <li>● Strong research in this area</li> <li>● Strong connection between research and industry</li> <li>● Well established position of photonics enabled manufacturing industries</li> <li>● Strong position in high performance markets</li> <li>● Strong in system integration of photonics components</li> </ul>	<ul style="list-style-type: none"> <li>● Manufacturing of components for imaging is limited, although some are well represented</li> <li>● Limited presence in manufacturing for consumer markets</li> <li>● Limited access to rare earth raw materials</li> </ul>
Opportunities	Threats
<ul style="list-style-type: none"> <li>● Increased political attention to more social needs like healthcare and defence/security might increase markets</li> <li>● Enhanced demand for more quality connects to EU strengths</li> </ul>	<ul style="list-style-type: none"> <li>● Credit crunch might limit governmental funding for public demand (e.g. healthcare, security)</li> <li>● Credit crunch might limit availability of resources for research and innovation, jeopardizing the pipeline between research and industry</li> <li>● Further globalisation in this field might undermine the added value of the EU research base</li> </ul>

#### 3.2.5 Impacts

The basic economic impact can be divided into two different elements. The first focuses on the economic impact to the enabled manufacturing industries, looking at the improvement of their production process. The second element focuses on the economic impact to final markets. In this qualitative assessment, the additional competitiveness of photonics will be addressed, as well as the overall economic growth that can be expected. Also potential impact on economic restructuring will be addressed if relevant:

■ **Increase in competitiveness of industries expected due to improved quality**

The scanning, sensing & imaging technologies are used in a significant number of manufacturing industries. Especially the use of these

systems for advanced automation (most major industries), quality control (most major industries) and specific manufacturing processes (limited number of industries) will be of importance to their competitiveness. This will lead to improved quality (testing), more efficient processes (automation) and new innovative products (precision manufacturing), which are crucial to their competitiveness. The overall accompanying economic growth will be limited, but significant, but to keep up the competitiveness these systems are essential.

#### ■ **Creation and increased competitiveness of (new) final markets**

The impact on the final markets and underlying manufacturing industries is of more importance. Looking at medical & healthcare activities, developments in scanning, sensing & imaging are of crucial importance to keep competitive and create new markets. Also, due to the increasing societal attention to healthcare and ageing, it is to be expected that the market growth will be significant. But also various other final markets will experience significant economic growth, like Transport, Defence & security, Environmental monitoring and control, Construction & built environment, Science. The use of these technologies will enable more efficient ways of fulfilling the societal and consumer needs, but also will create new functions. It is expected that photonics will be crucial to the competitiveness of the underlying industries, as well to the efficiency and effectiveness of the services provided with their products. The economic growth in these final markets is expected to be significant. Other sources show that several of these markets increase over 10% annually [Photonics21, 2010].

The assessment of the *environmental impact* of scanning, sensing & imaging also will follow the division into enabled manufacturing industries and final markets. The assessment will focus on climate change and waste production:

#### ■ **Balance on impact on climate change is complex and unclear**

In general, use of scanning, sensing & imaging leads to the acquisition of additional information at the cost of an increase in direct energy consumption. This is the result of substitution of labour by electronic devices and the introduction of new energy consuming devices. In some cases this increase in energy consumption is balanced by improved efficiency, although rebound effects are possible when higher efficiency leads to more overall consumption. Negative envi-

ronmental impacts are also possible where efficiency is not directly impacted e.g. surveillance. Also the preventive nature of e.g. health-care systems is an example of the complexity of this assessment; the indirect reduction of energy consumption of “prevented patients” counteracts the direct additional energy consumption of diagnosis and treatment. An estimation of the overall impact of scanning, sensing & imaging on climate change is therefore complex, frequently requiring the comparison of direct and indirect impact. However, a strict policy to encourage energy efficiency is in order.

#### ■ “Pros and cons” to waste production

Photonic scanning devices vary significantly in lifetime. Complex medical scanning systems have a long lifetime and a consumer camera can even be a throwaway device. All scanning and sensing systems include electronics and therefore are accompanied by complex waste disposal and recycling issues. Although there are many initiatives to enhance recycling and reduce waste, introduction of new devices will lead to additional waste. In the enabled manufacturing industries, the opposite trends can be seen. Scanning, sensing and imaging is used for quality improvement and more miniaturized production (processes and final products). A reduction of waste can be expected here.

Scanning, sensing and imaging will have high social impact. In the previous sections it has been made clear that many address societal issues. The assessment of social impact will be made on health, safety & security, the working & living environment and employment:

#### ■ Improved health

It is obvious that one of the major societal impacts can be found in the domain of health. New scanning systems will facilitate the increase of quality of healthcare and cure. Prevention or early diagnostics of diseases are facilitated, as well as enhanced treatment. It is to be expected that innovations in the field can be radical, introducing new diagnostics systems, but also new ways to efficiently and effectively analyse biopsies, blood samples and even genetic structures.

#### ■ Improved safety and security

Scanning, sensing and imaging will play an important role in the further increase of security of people, by enhanced security scanning at

airports and other public and private locations (surveillance and scanning of goods and persons). Both enhanced quality and reduced costs will lead to better detection of potential security risks. This technology area plays a crucial role. Also safety systems for cars will be further developed, preventing accidents and reducing congestion.

#### ■ **Enhanced quality of the working and living environment**

Already, sensory systems are in place to detect environmental hazards. New developments in scanning and sensing will increase the quality of this environmental monitoring, both in the living and working environment. Both cost reduction, miniaturisation and sensor system integration will enhance usability and quality of the information collected. Next to reduction in environmental risks, the quality of the working environment will be improved by further automation due to imaging enhanced robotic systems. These systems will also facilitate adjusting the working environment to the elderly.

#### ■ **Increasing employment**

Overall, all studies analysed show that almost all fields in scanning, sensing and imaging are growth markets. This will also be accompanied by an increase of employment. As the predicted economic growth is over 10%, employment in photonics research and industry will also be significant.

#### ***Scanning, sensing and imaging***

*The main conclusions for the economic, environmental and social impacts are:*

- *Overall economic impact is positive, mainly due to the **enhanced competitiveness** and creation of **new products** for new markets.*
- *The environmental impact is a **complex issue**, where reduction of impact due to reduced energy consumption and miniaturisation are counteracted by rebound effects.*
- *There is a positive social impact to be expected. New and enhanced products will be **beneficial to healthcare, security and working environments** and create new jobs.*

## 3.3 Information, communication and networks

### 3.3.1 Introduction

The value chain around information, communication and networks is core to the current and further development of an information intensive knowledge society, where the Internet, television and telecommunications are pivotal. With the further market growth of the smart phone, the development of IPTV and the accompanying increasing number of internet connected devices, the demand for high speed data communication is expected to continue to grow rapidly.

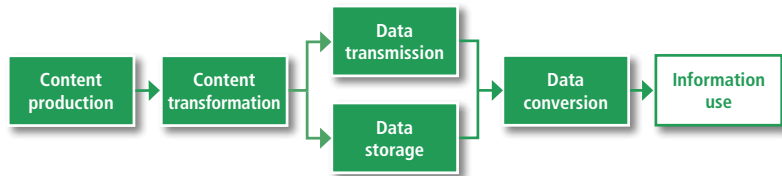


Figure 10: Functionalities surrounding the value chain of information, communication and networks.

Looking at the use of photonics in information and communication a few basic steps can be distinguished. The first step is to produce content, which provides the input for the communication (this part of the value chain is not considered here). The second step is to transform this content into a format that can be transferred, which is usually a digital one, but can involve compression steps and format conversion. The third step is the actual transfer of data, mostly using data communication networks. The fourth step involves the conversion of the data back to a format that can be actually used by the end user. During these steps, the use of photonics has become crucial, from using lasers and modulators to transform the electrical information into light, to using optical cabling and amplifiers to transfer the data, and finally optical receivers that convert the optical signal back to electrical signals that can be processed for final usage.



### 3.3.2 The European value chain

The **research** element of the European value chain in this area is used in the further development of information, communication and networking and includes a diverse set of disciplines. These range from insights in new materials for use in the data communications, to the further development of devices and software to enhance data intensity and processing power. In the production of **basic materials**, there is much overlap in the basic materials used for the production of semiconductors as well as many specialist glasses and associated raw materials used in optical fibre. The main **components** that are produced in this value chain include the photonic devices used for data conversion, amplifier systems and light manipulation systems (e.g. modulators, switches, routers) and fibre optic cable. The storage of data is often separate from transmission, although optical components also play a role here in optical data storage systems. The main usage of these technologies in **enabled manufacturing industries** is for data communication, which is common to almost all current economic activities. However, for some sectors, innovations in these technologies are crucial for their economic development, like Media production & broadcasting. Looking at the **final consumer oriented markets**, it is clear that the information, communication and networks sector is of importance to many markets. The most obvious is the use in telecommunications, including both Internet and fixed and mobile telephony, but is now integrating with media, publishing and broadcasting. Defence & security, science and transport (road, train, air) are also well known as data intensive application areas, as well as financial markets.

**Research and development** in the field of information, communication and networks is highly multi-disciplinary. Although the base for fibre optic cables is almost always silica, research into other materials is conducted to enhance the production process and increase data capacity in the future and provide insights into new storage methods. The next cluster of fundamental research areas focuses on the understanding of ultra high data rate optical transmission through cables and optical media. Connected to this, also research is conducted on the further miniaturization of optic devices and opto-electronics and investigates alternative systems with improved energy efficiency. Close to this area of research are the activities on optical computing. And a final crucial research area involves laser research and research on laser devices, as these technologies provide the source of light for data communication. Europe does

not have the research leadership in the highest bit rate systems it perhaps once had, but there are several centres of excellence in telecommunication and associated component research. The UK and France are main players in the field, although Germany is also strong. The fields of research that are strong include optical networking, integrated photonics and semiconductor components, including ultrafast optics.

The **production of components** like laser diodes and other optical devices is present in Europe. Although Asia is a major competitor in the production of low cost high volume devices, significant volumes of semiconductors for communication applications are made in Europe, although many of these are sent to Asia for packaging. Indeed the majority of component device packaging now takes place in Asia. More complex devices and other hardware are often manufactured in Europe, having about 45% of the global market. Also an increasing proportion of optical fibre cables are made overseas with China and India becoming major suppliers and North America remaining a strong supplier of more complex specialist fibre. Components for optical information storage systems are mainly produced in Asia and can be considered a low cost and declining market.

In the field of **integration of components to systems** and creation of telecom infrastructures, Europe has strong global players and is especially strong in network design. Especially large companies from France, UK and Germany are important to the world market. However, still in some areas, SMEs are of importance and also a significant number of companies focus on domestic markets. The number of companies who are active in the running of telecom networks are limited, as this requires large long term investments. Although most networks are national, an increasing number of network operators are internationally oriented. Manufacturing of purely optical storage systems has limited presence in Europe, although there are some large multinational data storage companies who are increasingly implementing optical communications solutions with enterprise storage networks.

The interlinkages between the different chains are limited. Linkage between research and industry is nationally organised and fundamentally different in the various countries. For example in Germany and the Netherlands, this linkage is very strong. Often this is because of the historic fact that the ICT networks were public, with close links between

research and providers. After the privatization of the communication networks, the relations were kept intact. As the different components are manufactured for global markets, the connection between the photonics industry and the telecom partners is also not so strong. However, partnership between the telecom providers and the system integrators is significant, as the physical networks are highly location based.

#### ***Information, communication and networks***

*The following important conclusions can be drawn from this assessment:*

- *Because of historic national orientation of its economy, EU research is strong but often nationally positioned, with also national contact to industry*
- *Production of components is shifted towards Asia, but more complex hardware is still strong in Europe.*
- *Europe has strong players in the deployment of telecom infrastructures.*

### **3.3.3 Present versus future**

The further penetration of smart phones, interactive internet TV and demand for ultra fast networks will even speed up the demand for developments of better Information, communication & networks. After large scale networks, small scale data transportation will go photonic. The shift towards optical networks is at full speed and the FTTH development will also create a new approach to the networks; USB 4.0 is now planned to be optical. This is accompanied by several technological challenges: Increase of speed, convergence and interconnectivity of networks and reduced energy usage. Developments can be seen in the development of ultrafast lasers, but also in encoding algorithms and greater use of high speed electronics. All-optical routers and processors, will make it possible to redirect data in the optical domain, although balance between all-optical and optoelectronic networks will be increasingly optimised to reduce energy consumption. Further developments are also likely in the use of photonics to transport data at the chip level with optical layers used for data links within computing processors and at a more futuristic level the potential of optical computing.

Optical storage, including e.g. DVD and blu-ray is expected to decline in the coming decade, partially due to increases in communication bandwidth which will allow more remote storage. Developments in optical storage are therefore limited; however potential breakthroughs are possible with metamaterials and plasmonics. Secure data transmission is also likely to leverage developments in quantum cryptography.

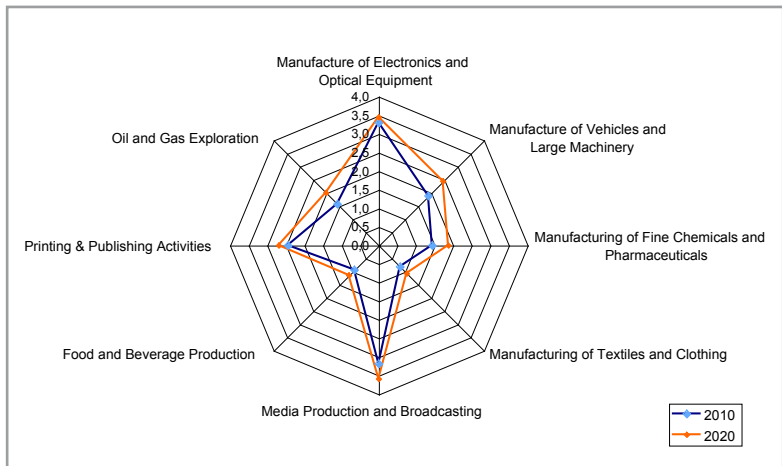


Figure 11: Overview of added value to competitiveness of information, communication and network technologies to enabled manufacturing industries based on Photonics survey.

The results of the survey show that the dependency of several enabled manufacturing industries is already at their peak and therefore any increase will be limited. In the areas where the use of these technologies are still limited, for example, fine chemicals & pharmaceuticals, a higher increase can be seen related to the further use of information such as real time monitoring and data processing as core element in the manufacturing process. In some cases, such as Manufacturing of vehicles & large machinery, dependency will be increased due to the further introduction of optical networks in vehicles.

Looking at the final markets, information, communication & network related technologies also show high and crucial importance with an obvious focus on telecoms infrastructure as well as science research and development. Other final markets are predicted to become much more dependent on developments in these technologies especially medical &

healthcare activities as well as environmental monitoring and recreation, culture & education with the clear connection to Internet growth. Communication networks also become more critical to electricity supply though the development of smart energy grids.

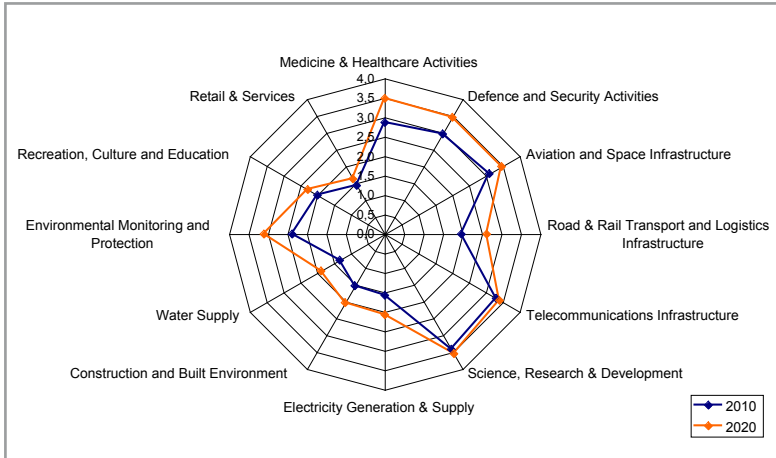


Figure 12: Overview added value to competitiveness of information, communication and network technologies to final markets based on Photonics survey.

**Information, communication and networks**

*The assessment of present versus future for this value chain shows:*

- *In all enabled manufacturing industries and final markets an **increase** in importance of this value chain is to be expected.*
- *Application of the technologies in enabled manufacturing industries, as well as final markets is **dominant in a limited number of areas***
- *In these limited application areas, the technologies are **crucial** to competitiveness.*

### 3.3.4 Strengths, Weaknesses, Opportunities, Threats

To further develop a strategy and policy to optimally benefit from the social and economic opportunities of Information, communication & networks, the Strengths, Weaknesses, Opportunities, Threats of Europe in this field can be analysed and identified.

The **strengths** of Europe are the following:

- In some research areas, like ultra-fast networks and network design Europe is a strong global player.
- There are several companies with strong domestic positions, from which they have been up scaling their activities to global markets. Here, the system integration expertise is a distinctive competence.
- In several countries, the relation between research and industry is strong, initiated by historical developments.
- Production of optical hardware systems and some components are considered a European strength.
- Main network providers have a strong presence in global markets and are working internationally.
- The developed European communication infrastructure is of the highest quality, also with strong representation in the research infrastructure.

The **weaknesses** of European research and industry are as follows:

- Telecommunication component costs remain relatively high and dependent on low cost labour assembly.
- Shortage of in house systems and component development by network operators.
- Energy consumption of some components, although small individually, is significant when considering the whole network.

Present and future developments in society provide the following **opportunities** for the research and industry in the field of Information, communication & networks:

- European and national society/governments show a high demand for ultra fast networks in order to have as many citizens connected to the Internet as possible (e.g. Commissioner Kroes calling for broadband connection to every European citizen). This is supported

by the increasing market for smart phones and internet TV.

- As many upcoming economies (BRIC) show strong economic growth, this is accompanied by an increase in demand for high quality telecom infrastructures.
- As these upcoming economies will also have better access to the Internet, this will open markets through e-business. However, European industries need to create new business models to make optimal use.
- The availability of high quality internet (speed/availability) and development of new ICT based services are strongly connected. Both of these elements are strongly present in Europe and the combination should provide further opportunities especially as communications becomes increasingly embedded in society e.g. through 'always-on' internet connectivity and associated devices such as smart phones.
- The demand for better communication infrastructure and pressure on reducing energy use can also lead to an opportunity for European research and industry.
- Several new technological developments, like FTTH, optical storage, ultrafast networks also provide new market opportunities.
- As the European Media and broadcasting industry is highly developed, this provides content for higher capacity networks.

Present and future developments in society provide the following threats for the research and industry in the field of Information, communication & networks:

- The strongest threat for the Information, communication & network value chain is the developments in Asia, becoming strong competitors especially on ultra fast networks.
- There are indications that a reduction of research in ultra fast networks, might take place. This would lead to a fall back of the strong EU position in this field.
- Increased energy demand of higher speed communications networks might lead to a significant threat to further development, being a risk to the energy system.
- Potential for capacity constraints in the core network following roll out of fibre optic access networks

**Information, communication and networks:  
a SWOT analysis for Europe**

Strengths	Weaknesses
<ul style="list-style-type: none"> <li>● EU is strong global player in some research areas</li> <li>● Strong historic connections between research and industry in several countries</li> <li>● Strong historic domestic position is now exploited to address the global, international markets</li> <li>● Strong position in more complex hardware</li> <li>● EU telecom infrastructure is among the best in the world</li> </ul>	<ul style="list-style-type: none"> <li>● Relative high costs of components and dependence on manual labour</li> <li>● Shortage of attention to in house systems and component development by network operators</li> <li>● Energy consumption of network is a problem, looking at the pressure on reduction of energy usage</li> </ul>
Opportunities	Threats
<ul style="list-style-type: none"> <li>● Further political attention to the increase of high quality telecom infrastructure</li> <li>● Increased market demand from BRIC countries with high economic growth</li> <li>● Global increase in attention to e-business</li> <li>● New technological developments, creating new opportunities for business</li> <li>● Attention to the knowledge society demands high quality telecom infrastructure</li> <li>● Increase is societal demand for media and communication</li> </ul>	<ul style="list-style-type: none"> <li>● Strong development of research and industrial base in Asia, due to upcoming demand in this region</li> <li>● Demand for high quality networks can lead to failure of the system (capacity constraints)</li> <li>● Reduction of research on ultra fast networks</li> </ul>



### 3.3.5 Impacts

The basic *economic impact* is divided into two different elements. The first focuses on the economic growth accompanied by the value chain, including both the enabled manufacturing industries and final markets. The second element focuses on the potential increase of competitiveness because of Information, communication and networks

#### ■ The telecom market will continue to increase

The overall growth of the telecom sector has been strong during the last decade it has fully recovered from the crash at the start of the millennium and the sector has also quickly recovered from the recent credit crunch. The telecom industry itself will be accompanied by significant economic growth, especially due to its enabling impact to knowledge intensive services and growing demand from especially industrial developments in China and India.

#### ■ Overall impact on economic growth is significant, with limited exceptions

The majority of the economic impact is based on the positive impacts developments in this area will have on most final markets. Entertainment, culture & education, Medical and Healthcare and telecommunication itself are especially likely to show significant economic growth. Within the enabled manufacturing industries Media & broadcasting should also see strong growth based on communication developments. Printing and publishing might show a negative effect, although a refocusing of activities and new business models may limit reductions and even show economic growth (e.g. ebooks with rented content).

#### ■ Significant impact on competitiveness for almost all industries and markets

Looking at competitiveness, this value chain will have a positive effect on almost all sectors. As data and information is (increasingly) crucial for almost all industrial activities, a higher quality information infrastructure will lead to an increase in competitiveness. The further shift towards a fully grown information and knowledge society requires the highest quality of communication infrastructure. Not only because of access to information, but also access to expertise and greater demands for security of supply and resistance to network failure.

The overall conclusion on the economic impact of this value chain is that the telecom sector itself will show continuous growth and will lead

overall economic growth to other industries and markets, with some negative exceptions. The impact on competitiveness is significant, mainly due to the ever growing trend towards the information/knowledge society, impacting almost all economic activities.

The assessment of the environmental impact of Information, communication & networks focuses on climate change and waste production:

■ **Uncertain impacts on climate change**

The last decades growth in the telecom infrastructure has been an important factor in the overall increase in electricity consumption. Greater communications capability has added products and services to the economy, this has resulted in additional use of energy consuming devices as well as a rapid increase in the energy required to operate networks. This effect will continue and may offset any environmental gains due to reduced travel and transport of physical goods and people and reduction of energy consumption of computers.

■ **Increased production of complex waste**

This value chain is accompanied by greater use of complex electronics devices. This equipment will lead to additional (complex) waste, especially because of the limited substitution effect and strong technological developments leading to shorter replacement / upgrade cycles.

The conclusion to be drawn from the environmental impact assessment is that the overall impact is complex and has unknown outcomes, mainly because of the need to balance direct and indirect effects occurring over different timescales. A full analysis must be carried out. However, a policy to support greening (energy consumption and recycling/waste composition) and standards for comparing energy consumption would reduce environmental impact.

Looking at social impact, the effect of Information, communication & networks is diverse. Due to its enabling character to better communication and access to information, it will lead to higher quality services and societal inclusion for example:

■ **Better and more informed Healthcare services**

Increased access to information will increase the quality of healthcare and may also reduce costs. Also availability of healthcare services to remote locations can be increased due to improved tele-health

services. The access to information will allow citizens to make informed decisions about healthy living. An upcoming area here is the introduction of healthcare applications for Smartphone's.

#### ■ **Increased security**

Fast and secure communication and online access to information (e.g. surveillance) will allow better security of public locations. But also information is crucial to the emergency services. High quality communication infrastructure is also crucial to developments in the offering of online information.

#### ■ **Reducing the gap between the "haves" and "have-nots"**

Access to the internet is becoming a fundamental social need and the majority of all European citizens are connected to the internet. However, for a significant number of citizens this access is not available, or of low quality, creating the so called digital divide. The result is that their inclusion in the economy and society is under pressure. Telecom infrastructure could reduce or increase this pressure depending on how universally access is made available to all.

#### ■ **Pro's and cons for wellbeing**

Better access to information and better communication will also increase wellbeing of citizens. At the top of the so-called Maslow pyramid<sup>6</sup>, is self-actualisation, which is highly facilitated by information and communication. However, to cope with the overwhelming access to information is not easy and there may be sections of society who cope less well with information overload.

#### ■ **Pressure on low skill employment**

As the availability of high speed internet will stimulate jobs with increased need for capacities to process information, people with poor capacities in this area will face the risk of being unwanted by employers. This can lead to a reduced demand for low skilled workers.

Overall, the social impact of this value chain can be regarded as positive. Better information and communication will lead to better decisions, both by public administration, citizens and industrial stakeholders. However, as communication and availability of information will increase, this might lead to pressure on people and organisations to cope with information overflow and potential exclusion. A policy is needed to counteract this risk and increase capacities.

<sup>6</sup> Maslow's hierarchy of needs, [http://en.wikipedia.org/wiki/Maslow%27s\\_hierarchy\\_of\\_needs](http://en.wikipedia.org/wiki/Maslow%27s_hierarchy_of_needs)

### ***Information, communication and networks***

*The main conclusions for the economic, environmental and social impacts are:*

- *Overall economic impact is positive, mainly due to the enhanced demand for high quality infrastructure, leading to general economic growth and enhanced competitiveness for using industries and markets.*
- *The environmental impact is a complex issue, where reduction of impact due to reduced energy consumption and miniaturisation is counteracted by rebound effects.*
- *There is a positive social impact to be expected. Better information access will lead to better healthcare and security. However, the information overload can lead to unwanted pressure on people and low skilled employment.*

## 3.4

# Screens and displays

### **3.4.1 Introduction**

This value chain is dealing with the production and deployment of screens and displays. Society has been fundamentally changed by the development of displays and the last two decades has seen an explosion in the number of display-based devices we interact with on a day to day basis, from domestic appliances to televisions, mobile phones and computers. Today, information is brought to us mainly by flat screen displays and even traditional paper is now challenged by e-books and tablet computers. Displays come in all sizes from a few cm in size, common in mobile phones, to giant displays used at sporting and public entertainment events. Even in outdoor advertising, large billboards are migrating from passive posters towards large dynamic areas.

The display is part of a functional system, where content is offered to the user and often allows interactive feedback.

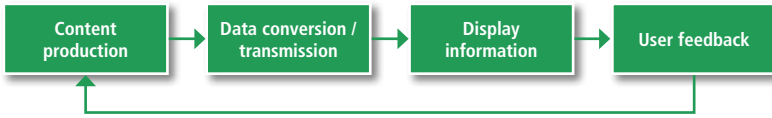


Figure 13: Different functionalities within the context of displays and screens.

The Figure above shows how this value chain is also closely connected to the Information, communication, network value chain. Although the data conversion and transmission is not included in this value chain, it has an essential relation with the development/manufacturing and application of screens & displays. Due to new functionalities, data management is getting to be the weakest link in further application. The display device itself can either emit light directly e.g. Plasma Television, or be made up of a uniform white light source, with an imaging device such as an LCD, which selectively blocks light at individual pixels. In the latter case the light source is commonly a LED or fluorescent light, not dissimilar to that used in general lighting, although some reflective displays can use background day/room light as a light source.

### 3.4.2 The European value chain

The first, more vertical, part of the value chain is **research**. Much fundamental research is currently oriented towards new types of display especially those based on potentially flexible plastic /organic electronics. There are also adjacent research areas, e.g. in image compression and software developments as well as new display formats such as 3D display, but also social science investigations into human interface particularly relevant to touch screen interfaces. The **basic materials** production involves both the chemical industry providing organic materials for the production of LCD and (O)LED base materials and other substrates, as well as the production of glass materials that are used as substrate and metallic oxides and inorganic materials (e.g. for electrodes). The production of **basic components** includes both the screens and back light units as well as the electronic components needed to drive the display. The use of displays in the manufacturing industry as part of their production process is mostly limited to use as a display for human interfacing to control manufacturing processes. Displays are used broadly in **final markets**, as they are core to the information society. The main user markets are media production and broadcasting (televisions)

computing and mobile communications (mobile phones), although the boundaries between these classifications are increasingly blurred (e.g. mobile TV).

**Research and development** for displays and screens focus primarily on improvement in performance, new types of screens and innovations in manufacturing. Research aims to improve lifetime, brightness, colour coverage, energy efficiency, response speed and resolution. The research on new types of screens and displays looks at, for example, the development of coloured electronic ink and flexible screens, as well as pico-projection, 3D and near eye displays. As well as performance, significant research attention is given to reducing costs in the manufacturing of screens and developing volume manufacturing processes. This is especially so for new and emerging display technologies which can only find market application with the development of cost effective high volume manufacturing processes. The European strengths are more oriented at the development of more radical new products (including design and human perception) and less at reducing cost for mass production. Also because of a historical development, the knowledge base on materials is strong in Europe.

The production of **base materials** is also considered strong in Europe, as the market for some of these input materials is dominated by European companies [IPTS, 2009; evaluation workshop]. This is strengthened mainly because of the strong connection to innovative European companies, who are in cooperation with research organisations, creating new display concepts.

The actual **production of displays (components)** is dominated by Asian companies, especially from China and Korea. However, these are mainly consumer oriented large volume products, where in the more niche oriented and high tech displays Europe still has a significant position. This includes the production of displays for non consumer markets like the automotive, healthcare and defence/security (professional markets) where the UK and Germany are relatively highly represented. Also here, new and innovative concepts for (still) niche markets are of importance for European companies, (e.g. near eye displays).

The applications in **enabled final markets** are very diverse and as displays, content and data transmission continue to develop in parallel

new applications continue to emerge. These new functionalities not only substitute existing elements within systems e.g. 3D replacing 2D television, but also create new functionalities like Medical Apps on smart phones.

Looking at the linkages between the different chains, it can be said that the strong European research position is connected to European companies, especially when looking at the production of basic materials and the development of new display technologies. Perhaps it can also be said that the strong research position (forefront of innovation) is not optimally used by the European industry as no high volume display production occurs in Europe, although connections between EU-research and Asian companies do exist opening some exploitation routes. The conclusion is that Europe has a strong research base, but from an industrial point of view focuses on a number of niches and does not access the volume display market.

### ***Screens and displays***

*The following important conclusions can be drawn from this assessment:*

- *The EU research strengths are focused on **new concepts, high performance and design.***
- *Next to research/industry connections in Europe, also strong connections in **Asian** industry are shown.*
- *Strong dominance of EU players for production of **base materials** for component production.*
- *Main production of displays is located in Asia; some **niche products** in Europe.*
- *European application of displays is mainly focused on (often non consumer) specialized **low volume high performance** products.*

### **3.4.3 Present versus future**

The future of displays is highly dynamic. Several new developments are now already surfacing, which will enhance the quality of present applications, but also introduce new functionalities.

The first trend includes new types of displays. The shift from fluorescent to LED backlights is just a start with OLED, AMOLED, displays already present in smaller devices. These developments focus on sharper, better colour, more energy efficient, cheaper, and thinner displays. More radical innovations are now surfacing including touch sensitive, 3D, Very Large Area displays and reflective electronic paper displays are already on the market and will change the consumer and the professional market. The introduction of flexible displays, miniaturized displays, holographic displays, enhanced touch/ motion feedback displays are on the brink of full market penetration. This will lead to new product concepts (e.g. rollable ebooks/ epapers) and rapid development/ enhancement of existing products (e.g. integrated pico projectors).

Looking at the impact of displays on enabled manufacturing industries, the impact of these technologies is clearly much higher in information industries such as Printing & publishing and Media production. Between 2010 and 2020 the survey respondents indicated that all industries will show a slight increase in dependency, but some will show a significantly larger increase, especially where today the dependency is limited.

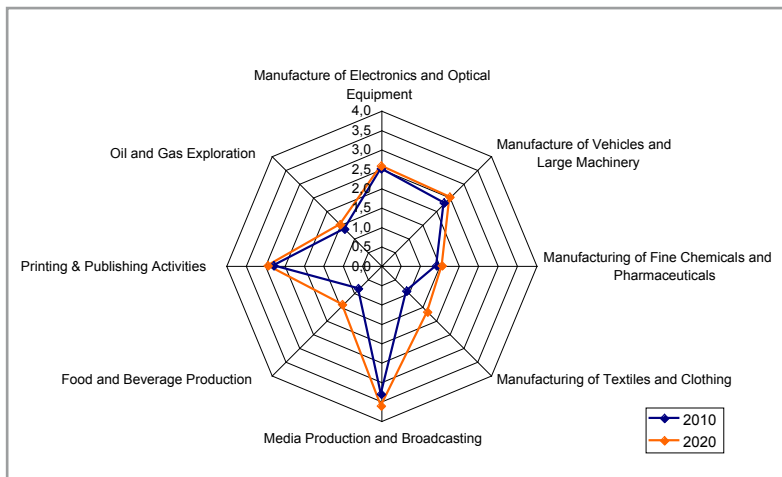


Figure 14: Overview of added value to competitiveness of screens and display technologies to enabled manufacturing industries based on photonics survey.



Food & beverage as well as textiles & clothing will experience a significant increase in impact, especially because of flexible displays used in packaging and materials. The fact that media production & broadcasting shows little change in dependency must not be seen as indicating limited change. As dependency is already almost at its peak, dependency will stay strong, but the technology creating this dependency may change rapidly. Touch screens, the tablets/e-readers and other new devices will keep on changing this industry.

Further changes can be seen in the final markets illustrated in Figure 1. As a high diversity of types of displays is mostly used in these final markets, the dependency of these markets shows more future changes. An increase in dependency is to be expected in Retail & services, as communication will become more dynamic using displays (e.g. in packaging, in store communication and interactive advertising). Also new types of displays will have impact on Recreation, culture & education, introducing new devices for communication and presenting information (e.g. 3D television, the tablet/e-reader, virtual services, new interactive ways of education). Other final markets will use the developments in combination with other trends in innovation, like the combination of lab-on-a-chip, with advanced displays to enhance possibilities for location based environmental monitoring devices.

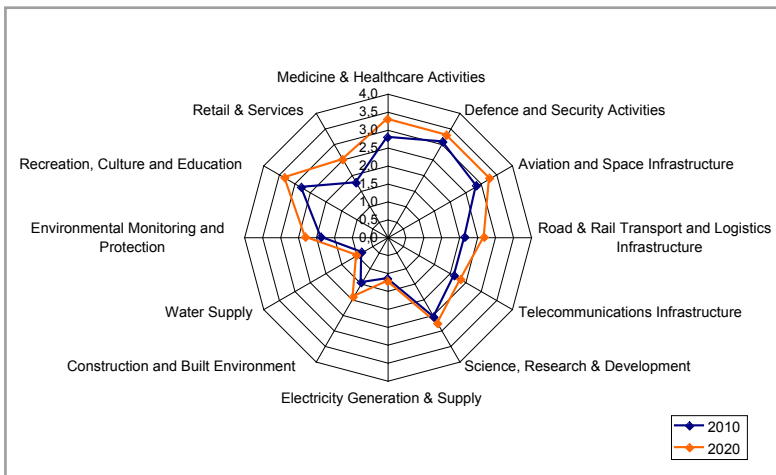


Figure 15: Overview of added value to competitiveness of screen and display technologies to final markets based on photonics survey.

The conclusion of this analysis is that developments in displays will create new applications that will continue to change our society, especially in the field of entertainment, education and communication. But also less obvious domains of application can expect the impact of these new technologies. Combination with other technological developments is needed to make optimal use of the opportunities. However, one additional note has to be made. As the production and development of OLED displays will also impact the lighting market, this overlap may give important added value to Europe.

### *Screens and displays*

*The assessment of present versus future for this value chain shows:*

- *Limited increased dependency to enabled manufacturing industries is expected; significantly more increase in dependency to competitiveness is expected in final markets.*
- *Application of the technologies in enabled manufacturing industries, as well as final markets is dominant in a limited number of areas.*
- *A broader dependency of final markets to these photonics technologies is seen.*

#### 3.4.4 Strengths, Weaknesses, Opportunities, Threats

The assessment of the Strengths, Weaknesses, Opportunities, Threats in the field of Screens & displays shows the characteristics of this value chain in Europe.

The **strengths** of Europe in this value chain are:

- Strong multi disciplinary approach to research. As the value chain is highly multi-disciplinary (including social sciences, as well as various technological sciences), this is important for future developments.
- Europe is strong in highly specialized products with advanced displays.
- The position of Europe in the research and production of base materials (and their linkages) is strong.
- Europe as a strong research base in OLED technologies, which could transfer to developments in lighting.

The **weaknesses** of Europe in this value chain are:

- Europe has limited organisations that are producing high volume consumer products (both components and final products).
- Limited European connection between research and volume industry in the field of displays (multidisciplinary), due to the shift of production to Asia.
- Limited presence of innovative SMEs (based on Photonics21 database). As SMEs can play an important role in benefiting from future developments of new types of displays (development new products), this limited number of SMEs is a weak spot in Europe.

The **opportunities** for the European research and industry in this value chain are:

- New technologies leading to new opportunities and developments in this field are strong. It will result in a highly dynamic market, where there is a ready acceptance of new developments and barriers to entry may be limited for niche products, although a route to volume production for consumer products will be required.
- The new developments are highly connected to perceptions of business and consumer need. Therefore, market demand is strong, but strong links to content providers/ developers are required, marketing and public relations will play a key role and there will be strong competition.

The **threats** for the European research and industry in this value chain are:

- Although European research in the development of displays is strong and Asia to some extent is depending on this research, strong development in Asian research can lead to a reduced position. This will also weaken European research in this field.
- The very rapid rate of change in the displays market results in very small windows of opportunity for new technology with the potential that new developments/ products may be rapidly superseded and technical performance alone may not be sufficient to succeed in the market.

### Screens and displays: A SWOT analysis for Europe

Strengths	Weaknesses
<ul style="list-style-type: none"> <li>● EU shows strong multidisciplinary research, including technical and social sciences</li> <li>● EU is strong in specialized and advanced displays</li> <li>● EU is world leader in research for base materials</li> <li>● The research base on the emerging new types of OLED displays is strong in Europe</li> </ul>	<ul style="list-style-type: none"> <li>● Limited number of display manufacturing industries</li> <li>● Connection between EU research and applied EU industries is not strong, as limited industry is present</li> <li>● Limited presence of SMEs in the field</li> </ul>
Opportunities	Threats
<ul style="list-style-type: none"> <li>● Vast number of new products expected, based on new types of displays</li> <li>● New developments are closely connected to emerging consumer needs and content production. This is strongly developed in Europe</li> </ul>	<ul style="list-style-type: none"> <li>● Asia is enhancing its research in this area, leading to a reduced edge of EU researchers</li> <li>● The rapid time to markets shows small windows of opportunities for new markets</li> </ul>

#### 3.4.5 Economic, environmental and social impacts

The economic impact of Screens & displays is limited. The following statements can be made:

- Economic growth of EU production of displays will be limited  
As the European industrial base for the production of displays is limited, the actual economic growth in this area will also be limited. However, some specialty products can show a significant exception, like head mounted displays or professional graphics displays.
- Use of new displays can initiate growth for enabled manufacturing industries  
The application of new displays provides opportunities for manufacturing of products for the final markets. Especially products used in final markets will have improved and additional functionalities that can lead to increased markets. Examples are large area displays for advertisement and 3D monitoring systems for science. These more

specialized areas have a critical mass in Europe and can expect economic growth. However, it can also have negative growth effects of parts of the Publishing & printing industry.

- Economic growth in a few final markets

In some final markets, economic growth can be expected. These mainly will be part of Publishing, entertainment, communication and education. However, the highest growth will be in upcoming new organisations, as adaptation to these new technologies will need a flexible organisation, although some more established organisations will certainly benefit from the opportunities.

- Increased competitiveness in various industries and final markets

The integration of new and highly advanced displays in existing devices and systems will create significant additional value to the systems, either by improving functionality, or quality. This increased competitiveness in both the enabled products and the increased efficiency and effectiveness of the workers who use them will be significant. This is important for a limited number of enabled (manufacturing) industries, like Media & broadcasting, as well as Publishing & printing. Especially final markets like Medical & healthcare, Defence & security, Retail & services, Recreation, culture & education will significantly benefit from these developments.

Screens and displays will also have a significant environmental impact. The following assessment can be made:

- The impact on climate change can be positive

New functionalities initiated by new types of displays will be accompanied by additional energy consumption. However, one of the main developments in displays is the reduction of energy consumption. Looking at e.g. the use in televisions, new generation of displays can provide a high positive reduction of energy consumption. Also introduction of e-ink, large area displays and other technologies can lead to a positive impact, but this needs further research especially addressing impact over the complete product life.

- Better displays can lead to more virtualisation

One of the most important barriers for teleworking, the paperless society and other virtualisation of products and activities is the lack of high quality displays. The developments can lead to a strong driver to further virtualisation of our society. Although this virtualisation leads to additional energy consumption by devices, the reduc-

tion of e.g. production of paper and transport can have an overall positive impact on climate change.

- More displays leads to more complex waste

As the development of new types of displays will be accompanied by an increase in the sheer number of displays sold, the production of complex waste will be increased. As the recycling of these components is limited, the further development and use of screens and displays is likely to lead to an increase of complex waste. This is further enhanced by the decreasing lifetime of many products that use displays (e.g. mobile phones) and increased upgrade rates caused by rapid product development (e.g. in televisions).

The social impact from the developments in screens & displays will be limited. The following benefits and drawbacks can be identified:

- Improved use of information

The most important overall social benefit will emerge from the improvement in management of information. The presentation and manipulation of information will be improved due to the highly improved human interfaces. Touch screens, smaller screens, 3D, more portable devices are just a few examples in these benefits. The result is that more information will be available in more places and displayed more realistically reducing the difference between remote visualisation and physical presence e.g. aiding remote surgery. Final markets like Retail & services, Transport, Medical & healthcare activities are just examples where this is relevant.

- Information overload

This also is the drawback, as it can lead to an information overload, and can lead to a sharper gap between the "haves" and "have-nots" due to individual capacity to deal with information overload.

- Improvements in quality and efficiency of education

Smart boards, tablets and other display based devices can lead to a significant improvement of the quality of education, as today's students are highly receptive to the use of pictures and videos. Also curricula can be more multi-media, stimulating the efficiency of the transfer of knowledge. But also the educational system would experience an improvement in the organisational process, using specialised organisational devices with advanced screens.

### **Screens and displays**

*The main conclusions for the economic, environmental and social impacts are:*

- *The EU economic opportunities are not in production of displays, but as **enabler** of new products for especially the final markets. Here, **competitiveness** can be highly depending on these new displays.*
- *The environmental impact is potentially **positive on energy consumption**, and can even further increase virtualisation. However, **complex waste** is to be expected and addressed.*
- *There is a positive social impact to be expected. Advanced displays play an important role in **better use of information**, especially for education. However, the **information overload** is also here an important risk.*

## 3.5

# Advanced lighting

### 3.5.1 Introduction

This value chain focuses on the activities around the revolution in lighting that occurs today as we move from the 19th century based incandescent light bulb to solid state lighting (SSL). The value chain of advanced lighting focuses on the economic activities around solid state lighting. Due to their low energy characteristics and long product life, LEDs are expected to offer a real alternative to traditional incandescent and fluorescent lighting. Other LED characteristics also offer new possibilities e.g. placing multiple LEDs in a light fixture can enable colour control and intelligent control can compensate for changes in daylight. Further developments include the potential for large area organic LEDs (OLEDs) to be used as lighting surfaces enabling new ways of lighting distinct from the traditionally highly localized light bulb.

The report confines itself to the discussion of advanced solid state lighting using organic and inorganic LEDs. The report specifically excludes the development and deployment of fluorescent and compact fluorescent lighting

(CFLs). Although the market penetration of CFLs relative to incandescent bulbs is not yet complete, CFL technology is relatively mature. Solid state lighting (O)LED lighting is generally accepted as offering significant further benefits over CFLs in efficiency, quality of light and the avoidance of Mercury found in CFLs. Thus solid state lighting (O)LED lighting is the main focus of market and technology development in the foreseeable future.

It is important to note that the linkages between displays and advanced lighting are strong and this connection will even grow. This is based on the development of (O)LED light sources that are used for lighting, as well as the use of backlighting for LCD displays.

### 3.5.2 The European value chain

The value chain of advanced photonics lighting is more complex than just the production of LED or OLED chips. **Research** on advanced lighting includes not only materials research in order to develop new more energy efficient (O)LEDs, with better colour characteristics, but also on better manufacturing processes. Human perceptions and experience of lighting forms another separate research area. The production process for inorganic solid state lighting is in principle based on wafer scale manufacturing methods common in the semiconductor industry, using III-V semiconductors. However, due to the rapid growth and potential benefits of organic LEDs, manufacturing of these types of lighting element are also of interest. They combine new polymer semiconducting base materials with other organic raw base materials. The **manufacturing** of solid state lighting **components** is very much a high volume industry and therefore favours large producers of both (O)LEDs. OLED manufacturing for general lighting is still an emerging market (approximately 5 years), offering potential for current and new suppliers. The manufacturing of lighting **fixtures** (luminaries) has different characteristics, due to the high degree of customization. Therefore it is more closely aligned to the design requirements of domestic, industrial or specialist lighting. Advanced lighting can play a key role in some specialized **manufacturing processes**, e.g. semiconductor lithography and stage lighting, but although providing critical functionality these markets tend to be small relative to the general lighting market and are therefore only considered briefly. Lighting is used in various **final markets**. The largest application can be seen in lighting in homes and commercial buildings, but also outdoor and automotive lighting are substantial application segments. Lighting **research** is highly related to that of the displays industry, as



the base materials are within the same family. Although the absolute number of research institutes working in lighting is limited, the potential number of research organisations that can contribute to this area is much higher as ~20% of the research organisations are conducting research in displays (Photonics21). This is mainly based on the strong historical position in displays, which has a strong overlap with lighting. Therefore European research in lighting is significant, especially looking at the colour characteristics and research in production processes, as well as new types of lighting panes (e.g. flexible panels). Also the more social sciences and humanity disciplines are well represented in Europe (e.g. design, human perception). Overall, strong country representation can be seen from Germany, France, Italy, the Netherlands and the UK.

There are not a vast number of European manufacturers of **components** (LED components, electronics), although some European manufactures are among the world's largest producers. As with production of flat panel displays, Asia (and the USA) are the largest producers of basic LED chips. A trend can even be seen that European manufacturers of these components move their production to Asia. However, in the market of the integration of the components into luminaries Europe is highly represented. About 15% of all companies mapped in the Photonics21 database work in the field of lighting. Some European multinationals are global players in both the consumer and professional markets, but also European SMEs are highly represented. Much is expected from OLED lighting, as this technology offers interesting characteristics on colour, energy saving and manipulation. Europe is at the forefront of developments, as the research and industry have a leading role. However, production of OLED panels is currently based mainly in Asia due to its current alignment with the display industry.

The use of lighting systems in **enabled manufacturing industries** is mostly limited to the general use. More specialised lighting (e.g. events lighting, disinfection, lithography) is limited, but European companies are strong in these high cost niche markets. However, these markets are too limited to discuss in detail.

Looking at the **final markets**, the absolute size of the market is still small. The largest market is in the architectural and industrial areas, mainly due to its energy saving characteristics but also due to improved lighting quality and greater design freedom. Europe has strong players in this field. Residential lighting (housing and street lighting) and

automotive lighting are fast growing markets, in which European organisations are major players. However, also here Asian and American companies are picking up quickly.

### ***Advanced lighting***

*The following important conclusions can be drawn from this assessment:*

- *The EU is strong in lighting related research, from different **disciplines including technology and social sciences** (e.g. design and human perception).*
- *Manufacturing of LED and OLED is **limited** in Europe.*
- *Consumer lighting and highly specialized lighting fixtures are **well established** in Europe, where the major manufacturers are located.*
- *The actual use of advanced lighting in final markets is still limited, but shows a **strong potential growth**.*

### **3.5.3 Present versus future**

Many of the current developments in the lighting, especially around LEDs, are focused on cost reduction. By 2012 the incandescent light bulbs will be banned in Europe and this transition will drive demand and price reductions in LED lighting. Further developments alongside organic and inorganic LEDs are also possible e.g. light emitting nanowires and quantum dots and possibly large areas light emitting plastics. Large area light emitting OLED panels may also offer new functionalities as well as further reduction of energy consumption. There will also be continued development of advanced light sources for scientific and specific industrial applications. Many of these will be lasers, which are addressed separately in this report, but the markets, applications and impact for many specialist non-lasing light sources will follow similar dynamics to laser developments and thus the laser section can be referred to for the value chain analysis for such specialist sources.

The survey results show that advanced lighting will not have a strong impact on the manufacturing processes of the enabled manufacturing industries. Dependency on advanced lighting is today limited and will not change significantly looking at 2020.

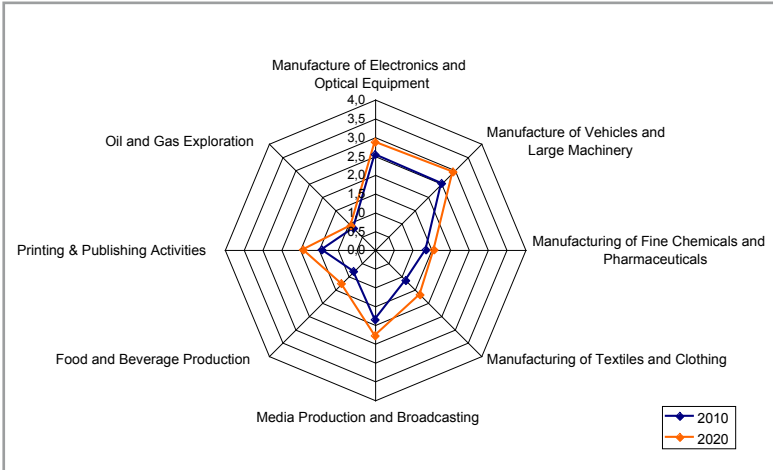


Figure 16: Overview of added value to competitiveness of lighting technologies to enabled manufacturing industries based on photonics survey.

Looking at the final markets, this picture is fundamentally different. Most of the final markets assessed show significant and even fundamental changes.

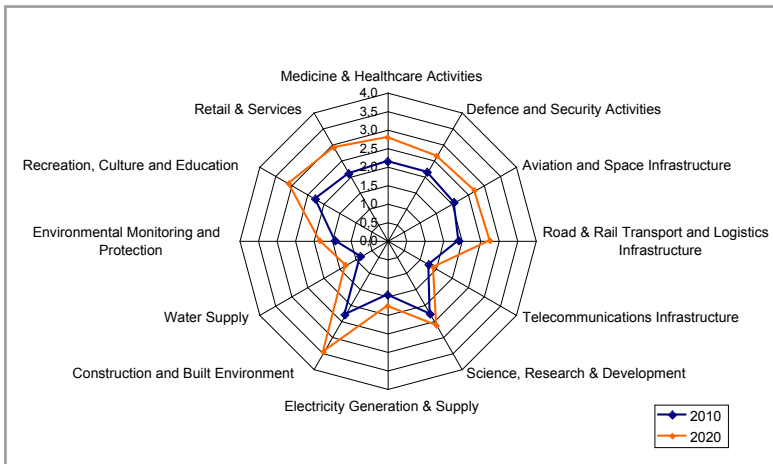


Figure 17: Overview of added value to competitiveness of lighting technologies to final markets based on photonics survey.

This is the result of the overall improvement of energy consumption by advanced lighting, but also additional functionalities are likely to have added value to the workers and consumers in these markets.

It is clear that retail & services, as well as transport show fundamental improvements. The energy consumption and ability to better light locations will not only reduce the energy consumption, but also improve the lighting quality, particularly important for the retail environment. Automotive and transport lighting opportunities are significant and LEDs are already rapidly penetrating these applications. Europe has a strong presence in both design and production of specialist fixtures for transport applications as well as strong presence in the final automotive market which will continue to expand the use of SSL in automotive and other transport interior cabins as well as displacing traditional exterior lighting. The improvement of lighting quality enabled by SSL also provides medical & healthcare activities with higher efficiency and effectiveness (e.g. by assessing the sterility of locations). Within recreation, culture & education, the entertainment business will have the opportunity to provide more sophisticated lighting (e.g. colour range and effects).

Overall, the conclusion is that the most future impact will be seen in the final markets, especially due to reduction of energy consumption and improvement of lighting quality.

### ***Advanced lighting***

*The assessment of present versus future for this value chain shows:*

- *The increase in dependency of a number of enabled manufacturing industries show a **significant increase**, also in some industries where this is not so obvious.*
- *The increase of dependency of advanced lighting to the final markets is estimated to be **relatively strong** and more than average (in regard to the other value chains). Especially the **reduction of energy usage** is an important driver.*

### 3.5.4 Strengths, Weaknesses, Opportunities, Threats

Looking at the previous description of the European value chain on advanced lighting, the **strengths** of the European research and industry lay in the long term presence of high quality industry in this field, both as manufacturers of light sources and fixtures:

- Europe is present on the global markets with several multinational companies based in Europe in the production of SSL based lighting systems.
- Because of historical developments, also research in Europe on social (design, human perception) and technological aspects can be considered strong (e.g. organic LEDs and plastic electronics).
- There is a strong presence of SMEs in the European industry, in various countries like Germany, France, Italy and the UK.
- The European research and industry is strong in the field of development of OLED displays. This can easily be connected to the lighting industry.

But also there are some **weaknesses** identified in the European research and industry base. These include:

- There is little manufacturing industry present in the production of OLED lighting panels. This is a strong growth market.
- The small number volume production of LED chip producers in Europe.
- The properties of LEDs mean producing high performance drop in replacements for traditional incandescent light bulbs is non-trivial.
- There is a lack of large scale demonstration projects in the field of SSL, so prove of economic and ecological benefits is difficult and market awareness is limited.

Although it is clear that advanced lighting is a strong growth market, some other related **opportunities** can be identified for the European research and industry in this field:

- The political climate to reduce energy consumption is still strong. In this field, it is supported by an economic benefit of reduction of costs. Therefore, opportunities for further growth are strong.
- Living standards are overall increasing, creating a demand for more sophisticated fixtures. As advanced lighting allows more manipulation of light, this creates an opportunity for research and industry.

- The European policy to ban incandescent lamps can create new market demand.

The **threats** to the European research and industry in the field of advanced lighting are the following:

- China and other Asia-Pacific countries show a strong desire and policy to develop an international competitive research and industry in the field of advanced lighting. This is supported by governmental funding and can create a competitive advantage, as China's domestic market is large.
- Several final markets are crucial to the full take-up of SSL as a core lighting technology. However many of these markets (e.g. construction, consumer) are conservative and there is a predominance of annual rather than life cycle costing putting SSL requiring a high upfront investment for long term gain at a disadvantage.
- The dominance of the Asian OLED display production is a strong threat to the further development of European players in this field.
- Research and innovations in the field of advanced lighting is not the barrier. Limited market demand is creating a barrier for up scaling of production. As governmental funding for greening is under pressure due to the credit crunch, this barrier will be even harder to break.
- Any reduction in access to the most advanced LED chips and components due to political or market developments would impact European development of SSL elements higher in the value chains such as Luminaires.
- The Chinese produced SSL lighting fixtures are still of inferior quality. This can lead to a negative image to advanced lighting, also disrupting market demand.

Looking at the SWOT, it is clear that this value chain is of economic interest to Europe. There is a strong basis for further development of this value chain, but support for the creation of partnerships and creation of market demand is needed.

### Advanced Lighting: a SWOT analysis for Europe

Strengths	Weaknesses
<ul style="list-style-type: none"> <li>● Several multinationals major players at the global market</li> <li>● EU strong in R&amp;D and in social sciences related to advanced lighting</li> <li>● Strong presence of SMEs</li> <li>● Strong position in OLED research, related to displays, also relevant for lighting</li> </ul>	<ul style="list-style-type: none"> <li>● Production volume of LED chips is small in Europe.</li> <li>● Fragmented/uncoordinated approach to research and markets compared to Asia, USA.</li> <li>● Lack of large demonstration projects in Europe</li> </ul>
Opportunities	Threats
<ul style="list-style-type: none"> <li>● Political pressure on and large potential for reduction of energy consumption, also having economic benefits.</li> <li>● SSL is connected to a trend within society for higher quality</li> <li>● The phase out of inefficient incandescent lamps and new (green) legislation</li> </ul>	<ul style="list-style-type: none"> <li>● European market will be taken over by foreign manufacturers &amp; service providers, with low quality products</li> <li>● Conservatism in the application markets.</li> <li>● External companies will benefit from R&amp;D done in Europe; migration of that R&amp;D outside Europe</li> <li>● Strong EU research position in this chain is of limited benefit, as main issue is up scaling of production</li> </ul>

#### 3.5.5 Impacts

The economic impact of advanced lighting is mainly based on the long term reduction of energy consumption. However, the new functionalities will have economic effects. The following conclusions can be drawn:

- Economic growth in the production of systems is strong  
 The production of advanced lighting systems is relatively low today, but is expected to grow exponentially worldwide. The question is if European companies can keep their strong position. The strong presence of SMEs in this field indicates that also smaller companies will benefit from this development. The advanced lighting systems have a strong substitution effect, but early replacement due to energy consumption benefits will lead to additional growth.

- Significant reduction of costs is to be expected in most of the final markets  
Being a significant part of the costs, with rising energy costs and reduction of energy consumption the accompanied costs for final markets (business and consumer) will also be significant. These benefits will be limited for the manufacturing industries. But also the longer life will reduce labour cost for replacing the traditional light sources in fixtures (sometimes equal to the reduction of cost due to energy consumption), although an initial investment is needed.
- Traditional lighting companies are increasing their competitiveness  
The new functionalities will create new markets. They will add to the competitiveness of the European SMEs when well supported by research.

It is clear that the further market penetration of advanced lighting systems will have positive effects on the environmental impact:

- Strong overall reduction of energy consumption  
The largest impact will be seen in climate change. The impact of the substitution of traditional lighting systems by low energy consuming advanced lighting will have a significant impact on the overall energy consumption, as this is a substantial part of the electricity consumption in our society. The total world electricity consumption is around 20 trillion kWh (US EIA, 2010), of which about 20% is used for lighting. Using SSL, an overall reduction of about 50% is possible, because of overall efficiency and cutting lighting spill because of enhanced manipulation.
- Reduction of waste is overall uncertain  
As the durability of SSL lighting is much higher, the production of waste materials is to be expected to be reduced. Also the toxicity of SSL lighting systems will be lower than fluorescent lighting systems. Preliminary Life Cycle Analysis studies show that SSL is much more environmentally friendly than incandescent lamps and more or less the same impact as CFL light sources. Further future development will even improve these figures.

The social impact of advanced lighting will be limited although the improvement in light quality over fluorescent light sources may have a significant social impact and lead to positive perception of SSL. Security and safety can also be improved, with more neutral and reliable



lighting of public locations (e.g. compared to false sodium vapour street lighting). The impact on employment will also not be significant, as it is a mainly a substitution market to CFL and incandescent lamps.

The conclusion of the impact assessment is that a full scale development and penetration of advanced lighting systems in the markets will have high economic and environmental benefits. The main benefits will be realized in final markets, with more limited indirect impact in manufacturing with the exception of automotive and transport applications which will be strongly impacted.

### ***Advanced Lighting***

*The main conclusions for the economic, environmental and social impacts are:*

- *The potential growth of this value chain is **high**, also leading to high potential reduction of energy costs. **New functionalities** will enhance especially the competitiveness of SMEs in regard to new markets.*
- *The environmental impact is **positive on energy consumption**. However the impact on waste is **uncertain**.*
- *Although there is some potential impact on **security**, the social impact to be expected to be **limited**.*

## 3.6

# Photonic energy systems

### 3.6.1 Introduction

The most immediate impact of photonics technology on Energy supply is with photovoltaic (PV) solar cells. PV cells built up into PV panels convert sunlight into electricity, helping to harness the greatest energy source available to us, the Sun, into useful electricity. Future developments may also see the generation of energy with laser driven fusion, although the practical development of fusion power plants is likely to take several decades.

Electricity generation with PV is still significantly more expensive than with traditional fossil fuels or nuclear technology and adoption in the EU has only taken place in those countries such as German and Spain with aggressive feed-in tariffs for PV. However many new technologies are in development offering the potential for greater efficiencies including enhanced poly crystalline silicon PV, thin film PV and dye sensitised PV and concentrator PV.

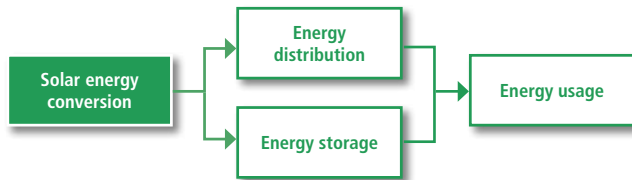


Figure 18: Functionalities within the context of photonic energy systems.

The use of these energy systems is increasing significantly and it can be said that this is one of the strongest growing areas in the field of photonics. In these systems, the photovoltaic material is the core of the value chain, but its manufacturing and application combines it with other technologies.

### 3.6.2 The European value chain

The *research* connected to this value chain includes not only the materials research needed to develop and enhance photovoltaic materials, but also includes research into the production of these materials, particularly relevant since large areas of high efficiency solar cells are normally required. There is also some aligned research on electrical storage and distribution and in particular on inverters for matching the low voltage DC output of PV systems to high voltage A.C. used in electricity grids and most electrical appliances. The most important *base material* currently used for the production of PV-cells is crystalline and amorphous silicon, which is also used, albeit with slightly different purity, in the production of integrated circuits. Also other basic materials are of increasing importance, due the rise of thin film PV, concentrator PV, dye sensitized and organic PV, although most of these technologies are still in their development phase. The production of solar cells and solar panels (*components*) that can be used in applications is done mainly by large companies, as the investments are large with large economies of scale. Solar cells and panels are not significantly used as a core step in

industrial **manufacturing** processes. The solar cells and panels produced are widely used in various **final markets**. The main use of solar panels is in construction and energy, as main supplier for electricity for the grid (power plants) and specific households or business. However, also an increase in application of solar cells can be seen in portable consumer electronics devices, like mobile phones.

**Research and development** is highly dominated by the photonics technologies, looking at both new materials for solar cells and panels and other ways of producing the components. The overall research community is estimated at around 1,500 employees (public+private). However, the number of research organisations in the Photonics21 database is limited to less than 5%, so European expertise is limited<sup>7</sup>. However, Europe also represents 25% of all research, although China is picking up pace quickly. Most research is conducted in Germany, although France, Italy, the Netherlands and the UK are also significant. However, as some PV research in inorganic and flexible systems is closely connected to research in displays, there is much more latent expertise.

The production of **basic components** in this value chains are solar panels, cells and invertors. These components are to be integrated in actual final products. There are a limited number of companies producing these components in the world, as is clearly a highly competitive international economy, dominated by large companies. Important is that the annual increase of production is 45%, but costs are also reducing by over 10% annually. Of all production, about 20% of the produced capacity was manufactured in Europe. Germany is by far being the largest producer, whereas Spain, Norway, the Netherlands, UK and Belgium are relatively small contributors.

The use of photovoltaic panels and cells in **manufacturing processes** is not significant. Energy systems are not a dedicated and inextricable element of manufacturing. If manufacturing uses PV generated energy, this will be part of the final market: Energy.

Of the **final markets**, construction and built environment is the largest. Germany has dominated both the European and global market for PV,

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<sup>7</sup> The small % of research organisation may reflect the limitations of coverage of the Photonics21 database which may not cover the numerous institutes in researching PV from a civil engineering, environmental, chemistry or construction background.

mostly due to the long term government policy and feed in tariffs (FITs). Similarly policy initiatives also saw Spain emerge as a very significant market, although this has now reduced following reduction of their previously attractive FITs. These market swings show the clear impact that government policy has on the PV market and such a dependency can be expected to continue with overall support potentially reducing due to public spending restrictions [renewableenergyworld.com, 2010].

It is interesting to note that private investors e.g. construction (42%) agriculture (18%) and private households (14%) are major final markets and utilities and governments play a relatively small role as customers, although they play a strong role in setting FITs that make the payback period for solar installation more attractive. [Solarbuzz, 2010].

#### *Photonic energy systems*

*The following important conclusions can be drawn from this assessment:*

- *EU research in the field is limited, but as it is an upcoming area can be considered to be strong in several countries.*
- *The EU has a strong manufacturing industry in this chain, but there is increasing competition from Asia.*
- *The actual use of photonic energy systems in enabled industries is limited, also in the future*
- *Use in final markets is also still limited, but shows a strong potential growth.*
- *Governmental policy is an important driving factor in this chain.*

All in all, this value chain is still limited in the number of research organisations and companies involved<sup>8</sup> but its impact is potentially significant. But this is also the case on a global scale and the European position in this domain has a critical mass to be further developed in a strong market.

<sup>8</sup> The limited number of players in the PV value considers only those involved up to and including solar panel production. A much larger number of organisations are involved in the construction industry and in installation mostly with a relatively small geographic focus. It is also complemented by a growing number of PV and sustainable energy supply service organisation covering areas such as advice and finances.

### 3.6.3 Present versus future

New photonic innovations will continue to improve PV efficiency in the next decade helping to make PV cost competitive with fossil fuel electricity generation. Technologies that will make this happen in 2020 include enhanced polycrystalline silicon PV, thin film PV, dye sensitised PV and further new developments such as imbedding nanoparticles into solar cells and/or nanostructured substrates. Some of these may provide significant improvements in efficiencies others will give incremental improvements to established systems. Some of these technologies will be too expensive for mass production, but will still be applicable using concentrator PV where sunlight is focused onto highly efficient yet expensive conversion cells. Capturing more wavelengths will also enhance the solar panel efficiency. By enhancing the efficiency, the material use will also be reduced, making the production cheaper. In other developments Flexible PV based on plastic electronics may give lower efficiencies but allow much lower cost enabling the mass use of solar cells on the exterior cladding of buildings, cars, clothing etc. Similar developments may also mature in smart windows and other multifunctional construction materials, offer modest electrical generation alongside core functions such as daylight transmission and shading.

A small emerging area of research and development is the direct conversion of solar energy to biomass using specialized catalysts [DOE, 2010]. This research is still in a highly experimental stage and efficient processes are not expected in the near future. Also research in this field is limited to a limited number of organisations, mainly outside Europe (Japan, USA).

The survey shows also an interesting view on the future of photonics energy systems.

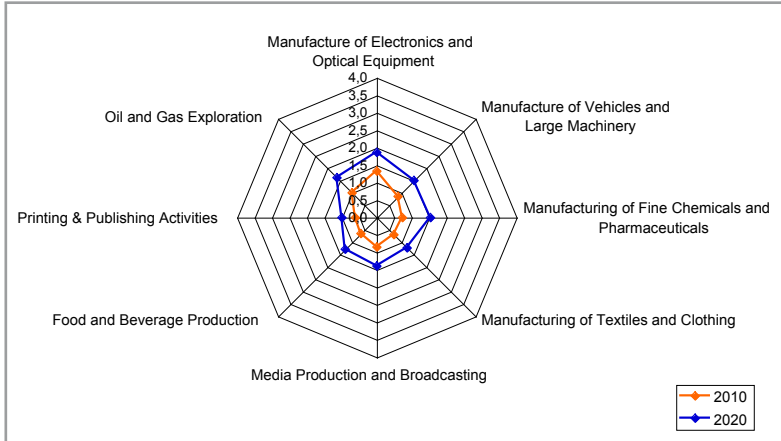


Figure 19: Overview of added value to competitiveness of photonic energy technologies to enabled manufacturing industries based on photonics survey.

It is clear that photonic energy technologies today are not viewed as critical to manufacturing industries and that, in the future, this will change only moderately. The slight increase shown can be the result of the use in small devices, like testing instruments, computers and packaging. Also perhaps some enabled manufacturing industries might generate energy on location.

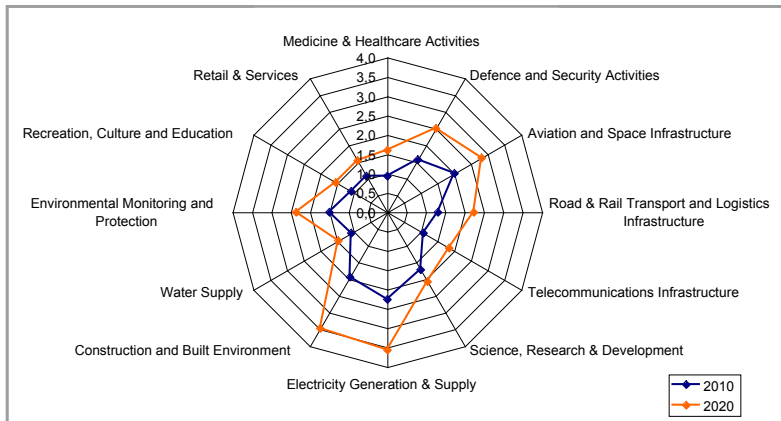


Figure 20: Overview of added value to competitiveness of photonic energy technologies to final markets based on photonics survey.

The result of the survey in regard to final markets is very different. In the field of energy, the impact today is modest and in construction quite limited, but the impact in these areas is anticipated to change radically with PV becoming a critical technology in both areas. Indeed in all the final markets considered, PV and photonics energy technologies are seen as becoming much more critical.

The outcome of the survey shows that in the coming decade, photonic energy systems will gain a strong position in the final markets. The difference between 2010 and 2020 indicate significant potential growth. This will be fuelled by a decrease in production costs and increase of efficiency.

#### ***Photonic energy systems***

*The assessment of present versus future for this value chain shows:*

- *The increase in dependency of a number of enabled manufacturing industries might be relatively high, but is **low on an absolute base**.*
- *The increase of dependency to the final markets is estimated to be **strong** and more than average (in regard to the other value chains). Especially the **reduction of energy usage** is an important driver.*

#### **3.6.4 Strengths, Weaknesses, Opportunities, Threats**

The European research and industry in the field of photonic energy systems shows the following **strengths**:

- The European research infrastructure is strong, internationally compared, especially in thin film cells, organic cells, polymers, building integrated PV and advanced stand-alone systems. Although in absolute terms, a limited number of organisations are involved in this research, in relative terms it is well above international average and expertise in adjacent fields is strong (e.g. plastic electronics research).
- The geographic spreading of the research organisations is good, although some countries like Germany show higher coverage.
- Historically, Europe was one of the first regions to focus on the commercialisation of photonic energy systems. This historical position

creates a strength because of existing networks between research, industry, consumers and governments.

- Europe has strengths in space frame construction techniques used in the automotive industry that are directly relevant to concentrator PV manufacture.
- The presence of so-called FIT policy (feed in tariffs) is providing an efficient policy that stimulates further development and implementation.
- Europe has strong export relationships with high solar nations (e.g. North Africa).

The *weaknesses* of European research and industry in the field of photonics energy systems are the following:

- The actual financial feasibility of photonic energy systems is highly dependent on governmental policy. If this policy changes, the European market can collapse.
- There is a strong concentration of European industry in Germany, which can jeopardize commitment of the European Union and supporting policy.

There are also various external *opportunities* to the European research and industry in the field of photonic energy systems:

- Although PV has been used in niche application for over 30 years it has only recently become a volume mass market with many new emerging product and process technologies creating opportunities to get involved.
- Public opinion toward photonic energy systems is positive and within the present institutional setting public demand is clear and positive.
- As greening of the industry is core in many national and European policies (the green deal), this provides a strong momentum for the further development of photonic energy systems (research and industry).
- Pressure on the availability of fossil fuels is leading to an increase in the overall energy price. This allows the further development of cost efficient photonic energy systems. Trends show that further cost reduction and increase in energy efficiency is to be expected.

There are also various external *threats* to the European research and industry in the field of photonic energy systems:

- As the financial position of many governments is under pressure, the



supporting policies for implementation of photonic energy systems are expected to be reduced. This will significantly lower demand for these systems.

- Large Chinese initiatives to develop and implement photonic energy systems can create a low cost research and manufacturing that will establish an even stronger position, which will relatively weaken the position of Europe.
- Various worldwide initiatives are now surfacing, e.g. in developing countries. These can provide even more momentum to the development of more efficient and lower cost systems.

The conclusion is that the value chain on photonic energy systems is highly dynamic and still in its infancy with significant further development to emerge. However, the future is highly uncertain and with significant risks.

**Photonic energy systems: a SWOT analysis for Europe**

Strengths	Weaknesses
<ul style="list-style-type: none"> <li>● EU has several multinationals major players at the global market</li> <li>● EU research is strong in several crucial areas, although it is still an upcoming area</li> <li>● Research is somewhat unevenly distributed along Europe</li> <li>● The connection between research and industry is good in Europe</li> <li>● EU policy in the field is highly stimulating applications</li> </ul>	<ul style="list-style-type: none"> <li>● Dependency on governmental regulation for economic feasibility is crucial</li> <li>● Dominance of German industry in Europe might weaken support from other EU countries</li> </ul>
Opportunities	Threats
<ul style="list-style-type: none"> <li>● Political pressure on sustainable energy generation is stimulating production</li> <li>● Cost of production is decreasing substantially, creating new market applications</li> <li>● Pressure on availability of fossil fuels, including the oil price, is enhancing economic feasibility</li> </ul>	<ul style="list-style-type: none"> <li>● The weak financial position of several countries is putting their policy under pressure</li> <li>● Large Chinese initiatives in this area are reducing the strong EU position</li> <li>● Economy of scale because of full market development can increase competitiveness</li> </ul>

### 3.6.5 Impacts

In the description of the *economic impact* of photonic energy systems, a distinction between the economic growth of the photonics component producers, competitiveness and reduction of costs due to use in final markets can be made:

#### ■ Potential large market demand

The market of the use of PV is growing rapidly and most systems comprise solar panels for energy generation to households and business (14.6 GW in 2010 [IMS research, 2010]). If the position of European players is consolidated, this economic growth in production will also take place in Europe.

#### ■ Strong economic growth in final markets

The implementation of photonic energy systems in construction and other final markets, will lead to an economic growth in these sectors. The degree of impact in construction may be heavily localised depending on regional subsidies for green energy. However, as costs reduce and performance increases solar power plants become increasingly viable, especially in sunnier regions, giving additional opportunities for significant economic growth.

Looking at *environmental impact*, two major issues are central:

#### ■ The energy pay back of photonic energy systems is positive and increasing

The main component of the environmental impact of photonic energy systems can be found in its reduction of use of fossil fuels. Although the manufacturing of systems is energy and resource demanding, it is commonly accepted that the overall net energy pay-back<sup>9</sup> is positive and estimated at around 3.5 years (EPIA, 2010). This will improve further as efficiencies in both production and conversion increase.

#### ■ Limited potential toxic risks due to production, use and discard

Some PV systems use of toxic chemicals in their manufacturing process, as well as part of their system. This can lead to environmental impact in the production cycle, and in recycling. Future technologies will reduce these impacts.

<sup>9</sup> The difference between the energy used for production of a PV-panel and the lifetime generated energy.

The **social impact** of photonic energy systems is significant in one key area:

#### ■ Increased social inclusion for remote communities

Power generation with PV offers the potential for sustainably providing electricity to locations not connected to the electricity grid. Particularly relevant in developing nations, but also to more remote areas generally, reliable power supply can significantly increase such communities integration with society (e.g. power is required to drive communication systems)

#### *Photonic energy systems*

*The main conclusions for the economic, environmental and social impacts are:*

- *The potential growth of this value chain is **high**, but competition will be strong. Industries that install the systems can expect increased economic growth.*
- *The environmental impact is **positive on energy consumption**. Production of (toxic) waste is limited.*
- *Some limited social benefits are expected, like the increased inclusion of people living in **remote locations**.*

## 3.7

# Laser systems

### 3.7.1 Introduction

The value chain around Laser systems can be considered very heterogeneous, with many types of systems included. Lasers are enabling technologies for many products and processes. Optical storage and communication applications described in the 'Data transmission, storage and processing' utilise approximately 50% of the world's lasers by value. Materials processing is the next biggest user of lasers where they are applied to the cutting welding and marking of a vast array of materials. Recent development have seen the number of material processing applications rapidly expand beyond traditional metals processing partly as a result of the development of new lower cost fibre lasers and partly due

to the development of industrial short pulse lasers. This trend is likely to continue as it becomes efficient to process more and more materials with lasers rather than by traditional machine tools. One specialist form of material process is medical surgery and lasers are increasingly used for a growing variety of surgical procedures. Further developments in materials processing are also emerging with additive layer processing where lasers are used to 'grow' parts from a powder rather than machine them out of a solid, particularly useful for very high value raw materials and/or complex parts.

Lasers also appear in a very wide range of instrumentation where they are used to remotely and highly selectively illuminate a sample whose unique response can be measured to give information about sample content, often in combination with the photonic sensor systems described in the section 5.1. As more lasers are developed and refined into industrial compatible devices the number of instrumentation applications continues to expand and as these become more mature the same laser based instrumentations are increasingly applied to medical applications.

Lasers also have a key role to play in the printing industry. Not only are lasers an essential element of office based laser printers, laser technology is also applied to many high volume printing processes especially the dynamic production of printing plates. Whilst printing applications are relatively mature advances are still being made in the parallel laser processing. Lasers are also beginning to play a part in the printing of plastic electronics. Plastic electronic could provide a step change in the cost of producing basic electronic devices enabling many applications from flexible e-books to smart packaging, and lasers may play a key enabling role in the required manufacturing technologies.

Lasers are also being considered for defence applications both with directed energy weapons and laser based counter measures. Finally laser based fusion, although highly complex, also offers the potential for almost infinite energy supply.

### 3.7.2 The European value chain

**Research** in lasers focuses on shorter pulses, extended spectral coverage, cost reduction, higher power/ brightness (e.g. laser diodes), energy efficiency, lifetime and new laser architectures (e.g. fibre lasers). Semiconductor laser diodes make up a significant proportion of laser devices. The

**basic material** inputs for these devices are closely related to those of the semiconductor industry, although with an emphasis on non-silicon systems such as Gallium Arsenide. Laser diodes themselves are also often a key **component** in more complex laser systems which additionally require specific crystals and or highly specialist glass materials that are processed into key laser components. Many lasers also rely on electro-optic devices where electric fields are applied to optical components requiring specialist component preparation and associated drive electronics. Indeed precision electrical sub-systems are a key element of almost all lasers.

Lasers are often used as devices for **manufacturing**. Examples are the cutting and welding robots in the automotive industry, but also they are used in semiconductor trimming, industrial marking, the production of PV and the textile industry. Although not fully realized by the public, lasers are often embedded in many **final end user markets**. Consumers use lasers in consumer electronics (DVD, Blu-ray, mouse pointers, etc.), but also they are used in healthcare for both diagnostics and treatment; laser eye surgery and dental care. They are also used in the defence industry (weaponry) and transport sector (tracking, automated guidance, measurement) and construction (laser levels, distance measurement).

**Research** in lasers (and related areas) is addressed by some 30% of all research organisations mapped by Photonics21, making this area a relatively large part of the European photonics research community. Some other areas are also researched in close proximity to laser research, like spectroscopy, non-linear optics and research in optical measurement with many organisations focusing on both. Applications research in materials processing is also strong as is research on diagnostics and measurement. Although addressed by almost all 27 EU countries, France, Germany and UK are strongly represented in this area, even in regard to their high representation in photonics research in general.

In laser **components**, a basic distinction can be made between laser diodes and non-laser diodes, based on the production process as well as application area. The majority of laser diodes are low cost high volume products, mainly produced in Asia, although a significant proportion of higher value laser diodes used mostly in communications and other applications, such as materials processing are manufactured in Europe and North America (45% of diode market [Pennwell / Strategies Unlimited 2010]). Europe is a major producer of non-diode lasers (high value, low

volume), with several world leaders in the materials processing sector. Looking at applications in the **manufacturing industry** as part of their production process, telecom and industrial cutting and welding are the most important areas of application. The European position in lasers for telecom is significant. But Europe is not a world leader in the field, although the more general role of Europe in telecom hardware can be considered strong (see section 5.2). In materials processing such as industrial cutting and welding, Europe is a major force, with many SMEs and large global players. Both Germany and UK show strong presence. Laser systems for lithography are significant in Europe, but the US is market leader.

Applications of lasers in **final markets** are diverse. As the consumer market is mainly based on diode lasers, the presence of Europe in this area is not strong and Asian manufacturers are dominating this market (e.g. Blu-ray, DVD etc.). For more professional final markets, the presence of European players is significant. Often SMEs, but also some large multinationals, show activities in these markets, especially in Healthcare and Science. Germany shows the most company activity, but the Netherlands, France, UK and Italy are also significantly represented. There is some presence of European companies in the field of Defence and security, but overall this market is more dominated by the US.

In this field, connection between research and industry is considered of high importance. Looking at manufacturing oriented laser systems, the connections between manufacturers of laser production systems and the actual manufacturing industry is generally strong (although often not based in Europe). This is the consequence of being a high value, low volume market, with often tailor made laser systems.

#### *Laser systems*

*The following important conclusions can be drawn from this assessment:*

- *EU research in the field is high and crucial to the industry, with **well established connections**.*
- *The EU industry has a strong world **leading position** in the production of high performance laser systems for manufacturing.*
- *The EU position on **consumer lasers is weak**, as Asia is dominating this market.*

### 3.7.3 Present versus future

A huge variety of lasers have been developed since they were first invented 50 years ago. These range from the very small devices used in CD players to the laser ignition facility in California covering the equivalent of several football fields. Future developments will focus on:

- New wavelength bands. In the UV, below 200nm, cheaper and easier to use lasers are expected for lithography applications and in the infrared, especially new 2-4 $\mu$ m lasers are expected especially for sensing applications.
- Maximum average output power. The most powerful lasers today have outputs in the Petawatt range (10<sup>15</sup> W) and Exawatt (10<sup>18</sup>W) lasers are expected in 2020. Commercially available in 2010 are several kilowatt gas and fibre lasers and in 2020 probably mega Watt lasers will be available off the shelf. Also the further development of semiconductor lasers will proceed, making high power lasers even more compact and easy to use.
- Maximum peak output power. Even more power is possible when using pulsed lasers, and using low average power high peak power is key to many applications to avoid thermal damage. Peak powers available from industrially robust pulsed laser can be expected to continue to rise in the future, at least partially driven by a move to shorter pulse systems.
- Maximum power efficiency. Looking at power consumption, getting more optical Watt for less electric Watt will be a central performance issue for future laser development. In this field developments in semiconductor and fibre lasers are likely to be key.
- Increased range of vertical cavity surface-emitting lasers (VCSELs)
- Silicon integrated lasers for use in on and, off chip communications.

It is clear that the use of lasers in enabled manufacturing industries is already very high in several industries and likely to continue. Also the application in other industrial areas can gain in importance, like in the production of textiles & clothing, as well as fine chemicals & pharmaceuticals.

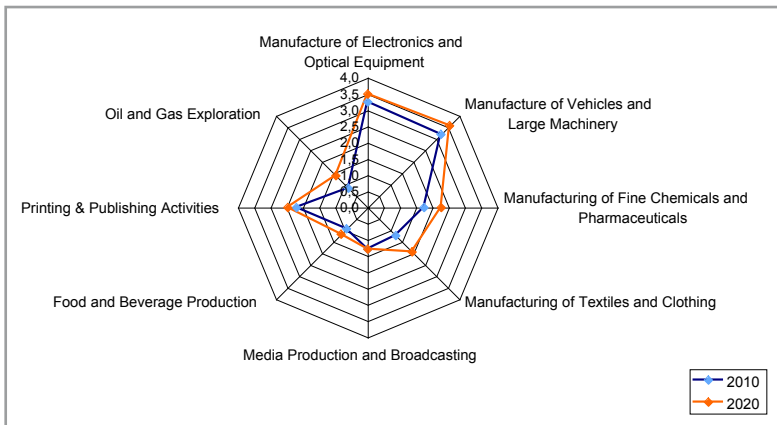


Figure 21: Overview of added value to competitiveness of Laser technologies to enabled manufacturing industries based on Photonics survey.

The application and added value of lasers to final markets is also diverse. Some markets, e.g. telecom infrastructure, are highly benefiting from these technologies, but for other ones the added value is limited. The further developments for the coming decade will add additional criticality to areas in Environmental Monitoring, and Defence and Healthcare. However, in general the application of lasers will be sustained rather than change radically.

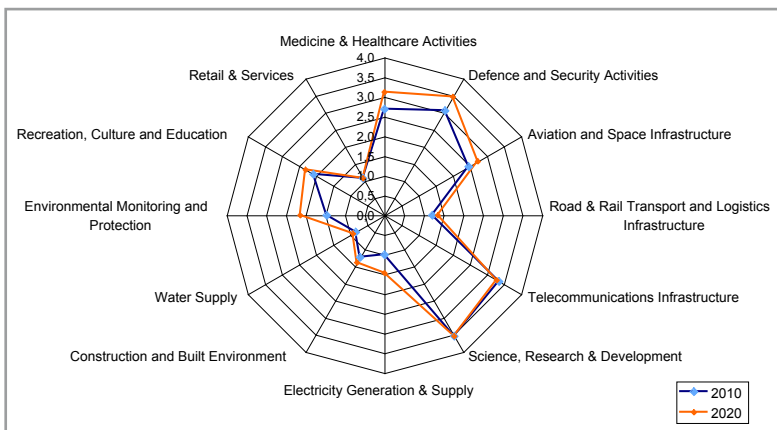


Figure 22: Overview of added value to competitiveness of laser technologies to final markets based on photonics survey.



These overviews do not imply that no developments in the industrial applications and final markets are expected. Rather the areas showing strong application today will continue to show strong application and dependency in the future.

### *Laser systems*

*The assessment of present versus future for this value chain shows:*

- *The overall increase in dependency of both enabled manufacturing industries and final markets are **positive but limited**.*
- *However, some enabled industries a final markets show high dependency on laser systems for their competitiveness **today**, which will **not change** in the coming decade.*

### **3.7.4 Strengths, Weaknesses, Opportunities, Threats**

Laser systems are developed and supplied into a truly global and dynamic market. The overall position of Europe in this area is good with following key **strengths**:

- Europe has significant global players in laser production and world leaders in laser based materials processing.
- There is a well established European based supply chain for material processing.
- The research base on lasers in Europe can be considered strong, with strong connections to industry.
- European research and industry show strong participation on new developments in Lasers, like high power fibre lasers. Also participation in diode lasers (increased performance) is strong, enabling more application to be directly addressed with this lower cost laser technology.

However, there are also some **weaknesses** in the European research and industry base in this field:

- Potential shortage of high volume production of low cost lasers in Europe, although there is some production of the basic semiconductor devices which are subsequently packaged in Asia.
- The dependency on high skilled personnel (researchers and production) is strong and skilled personal are in increasingly short supply.

- Reliance on far eastern producers of select specialist crystalline materials used in some lasers.

Although the previous section shows that in the future a limited number of new industrial and final markets are to be expected, several external opportunities can be identified:

- Increased use in high efficiency materials processing can be realised, especially in key growth areas such as manufacturing of photovoltaic cells.
- The trend to customisation of products and more complex industrial design requiring new materials processing methods. This requires new production system, often of which laser systems are a crucial component.
- A continued growth in demand for telecommunication services is to be expected and Lasers are considered a crucial element, especially.
- Although not well covered in Europe, growth in new laser based consumer devices such as pico-projectors is to be expected.

Looking at today and the near future, the European research and industry base also face some *threats*:

- Dominance of low cost semiconductor laser production in Asia. Developments in the performance of these low cost systems can penetrate the markets where Europe is strong.
- The laser supply market is highly global, with a competitive nature. Although the strengths of Europe are sufficient to keep the profit margin high, competition can reduce this significantly.
- Optical storage in consumer devices is expected to decline in preference to remote accessed services (e.g. streamed video on demand). This will also put pressure on companies in other world regions to reconsider their markets, potentially initiating new competition higher power laser segments.
- Laser based welding technologies can be faced with new developments in adhesive technologies. This might be a substitution to these photonics based manufacturing technologies especially with increase use of composite materials.
- Rare earth materials are especially of importance for the production of Lasers. Geopolitical considerations might put pressure on the availability of these materials for European companies.

Concluding, it can be said that the strength of European research and industry is high in especially high cost / low volume markets (e.g. manufacturing). Presence in low cost high volume markets is low. This is positive, as competition to the European industry is limited. However, this is mainly based on the strong connections to research and this needs to be sustained in the future. Competition from other world regions can be expected to grow. Besides a continuous development of laser technologies in existing markets, some additional markets can be expected, like PV production technologies.

### Laser systems: a SWOT analysis for Europe

Strengths	Weaknesses
<ul style="list-style-type: none"> <li>● EU is a world leader in several research areas and production of laser systems. Especially lasers for manufacturing are highly represented in Europe</li> <li>● The pipeline between research and industry in these areas is very strong</li> <li>● European research and industry is participating in various new industrial developments, e.g. for low cost high power laser systems</li> </ul>	<ul style="list-style-type: none"> <li>● The production volume in Europe for low cost laser systems is low</li> <li>● The dependency of the industry to research for high skilled personnel</li> <li>● Reliance on far eastern producers of select specialist crystalline materials</li> </ul>
Opportunities	Threats
<ul style="list-style-type: none"> <li>● Increased attention to highly efficient materials processing and customization of products</li> <li>● Continued growth of the telecom sector, increasing demand for laser systems</li> </ul>	<ul style="list-style-type: none"> <li>● Upcoming research and industry for high performance laser systems in Asia</li> <li>● Increased competition from other world regions in the area of high performance laser systems</li> <li>● Emergence and shift to non laser based technologies for welding functionalities</li> <li>● Decline in consumer market demand for optical storage, initiating a shift towards other markets of those manufacturers</li> <li>● Availability of rare earth materials</li> </ul>

### 3.7.5 Impacts

As laser technologies are an efficient and effective production technology and also in various final markets considered a key technology, one can expect various economic impacts:

- **Short term economic growth of laser production is certain**

Due to the further demand for lasers in final markets (e.g. telecom, healthcare) and for manufacturing processes, it is safe to expect the overall production of laser systems to increase. Although a reduction in costs can be expected because of increased competition overall economic growth is to be expected.

- **Laser based production is key to many automation processes**

Being a key technology to automated robotized manufacturing, laser systems will continue to play a part in the increase of competitiveness in manufacturing industries. Better (faster, higher quality, more energy efficient, more application areas) laser systems can improve the efficiency of the production systems. Not only by e.g. cutting, welding and ablation, but also using them for testing/measurement purposes. Being a highly flexible part of the production process, lasers are key to a more future oriented way of manufacturing.

The environmental impact of laser systems is complex considering different elements of energy consumption and the impact of producing and discarding lasers:

- **Environmental impact of the production and discarding of lasers**

Both in the production and end life of laser systems environmental impact can be seen. In some cases heavy metals and other potentially toxic materials are used although decreasingly so. In most cases lasers are complex devices, with multiple materials making recycling difficult.

- **Absolute energy consumer, relative energy reducer**

Laser systems are by definition energy using devices. So the introduction of more laser systems will be accompanied by additional energy consumption. However, new laser systems are mostly more energy efficient than the ones they replace, and also more energy efficient than most other technologies they replace (being highly efficient in performance). However, an increase in efficiency can still be gained care must be taken with other technologies such as LED

light sources or adhesive bonding may offer further efficiency gains in the future.

#### ■ Reduction of waste using the precision of lasers

As laser systems are highly precise in their functioning, the waste produced using the technology is usually reduced. However, due to the high temperature, in some production processes air pollution can be generated but generally laser ablation is more environmentally friendly than chemical ablation.

The social impact of lasers is limited. A few can be mentioned, like the added value of laser systems to the improvement of quality of health-care (surgery, as well as the use in dentistry) and the improved working environment because of (automated) laser systems for manufacturing. A third example is the enhanced access to communication networks due to advanced laser systems. As pressure on data communication leads to an increase in bandwidth annually, new lasers are developed that enhance the data efficiency significantly. This leads to a high quality data network, now considered to be a core societal need.

#### *Laser systems*

*The main conclusions for the economic, environmental and social impacts are:*

- *The potential short term economic growth of this value chain is **high**, but competition will increase. However, laser systems will become **more important** for manufacturing*
- *The environmental impact of lasers is **heterogeneous**, and can not be assessed. Energy efficiency is improving, but shows rebound effects and waste production is unclear.*
- *Some limited social benefits are expected in the field of **better working**.*

## 3.8

# Conclusions for the value chain analysis

The first overall conclusion that can be drawn is that the photonics industry is in a constant state of flux; new products are emerging, semi-old ones are disappearing. This highly dynamic product portfolio requires a constant adjustment of manufacturing systems, often based on photonics technologies. This is in line with one of the strengths of the European research and industry, but needs to be supported (both research and industry). Although these new markets are highly dynamic, with high uncertainty on what the winners are, the underlying manufacturing systems are usually more stable. An example is the production of solar cells, where an enormous increase in demand and production is seen. But although production experiences uncertain markets, and several alternative technologies, the underlying laser based manufacturing systems are in strong demand and are being applied to all the solar cell technologies. This need for manufacturing systems can be seen as a strength of the European industry, connected to an extensive European knowledge base and experiencing high profit margins.

The second conclusion is that in several value chains, especially the European industrial linkages are limited. The overall industry has a strong global character and shows limited interdependencies. However, the vertical value chain with research organisations is often more crucial, as the availability of highly skilled and innovative personnel is crucial to the industry and supplied by research organisations. This pipeline is of high importance to the competitiveness of the European photonics industry.

In the coming decade, it is expected that the dependency of the European economy on photonics to their competitiveness will only increase. All value chains assessed show this increase across the border, although some chains show more increase than others. The overall increase in dependency of the final markets is in average higher than the enabled manufacturing industries, which leads to the conclusion that market demand can be expected to grow and show new emerging markets.

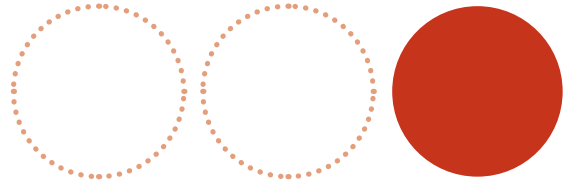
Looking at the impact of photonics, the conclusion can be drawn that overall there is a potential positive impact economic growth. Almost all value chains show a significant, even strong potential for short term economic growth. Also the added value to the competitiveness is clearly positive. However, due to increased global competition, the long term position of Europe in the field of photonics is unclear.

The environmental impact shows a more unclear final result. Although the potential positive effect on the reduction of energy consumption and increase in sustainable energy generation is clear, rebound effects might jeopardize the final outcomes. The production of waste is a point of attention, as the further development of new products will be accompanied by increases in waste. The final outcome of these results is complex and need to be research in order to draw significant conclusions.

The overall social impact is positive. Especially healthcare, security, and overall wellbeing are expected to benefit from the developments in photonics. Also the overall increased employment in the sector is beneficial for society, as well as the initiated new jobs in other sectors. The expected improvements in the working environment are limited, but positive. A point of attention is the information overload that can be the result from the improved organisation of communication and information. This can lead to a societal problem.







# Leverage of photonics

## 4.1

# Introduction

One of the main objectives of the study was to assess the leverage of photonics technologies to the broader European economy<sup>10</sup>. The indication of the importance of photonics technologies to the European industry and society at large is of high relevance to the development of policy to support photonics research and innovation.

To provide an indication of the leverage of photonics, an experimental method is used to indicate the overall impact of photonics on the rest of the European industry. In this method, **Photonics leverage** is defined in the following way:

*The proportional contribution photonics makes to the value of an end product or service, either by enabling/enhancing the productivity of the manufacturing process, or by providing/enhancing functionality in the end device, without which the end product would not be competitive.*

Thus leverage is a reflection of the dependency of a product (or service) on photonics technology. In other words: if photonics technologies were not available, what proportion of the functionality of the end product would be reduced? This dependency is based on a survey among **42 photonics experts**, using a semi-quantitative scale, looking at 8 enabled manufacturing industries and 11 final markets and their dependency on the six photonics technologies identified (see 4.2). Having estimated the contribution of photonics to an industry and market, it can be quantified in a variety of ways. Here we used two main measures:

1. The **photonics market leverage** (PML) which is the size of the market affected i.e. the economic market value of photonics enabled manufacturing industries and final markets, that are impacted by photonic technologies, either by improving its productivity or creating a new or better product (or service) with additional functionality.

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<sup>10</sup> Note that a distinction is made between the photonics industry, the photonics-enabled industry and final markets. The photonics industry is discussed in chapter 2, as photonics technologies are core to this industry and leverage of photonics is considered at 100%.

2. The photonics employment leverage (PEL), which is the number of jobs dependent on photonics i.e. the number of workers in photonics enabled manufacturing industries and final markets that are significantly dependent on photonic technologies, regarding their productivity, safety, or other aspects positive to their work.

Both are calculated in the same way: By multiplying the overall relevant market size/employment figures by the leverage proportion indicated by the experts.

The outcomes of this experimental approach can be found in Annex B. The conclusions will be discussed in the following section. However, the survey itself also provided additional information on the future of photonics, as the survey also asked the experts to give their opinion on both the situation in 2010 and 2020. These results will also be discussed.

## 4.2

# Leverage assessment on markets and employment

As stated, the assessment of the leverage of photonics to markets and employment is experimental. Also the results should be looked at more in a relative way than in an absolute way. In Annex B the assessment is made, including a detailed description of the method and the results. Several conclusions can be drawn from the assessment, which are included in this section.

### **Photonics is relevant for 8 enabled manufacturing industries and 11 final markets**

Looking at the enabled manufacturing industries and final markets, Table 2 provides an overview of which industries and markets are considered to be significantly impacted by photonics industries.

Enabled manufacturing industries	Final Markets
Manufacture of Electronics and Optical Equipment	Medicine & Healthcare Activities
Manufacture of Vehicles and Large Machinery	Defence and Security Activities
Manufacturing of Fine Chemicals and Pharmaceuticals	Aviation and Space Infrastructure
Manufacturing of Textiles and Clothing	Road & Rail Transport and Logistics Infrastructure
Media Production and Broadcasting	Telecommunications Infrastructure
Food and Beverage Production	Science, Research & Development
Printing & Publishing Activities	Electricity Generation & Supply
Oil and Gas Exploration	Construction and Built Environment
	Environmental Monitoring and Protection
	Recreation, Culture and Education
	Retail & Services

Table 2: Overview of significantly relevant enabled manufacturing industries and final markets.

In the table, 8 enabled manufacturing industries are included, from large industries like the car industry, to small industries including exploration for fossil fuels. It does not have to be stated that the importance of photonics to all industries is not the same and varies significantly. However, photonics is considered to be of importance to the competitiveness of each industry, from being a key technology to robotized manufacturing to its importance in remote assessment of oil wells. This also is the case looking at the final markets, where 11 are identified as being leveraged by photonics.

**About 20-30% of the EU sectors show a significant importance for photonics**

Analysing the broad scope of the European industry, about 20-30% of all sectors are impacted by photonics technologies<sup>11</sup> (looking at the NACE 3-digit level). About half of those sectors even show a higher dependency to photonics and are believed to be *significantly dependent* on the six photonics technologies for the competitiveness of their activities; it can be said that without photonics, their competitiveness would be under pressure. The other half of the 20-30% show an *intermediate dependency* for their competitiveness; this can be translated as: without photonics, these organisations will experience problems, but can overcome them with some efforts.

<sup>11</sup> Important to note is that the assessment shows the leverage of the number of sectors and does not take into account that some sectors are larger than others.

### **Photonics is a driver to competitiveness of at least 10% of the EU economy**

The previous statement considers the number of sectors that are dependent on photonics for their competitiveness. However, not all sectors are evenly sized; e.g. Retail & services employs about 25 million workers, whereas the photonics industry itself only employs some 290,000. One of the elements of the experimental Leverage assessment focused on taking into account these differences in size. Using the approach described in the introduction and Annex B, the estimation shows that at least 10% of the European economy is significantly dependent on one or more of the six photonics technologies for their competitiveness. The approach takes into account that although photonics is only crucial for some sectors, the contribution of several other, less dependent sectors also contributes to the overall leverage. Industries highly dependent on the six photonics technologies are the Electronics and optical industry and Media & broadcasting; examples of highly dependent final markets are telecom and science. Examples of less dependent sectors with large sizes are Retail & services and Medical & healthcare activities.

### **Photonics of significant importance to about 1 in 10 EU workers**

Photonics is important for almost everyone's daily life. Especially IT workers are often dependent on photonics to do their jobs efficiently and effectively. The survey looked at the six photonics technologies and assessed in which enabled manufacturing industries and final markets these (more research oriented) photonics technologies have significant impact on competitiveness and "doing their job safely, efficiently and effectively". The experimental approach showed that about 1 in 10 jobs in Europe, in one way or another, are depending on photonics technologies to enhance their work and working environment. Compared to the 290,000 people employed by the photonics industry itself, the estimation shows that a leverage effect of about 100 fold is not unrealistic. More sophisticated lighting, better diagnostics, safer working environments by scanning and sensing, increased manufacturing efficiency and better access to information are a few examples of how the working environment can be improved. The assessment showed that the positive impact has a broad scope, which is in line with the previous conclusion. With regard to individual sectors, it is clear that Retail & services, Recreation & Education and Defence & security show a large number of workers depending on photonics for their work.

### Priority also to be given to large sectors with limited dependency

One of the most important outcomes of the leverage assessment is that a large part of the overall leverage of photonics to the EU economy comes from sectors where photonics play a significant, but limited role (like retail and healthcare). Their sheer size makes their contribution to leverage important. For example, individual retailers might experience limited benefits from new developments in advanced lighting and photonics enabled logistical systems. But the overall contribution to the sector is significant because so many companies will experience these limited benefits, leading to a high absolute benefit. The Leverage calculations show that well over 60% of the leverage calculated originates from sectors which the experts indicated as “intermediately depending on photonics for their competitiveness”. This is the case for both the assessment of markets and employment.

*The overall leverage of photonics to the enabled manufacturing industries and final markets is significant. Based on an experimental approach, it can be concluded that roughly 10% of the European economy is dependent on photonics for their competitiveness, both looking at markets and working environment (jobs). Important conclusion is that over 50% of the leverage depends on the contributions by sectors where the overall dependency is limited, but the sector size is large.*

## 4.3

# Trends in industries 2010-2020

The analysis of the data on the two kinds of leverage was made looking at 2010. However, the data also provide the opportunity to compare 2010 with 2020, as the expert survey included a question about dependency in 2020. It must, however, be noted that a full analysis of the projected industry and market size in 2020 was not conducted. Therefore, the results must be regarded only as indicative.

The first analysis to be made is the assessment of how the dependency of photonics to their competitiveness of enabling manufacturing industries will change in the coming decade. Based on the survey, the outcomes in 2010 and 2020 are shown in the following figure.

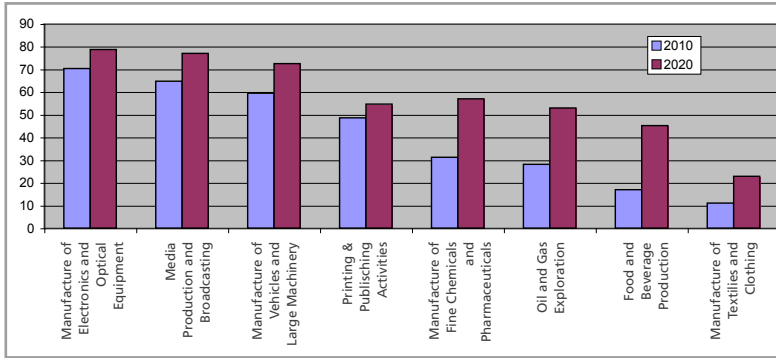


Figure 23: Overview of the average survey results on impact of photonic technologies to selected manufacturing industries, comparing the LIM scores in 2010 and 2020.

It is clear that, overall, all of the photonics enabled manufacturing industries are expected to experience a significant increase in dependency on photonics technologies in the coming 10 years. Although the industries where present dependency is low show the highest increase, this is not strange because of the “room for improvement”. However, it is perhaps more surprising that even many mature markets also show significant increases in dependency. This contributes to the earlier conclusion that photonics is still in its early stage of industrial evolution.

However, it is interesting to see that industries that are now not regarded as important application areas for photonics will also show a strong increase in importance. The two lowest enabling industries (Food/beverage and Textile) are expected to double in LIM, which means that photonics will shift from “marginal importance” to “intermediate importance” to the industry. Also the other industries show a shift in nature of dependency to photonics.

For the final markets, the most dependent ones are research, defence and aerospace; the dependence of water supply and retail (despite the ubiquity of laser bar code readers) was considered limited.

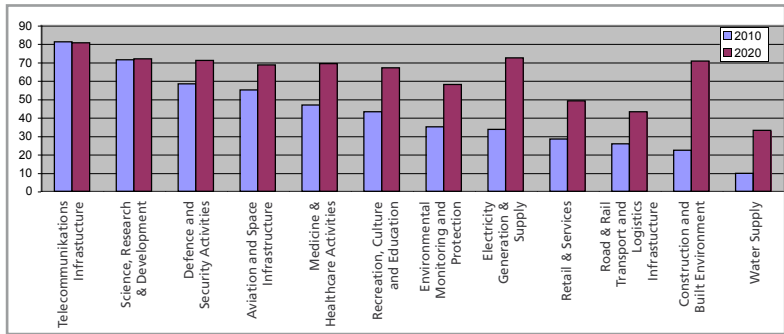


Figure 24: Overview of the average survey results (LIM) on impact of photonic technologies to selected markets, comparing the scores in 2010 and 2020

It is interesting to see how the developments in consumer markets are connected to the highest increases in dependency by 2020. Surprisingly, the final markets with the most potential growth in leverage are in construction and environmental activities, followed by medicine, whereas the growth in the dependency on photonics of telecommunications is comparatively low, because telecommunications is already heavily dependent on photonics technology. However, this overview can be wrongly interpreted. The fact that there is limited growth in dependency does not imply that there is necessarily little scope for further innovation. Admittedly, where markets are more mature and already show high dependency on photonics; more innovation is often difficult. The dependency of Science, research and development on photonics, for example, is at more or less its top level. Also, it should be noted that these overviews do not include changes in market size; e.g. the telecom market is expected to grow significantly, but this is not reflected in the LIM.

There is no area where a significant decline in dependency on photonics technologies is expected by the experts, although this could be conceivable. This shows that photonics is still a growing and developing industry and that increases can be expected, especially in several areas where photonics plays a modest role today. New markets will open up for photonics technologies – with fresh demand either from industries or end-consumers; this is expected, for example, in the food and beverage manufacturing industry. In such areas, “universal” photonics technologies that can have many applications like scanning, sensors and imaging technologies will drive the rapid growth in dependency. Growth in dependency comes about in three ways.



1. Industries where photonics technologies will be newly introduced (here high growth rates could be expected. If this also occurs in big and stable industries like food and beverage manufacturing, the impacts could be especially large).
2. Higher demand for photonics technologies due to a growth of an industry, sector or market which is already highly dependent on photonics and/or further increased penetration of photonics within such sectors.
3. Photonics technologies creating totally new possibilities and markets, i.e. disruptive innovations (this cannot be sufficiently measured with the standard methods that have been used like market statistics and the survey about existing industries and markets).

*Overall, the conclusion to be drawn is that the present dependency and opportunities of photonics technologies to industry and final markets in general is already strong, but it is to be expected that this will grow significantly in the coming years. Especially in areas where the presence of photonics technologies is limited (e.g. retail and healthcare), these can be considered interesting growth areas. It can be stated that photonics is still very much in its industrial growing stage.*

## 4.4

# Trends in leverage from photonic technologies

### Overview on most leveraged industries and markets of photonics

The data collected also provides an opportunity to analyse the six photonic technologies. The following table shows the leverage impact measure (LIM) for top industries and markets impacted by each of the 6 photonics technologies in either 2010 or 2020. This shows the areas where each technology has the highest LIM and at what relative level.

Technology area	Top 4 leveraged industries and markets 2010 /2010	LIM 2010	LIM 2020
<b>Scanning, sensing &amp; imaging</b>	Manufacture of Electronics and Optical Equipment	70%	79%
	Telecommunications Infrastructure	69%	71%
	Science, Research & Development	68%	72%
	Aviation and Space Infrastructure	55%	69%
	Medical and Healthcare Activities	47%	69%
<b>Information, communication and networks</b>	Telecommunications Infrastructure	81%	81%
	Science, Research & Development	65%	72%
	Manufacture of Electronics and Optical Equipment	64%	70%
	Media Production and Broadcasting	59%	75%
<b>Screens &amp; displays</b>	Media Production and Broadcasting	65%	77%
	Defence and Security Activities	55%	61%
	Aviation and Space Infrastructure	51%	61%
	Printing & Publishing Activities	49%	55%
	Medicine & Healthcare Activities	46%	61%
	Recreation, Culture and Education	43%	67%
<b>Advanced lighting</b>	Manufacture of Electronics and Optical Equipment	38%	49%
	Manufacture of Vehicles and Large Machinery	37%	54%
	Science, Research & Development	33%	45%
	Defence and Security Activities	30%	40%
	Construction and build environment	1%	68%
<b>Photonic energy systems</b>	Electricity Generation & Supply	34%	73%
	Aviation and Space Infrastructure	26%	46%
	Construction and Built Environment	22%	71%
	Science, Research & Development	18%	30%
	Environmental Monitoring and Protection	11%	35%
<b>Laser systems</b>	Science, Research & Development	71%	71%
	Telecommunications Infrastructure	67%	64%
	Manufacture of Electronics and Optical Equipment	62%	72%
	Manufacture of Vehicles and Large Machinery	59%	73%
	Defence and Security Activities	53%	69%

Table 3: Overview on the top 4 leveraged enabled manufacturing industries and final markets of the six photonic technologies, based on an assessment made by experts of their dependency in 2010.

Several sectors including Information, networks & communication, Laser systems and Scanning, sensing & imaging and Screens & Displays have notably high leverage across at least 4 industries and markets. This illustrates not just that a single photonics technology has broad leverage, but very high leverage in many areas and one photonics technology can underpin development in diverse end markets. However, this analysis must be accompanied by two other perspectives:

1. The overall leverage of a photonics technology on European industry and markets must be accompanied by a reflection of the actual size of the enabled manufacturing industries and final markets.
2. The analysis is based on the assessment in 2010. To draw conclusions for innovation policy, these figures need to be compared to the assessment for 2020.

**Leverage of enabled manufacturing industries will increase significantly**

The next analysis shows the result of the assessment of the differences between the expert views on the overall importance of the six photonic technologies regarding 2010 and 2020. As this is an average of the survey results over all enabled manufacturing industries and final markets, this distinction can be made looking at the results.

The first result shows the outcomes of the survey looking at the photonic technologies and their dependency towards competitiveness regarding the enabled manufacturing industries (2010 and 2020).

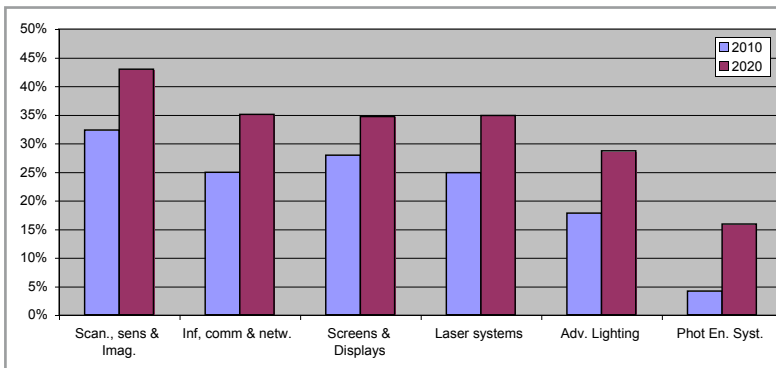


Figure 25: Overview of the average LIMs on photonic technologies of enabled manufacturing industries, comparing the scores on 2010 and 2020.

The overall changes in photonics leverage for enabled manufacturing industries, regarding the six photonic technologies show that there is a significant overall increase expected by the experts in the coming decade. It is striking that *all* technologies show a significant increase, leading to the conclusion that the manufacturing industry will become significantly more dependent on photonics for their competitiveness. Even the photonics energy systems, which were estimated to be of little importance to enabled manufacturing industries, show a significant increase. Also technologies that already have a high impact, show a significant increase. The overall conclusion is that all of the technology areas show a significant increase in leverage and it is to be expected that photonics innovations will surface in the coming decade and create new competitive opportunities for the enabled manufacturing industries.

### **Market leverage of enabled manufacturing industries is balanced**

This overall averaged assessment of the leverage of photonic technologies to the enabled manufacturing industries, can be researched in more detail when connected to the market data. The previous assessment was based on the expert survey and all industries attributed to the overall leverage in the same way. However, connecting to market data will create an overview that takes into account the different sizes of the relevant industries. Then if only one large industry will experience a large increase in leverage, the overall impact of a photonics technology will increase.

In the following figure, the results for the enabled manufacturing industries are shown. Although the assessment can also provide an absolute view on markets, the provided data is *normalized*, as the outcomes are more relevant looking at the relative differences between the different technologies.

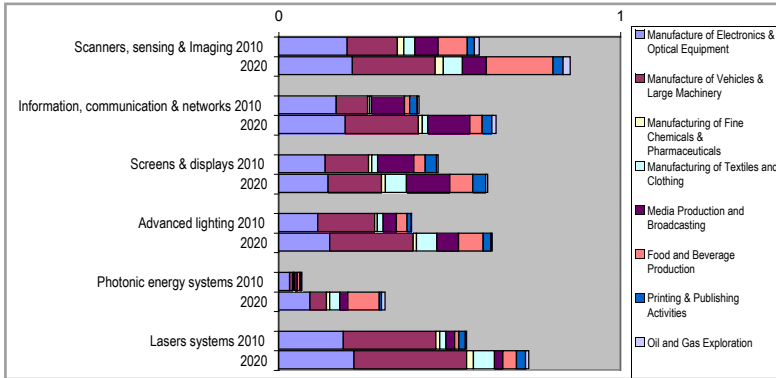


Figure 26: Accumulated economic impact of all photonic technologies in 2010 and 2020, looking at enabled manufacturing industries and (normalized).

Incorporating the industry size changes the view on leverage for some technologies. The technology with the overall highest LIM both in 2010 and 2020 still is Scanning, sensing & imaging. However, the difference with the Laser systems is now limited, indicating that the industries where Laser systems are applied in are larger than the Scanning, sensing & imaging related industries. However, the overall increase of impact in Laser systems is somewhat reduced, compared with Scanning, sensing & imaging. This leads to the conclusion that application of this last technology will create more new markets. However, it is striking to see that the overall view on leverage between the different technologies is not significantly affected by taking into account the size of the industries. The conclusion to be drawn from this is that the overall application of all technologies in industries is not unbalanced, but relatively evenly spread over all industries relevant to photonics in general. So the need for a strong industrial focus is of limited relevance.

Increase in leverage the strongest in Lighting and Energy markets

The two previous assessments can also be done for the final markets. In the following figure, the experts' views on the overall importance of the six photonic technologies to the final markets are given (2010 vs. 2020). Where the previous assessment focused on the outcomes for the industry itself, this assessment focuses on changes of dependency of photonics in the different application areas in the user domain (final markets).

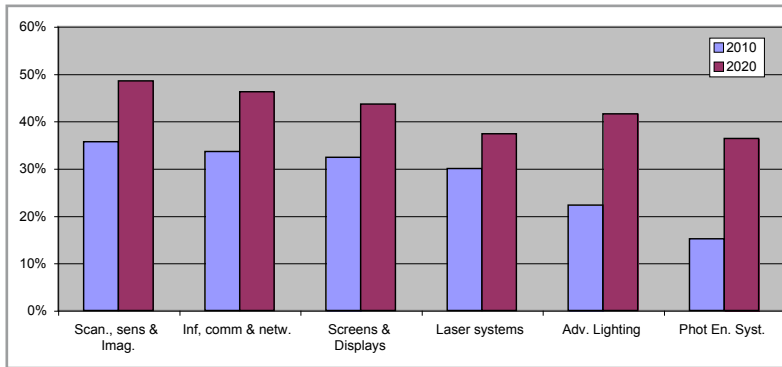


Figure 27: Overview of the average LIMs on photonic technologies of final markets, comparing the scores on 2010 and 2020.

Also here, it is clear that in the experts' opinion all photonics technologies are also going to have an increasing impact on the final markets. Also here, both the photonics technologies that already have an established position in the final markets show a significant increase in dependency, but less established technologies are expected to have a strong increase. Advanced lighting and photonic energy systems show a more than doubling of LIM, which is translated into going from “marginal importance” to “intermediate importance”, or even “important” (shift in scale). Taking into account that this is based on an average assessment over all final markets, the conclusion can be that in the coming decade their significance for the markets will fundamentally change. But even the photonic technologies that show a significant LIM today will increase in importance in the coming decade. Although the increase is not as fundamental as in the previous discussed technologies, still the impact can be changing markets. Overall, the increase in leverage of the final markets is believed to be higher than that of the enabled manufacturing industries.

**Market leverage of the photonic final markets emphasise Displays, Lighting and Energy**

Connecting the leverage impact measures to the market data shows that the already high increases in advanced lighting and photonic energy systems are even more important. The size of the related markets is contributing to the overall market leverage and leading to the conclusion that these technologies might be priorities, especially for lighting. But also the photonics technology on Screens and Displays shows that when linked to the related market size, additional priority can be given.

Overall, this is the result of the large size of the related market on Retail & services. For advanced lighting and photonic energy systems, the market of Construction & built environment is boosting leverage. The overall conclusion is that the priorities in leverage of the final markets are highly influenced by the size of the related markets.

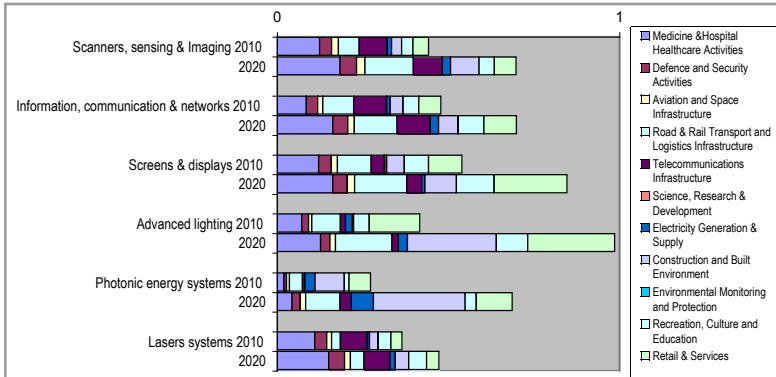


Figure 28: Accumulated economic impact of all photonic technologies in 2010 and 2020, looking at final markets and (normalized).

A remark to be made is that the growth in leverage in other areas such as Telecommunications appears more modest. This is because the approach does not take into consideration growth in the underlying market and the influence of photonics is already very high – illustrated by the LIM of 81% seen in Table 3. Significant growth in leverage will certainly occur in this area and thus the results should be read with care and, policy set to account not only for areas where the growth in photonics LIM is significant but also areas where the LIM is already high and the underlying or expected market growth significant.

*The conclusion to be drawn from the trends analysis is that the dependency of competitiveness to photonics will significantly increase. This is the case for the enabled manufacturing industries, but even more to the final markets. The incorporation of the size of the sectors have limited influence on the outcomes on the enabled manufacturing industries, but stress the importance of advanced lighting, screens & displays and photonic energy systems.*

## 4.5

# Conclusion on the leverage assessment

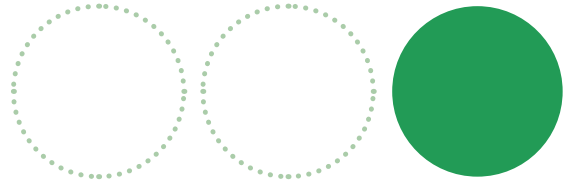
The assessment of leverage was an important aspect of the study, and was made using an experimental approach. Therefore the results must not be taken as absolute numbers, but merely as strong indications.

However, these indications can provide some valuable insights. The *first* insight is that the leverage of photonics to the rest of the European economy is significant. Both the indications of the number of sectors, the size of the market and the jobs impacted by photonics, point in the direction that at least 10% of the European economy is significantly dependent on photonics for its competitiveness. This can be interpreted that without further development in the six stated photonics technologies, their competitiveness will be under pressure. Import might limit the damage, but as Porter clearly indicated in his famous work “Competitive advantage of nations”, the local relation between research and industry is important to fully benefit from innovative opportunities [Porter, 1990].

A *second* important conclusion to be drawn is that the size of enabled manufacturing industries and final market changes the view on the importance of photonics technologies. It is easy to identify application areas where the impact of photonics is very high and set them as priorities. However, some areas where limited impact is to be expected can be potential priorities because of the sheer size of the area, like Retail & services. The conclusion is that policy development needs to take into account that less obvious application areas can also be of importance for photonics.

A *third* conclusion to be drawn is that the future dependency of enabled manufacturing industries and final markets will increase significantly, and within all six analysed photonics technologies. This means that photonics is a highly dynamic and increasing technology and will become even more “key technology” in the next decade. Therefore, it can be seen as an important driver for innovation, also with new research based opportunities. Relating the outcomes with the industry and market size enhances these findings and also underlines the second conclusion.





# Main drivers for change

## 5.1 Introduction

The photonics industry and market will be influenced by many different kinds of societal and economic factors (examples include the ongoing globalization and population ageing, or changing the workforce and consumer demand). Both these factors lie outside the photonics industry, but with crucial impact. The question is what the most important external factors are and what might be the consequences for the photonics industry? This chapter provides an overview of these driving factors that are exogenous to the photonics industry & research and have high potential impact.

Such external factors are generally beyond control of a firm and sometimes take the form of opportunities and threats. As the descriptions will show, these factors sometimes reinforce each other. In this study, the factors are used as building blocks for the development of scenarios (See Annex C), but also have their own merit to inform the reader about changes that need anticipation.

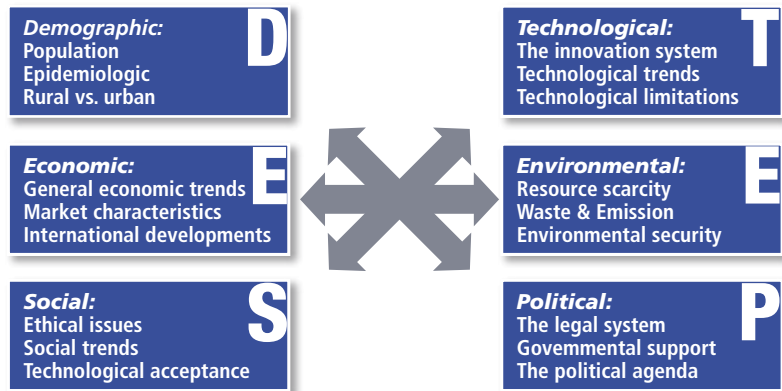


Figure 29: The DESTEP factors (Fahey, 1986).

An approach often used to identify and assess these external factors of change is the DESTEP approach. The DESTEP analysis is an often used approach to assess the external macro environment that affects firms.

It looks at the **Demographic, Economic, Social, Technological, Environmental** and **Political** factors in the external macro environment.

Based on desk research and expert interviews, an assessment has been made of these DESTEP drivers of change which may have future influence on the photonics industry. The outcomes of the assessment are shown in the following overview.

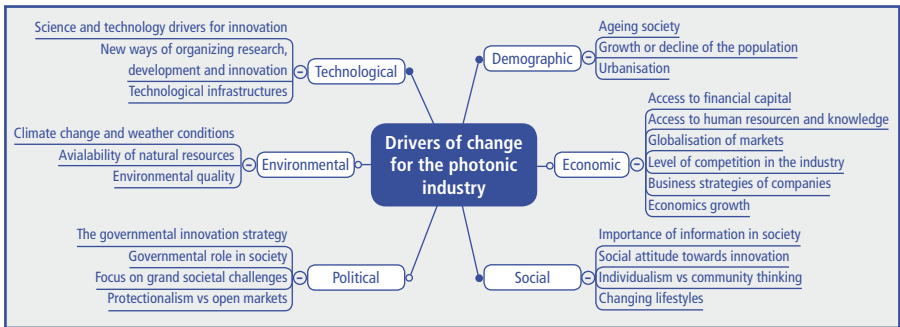


Figure 30: Overview of the most important driving factors of change for the photonics research and industry.

A more detailed description of these drivers of change is provided in the following sections, including a qualitative indication of their potential impact on the photonics (enabled) industry.

## 5.2 Demographic drivers

Although the *world population* continuously increases, the population size in many European countries is shrinking. Factors like declining birth rates and migration have negative effect on the overall population. On the other hand, the increasing medical care, safety, food quality and other socio-economic factors are counteracting this trend. Other countries like China, India and African countries still show an increase in their population and are becoming an important market for photonic products. The impact can be that domestic markets will be decreasing, but the BRIC related markets will increase, leading to changing market char-

acteristics. This changing population size will have a strong effect on the market demand, but also changes both the market size and structure, as well as the overall available workforce. The following factors are important to the photonics industry:

- Decrease in population of especially the western world regions will lead to **decrease in demand**. However, other world regions will see an increase in demand. The photonics industry needs to fully enhance its scope to the global market.
- Due to the stagnation of population growth in several EU regions, also the **availability of high quality human resources** can become a limiting factor.

Next to the quantitative characteristic of the population, also the qualitative aspect is a driver of changes, mainly on *ageing*. By 2020, 19% of the European population will be older than 65 years of age (UN population statistics). Life expectancy has continuously risen within Europe due to better hygiene and medicine, decreasing infant mortality and increasing wealth. At the same time birth rates have declined within Europe and are in some countries already below what is defined as “replacement level” of 2 children per woman (the “replacement level, however varies in relation to mortality rates)<sup>12</sup>. This also has a severe effect on the photonics industry, in various ways:

- As the need for efficient and effective healthcare is increasing, the photonics industry could play an important role for **improving healthcare**, delivering sophisticated methods for early diagnostics, preventative measures and telemedicine.
- But ageing also **changes the need for products**. The demand characteristics of younger people are different from those of the elderly. The photonics product portfolio needs to change accordingly.
- Next to these changes in market demand, ageing will also have a serious effect on the **labour force available**. Next to a quantitative reduction, also older people have different capacities than younger people (e.g. physical strength), stressing the photonics industry to adjust their organisation and production to this older workforce.

**Urbanisation** is the third demographic factor to be discussed, and is

<sup>12</sup> <http://www.springerlink.com/content/v61858k024860879/>

about the growth of urban areas due to more and more people migrating from rural areas towards cities. This trend is especially present in emerging and developing countries where the discrepancies between rural areas and cities in regard to job opportunities, education and infrastructure are much greater than in post-industrialised countries. However in Western countries, a trend can be seen of people migrating back to the rural areas, e.g. facilitated by high quality ICT infrastructure. These changes in urbanisation especially have an impact on **demand for products** and the technological infrastructure in general. For the photonics industry the following implications are relevant:

- Urbanisation has also come with an **increase in businesses and services** and thus represents a higher demand for photonics-related technologies like ICT, lighting and infrastructure-related devices (e.g. on streets, in public transport etc.).
- The attractiveness of rural areas can be improved by **investments in advanced communication technologies** e.g. for widening the access to fibre optic technology.

*Main messages of **demographic** drivers of change for the photonics industry*

- *Strategy is needed to support firms who are often born global, with an international focus from their outset, as well as encourage more domestically focused organisations to broaden their market focus*
- *Changing characteristics of the labour force require the photonics industry to anticipate an elderly workforce to ensure availability, like automation, or manufacturing activities.*
- *Changing demographics will change consumer demand. New products and services need to be developed that put the EU photonics industry in a more competitive future position and will help emerging issues in the field.*
- *The development of low cost / high quality telecom infrastructures to enable rural areas to stay connected and reduce pressure on the urban areas.*

## 5.3

# Economic drivers

**Economic growth** is a crucial driving factor for industry and describes the overall economic situation of a country or a region and its growth or decline. The overall economic situation impacts customer demand, but also the private resources that are available for research, development and innovation. The present economic conditions (especially in the EU and the US) during the recession had a negative impact on most industries, including the photonics industry. However, many areas of photonics have remained stable through the recession especially those focused on the research and life sciences markets. The following implications are relevant for the Photonics industry:

- Governmental investments in research and public demand are under pressure, e.g. to support development and implementation of green technologies, in which photonics plays a major role. Growth in these areas may be jeopardised by reductions in public spending, as some sectors such as photovoltaics are heavily dependent on **government funding**.
- Economic uncertainty leads to reduction of employment stability and a delayed consumer spending on luxury and/or high technology goods. As photonics is often used as the enabling technology in many products (e.g. 3D displays) or manufacturing processes, demand could well be suppressed if consumers opt for **cheaper and less advanced products** or delay upgrading/ replacing goods such as consumer electronics.
- **Access to human capital** in a time of recession is good, but can be critical after economic growth is back on track. In the photonics industry the availability of high quality personnel is crucial.

Business investments are usually funded by external sources. It is clear that this **access to financial capital** is crucial to the survival of companies. In the present recession, this access to financial capital is a problem, especially for SMEs. Both public and private funding now are under pressure, as governments and banks both are struggling to get the financial position in order. An essential element here is that rising countries like China and India are willing to support business development

and access to financial capital is strong. This has strong implications for the photonics industry:

- The photonics industry can be characterized as a high tech sector, where relatively large investments are needed to further develop the industry. Some parts of the industry are mature sectors, where the impact of photonics to the industry is still in its early stages, in need of financial capital.
- As an important competitor, the easy access to financial capital in China can lead to **pressure on the competitiveness of the European industry**. Thus, photonics relies heavily on the access to finance used to support innovation and development, both within the photonics industry, but especially in the industries enabled by photonics.

**Globalisation** is not only about increase in markets. It is also about the continuing integration of economies, cultures, societies, politics, transport, communication and crime. This globalization changes the economic structure of our society, offering new opportunities but also threats. The **brain drain** of human resources is a good example of this two edged sword, leading to new high quality personnel from China and emigration of graduates, highly relevant for photonics research. But also the inter-connectivity of the economies creates challenges like **international crime** and security risks, because of their **global dependencies** (e.g. the present economic crisis). The photonics industry will be faced with various effects from this globalisation:

- The **brain drain** is a high risk for the European photonics industry, as it is depending on high quality personnel. This demands organisational adjustments to secure availability of highly skilled personnel.
- Already, photonics research and industry are highly globalized and the value chain analysis shows weak chain linkages. **New business models** are needed, organizing the use of low cost personnel and global knowledge (e.g. off shoring and open innovation).
- Next to these new structures, globalisation also is accompanied by the need for high quality communication infrastructures, leading to **new demand for photonic products**.

One of the most important production factors for industry are **human resources**, in particular highly qualified personnel: engineers and technicians as well as, researchers. Various reports show that the fu-

ture availability of sufficiently qualified human resources is not certain. Besides the ageing and brain drain discussed in previous sections, also both the overall availability of highly skilled engineers and the connection between education and business are suboptimal. The availability of human resources can fundamentally jeopardize the functioning of companies, especially for a high tech industry like photonics. As in all other major high tech industries, a lack of qualified human resources and experts can also provide problems for the photonics industry throughout the whole value chain, especially in R&D and product development:

- The photonics industry might experience an absolute degradation of their business position, as the lack of skilled personnel will have an effect on their present **production** processes.
- As the photonics industry is still in its early stages, lack of highly skilled personnel will limit innovation, leading to **less competitive products** and limited participation in new markets.

In free market economies there is domestic and global **competition**. Within the present economic situation, especially Asian and Latin American countries are showing economic growth and increasingly competing with Europe. Besides the major so-called BRIC<sup>13</sup>-countries others are emerging (e.g. Vietnam, Indonesia, Malaysia) or already competing like Singapore. Looking at the photonics industry, the market is highly global and analysis shows that:

- The **need for distinctive competencies** is strong. The globalisation of the economy is further increasing, leading to a demand for product diversification, cost reduction and other ways to distinguish the product portfolio. This is stimulated by the present economic situation, but the early evolutionary stage of photonic technologies provides opportunities.
- The growing competition of Asia and Latin America in regard to general innovation combined with a **demographic structure favourable for employment** (many young people with an increasing ratio of well educated persons) could lead to challenges for the European photonics industry in general.
- The **strong investments in innovation** by e.g. China can be a major threat to the competitive edge of the European photonics industry and investments in innovation are needed to address this.

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<sup>13</sup> Brazil, Russia, India and China



*Main messages of **economic** drivers of change for the photonics industry*

- *Anticipate reduced governmental spending. It is likely to affect photonics related products that aim at addressing societal grand challenges like energy reduction and sustainable transport.*
- *Anticipate in (getting and) keeping high quality personnel. Already the photonics industry is facing shortage on highly skilled personnel. When the economy grows and ageing affects the labour force, problems will increase, emphasized by further brain drain to strong emerging economies.*
- *Access to financial capital might highly jeopardize the competitive position of the industry, especial of SMEs. Being a high tech industry, additional policy is needed to support these companies.*
- *Innovation is also under pressure due to the recession. Anticipation and support is needed to better anticipate future markets, as especially the BRIC countries have access to financial support of research and innovation.*
- *Globalisation increases markets, but also integrates economies. New business models need to be explored in order to make use of the strengths of other societies and address the weaknesses in Europe, emphasised by weak value chain linkages of the photonics industry.*
- *Further development of the European research and product portfolio demands anticipation of future global competitors. Selecting opportunities based on existing strengths is crucial and a general supporting policy is accompanied by reduced effectiveness.*

## 5.4

# Social drivers

European countries have generally already entered the post-industrialised development phase of the so-called *information society*. Knowledge and information are becoming an increasingly important resource for modern societies and are essential for innovation and the economy. More knowledge and fast communication provide a competitive advantage and are highly connected to the photonics industry:

- Further development of **communication infrastructure** (in quantity and quality) will continue in the coming decades, supported by the growing need for new photonic devices.
- **Information, communication and entertainment** will be the core drivers for innovation, indirectly leading to a further demand for speed, safety and reliability. Despite the recession, further growth in these three markets will continue. New gadgets, new media, faster internet, are just three examples of the effect of the ongoing increase of the use of information in our society.

Traditionally, human beings are reluctant to accept changes. However, technologies and innovations often are seen to play a key role in solutions to societal challenges like mobility, environment and security. The acceptance of these innovations depends on the *societies' attitude* towards their implementation, as well as legislation. Photonics is on the way to becoming a universal technology similar to electronics. Many innovations are impossible without photonics and likely to be accepted and even fostered without discussion. In general it is rather unlikely that photonics will generate similar controversies as nanotechnology or genetic engineering. Therefore the question of social acceptance may not be about photonics as such, but about the acceptance of the technologies that photonics enable. One could say that the societal attitude towards photonics enabled products is positive.

One of the most prominent differences between the United States and Europe is the social attitude towards the balance between *the individual and society*. One could say that the US looks at this as "maximizing opportunities for the individual is beneficial for society as a whole",

whereas the European countries approach the balance as “a well organized society is good for the individual”. However, also in Europe a trend towards a more American approach can be seen, maximizing the opportunities of individuals. This would also have consequences for the photonics industry:

- An important consequence might be a changing **customer and societal demand**. Societal support to challenges like environment, healthcare and defence might be reduced, as the individual preferences are more dominant. E.g. environmental technologies like PV and energy reduction would find less governmental support.
- Also support for investments in large **radical innovations** might be reduced. A more **gadget oriented**, fragmented business strategy is then to be followed. If a more social view on society would be taken, large system innovations will be supported, as well as innovations that address the **grand challenges**.

*Main messages of **social** drivers of change for the photonics industry:*

- *The driver of ICT for new innovation is still at the core of our society and will further initiate new demand for related products, especially in the fields of information, communication and entertainment.*
- *Societal acceptance of innovations related to photonics is highly positive, although some application areas might be controversial (e.g. privacy).*
- *National trends towards policy to stimulate individual innovations can be seen. This might have strong implications towards the character of demand for photonics enabled products (less societal challenges), also leading to a more general policy support. It will reduce opportunities for more radical innovations.*

## 5.5 Technological drivers

Core to this cluster of drivers are the opportunities arising from *new scientific* developments. Academic and applied research in various fields also have an impact on the photonics industry and are a major driver for innovation. These science drivers for innovation will also have a more indirect impact on the photonics industry:

- The further **miniaturisation** of products and processes emerge from new developments in biotechnology, materials technologies as well as electronics. Such miniaturization will also enable the use of photonic technologies in new miniaturized systems, creating new markets.
- Close to miniaturization is the **increasing intelligence** of systems, due to software development, but also smarter materials. As the processing of (complex) information can be faster and lead to more information, more traditional photonic sensory systems can increasingly be used as part of the machine/environment interface.
- The so-called **ubiquitous networks**, where connection to the internet is everywhere has boosted the development of the smart phone (and use of screens). But also other opportunities arise, like the Internet of things, where photonics sensors are also instrumental for the actual implementation.
- The miniaturization, increasing intelligence and ubiquitous networks also add up to a new emerging wave of innovations: **Robotization**. Although already emerging in the 1960's with industrial robots getting smaller, smarter and more autonomous, robots are expected to be developed for more consumer purposes. These will also include many photonic components, especially imaging and sensing devices.
- Research in biotechnology and other medical sciences will lead to more **insight in how the human body and mind works**. These insights will create new opportunities for consumer-oriented products (e.g. early diagnostic devices) as well as for the healthcare sector (e.g. robotized surgery). Also here, photonic technologies are crucial, both for scanning and visualisation.
- **Understanding society** and why people behave the way they do is core to several social sciences. Although not obvious, this also has an effect on the application of photonics. An example is the develop-

ment of swarming surveillance systems, where photonic sensors are used to e.g. predict riots and criminal activity. Better prediction of epidemics and pandemics can also lead to a new demand for photonics-enabled devices.

- Next to the insights in how our society works, also new **insights in our ecosystem** can lead to new photonics-enabled products and further use of existing technologies e.g. more predictive knowledge on natural disasters can drive the development and use of (new) photonic devices.
- Theoretical insights in material science and physics, as well as the previously discussed societal and ecological dynamics can also be used to simulate the physical world. This virtual modelling and testing will have a high impact on business and policymaking, through low cost development and testing of (consumer) products and suggestions for policy interventions. Often this virtualisation is accompanied by photonics-enabled man-machine interfaces.
- The last driver of innovation that is emerging from science is the **convergence of technologies**. A new trend in science and innovation is the increasing overlap and multi-use of scientific disciplines (e.g. nanotechnology, biology, ICT and photonics). New opportunities arise, like brain scanning to create ICT devices to, for example, counteract depression. Also here, opportunities for photonics emerge, both for novel interfaces, as well as new sensory systems (e.g. devices for bioinformatics).

Next to these drivers for innovation, a second factor emerging from the technology perspective is the **organisational side of technology and research**. New organisational business models to research are now surfacing, from Open innovation<sup>14</sup> to more global, internet facilitated, research. This leads to new ways of cooperation between science and industry, also being important to the photonics research and industry. Other new trends are crowd funding of research, user centred innovation, and the well known 'off shoring' of business. Also for the photonics research and industry these are of importance. The organisational structure of the pipeline between research and business today is crucial for survival of companies. New ways of organising research, especially internationally, might disrupt this pipeline, but also provides opportuni-

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<sup>14</sup> Philips has initiated an open *innovation initiative*, providing housing where research and industrial organisations can locate in close proximity. On this High Tech Campus Eindhoven, means are provided to initiate and support cooperation, like shared research facilities ([www.hightech-campus.nl](http://www.hightech-campus.nl)).

ties. For the photonics industry the following implications are relevant:

- Research will be more **internationally organised**, where the internet might facilitate the shared use of research facilities and the sharing of costs.
- The combination with **off shoring** and internationalisation of research might result in new research networks and new business models.
- Also new ways of funding research might be interesting for the industry, like the concept of **crowd funding of research**<sup>15</sup>. It might create new connections with users and this trend is connected to the **user centred innovation**, where innovation is in cooperation with consumers.

The trend of the **knowledge economy** is highly relevant for the photonics industry. The shift towards more high tech and knowledge intensive business will lead to an increase in communication and sharing of knowledge. This will lead to an increasing need for high quality communication infrastructure. If new demands for **high speed internet** will emerge, this stimulates specific new photonics activities. But also this high speed internet will initiate new opportunities for organising virtual research, even leading to new demands for devices where **sharing of research** can be facilitated.

*Main messages of **technology drivers of change** for the photonics industry:*

- *The non photonic research also offers new opportunities for new products and markets. A multi-disciplinary approach towards research and innovation is needed to benefit optimally from the opportunities of the developments in science.*
- *The way research and innovation is organised will change. More international networks, interaction with consumers and new ways of funding will also change business. The photonics industry needs to anticipate these developments to ensure their access to capital.*
- *The knowledge economy is not yet fully in place and still needs attention. The photonics industry plays an important role to facilitate communication. Improvements of the infrastructure and also connection to shared facilities provide an opportunity for the industry.*

<sup>15</sup> See <http://www.crowdfundingformula.com/>

## 5.6

# Ecological drivers

The general consensus is that **climate change** is happening and could cause grave problems for societies. Carbon and greenhouse emissions (largely attributed to fossil fuel usage) are considered to be the main factors contributing to climate change and disruptions of eco-system equilibriums. Even basic human necessities such as the availability of clean water, food and shelter could be endangered by possible impacts of climate change. The photonics industry plays an important role for:

- **Reducing the risk** of potential consequences of climate change (e.g. utilisation of solar energy) but also provides solutions to be better prepared for possible negative developments.
- Advanced sensor systems in which photonic solutions play an increasing role can be used to provide earlier and **better warnings** about floods or dangerous weather conditions and research in advanced lighting technologies can contribute to new developments for indoor farming.
- Photonic technologies can also be utilised for **advanced water treatment technologies** (e.g. desalination, disinfection and purification).

With rising living standards around the world, the demand for energy and other **natural resources** is growing. The concerns are not only over fossil fuels and raw materials used for industrial production, but also over clean water, arable land and food. Many modern technologies (incl. photonic applications, but also e.g. advanced batteries) depend on rare earth materials, which are only available in a limited number of locations globally and are difficult to extract in a sustainable way. As the overall global standards of living will increase, the demand for these resources will increase accordingly. The increasing scarcity of natural resources will have a significant impact on the photonics industry:

- The scarcity of energy and water will provide an opportunity for photonics in the development of new products based on the decreasing availability of those resources.
- The photonics industry will be impacted most by the tensions in the availability of rare earth materials. This can lead to tensions in

the market, especially because many of the economically available sources are in the hands of just a few countries. This might lead to a restructuring of the global photonics industry, with severe risks to European companies.

### Availability of rare earth materials

Rare earth materials are a collection of 17 chemical elements that tend to occur in the same ore deposits and exhibit similar chemical properties. Although they are relatively plentiful in the Earth's crust, they are typically dispersed and therefore economically exploitable in a limited number of places. They are crucial to various photonics products (e.g. Ho, Sc, Sm, Er, Tm, Tb, Dy, Yb, Lu, for applications like lasers, sensors, lenses and lighting) because of their specific properties. The limited number of economically exploitable locations is increasingly leading to geopolitical considerations, as these locations in general are outside of Europe (e.g. Brazil, Australia, India, China). E.g. China has regulated the market, moving Chinese manufacturers up the supply chain. Future developments therefore can lead to a reduced position of European companies, as access to these materials can be problematic.

Increasing demand for green products is the result of a long term public attention to *environmental problems*. A societal trend that emphasises the importance of being sustainable is becoming more common. This will include the reduction of energy use, but also recycling, reduced use of toxic materials and reduction of environmental impact in the manufacturing processes. These issues are also relevant to the photonics industry:

- The reduction of energy use provides an opportunity for the photonics industry, but also attention to the **energy use within the photonic components manufacturing processes** should be given.
- Also, other environmental impact issues are relevant and should be addressed, like **toxicity of the components and recycling** of materials. As photonics enabled products show a short product life, attention is needed to reduction of environmental impact (cradle to grave).



- But even more important is the **environmental impact from using** photonics-enabled products as often these products introduce additional energy usage.

*Main messages of **environmental** drivers of change for the photonics industry:*

- *The grand challenge on Climate change will mostly provide opportunities for photonics with new products to reduce the emission of greenhouse gasses. This is strongly connected to the role photonics plays in the production of energy and water and environmental monitoring. Increased pressure on availability of fossil fuels and climate change will increase the opportunities.*
- *A major issue is the availability of rare earth materials. Being a key resource, scarcity of such materials will lead to fundamental issues within the industry. A policy is needed to anticipate this problem and is crucial for the survival of the industry.*
- *Attention should be given to reducing the environmental impact of both the production and use of photonics-enabled products, as well as to the disposal / recycling of such products at the end of their lifetime. Having a short life and additional energy consumption, this is needed to reduce possible environmental issues.*

## 5.7

# Political drivers

Innovation and new product developments are being regarded as drivers for economic growth. **Public innovation policy** has strong influence on the capacities and strategies of industries towards research and innovation, being about 50% of all funding for innovation and research (public and private). The policy directly and indirectly influences decisions, for example research funding, taxation, education, laws and reg-

ulations. Within the current situation of economic challenges, “innovating out of the crisis” has become an important focus for many countries. Many countries have begun to identify the main challenges (see Grand Challenges below) to society and use these to drive innovation policy and strategy. This is also of importance to the photonics research and industry areas:

- **Availability of funding** facilitating cooperation (Research to Business and Business to Business) is major driver for research and innovation within the EU photonics industry.
- Also, the trend towards a more **European research and innovation strategy** might provide opportunities (e.g. Joint Programming).

Close to the governmental policy on research and innovation is the **role governments** are willing to take in society. Will governments direct industry towards specific thematic issues, or will the governmental policy be more general and stimulate further research and innovation? In the first case, governmental regulation and focus on selected grand challenges will be directive, where government will also be partner in the further priority setting. In the later situation, the government will provide the framework within which the industry and consumers will find balance. In both cases, especially the innovation portfolio would be significantly different. Also, for the photonics industry this has severe impact:

- If the **governmental grand challenges approach** would be leading, innovations in healthcare, energy, mobility, ageing, etc. would be supported by governments. More radical photonics based innovations are possible, but there would be a strong need for companies to create networks.
- In case of **general support on innovation**, governmental funding will be more supportive to individual firms and research organisations are creating more incremental innovations (less support and less mass). From the content side, the more consumer oriented innovations will be core. The photonics industry needs to anticipate the actual consumer trends and create a business strategy accordingly.

*Main messages of **Political** drivers of change for the photonics industry:*

- *The availability of National governmental funding for re-search and innovation seems to be under pressure. Especially a highly innovative industry like photonics can be faced with shortages in the development of innovation capacities and new innovations.*
- *The trend towards more European research is initiated by the European Commission. This will both lead to more focus and higher critical mass within Europe on research. On the other hand, creation of new markets would require increased support to start-ups. Both sides are highly relevant for the dynamic photonics industry.*
- *The governmental focus on grand societal challenges will provide more coordinated funding and different market demand, whereas a more general approach will stimulate more short term gadget oriented products, slightly in favour to SMEs. The character of the photonics industry will significantly change and anticipation is needed.*

## 5.8

# Conclusions for the drivers of change

Looking at the identified **Demographic** drivers, the changes will have significant effect on the market demand, but also the changes in labour market can lead to significant problems for the photonics industry.

The **Economic** drivers show that globalisation and pressure on governmental finances will put pressure on competitiveness, as funding for innovation can become problematic. Also, the availability of human resources can become a problem.

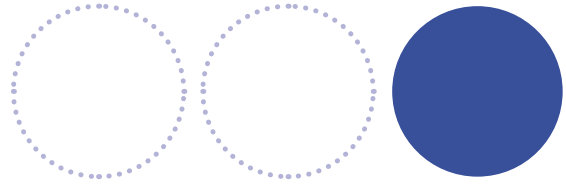
The **Social** trends show that photonics is highly aligned with the developments in demands, looking for more, better and innovative information and communication.

The **Technological** drivers show that input from other disciplines can be a source of inspiration and the knowledge economy will continue to create demand. Changes in the organisation of research will require adaptation and new business models.

Climate change will still be the most important **Environmental** driver, but attention is needed to also other environmental issues than climate change, like waste reduction/recycling and reduction of toxic emissions. The availability of various raw materials can lead to further tensions.

Last but not least, the analysis of **Political** drivers shows that governmental policy is crucial for the industry. Coordination within Europe to align research and innovation is of importance in this globalized world and focusing on grand challenges might be instrumental.

Overall it can be concluded that the external driving forces to the photonics research and industry are strong. Although these factors are general to the European economy, the photonics industry is highly affected by these factors because of its relatively young character. Research and innovation are important to the sector and it shows highly dynamic heterogeneous economic activities. This dynamism is susceptible to changes in the external environment. Therefore, attention needs to be given to support research and industry to both anticipate these changes and deal with some of the major challenges.



# Scenario analysis

## 6.1 Introduction

To assess the future of the photonics research and industry a scenario analysis was conducted. Based on the previous described Drivers of change (chapter 5), two prioritized factors were identified that have high impact on the future of photonics and also are highly uncertain. These two factors were:

1. The rate of economic growth, with one side being low economic growth and the other side high economic growth;
2. The role of the government in our economy, taking the position from a full market driven economy, to a governmental supervised market.

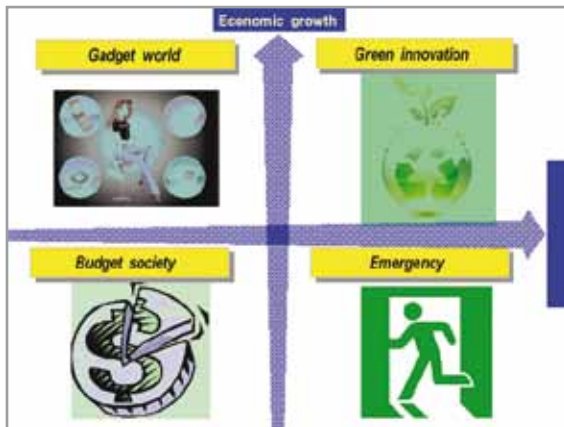


Figure 31: The four Leverage scenarios for analysis.

Positioning those two main drivers within a scenario framework, led to four scenarios (see Figure 31).

The first scenario (**Gadget world**) shows strong economic growth, but governmental and public intervention is limited. This leads to a society and economy that is oriented towards individual consumer needs, where consumers have money to spend. The second scenario (**Green innovation**) still has

strong economic growth, but because of governmental intervention attention is given to more long term societal needs. In the third scenario (**Budget society**), the consumer has limited budgets, but the consumer will be in the driver seat for spending. The last scenario (**Emergency**) also shows limited economic growth, but the role of government in where to invest is strong, leading to focus on only priority issues.

Of those four worlds consistent scenario logics can be found in Annex B. During an expert workshop, the four scenarios were used to discuss the different value chains within different future contexts. Especially the Strengths Weaknesses, Opportunities and Threats were the object of discussions. In the following sections, the outcomes of the scenario based SWOT analysis are provided. More specific impacts on particular values are incorporated in the discussion of the future of these value chains in chapter 3.

## 6.2

# Gadget world

The first scenario is ***Gadget World*** and depicts a future in which high economic growth is combined with an open and free global market. Governmental guided societal orientation is limited and consumer interests drive the market demands with expectations of improving standard of living.

The European research and industry is in general not well suited for a consumer demand driven market, the strengths of the European research and industry to operate in this scenario are under pressure. Many of the core activities of the European industry are more focused on societal demands, than the production of consumer oriented gadgets (relative to the rest of the world). This also is reflected in the European strengths in healthcare, transport, defence & security, telecom, science, etc. It is known that Asian research and industry is more oriented towards (low costs) consumer goods production, however Europe does have strengths in the production of high value machinery used in volume manufacture. Due to the increasing standards of living, more society oriented markets will still be important such as healthcare, telecommunication and construction. Markets like education, science, defence & security, transport infrastructure, environment, energy are under pressure in this scenario.

The fact that there are many SMEs present in Europe is positive, as these companies usually are better suited for addressing consumer needs where fast time to market is required. Europe is also well positioned

to take advantage of the emphasis on high quality. This is closely connected to the present strengths of industry on design, creativity and innovation.

Another positive European strength in this scenario is the European focus on manufacturing technologies. As a consumer oriented world also decreases the time to market, this also often increases the continuous need for new manufacturing systems.

To adjust to this scenario, certain elements in the present European innovation system, e.g. research, would benefit from greater focus on consumer demands and shorter term impact. In the Gadget world, consumers have a high standard of living. This scenario will also be accompanied by high overall market growth. When adjusted to the new market demands, this will provide an opportunity for the European photonics industry. Also the global free and open markets will enable new ways of global cooperation, although new business models need to be explored. Lifting restrictions on certain defence & security technologies can also enable new markets.

With a strong open consumer driven market, it is to be expected that there will be a highly competitive market, where high volume production of many major products occurs in Asia. However, today research and the manufacturing systems are significantly located in Europe. The major threat is that the knowledge base and production of manufacturing systems will also relocate to Asia, which will lead to a diminished photonics industrial base and limited domestic support for enabled manufacturing industries and final markets.

## 6.3

# Green innovation

The second scenario is *green innovation*, where sustainability represents a major driver for innovation and technological development strongly supported by both governments and consumers. Energy efficiency, environmental protection and responsibility become important/ dominant competitive dimensions for industry supported by strong governmen-



tal regulations and standards (e.g. emission standards, limits on energy consumption etc.).

Within this scenario society is generally risk averse and decisions are primarily governed by the precautionary principle. There is also likely to be greater focus on identified societal grand challenges (e.g. ageing, healthcare, security, safety) where these present a challenge to sustainability. Regulations also affect products that are not related directly to environmental issues, e.g. computer games that may promote violence, cars that may unnecessarily endanger people or food that may have negative health effects. The acceptance of new technologies depends on their long term impact on sustainability and risk assessment. New technologies may also be perceived with some ambivalence as potentially providing a near term solution, but also a possible presenting risk throughout their lifecycle.

In order to be realized, this scenario requires a degree of economic prosperity and good access to human and natural resources. In contrast to the Emergency scenario below, the immediate general environmental conditions are not alarming, but there is considerable societal and governmental concern that they may worsen if no action is taken to ensure sustainability. In this scenario, markets may not be fully open if sustainability constraints are placed on international trade partners.

The industrial and research base in Europe is well suited for this scenario. The present strengths and focal areas are in line with several grand challenges (e.g. environment, ageing, healthcare, security, safety). Indeed today's industrial and research focus already incorporates the political and societal agenda on grand challenges and increasingly sustainability. Also the innovation system and the organisation of research and innovation are already aligned with a thematic oriented research policy, supported by public funding. Access to financial capital is secured, as economic growth is positive.

This scenario may also be associated with significant central investment in sustainable technology. The SMEs that dominate photonics sector may have more difficulty in responding to such opportunities as SMEs

generally have more difficulty in accessing the larger capital sums that may be required to exploit such opportunities. However, orientation towards incremental innovations is low and more towards radical and complex innovations to the benefit of SMEs. However, these radical innovations are more risky and can be unsuccessful.

One possible threat to European research and industry will come from accelerated innovation and development markets unconstrained by sustainability requirements (i.e., from organisations based in locations with fewer or no regulatory requirements covering energy efficiency, waste, recycling and other sustainability parameters). This may reduce the competitiveness of European organisations, as sustainability requirements may increase the cost base of European industry relative to other geographic locations and may have particular impact on a European photonics industry due to its strong focus on international markets.

## 6.4 Budget society

In the third scenario (**Budget society**), economic growth is limited and the consumer will have a strong influence on the market demand. Governmental policy will be limited and more general.

In this scenario, the European research and industry are potentially negatively impact more than other global players. Both the present industrial and research capacities are in general suboptimal aligned with the low cost market demands and very limited societal demand. Some areas like the telecom and entertainment and other markets that are increasingly considered basic needs will still experience a strong economic position, but cost pressure will be severe. There are some low cost technologies in Europe (e.g. CMOS) and also the production of base materials will still see a continued solid position, as high investments in competitive industries in other regions is difficult.

The photonics industry that focuses on the production of manufacturing technologies will experience, although reduced, a solid economic position. As consumer production in a budget society will in general

change to low cost goods, new and more efficient manufacturing processes are needed.

The opportunities in this scenario are limited. The further development of existing strengths of low cost components would provide additional growth, but as the European research and industry is limited in these products, this will be limited. Some developments in further greening of photonic technologies would also be of interest, if they can lead to a significant reduction of energy consumption, but there will be constraints on the initial capital investment required with reduced government intervention. Some research areas will be of interest to other regions, as building up a knowledge base is costly.

The threats to the European research and industry will be at all fronts. As the market is open and competition is mainly on low costs, especially Asian companies will penetrate most markets based on low costs. As quality is of less importance in this scenario, Asian competition will be severe. Although the photonics based manufacturing processes will still be in demand, reduction of funding to research organisations might jeopardize long term viability.

## 6.5

# Emergency

The last scenario is based on limited economic growth, but in this case governments have a significant role in where investment is made, leading to focus on only priority issues. In this scenario, the thematic focus of governments will direct and facilitate certain innovation areas that are connected to grand challenges that can lead to severe and immediate issues when not addressed. Examples are issues on security threats and financial problems with healthcare. In this scenario, these immediate threats are on the agenda, because of calamities that have happened (e.g. a terrorist attack and radical increase of costs of healthcare). The actions are more curative and long term preventive issues like the climate change will be of less importance and total budgets available will be limited.

Certain strengths of European research and industry are well aligned with the thematic areas that are priority on the political agenda e.g. Defence & security and healthcare. However, strengths in transport and telecom infrastructures will be of less importance and left to the market. This will lead to fewer investments from governments for these issues and European strengths on these areas will be under pressure. There is likely to be more emphasis for example on communications security rather than speed and much less emphasis on green issue such as photonic energy systems, although there may be some rebound here related to off grid power supply. Also investments in the overall increase of competitiveness of European research and industry will be limited and e.g. SMEs will be less supported in start-up initiatives. Also, like the Budget scenario, the strengths in photonic manufacturing technologies will still be of importance, although the openness of the global market is limited; reduced economic growth will reduce investments in development of these technologies elsewhere.

The Asian developments in new more consumer oriented research and industry will be of less importance to the global economy, although low cost production will remain a crucial competitive advantage.

The opportunities in this scenario will focus on the thematic issues relate to the relevant emergency. Threats to the European research and industry base in the field of photonics are in the further reduction of the capacities. European research will be under pressure in areas not aligned to the emergency themes and this can lead to a significant reduction of capability allowing other regions to dominate in area where priority is reduced. A critical threat is that if a reduction of support of public research will occur, also the pipeline from research to industry of well educated personnel will be under pressure. This would even lead to a critical reduction of more global and highly competitive manufacturing industries like the Laser industry. The photonics technologies would not be supported because they are not included in the societal themes.

## 6.6

# Conclusions

The objective of the scenario analysis was to identify strengths, weaknesses opportunities and threats related to photonics in different futures. The scenario analysis can be seen as a way of reflecting upon the SWOTs of the individual supply chains given in chapter 3.

The first conclusion that can be drawn from the scenario analysis is that the photonics industry at large is robust against different futures. The market (scope, product demand, competition) is likely to change in the coming decade, but overall the innovative character of the industry and European strengths are well suited for a dynamic market. This is even enhanced by the early stage of industrial evolution of the industry, providing many opportunities. This clearly shows in the analysis, where in all scenarios, e.g. the strong position of the European manufacturing industry profits. Also a large number of SMEs is flexible and can adapt to each scenario.

In several scenarios, the lack of volume production in Europe is mentioned as a weakness. In scenarios where the market is shifted towards more consumer oriented products, the present strong linkage between European research and industry might be less valuable. Although many European organisations have good links to Asian and other volume manufacturers, the lack of indigenous volume manufacture reduces the potential economic gain as products move into high volume and reduces connectivity between early stage research and volume production.

Gadget world	Green innovation
<ul style="list-style-type: none"> <li>■ <b>Strengths</b> <ul style="list-style-type: none"> <li>– Strong presence of SMEs</li> <li>– Focus EU industry on manufacturing</li> </ul> </li> <li>■ <b>Weaknesses</b> <ul style="list-style-type: none"> <li>– Weak connection in product portfolio</li> <li>– Limited presence of high volume manufacturing industries</li> </ul> </li> <li>■ <b>Opportunities</b> <ul style="list-style-type: none"> <li>– High standard of living</li> <li>– Open global economy</li> </ul> </li> <li>■ <b>Threats</b> <ul style="list-style-type: none"> <li>– Emphasis on high volume markets</li> <li>– Relocation of research to Asia</li> <li>– Limited domestic support for enabling industries</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>■ <b>Strengths</b> <ul style="list-style-type: none"> <li>– Strong connection to present policy</li> <li>– Research and industrial base fits demand</li> <li>– Pipeline between research and industry</li> </ul> </li> <li>■ <b>Weaknesses</b> <ul style="list-style-type: none"> <li>– Strong presence SMEs are of limited importance</li> </ul> </li> <li>■ <b>Opportunities</b> <ul style="list-style-type: none"> <li>– Further emphasis on low energy products</li> </ul> </li> <li>■ <b>Threats</b> <ul style="list-style-type: none"> <li>– Increased attention to greening of products from other world regions</li> <li>– Increase in competition in global markets</li> </ul> </li> </ul>
Budget society	Emergency
<ul style="list-style-type: none"> <li>■ <b>Strengths</b> <ul style="list-style-type: none"> <li>– Limited number of low cost subsectors fit to these demands</li> <li>– Still demand for some strong EU industries (no change)</li> <li>– Innovative manufacturing is still needed</li> </ul> </li> <li>■ <b>Weaknesses</b> <ul style="list-style-type: none"> <li>– Limited EU presence of high volume producers</li> <li>– Limited overall EU focus of low cost products</li> </ul> </li> <li>■ <b>Opportunities</b> <ul style="list-style-type: none"> <li>– Some niche markets reducing energy consumption</li> <li>– Export of knowledge in some areas</li> </ul> </li> <li>■ <b>Threats</b> <ul style="list-style-type: none"> <li>– Strong competition on various markets</li> <li>– Quality is of less importance</li> <li>– Reduced funding for research further decreases competitiveness</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>■ <b>Strengths</b> <ul style="list-style-type: none"> <li>– Certain EU markets are well developed</li> <li>– Pipeline between research and industry in those markets</li> </ul> </li> <li>■ <b>Weaknesses</b> <ul style="list-style-type: none"> <li>– Weak connection in product portfolio</li> <li>– Limited presence of high volume manufacturing industries</li> </ul> </li> <li>■ <b>Opportunities</b> <ul style="list-style-type: none"> <li>– Greening of the industry and focus on safety/security</li> <li>– High volume will be less important</li> </ul> </li> <li>■ <b>Threats</b> <ul style="list-style-type: none"> <li>– Reduced investments of governments</li> <li>– Increased focus of other world regions to photonics in a broad sense</li> <li>– Reduced attention to innovative photonics</li> </ul> </li> </ul>

The analysis carried out shows that the main competitive advantage of the European research and industry is its focusing on the high end markets. Innovativeness and performance are crucial. Examples of industries are manufacturing equipment, healthcare, science, defence & security, professional lighting. This leads to higher profit margins, but needs the current strong research design and development base to be maintained. When the focus of the market will shift towards low cost and high volume, the overall sound position of the European research and industry will be at risk. The manufacturing industry will be an exception.

Public investments in photonic research were and are crucial to the European industry base and have played a significant role in its competitiveness. In the scenarios positive to the European research and industry, the governmental role is strong. But even in scenarios where the role is limited, the historic support is at the base of the competitive advantage of European research and industry. The relationship between the national and European governments and the research and industry base is relatively strong. Governmental intervention does support more long term focus and investments in the development of certain key capabilities, but this can distort the development of certain markets when one technology receives substantially more support than another. As such support is often on a national basis this can also lead to localisation of some markets.

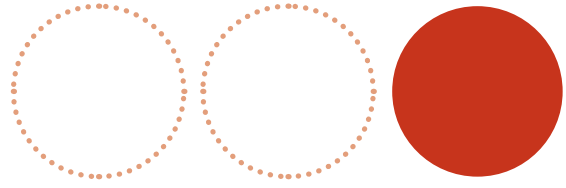
In all scenarios, the focus on energy is an important factor. It is clear that in "Green innovation", focus on reduction of energy consumption is of importance, but also the cost factor is also of importance to other scenarios. Although the focal photonics products for the future are uncertain, reduction of energy consumption is crucial.

The different scenarios show that the future regarding photonics is uncertain. Attention to SMEs and facilitation of start-up companies is of importance to create a more dynamic industry, with high response to new opportunities. In photonics, the connection between SMEs and research is strong and SMEs can address easily the challenges of a dynamic market. However, policy is needed to fully engage them in the supply chain and foster their expansion especially through collaboration to benefit optimally from the strong presence of this type of companies.

*Main messages from the scenario analysis:*

- *The European photonics research and industry at large is robust against future developments, because of its highly innovative nature and strong position in manufacturing.*
- *Lack of volume production can jeopardize the linkage of certain parts of European research to industry, weakening the latter's position.*
- *Focus of the European research and industry in general should be on high performance, low volume, highly innovative markets (although in some markets, the European industry is a major player in high volume markets).*
- *The relationship between governments, research and industry is a crucial factor to competitiveness. Especially public support for research and innovation increases the competitive advantage, including the opportunity for more radical innovations.*
- *Focus on reduction of energy consumption, or greening of photonics not only is crucial for environmental sustainability, but also to the economic sustainability.*
- *Support of SMEs, especially to enhance their participation in supply chains will further enhance the competitiveness of the photonics research and industry due to their capacity to adjust to new opportunities.*





# Final conclusions

## 7.1

# Introduction

The principal goal of this study was to investigate the leverage effect of photonics technologies on photonics-enabled applications and markets in order to illustrate the impact photonics has on these markets and related value chains. To achieve this, the study reviewed the current European photonics industry and compared this to a quantitative assessment of the value of European markets leveraged by photonics based on expert survey and extensive end market data. To better understand the European position, a full analysis of 6 key photonics value chains was conducted including their areas of greatest impact, potential impact changes looking toward 2020, possible future developments as well as potential responses to future scenarios. Finally, following consideration of the key value chains within a number of future scenarios, a number of conclusions can be drawn about the European photonics industry in general and its capability to respond to future changes and extend its impact in other markets.

In this chapter, the various messages from the assessments are integrated and presented in separate sections, including recommendations for policy. The separate conclusions on the various assessments can be found in the corresponding chapters.

## 7.2

# The European photonics research and industry base is globally significant

The economic assessment of the European industry and European research in the field of photonics shows that this market is significant in global terms. **European share of the global photonics market is about 25%, with the industry dominated by SMEs**, often focussing on do-

mestic markets. Although precise figures on research are not available, the outputs of the **1,000-2,000 research organisations estimated to be engaged in photonics research** are considerable. Also the value chain analysis showed that in most of the European industrial strengths, a research base is present. The European research base is not only highly connected to European industry, but also provides knowledge to other world regions. The leverage assessment shows that the importance of photonics to the rest of the European economy is significant. **About 20%-30% of Europe's economic sectors are estimated to be dependent on photonics for their competitiveness** (up to a certain level) and **1 in 10 European workers are depending on photonics for their daily activities**. However, this strong position is not consistent across all parts of photonics, with certain sectors highly dependent on photonics and others with a marginal dependence.

It can be concluded that the European photonics research and industry base is strong. Therefore, the following recommendations are made:

- The strong position of Europe and the significance of the overall photonics markets to the European economy justify a separate policy on photonics.
- The heterogeneous character of the photonics industry requires a combination of generic policy and thematic policy to ensure the optimal benefits are gained from the opportunities enabled by photonics.
- As the photonics market is highly global, the rare earth scarcity issues need to be addressed to ensure future growth in specific areas. Research in alternatives can be part of this approach, as well as trade agreements.
- The highly global character of the market will continue to grow in the future. Emphasis therefore needs to be given to the provision of support for SMEs in addressing this global market.

## 7.3

# The field of photonics is growing fast and creating vast opportunities

The study showed that the field of photonics is still in its early stages of development as an industry and is predicted to grow significantly in the coming decade. Not only the growth rates of the last decade and the recent quick recovery from the credit crunch but also the leverage assessment shows that the photonics industry is still in its early stages. However, also the heterogeneous character is clear and some areas are in their early stages of industrial development (e.g. photovoltaics, 3D displays, high power diode lasers), while others are already in their so called late phase of development (LCD displays, optical storage systems, consumer scanners). The conclusion is that innovation is at the core of this dynamic market, providing many opportunities for (new) market developments; new innovations will emerge, creating new products and related services.

To deal with this dynamic market development, the following recommendations are provided:

- To fully exploit the opportunities of this growing field, research and innovation is core. Full support is needed to provide a competitive base for this exploitation.
- Although some areas are clearly fast growing and can be seen as priorities for policy, many new research and application areas will emerge. In policy, start up initiatives need to be addressed.
- Photonics are expected to bring a range of new innovations, but which ones are not clear yet. Focus on all opportunities demand takes a lot of effort and therefore will in general not be done by all companies. This can lead to limited anticipation on new other opportunities. Policy support to periodically identify new potential opportunities is needed (conferences, foresight studies), however in close cooperation with research and industry.

## 7.4

# Also focus on large sectors where photonics has the potential to enhance competitiveness

One of the most important outcomes of the leverage assessment is that photonics also creates significant leverage in sectors where the dependency on photonics for their competitiveness is at present minimal. Retail and healthcare show significant but minimal dependency, but due to their size the overall leverage is high. Over 50% of the calculated leverage of photonics to the European economy is due to this combination of small dependency and large size.

Traditionally, focus of policy is on application areas where the absolute leverage is high. This outcome leads to the following recommendations:

- Subsequent to areas where the application of photonics has a major impact, attention also needs to be given to large sectors where the current penetration of photonics is limited (e.g. retail and healthcare). The resulting leverage could be large.

## 7.5

# Establish a specific policy to support SMEs

The study shows that SMEs dominate the company size portfolio. The dynamic character of the market is suitable for flexible and innovative small companies enabling emerging opportunities to be rapidly exploited, but the innovative character of the sector also requires access to financial capital. Moreover, due to the high tech character of the indus-

try, linking the activities of different organisations in the value chain (horizontal and vertical) is of importance to optimally benefit from the opportunities. Besides SMEs not being strongly present in certain areas, also the position in a larger value chain is sometimes difficult. One example may be solid state lighting where there are a small number of large and globally orientated LED chip suppliers and a large number of smaller regionally based luminaries suppliers integrating chips.

The following recommendations are given:

- Set up a specific policy to support SMEs for participating in the various value chains. This must include support of risky start-up initiatives, as well as support for participation in the supply chains.
- Support the creation of SME spin-offs from research organisations. This is of importance because of the research intensive character of photonics markets.
- Improve access to finance for photonics businesses where there are risks but, at the same time, significant opportunities for growth.

## 7.6

# Support the vertical connection between research and industry

The assessment shows that the horizontal elements in the value chains are often of limited importance and globally organised. Suppliers of photonic components can be situated in Asia, while the assembly of user oriented products is done in Europe. Also the linkages are often weak (quick change of supplier, based on cost reduction). However, the linkages between research and industry (so-called vertical value chains) are of more importance and often well established. Highly skilled personnel are a result of long term relationships between companies and universities. This pipeline is crucial for the competitiveness of companies and research done at universities is an important input to innovation of European industry. However, changes in the organisation of innovation

are now taking place and new innovation schemes are emerging, such as open innovation and user centred innovation. The linkages with research from other areas have also proven to be productive in initiating different products (e.g. combining cognitive research with the development of new types of displays).

This assessment of the relationship between research and industry leads to the following conclusions:

- Anticipate the changes now occurring within the innovation environment. New organisational approaches to share knowledge and organise research are needed to equip the photonics research and industry base in Europe. These new business models depend on the area of application and should be researched and tested.
- Being a high tech market, incorporation of new scientific and technological developments and insights into multidisciplinary photonics research creates new opportunities. Focus on multidisciplinary will initiate the development of new and highly competitive applications.

## 7.7

# Participate actively in photonics as government

Historically, the participation and involvement of governments in the area of photonics is often seen. The telecom industry and the stimulating effect of governmental policy on photonic energy systems are two examples where the connection is clear. This participation is not only by funding research, but also through funding of demonstration projects. It can even be said that governmental support is needed to create more radical innovations, to be expected within the next decade. However, the credit crunch has put pressure on EU Member States to get their financial situation under control, sometimes leading to reduction of funding for photonics research and innovation. This might jeopardize the earlier mentioned pipeline between research and industry. Another issue is the sometimes national character of photonics industries, where

a more coordinated European approach might be more beneficial and effective in the use of resources.

The following recommendations are to be made:

- Initiate new demonstration projects in photonics markets where the economy of scale and creation of a positive “image” can reduce the important barriers for full market development.
- Ensure funding of research in photonics areas where this pipeline is crucial for the survival of companies. Also funding of other areas can initiate new competitive business start-ups.
- Coordinate innovation policy on a European level to maintain the strong European position in regard to other world regions.

## 7.8

# Create an active policy to ensure the availability of highly skilled personnel

Close to the active participation of governments in photonics related innovation policy, is the creation of an active policy on education. It is clear that various trends are undermining the availability of highly skilled personnel for the photonics industry. Not only the brain drain, but other demographic trends on ageing are both qualitatively and quantitatively changing the characteristics of the labour force. Next to the increase of industrial activities, older personnel and tensions on the labour markets will make it harder for the industry to recruit adequately skilled personnel. Being a high tech and innovative industry, this is crucial for the industry to survive.

The recommendation is therefore made that:

- An initiative is implemented to get more high skilled personnel educated for the photonics industry. Students participating in science and engineering degree courses at university should undertake at



least one course related to photonics during their 3-4 years as an undergraduate. The argument for this step is based on the increasing importance and pervasiveness of photonics in products and services in any developed economy. In cooperation with research, as well as coordinating activities among the EU Member States, a policy is needed to address this crucial issue.

- Further automation of industrial activities and measures to support older personnel in their activities are needed to be researched.

## 7.9

# Focal areas: Non-consumer markets, with exceptions

The assessment of the photonics research and industry shows that in many cases the strong position of Europe is on the non-consumer oriented markets. Low cost production is mostly based in Asia where the competitiveness of manufacturing is high. But European companies are also often well represented in more societal markets like healthcare, science and security, where governments have considerable influence on the market characteristics. There are some exceptions, like the production of lighting, base materials and other high volume components. However, overall the European photonics industry can be considered as focused on high performance and low volume markets.

This assessment leads to the following recommendations:

- Enhance the innovation policy and focus on high performance and low volume applications. This is needed to maintain the competitive advantage to other world regions.
- Support some dedicated established high volume markets (e.g. lighting, photonic energy systems), possibly with demonstration projects and focused research, where high productivity manufacturing equipment can offset the low cost labour advantages of low labour cost economies.

## 7.10

# Social impact is overall positive, but focus on the negative impacts

The assessment of the six value chains clearly shows that in the majority of cases, photonics can have a positive impact on social issues. This is particularly the case for healthcare, security, employment and the digital divide where the positive impact is clear. However, the information overload initiated by high quality access to information and communication can initiate a negative societal impact. This needs to be researched and countermeasures need to be identified.

## 7.11

# The environmental impact is unclear, but potentially positive

The environmental impact assessment of the six value chains showed that a decisive conclusion cannot be drawn. Although the preliminary assessment of the impact on climate change shows that there might be a reduction of unsustainable energy usage, there are high risks on rebound effects. Whilst reduction of energy consumption of products is clear, overall new functionalities can initiate such a strong overall usage that the net gain is negative. The further development of the photonic energy systems and advanced lighting show a more positive outcome. As regards waste, the increased complexity and overall increase in waste might be negative. However, analysing this complex environmental impact is beyond the scope of the study and the recommendation is therefore that this should be further researched.

A clear conclusion can be drawn on energy consumption. As the market developments are highly consumer driven and difficult to regulate,

strong emphasis on reduction of energy consumption in research programs (consideration of energy consumption in developing new products) is needed in order to ensure research focus in this area. As for the benefits, these will not only be on the environmental side of sustainability, but also economic benefits are gained by reducing energy consumption in an economy where the price of energy is likely to increase significantly.

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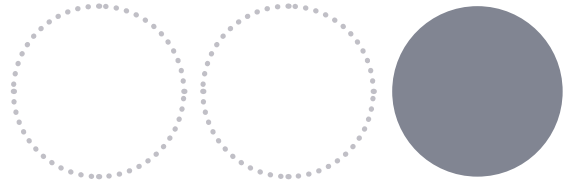
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# Annexes



# A Overview of photonics technologies in application domains

## Examples of photonics technologies for enabled manufacturing industries

	Scanning, sensing and imaging	Information, communication and network	Screens and displays	Advanced lighting	Photonic energy systems	Laser systems
<b>Manufacture of Electronics and Optical Equipment</b>	Lithography/images for semiconductor fabrication Metrology systems for process control	Factory intranets	Advanced process control systems (e.g. tactile, 3D) Augmented reality	Low energy lighting illumination systems with light guides		Marking, drilling and high efficiency materials processing
<b>Manufacture of Vehicles and Large Machinery</b>	Imaging systems for robotic manufacturing Imaging systems for robotic manufacturing Optical scanners for quality control Proximity cameras	In vehicle optical networks Factory intranets	Advanced process control systems Head up displays and augmented vision systems	Low energy low profile indicator lighting Headlights Merino lighting		High power, energy saving cutting and welding. Rapid prototyping
<b>Manufacturing of Fine Chemicals and Pharmaceuticals</b>	Imaging systems for robotic manufacturing Composition sensing systems for quality control	Reduced energy optical networks Low cost optical networks	Advanced process control systems (e.g. tactile, 3D)	UV based disinfecting lighting systems		Laser based chemistry Laser based research
<b>Manufacturing of Textiles and Clothing</b>	Imaging systems for robotic manufacturing Optical scanners for quality control & cutting	Reduced energy optical networks Low cost optical networks		Precision colour lighting for quality control		Laser cutting and templating
<b>Media Production and Broadcasting</b>	Computer generated imaging Cameras including 3D and HD light sensors	High capacity optical access and core networks Data storage networks	Television and computer displays Video Production suites Very Large Area Displays	Colour adaptable lighting Low thermal impact stage lighting.		
<b>Food and Beverage Production</b>	Imaging systems for robotic manufacturing Sensing & imaging systems for orientation & quality control	High speed factory intranets	Advanced process control systems (e.g. tactile, 3D)	Disinfecting lighting systems		
<b>Printing &amp; Publishing Activities</b>	Virtualisation of libraries Digitisation of historical print media	Reduced energy optical networks Ultra fast optical networks Interactive media	Ebooks, Enk, flexible and tablet displays Large Area Displays Digital proofreading	UV curing	Photovoltaic augmented power supplies	Laser printing, High volume commercial computer plate direct printing, Precision thermal printing.
<b>Oil and Gas Exploration</b>	Detection systems Multi spectral identification of wells Temperatures & stress sensors to verify well integrity	Condition monitoring of production Remote monitoring		Low voltage lighting		



Examples of photonics technologies for Final Markets

	Scanning, sensing and imaging	Information, communication and networks	Screens and displays	Advanced and lighting	Photonic energy systems	Laser systems
<b>Medicine &amp; Healthcare Activities</b>	Biomedical imaging Advanced early diagnostics. Endoscope camera. Pill cameras. Conditions monitoring	Telemedicine surgery Remote Care assistance Brain-Computer Interfacing	Robotic surgery, keyhole/endoscope surgery	Photodynamic therapy, Surgical lighting		Targeted treatments Lasersurgery. Lightbased pathology/diagnostic systems e.g. cell counters
<b>Defence and Security Activities</b>	(Night)vision and imaging devices Surveillance systems Bodycameras Security document scanning Scanners for material inspection Security/ safety scanning (people/goods)	Advanced encryption and secure networks. Line of sight communication systems Advanced	Stereoscopic displays Augmented reality displays Simulators/displays Head-up displays Large Area Displays Headmounted displays Augmented Reality	Infrared lighting Low energy lighting High reliability lighting on airfields	Photovoltaic augmented power supplies Solarpanels for energy supply in spacecraft	Laseweaponsystems. Laserbased infrared counter measures Photonic gyroscopes for navigation
<b>Aviation and Space Infrastructure</b>						
<b>Road &amp; Rail Transport and Logistics Infrastructure</b>	Camera systems for monitoring cartraffic Sensors for detections objects on rails/ surfaces Detectors of defects, wear Detectors for fibre communication systems Microscopic systems Specialised cameras Astronomy Telescopes Biosensors for biological and chemical analysis	Vehicle-to-vehicle communication In vehicle communication High capacity fibre optic Access and core networks Data storage networks Globalisation & virtualisation Research facilities with high speed fibre optic networks	Advanced in vehicle displays (projection, 2d/3D) 3D and interactive displays 3D interactive displays	Advanced LED streetlighting, traffic and signalights. Low energy vehicle lighting Low energy lightsources for shorthead communications Low energy lightsources	Vehicle PV Powering of remote Communication relay sites Powering of remote sensors	Lasersources for optical fibre Communication systems Laser based sensing systems
<b>Telecommunications Infrastructure</b>						
<b>Science, Research &amp; Development</b>						
<b>Electricity Generation &amp; Supply</b>	Optical diagnostic systems for nuclearfusion Detection of defects, wear Construction monitoring, material control and seismic measurements Security systems Environmental sensing and scanning Geoobservation/surveillance cameras(mobile) Office scanning systems	Electrical grid balancing using fast fibre networks Remote stress strain monitoring. DVD and Blu-ray optical storage Fast computing and data transmission technologies (e.g. for gaming) High speed networks for payment processing	3D optical presentations/ simulations Interactive wipe boards, Augmented and VR displays 3D displays for entertainment Displays for mobile devices Very large area displays for arena & sports venues Large area displays. Electronic price displays. Video based advertising displays	Low energy lighting, Colour adaptable lighting Remote sensors Low energy lighting Specialized lighting for recreation (e.g. concerts) Low energy lighting, Colour adaptable/ product optimised lighting	Photovoltaic's power generation Photovoltaic's on/ in building powergeneration Powering of remote environmental monitoring	Lasertechnology for nuclear fusion Laserleveling, Distance and alignmentmeasurement Prototyping in architectural design. Laser based sensing systems e.g. turbidity
<b>Construction and Built Environment</b>						
<b>Environmental Monitoring and Protection</b>						
<b>Recreation, Culture and Education</b>						
<b>Retail &amp; Services</b>	Logistical scanning Scanning for quality control Video surveillance systems					Lasers for optical storage (DVD/ Blu-ray) Laser shows/ displays. Barcodes scanners

## B

# Backgrounds on leverage assessment

### B.1 What is leverage

One of the main objectives of the study was to assess the leverage of photonics technologies to the broader European economy<sup>16</sup>. The indication of the importance of photonics technologies to the European industry and society at large is of high relevance to the development of policy to support photonics research and innovation. Before the final results can be shown, the concept of leverage has to be made clear as this is rather new and rarely researched.

The results of the leverage assessment presented in this report need to be taken with caution. First, the method used to determine leverage is new, experimental and not scientifically validated. Second, the assessment of the dependency of the enabled manufacturing industries and final markets on photonics for their competitiveness is based on expert judgement. As this assessment involved mainly experts from the photonics area this might have led to a bias. Under these circumstances the reader is warned that the figures reported here on leverage need to be put into context. However, the researchers believe that the results provide a valid indication of the leverage of photonics to the European industry.

The leverage described in this section reflects the impact of photonic technologies to both photonics-enabled manufacturing industries (manufacturing processes and products), or the use of photonics-based products in final markets. **Photonics leverage** is defined in the following way:

<sup>16</sup> Note that a distinction has been made between the impact of photonics technologies on the photonics industry, the photonics enabled industry and final markets. The impact of photonics technologies internally within the photonics industry is discussed in chapter 2, as the economic effects are clear.

*The proportional contribution photonics makes to the value of an end product or service, either by enabling/enhancing the productivity of the manufacturing process, or by providing/enhancing functionality in the end device, without which the end product would not be competitive.*

Thus leverage is a reflection of the dependency of a product (or service) on photonics technology: in other words if photonics technologies were not available, what proportion of the functionality - and thus the value - of the end product would be reduced? This can be characterized by a factor which can take the value of 0-100%, from totally independent to fully dependent.

Having estimated the contribution of photonics to a specific product/service or sector it can be quantified in a variety of ways. Here we use two main measures:

3. The **photonics market leverage** (PML) which is the size of the market affected i.e. the economic market value of photonics enabled manufacturing industries and final markets, that are impacted by photonic technologies, either by improving its productivity or creating new or better a product (or services) with additional functionality.
4. The **photonics employment leverage** (PEL), which is the number of jobs dependent on photonics i.e. the number of workers in photonics enabled manufacturing industries and final markets that are significantly depending on photonic technologies, regarding their productivity, safety, or other aspects positive to their work.

Both are calculated in the same way: By multiplying the overall relevant market size/employment figures by the leverage proportion (expressed as a percentage).

## B.2 How to assess leverage

The previous section describes leverage in broad terms, but an actual computation is more complex. The assessment of the dependence of particular enabled manufacturing industries or final markets on specific photonic technologies was done through a survey and the market quantification uses data available from statistical databases.



Figure 32: Approach to the survey.

The survey was conducted among photonics and non photonics experts, asking them to estimate the overall dependency of certain industries or markets on photonics technologies. In this survey, four elements were to be made operational: 1) How to define enabled manufacturing industries and final markets; 2) How to structure photonics technologies; 3) How to rate their dependency and 4) Making a difference between 2010 and 2020.

To make the survey operational, the *first step* was to identify and define the relevant photonics-enabled manufacturing industries and final markets. Traditional classification structures like NACE<sup>17</sup> and CPI<sup>18</sup> use a vast number of classes to be addressed (hundreds). To make an expert survey practicable possible, an aggregation and selection of industries and markets was needed. Using the expertise and experience of the study team first a ‘long list’ of 98 industries/markets most likely to be dependent on photonics was compiled. This was then condensed to just 19 enabled manufacturing industries and final markets using select combinations of the previous 98 relevant industries. The 19 enabled manufacturing industries and final markets are listed in the table below. The connection to the underlying NACE subsectors can be found in Annex F.

<sup>17</sup> NACE: Nomenclature statistique des activités économiques dans la Communauté européenne, is a European industry standard classification system consisting of a 6 digit code.

<sup>18</sup> CPI: Consumer Price Index is a statistical structure developed by the United States Bureau of Labour Statistics to measure changes through time in the price level of consumer goods and services purchased by households.

Enabled manufacturing industries	Final Markets
Manufacture of Electronics and Optical Equipment	Medicine & Healthcare Activities
Manufacture of Vehicles and Large Machinery	Defence and Security Activities
Manufacturing of Fine Chemicals and Pharmaceuticals	Aviation and Space Infrastructure
Manufacturing of Textiles and Clothing	Road & Rail Transport and Logistics Infrastructure
Media Production and Broadcasting	Telecommunications Infrastructure
Food and Beverage Production	Science, Research & Development
Printing & Publishing Activities	Electricity Generation & Supply
Oil and Gas Exploration	Construction and Built Environment
	Environmental Monitoring and Protection
	Recreation, Culture and Education
	Retail & Services

Table 4: Overview of the enabled manufacturing industries and final markets used for the leverage assessment.

Eight enabled manufacturing industries were identified as being significantly predominantly users of photonic technologies in their manufacturing. Eleven final markets were identified, where photonic technologies were considered to have a significant contribution in the products used by final customers/ consumers<sup>19</sup>. However, many of the enabled manufacturing industries bridge both of these categories with photonics making a contribution to both manufacturing and appearing in the final product.

The **second step** to the survey questionnaire was the structuring of photonics technology. The six photonic technology clusters identified previously (see section 1.3) were also used as a categorization structure in the survey. This led to a manageable 19 by 6 matrix of questions, which were to be answered by experts. The third step of rating the dependency was based on a semi-quantitative scale<sup>20,21</sup>. In the last **fourth step** a distinction was made between 2010 and 2020 in order to also be able to assess the dynamics in leverage for the future.

<sup>19</sup> It is clear that photonic technologies also have leverage on other industries and final markets, so our estimates should be taken as conservative.

<sup>20</sup> A semi-quantitative scale of 5 classes was used: 1 = Not relevant for the competitiveness; 2 = Of marginal importance for the competitiveness; 3 = Of intermediate importance for the competitiveness; 4 = Important for the competitiveness; 5 = Crucial for the competitiveness.

<sup>21</sup> Some 42 experts participated in the survey. The experts consulted were both photonic experts as well as more industrial experts in the photonics enabled industry.

The outcome of the survey provided a list of indications from the experts on their view of dependency of the industries and markets to photonics technologies. To translate the outcomes of the survey to a usable indicator for calculations, the **leverage impact** measure (LIM) was devised<sup>22</sup>. This LIM is the indicator for dependence of a specific industry/market on photonics technology and has a range from 0 to 100%. The LIM can be greater than the percentage that photonics represents in the final bill of materials of a product. If the functionality of a product is highly dependent on photonics, but just a small portion of the product is photonics technology, the LIM can be a 100%. An example is a DVD player with only a low cost diode laser and photonic sensor as photonics components, still being totally dependent on photonics technologies. Another element is that if a product depends on multiple photonic technologies, the LIM can not exceed 100% and the photonics technology with highest LIM is dominant. This approach reflects the logic that the maximum dependency is not reduced in any way if other technologies are less crucial to a particular application.

To complete the leverage assessment, the LIM data was combined with a quantitative assessment of the size of the various impacted industries and markets. For the economic data, the Eurostat database was used<sup>23</sup>. To populate these clusters of economic activities with economic data only relevant for photonics, they were connected to the NACE sectors (3-digit) that show significant dependency on photonics. In this way, e.g. the manufacturing of electronic and optical components do not include "31.1 Manufacture of electric motors, generators and transformers". A detailed overview of the NACE industries attributed to the Enabled manufacturing industries and Final markets is provided in Annex F. Eurostat is also used for production data. However, turnover data for service sectors are taken from a variety of sources and have been cross checked to ensure compatibility with the manufacturing data. For

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<sup>22</sup> The choices made by the respondents to the survey are semi-quantitative and thus can be translated into LIMs. Based on further expert consultation we assigned typical fixed percentages as benchmarks to the values of the scores. "Crucial" should be interpreted as at least a 90% LIM and this is represented by a value score of 4. The other benchmark values were chosen similarly with score value 1 = 1% and score value 2 = 10% and a score value of 3 = 50% - thus giving a roughly logarithmic scale which agreed well with independent LIM estimates made by the project team. Once converted into LIM percentages the scores were averaged between respondents in the usual way.

<sup>23</sup> Eurostat provides robust economic data, albeit, slightly out of date (the latest consistent information at the time was available for 2008) and with some imprecision in regard to the correspondence between NACE and RAMON code systems.

tradeable goods import and export data are also derived from Eurostat<sup>24</sup>.

This leads to the following equation for the calculation of the photonics market leverage:

$$PM_{\text{Industry/market}} = LIM_{\text{industry/market}} \cdot \text{Market size}_{\text{industry/market}}$$

This calculation of the PML is specific to each sector and market, but a summation over all industries and markets analysed will provide a macro overview of the total leverage.

This same approach can also be followed to assess the photonics employment leverage. Based on the same sources and approach, this would lead to the following equation:

$$PEL_{\text{industry/market}} = LIM_{\text{industry/market}} \cdot \#Empl_{\text{industry/market}}$$

Also here, the assessment of the PEL is sector and market specific and a summation over all industries and markets analysed will provide a macro overview of the total leverage regarding employment

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<sup>24</sup> To give a true representation of the actual economic activity in the impacted industries and markets sectors in Europe, the total European market is taken as imports plus production less exports within each sector. This calculation is important to fully capture the levels of European economic activity in each sector. For example, goods which are imported and used in Europe, but manufactured elsewhere can still be highly dependent on photonics and are fully accounted for using this methodology.

### B.3 Overall outcomes of the Leverage Impact Measures

Based on the survey results and quantitative data from various statistical sources, the values of on LIM, PML and PEL were computed. An overview of the results is given in the following table.

Impact Summary	EU-Market (€bn)	Employment (1000's)	Photo-nics LIM Max 2010	Photo-nics Market Impact PML (€bn)	Photo-nics employment impact PEL (1000's)
<b>Manufacturing</b>					
Manufacture of Electronics and Optical Equipment	462	4320	70%	325	3039
Manufacture of Vehicles and Large Machinery	682	4118	59%	405	2448
Manufacturing of Fine Chemicals and Pharmaceuticals	88	1030	31%	27	321
Manufacturing of Textiles and Clothing	440	2218	11%	48	244
Media Production and Broadcasting	246	756	65%	159	489
Food and Beverage Production	900	4000	17%	152	674
Printing & Publishing Activities	104	243	49%	50	118
Oil and Gas Exploration	74	203	28%	21	57
<b>Final Markets</b>					
Medicine & Healthcare Activities	974	5331	47%	456	2497
Defence and Security Activities	246	5342	58%	144	3115
Aviation and Space Infrastructure	128	1101	55%	71	606
Road & Rail Transport and Logistics Infrastructure	1393	6104	26%	358	1568
Telecommunications Infrastructure	431	954	81%	350	774
Science, Research & Development	4	940	71%	3	671
Electricity Generation & Supply	321	933	34%	108	313
Construction and Built Environment	1384	13548	10%	138	1355
Environmental Monitoring and Protection	3	171	35%	1	60
Recreation, Culture and Education	598	9442	43%	258	4075
Retail & Services	1892	25272	28%	538	7191
<b>Total</b>	<b>10371</b>	<b>86027</b>		<b>3613</b>	<b>29614</b>

Table 5: Overview of Leverage Impact Measure (LIM) impact to employment and EU market, regarding enabled manufacturing industries and final markets.



Although the survey conducted also questioned the participants about the LIM of 2020, in this overview only the 2010 results are shown. The data on LIM 2020 is used in the description of future characteristics. Further discussion about these outcomes can be found in the following sections.

## B.4 Leverage on EU markets

This section presents a detailed consideration of leverage on specific markets. By multiplying the LIM percentages with the economic data from the combined NACE sectors, we have derived a picture of the photonics market leverage (PML), providing an indication to what extent a sector is dependent on photonics. This figure indicates the economic market value of photonics enabled manufacturing industries and final markets that are impacted by photonic technologies, either by improving their productivity or creating new or better products (or services) with additional functionality.

The overall value of PML can be calculated – this amounts to €3.6trillion. It might seem useful to put this number into perspective by comparing it with the overall EU GDP. However, this direct comparison is complex and potentially misleading. The PML is based on the overall size of all individual EU markets which is considerably higher than GDP<sup>25</sup> because the output of one industry often forms part of the turnover of another. In calculations of GDP this issue is resolved by including only value added (profit and wages) rather than turnover for services sectors such as retail.

If value added data is used for the service sectors of transport, retail, telecommunications and science research and development using available value added data from: ‘Main features of the EU services sector’, Eurostat 78/2008 then photonics leverage with respect to manufactured output and value added for key service sectors reduces to €2.8trillion, equivalent to 23% of European GDP (€11.8trillion). Any comparison between leverage and GDP is further complicated by the effect of the balance of trade – the difference between EU consumption and production.

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<sup>25</sup> This is illustrated by the fact that in 2005 the turnover of all EU27 non-financial services enterprises alone was roughly the same as the whole of GDP. A recent Eurostat report states: “Services were the main activity of 14.5 million enterprises in the EU-27 in 2005, which generated a turnover of EUR 11 974 billion Producing a value added of EUR 2 991 billion and employing 76 million persons”. This single sector turnover is equivalent to EU GDP of 11.8 trillion.

The result of the calculation of PML based on turnover of about €43.6trillion can be compared to the European photonics market value of €58.5 million (section 2.3) for the same period (2008). The ratio of photonics market leverage (PML) to the size of the photonics market is thus ~62<sup>26</sup>. The high value of this ratio indicates the fundamental nature of photonics whereby the technology frequently provides the enabling step, yet represents a small contribution of the total product cost.

The relative impact of photonics in different sectors is illustrated in the following chart.

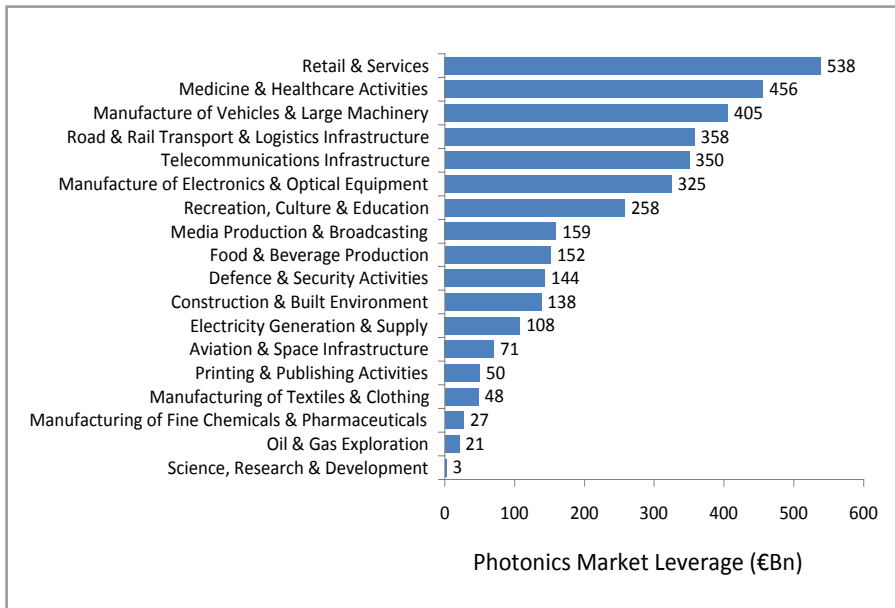


Figure 33: Photonics Market Leverage (PML) in 2010 (billion Euro) - total €3.6 trillion

It is clear that several markets are significantly impacted by photonics with a PML of €300-€500bn reinforcing the wide ranging importance of photonics to very diverse industries/markets from electronics manufacture to automotive, healthcare, telecoms, transport and retail. A number

<sup>14</sup> It is not possible to calculate this ratio for individual manufacturing or final market sectors as there is not a one to one link between a single photonics technology sector and a single end market, e.g. lasers can appear in many different end products / manufacturing processes.

of the most significantly impacted markets such as Retail and Healthcare feature because of the combination of huge market size and modest but still significant dependency. Others such as Telecommunications and Electronics manufacture feature because they have very high dependence on photonics and are still significant markets. Science research and development appears less significant because, although photonics dependency is high, the total market size is much less (although published estimates of the size of the EU research market vary significantly with some 10X large than the Eurostat figure used here).

Overall, the conclusion that can be drawn is that photonics technologies have high impact on a large part of both EU industries and final markets. Although crucial dependency is only relevant for some final markets, several industries experience crucial dependency on their production processes and could not survive without them. However, many final markets and enabled manufacturing industries experience significant dependency and efficiency and effectiveness of manufacturing and our daily lives is impacted strongly.

## B.5 Leverage on EU employment

The second type of leverage to be assessed has a social character and looks at the dependency of workers on photonics to do their jobs efficiently and effectively. This section is about the number of workers in photonics enabled manufacturing industries and final markets that are significantly dependent on photonic technologies, regarding their productivity, safety, or other aspects positive to their work.

In total the leverage of photonics on employment in Europe (PEL) is found to be ~30 million jobs, The leverage of photonics on employment represents ~14% of the total EU employment of 214 million. This is broadly similar to the 23% fraction of GDP impacted by photonics indicated above when taking the value added contribution from service sectors. As the number of jobs in Europe directly related to the photonics sector is estimated to be around 265,000 in 2008/2010 [Extrapolated from SRA, 2010], the ratio between workers directly involved in the photonics industry and workers depending on photonics is ~110. This again shows the very high enabling nature of photonics. The increase above the ratio between the direct photonics market and PML can in-

terpreted in a number of ways. For example, it may indicate that photonics technology has a disproportionately higher impact in high labour content sectors. Both the medical and retail sectors can be characterized in this way and the above analysis indicates both are significantly impacted by photonics, but in both cases the actual value of the photonics components is modest e.g. lighting and bar code reading in retail.

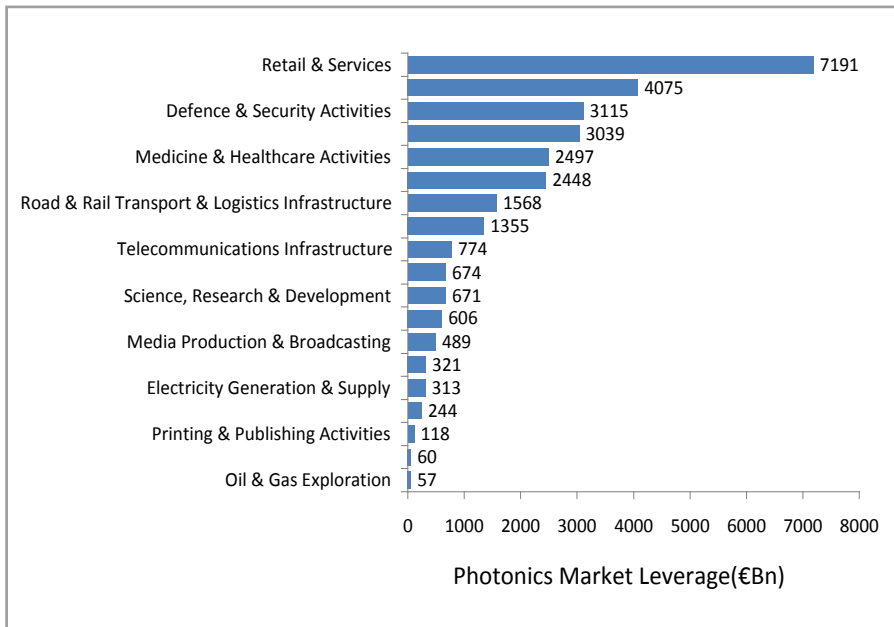


Figure 34 Photonics Employment Leverage (PEL) in 2010 (1000 jobs) - total 30 million

Looking at the employment perspective in final markets, given above, it is clear that the pattern of dependency on photonics is different than those of the PML. Retail remains on top, helped by the very large number of people employed in this sector. Recreation & education and Defence & security also appear higher due to the relatively higher numbers employed in these sectors. It is clear that the manufacturing industries show less relative PEL than PML, as they are usually more capital and less labour intensive.

The overall conclusion of this assessment is that photonics technologies have a relative high impact on the employment in Europe. Especially

some final markets are significantly dependent on photonics technologies to facilitate their workers in doing their work efficiently. Major final markets in terms of PEL are: retail & services, medicine & healthcare activities & recreation, culture & education and defence & security.

## C

# Four future scenarios of Photonics

## C.1 Introduction to the scenarios

Scenario analysis is an often used method to assess potential future changes in order to develop anticipatory intelligence. This study also used Scenario analysis for this purpose and created four different worlds that acted as reflection to the development of the photonics market. In these worlds, the identified drivers of change acted as the profiling elements, taking on different shapes. In this Annex, the followed approach and the developed scenarios are described.

The first step in the scenario analysis was the identification two drivers of change that will 1) have major impact on the development of the photonics market and 2) are highly uncertain in its occurrence. These two drivers acted as two axes to a Scenario analysis matrix. The two main drivers are set to take two opposite extreme values, leading to four different "worlds".

The project team discussed the described drivers of change from chapter 5 and came to the conclusion that both the economic growth and the role of government in our economy were the major determinants to the photonics industry, incorporating and touching many other drivers of change:

3. The rate of economic growth, with one side being low economic growth and the other side high economic growth;
4. The role of the government in our economy, taking the position

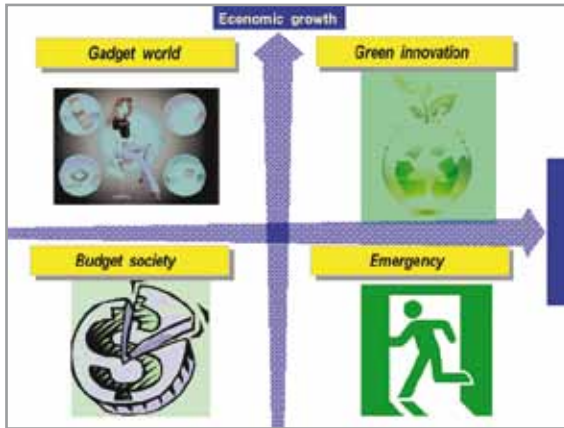


Figure 35: The four Leverage scenarios for analysis.

from a full market driven economy, to a governmental supervised market.

Positioning those two main drivers within a scenario framework led to four scenarios. The first scenario shows strong economic growth, but governmental and public intervention is limited. This leads to a society and economy that is oriented towards individual consumer needs, where consumers have money to

spend (Gadget world). The second scenario still has strong economic growth, but because of governmental intervention, attention is given to more long term societal needs (Green innovation). In the third scenario, the consumer has a limited budget, but the consumer will be in the driver seat for spending (Budget society). The last scenario also shows limited economic growth, but the role of government in where to invest is strong, leading to focus on only priority issues (Emergency).

Of those four worlds consistent scenario logics can be found in the following sections, including the incorporation of the identified drivers of change (Chapter 5). During an expert workshop, the four scenarios were used to discuss the different value chains within different future contexts. Especially the Strengths, Weaknesses, Opportunities and Threats were the object of discussions.

In the following sections, the four scenarios are described.

## C.2 Scenario 1: Gadget World

This scenario depicts a high growth, high tech society that is more free-market-driven than the “Green Innovation” and where other consumer interests beside ecological aspects like fun, recreation, technological experimentation, life-style and “showing ones wealth” play an important/

dominant role. This scenario derives from a very high economic prosperity – at least for a sufficient number of people and industries – to enable free-market driven and privately financed innovation and allows for a sufficiently affluent consumer base.

<b>Gadget world</b>	
<p><b>Demographic driving factors</b></p> <ul style="list-style-type: none"> <li>– Attention to the elderly, including need for support</li> <li>– Limited increase in population due to immigration</li> <li>– Limited shift towards the city</li> </ul> <p><b>Economic driving factors</b></p> <ul style="list-style-type: none"> <li>– Full open markets, many SME's</li> <li>– Significant economic growth, especially in ICT</li> <li>– Business strategy on fast track innovations</li> <li>– Relative strong HR, but funded by industry</li> <li>– Strong competition between companies</li> </ul> <p><b>Social driving factors</b></p> <ul style="list-style-type: none"> <li>– Focus on individuals in stead of communities</li> <li>– High attention to the user</li> <li>– Lifestyle is on material goods and high tech innovations</li> <li>– Demand for innovation and new products</li> </ul>	<p><b>Technological driving factors</b></p> <ul style="list-style-type: none"> <li>– ICT developments are strong, including miniaturization and other ICT related drivers</li> <li>– Many new innovations and some focused breakthroughs</li> <li>– Attention to infrastructure</li> </ul> <p><b>Environmental driving factors</b></p> <ul style="list-style-type: none"> <li>– Limited attention to environmental footprint</li> <li>– How to deal with waste and energy is issue</li> <li>– Strong resource scarcity</li> </ul> <p><b>Political driving factors</b></p> <ul style="list-style-type: none"> <li>– Limited involvement of politics to science and innovation</li> <li>– Focus of governmental to general support on innovation</li> <li>– Financial support of governments to research and innovation, because of economic growth</li> </ul>

Governmental regulations and interventions constraining research and development are rather low, thus giving more room for experimentation and riskier “radical” innovations. Risk perception is generally low and innovation is regarded as more important than precaution. The product palette that gains interest is wide and ranges from medical and health related technologies over next-generation mobile and web devices to virtual reality and entertainment robots, whereas “gadgets” play an important role. In contrast to the “Green Innovation” scenario, technology, especially in the areas of ICT, multimedia and entertainment, is far less perceived as a potential risk.

Consumer behaviour is to a great degree inspired by early adaptors and a “technological elite” that is then being imitated by general adoption within society. This drives competition and innovation and results in rapid innovation cycles and socio-technical changes.

### C.3 Scenario 2: Green Innovation

This scenario depicts a setting where sustainability represents a major driver for innovation and technological development strongly supported by both governments and consumers. Energy efficiency, environmental protection and responsibility become important/ dominant competitive dimensions for industry supported by strong governmental regulations and standards (e.g. emission standards, limits on energy consumption etc.).

Green innovation	
<p><b>Demographic driving factors</b></p> <ul style="list-style-type: none"> <li>– Attention to the elderly</li> <li>– Normal population growth</li> </ul> <p><b>Economic driving factors</b></p> <ul style="list-style-type: none"> <li>– Significant access to financial capital</li> <li>– Limited open markets, limited SMEs</li> <li>– Limited but significant economic growth</li> <li>– Business strategy focusing on public funding</li> <li>– Relative strong HR</li> <li>– Coordination and cooperation is of importance</li> <li>– Limited globalized markets, due to governmental role</li> </ul> <p><b>Social driving factors</b></p> <ul style="list-style-type: none"> <li>– More focus on communities in stead of individuals</li> <li>– Limited attention to the user to information</li> <li>– Lifestyles focus on green innovations</li> <li>– Innovation in gadget are less important</li> </ul>	<p><b>Technological driving factors</b></p> <ul style="list-style-type: none"> <li>– Innovation oriented towards greening and nature, less to radical innovations in ICT</li> <li>– Room for radical innovations</li> <li>– Attention to infrastructural innovations</li> </ul> <p><b>Environmental driving factors</b></p> <ul style="list-style-type: none"> <li>– Strong attention to environmental footprint</li> <li>– Market focus for reduction of energy, limiting environmental impact</li> <li>– Significant, problems with resource scarcity</li> </ul> <p><b>Political driving factors</b></p> <ul style="list-style-type: none"> <li>– Strong involvement of politics to science and innovation</li> <li>– Focus of governmental funding to grand challenges</li> <li>– Governmental regulation is a driving force: Green deal</li> <li>– Focus on cooperation on research on Grand challenges</li> </ul>

Within this scenario society is generally risk averse and decisions are primarily governed by the precautionary principle. The acceptance of new technologies depends on their environmental impact / contribution and risk assessment. New technologies may also be perceived with some ambivalence as potentially providing an environmental solution, but also a possible environmental risk throughout their lifecycle. In regard to the three dimensions of environmental sustainability, economic sustainability and socio-political sustainability, the environmental component tends to drive the others (e.g. “green jobs” and improvements in quality of life). Regulations also affect products that are not related directly to environmental issues, e.g. computer games that may promote violence, cars that may unnecessarily endanger people or food that may have negative health effects.



In order to be realized, this scenario requires a degree of economic prosperity and good access to human and natural resources. In contrast to the Emergency scenario below, the immediate general environmental conditions are not alarming, but there is considerable societal and governmental concern that they may worsen if no action is taken to ensure environmental protection.

### C.4 Scenario 3: Budget Society

The “budget society” derives from a sustained poor economic situation shaped by the necessity to cut costs and reduce spending by governments, industries and individuals.

Within this scenario, industries can have difficulties in obtaining sufficient financial resources (e.g. loans or governmental support), their innovation capacities decrease and they are forced to rationalize with workforce reductions and reduced new product development. This, together with underlying increases in health and pension costs put further stress on social insurance systems (unemployment benefits, welfare benefits).

Budget society	
<p><b>Demographic driving factors</b></p> <ul style="list-style-type: none"> <li>– Limited attention to the elderly</li> <li>– Stable population</li> <li>– Stronger shift towards cities</li> </ul> <p><b>Economic driving factors</b></p> <ul style="list-style-type: none"> <li>– Open markets, highly competitive on price, many SMEs</li> <li>– No, or negative economic growth</li> <li>– Business strategy on cost reduction and incremental innovations</li> <li>– Problems with finding good personnel</li> <li>– Limited cooperation, but consolidation of firms</li> </ul> <p><b>Social driving factors</b></p> <ul style="list-style-type: none"> <li>– Focus on individuality</li> <li>– Limited attention of the user for innovations in general: No real innovations</li> <li>– Markets have niche character, aligned with commodity products</li> </ul>	<p><b>Technological driving factors</b></p> <ul style="list-style-type: none"> <li>– Limited inventions and new research</li> <li>– Room for incremental innovations</li> <li>– No significant attention to infrastructural improvements</li> </ul> <p><b>Environmental driving factors</b></p> <ul style="list-style-type: none"> <li>– Limited problems with resource scarcity</li> <li>– Environmental impact limited problem</li> <li>– Climate change is not a big issue</li> </ul> <p><b>Political driving factors</b></p> <ul style="list-style-type: none"> <li>– Open markets for company access</li> <li>– Limited globalization</li> <li>– Limited governmental stimulation towards radical innovations</li> <li>– No attention to grand challenges, more fragmented approach</li> </ul>

The overall wealth of consumers declines and negatively affects industries. Access to 'high knowledge' human capital and new/emerging technology is rather low due to budgetary constraints. Cheap products and cheap production methods, as well as cheap imports, represent the first choice and low prices are the major criterion for consumer decisions. The overall ecological consciousness with this scenario declines, especially with consumers, but also, to a lesser extent, by governments. In settings with higher governmental intervention, e.g. in the context of environmental policy, the tendency towards "green products" remains higher, although resources to provide green technology adoption incentives are reduced.

The acceptance of new technologies is rather indifferent, mainly due to the fact that they are either not available or not affordable. Risk perception is rather high, but primarily oriented towards social security, income and job security.

## C.5 Scenario 4: Emergency

This scenario is set in a world of emergency associated with environmental and/or major conflicts including sustained terrorist attacks that lead to a scarcity in resources necessary for human existence. Although in its most dramatic form this scenario is rather unlikely in Europe or other highly developed countries, extreme weather conditions (e.g. draughts, extreme heat or cold periods, flooding, pathogens that affect humans, animals or plants etc.) can have serious impact.

In contrast to the "Green Innovation" scenario, innovation is considered here as a necessity to avert further threats. Environmental consciousness is high, but less focused on preventative measures seen in the "Green Innovation" scenario, but much more on resolving immediate dangers. This is also reflected in the attitude towards new technologies, where everything that might have a chance to improve the status quo is accepted out of immediate necessity. Governmental regulations are high, which is a result of requirement within social democratic and welfare-oriented systems to prevent additional social conflicts.

Emergency	
<p><b>Demographic driving factors</b></p> <ul style="list-style-type: none"> <li>– Negative population growth, due to constraints on immigration</li> <li>– Limited shift towards cities</li> </ul> <p><b>Economic driving factors</b></p> <ul style="list-style-type: none"> <li>– Almost closed markets, with strong attention to risks</li> <li>– Stable economy, or even recession</li> <li>– Business strategy on public funding</li> <li>– Relative strong HR on niche markets</li> <li>– Coordination and cooperation is of importance</li> </ul> <p><b>Social driving factors</b></p> <ul style="list-style-type: none"> <li>– Focus on communities in stead of individuals</li> <li>– Limited attention to the user needs</li> <li>– Community risks are of crucial importance</li> </ul>	<p><b>Technological driving factors</b></p> <ul style="list-style-type: none"> <li>– Strong research and innovation in specific areas</li> <li>– Room for radical innovations, but with limited scope</li> <li>– Attention to infrastructure, due to risks</li> </ul> <p><b>Environmental driving factors</b></p> <ul style="list-style-type: none"> <li>– Strong attention to environmental crises</li> </ul> <p><b>Political driving factors</b></p> <ul style="list-style-type: none"> <li>– Strong involvement of politics to science and innovation</li> <li>– Focus of governmental funding to grand challenges</li> <li>– Many interesting areas are not addressed</li> <li>– Focus on cooperation on research in specific areas</li> </ul>

The economic prosperity is negatively affected and mastering this scenario gets increasingly challenging as even less economic, natural and human resources are available. In this scenario, innovation means survival setting it apart from the other scenarios.

# D

## Overview of experts consulted in interviews and the workshop

Name	Organisation
Chris Dorman	Coherent
Ursula Tober	VDI / Photonics 21
Ian Vane	Amazing communications
Thomas Rettich	Trumpf
Stefan Kaierle	Fraunhofer Institut für Lasertechnik / PhotonAix
Mike Böttger	CoOPTICS
Andreas Ehrhardt	OptoNet, Photonics BW?
Jean-Claude Sirieys	Optics Valley
Jens Neugebauer	Fraunhofer HQ
Tom Pearsall	EPIC
Bruno Smets	Phillips
Marta C. de la Fuente	Indra Sistemas
Alastair Wilson	Electronics Sensors and Photonics KTN
Martin Gluh	Carl Zeiss / Photonics 21 WG3
Mike Wale	Oclaro
Markus Wilkens	VDI / Photonics 21
Christian Hinke	Fraunhofer Institut für Lasertechnik / PhotonAix
Klaus Schindler	Optonet

# E

## Overview of sources used in the economic assessment

Source and date	Relevant contents	Comment
1. Photonics in Europe Economic Impact, Optech Consulting, December 2007	European photonics by sector 2005  European photonics by country 2005  Definitions	Based largely on material used in 'Optische Technologien, Wirtschaftliche Bedeutung in Deutschland'
2. Optische Technologien – Wirtschaftliche Bedeutung in Deutschland: Aktualisierung 2010, Optech Consulting, April 2010	German sector overview 2008  Worldwide market 2008	Partial update of 'Photonics in Europe Economic Impact'
3. Brief of Spanish Photonics Technology Sector, Southern European Cluster in Photonics and Optics, May 2010	Spanish sector overview 2006	
4. Update from Southern European Cluster in Photonics and Optics, May 2010	Italian sector overview 2007	
5. Photonik In Der Schweiz Wirtschaftliche Bedeutung, Optech Consulting, Oktober 2009	Swiss sector overview 2008	Uses same methodology as 'Photonics in Europe Economic Impact'
6. Report on Swedish photonics industry European Optical Society, May 2008	Swedish sector overview 2007	Limited data on production values by sub-sector
7. PPE KTN	Update on UK section	Some quantitative updates to 2009 and qualitative
8. TNO	Update on Netherlands section	Qualitative only

Table: An overview of the provenance of the data used to provide the overview of the EU photonics sector.

Note that [Optech Consulting, 2007] includes defence photonics as a sector, whereas the two reports focussed on Germany, including [Optech Consulting, April 2010] which provides recent data, do not. To enable comparisons, we have assumed that the defence photonics category has grown in line with total US military spending from 2005 to 2009. This assumption is reasonable we believe and for example the US market for military lasers follows this trend in recent years ([Optech Consulting, 2009] - 50 & 52). Where appropriate, we distinguish 'civil' photonics from all photonics including defence – note that security and 'homeland security' applications are included in 'defence' for this purpose.

# F

## Overview of connections made between the leveraged industries and markets and the NACE sectors

Survey mapped category	NACE Category
Telecommunications Infrastructure	J61 - Telecommunications
	J61.2 - Wireless telecommunications activities
	J63.1.1 - Data processing, hosting and related activities
Manufacture of Vehicles and Large Machinery	C28.1 - Manufacture of general-purpose machinery
	C28.4 - Manufacture of metal forming machinery and machine tools
	C29.1 - Manufacture of motor vehicles
	C29.2 - Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers
	C30.3 - Manufacture of air and spacecraft and related machinery
	C30.9.1 - Manufacture of motorcycles
Medicine & Healthcare Activities	Q86.1.0 - Hospital activities
	Q86.2.3 - Dental practice activities
Media Production and Broadcasting	C18.1 - Printing and service activities related to printing
	J59.1.3 - Motion picture, video and television programme distribution activities
	J60.2 - Television programming and broadcasting activities
	M73.1 - Advertising
	M74.2 - Photographic activities
	N82.1.9 - Photocopying, document preparation and other specialised office support activities
Manufacture of Electronics and Optical Equipment	C26.1.1 - Manufacture of electronic components
	C26.1.2 - Manufacture of loaded electronic boards
	C26.2 - Manufacture of computers and peripheral equipment
	C26.3 - Manufacture of communication equipment
	C26.4 - Manufacture of consumer electronics
	C26.4 - Manufacture of consumer electronics

Manufacture of Electronics and Optical Equipment	C26.5.1 - Manufacture of instruments and appliances for measuring, testing and navigation
	C26.6 - Manufacture of irradiation, electromedical and electrotherapeutic equipment
	C26.7 - Manufacture of optical instruments and photographic equipment
	C26.8 - Manufacture of magnetic and optical media
	C27.1.2 - Manufacture of electricity distribution and control apparatus
	C27.3 - Manufacture of wiring and wiring devices
	C27.4 - Manufacture of electric lighting equipment
	C29.3.1 - Manufacture of electrical and electronic equipment for motor vehicles
	C33.1.3 Repair of electronic and optical equipment
Road & Rail Transport and Logistics Infrastructure	C33.1.6 Repair and maintenance of aircraft and spacecraft
	H49 - Land transport; transport via pipelines
	H49 - Other land transport
	H49.2 - Transport via railways
	D35.1.1 - Production of electricity
	H52.2 - Cargo handling and storage; other supporting transport activities; activities of other transport agencies
Electricity Generation & Supply	D35.1.1 - Production of electricity
Oil and Gas Exploration	B6 - Extraction of crude petroleum and natural gas
Defence and Security Activities	C25.4 - Manufacture of weapons and ammunition
	O84.2.2 - Defence activities
Aviation and Space Infrastructure	H51 - Air transport
Recreation, Culture and Education	P85.4.1 - Post-secondary non-tertiary education
Defence and Security Activities	N80 - Investigation and security activities
	C25.4 - Manufacture of weapons and ammunition
Science, Research & Development	M71.2.0 - Technical testing and analysis
	M72.1.1 - Research and experimental development on biotechnology
Environmental Monitoring and Protection	E38.3.2 - Recovery of sorted waste materials
Manufacturing of Fine Chemicals and Pharmaceuticals	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations
	C32.5 - Manufacture of medical and dental instruments and supplies
Recreation, Culture and Education	P85.2 - Primary education
	P85.3 - Secondary education
	P85.4.2 - Tertiary education
Food and Beverage Production	C10.3 - Processing and preserving of fruit and vegetables





