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Sectoral Innovation Watch

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Electrical and Optical Equipment Sector

Final sector report

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Europe INNOVA Sectoral Innovation Watch

Detailed insights into sectoral innovation performance are essential for the development of effective innovation policy at regional, national and European levels. A fundamental question is to what extent and why innovation performance differs across sectors. The second SIW project phase (2008-2010) aims to provide policy-makers and innovation professionals with a better understanding of current sectoral innovation dynamics across Europe

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Central to the work of the Sectoral Innovation Watch is **analysing trends in, and reporting on, innovation performance in nine sectors** (Task 1). For each of the nine sectors, the focus will be on identifying the innovative agents, innovation performance, necessary skills for innovation, and the relationship between innovation, labour productivity and skills availability.

Sector Innovation Performance: Carlos Montalvo (TNO)	
Automotive: Michael Ploder (Joanneum Research)	Knowledge Intensive Business Services: Christiane Hipp (BTU-Cottbus)
Biotechnology: Christien Enzing (Technopolis)	Space and Aeronautics: Annelieke van der Giessen (TNO)
Construction: Hannes Toivanen (VTT)	Textiles: Bernhard Dachs (AIT)
Electrical and Optical Equipment: Tijs van den Broek (TNO)	Wholesale and Retail Trade: Luis Rubalcaba (Alcala) / Hans Schaffers (Dialogic)
Food and Drinks: Govert Gijsbers (TNO)	

The **foresight of sectoral innovation challenges and opportunities** (Task 2) aims at identifying markets and technologies that may have a disruptive effect in the nine sectors in the future, as well as extracting challenges and implications for European companies and public policy.

Sector Innovation Foresight: Matthias Weber (Austrian Institute of Technology)	
Automotive: Karl Heinz Leitner (AIT)	Knowledge Intensive Business Services: Bernhard Dachs (AIT)
Biotechnology: Govert Gijsbers (TNO)	Space and Aeronautics: Felix Brandes (TNO)
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Task 3 will **identify and analyse current and potential bottlenecks that influence sectoral innovation performance, paying special attention to the role of markets and regulations.** Specifically, the analysis will cover the importance of the different factors in the propensity of firms to innovate.

Role of markets and policy/regulation on sectoral patterns of innovation: Carlos Montalvo (TNO)	
Katrin Pihor (PRAXIS)	Klemen Koman (IER)

Task 4 concerns **five horizontal, cross-cutting, themes related to innovation**. The analyses of these horizontal themes will be fed by the insights from the sectoral innovation studies performed in the previous tasks. The **horizontal reports will also be used for organising five thematic panels** (Task 5). The purpose of these panels is to provide the Commission services with feedback on current and proposed policy initiatives.

Horizontal reports	
National specialisation and innovation performance	Fabio Montobbio (KITes) and Kay Mitusch (KIT-IWW)
Organisational innovation in services	Luis Rubalcaba (Alcala) and Christiane Hipp (BTU-Cottbus)
Emerging lead markets	Bernhard Dachs (AIT) and Hannes Toivanen (VTT)
Potential of eco-innovation	Carlos Montalvo and Fernando Diaz Lopez (TNO)
High-growth companies	Kay Mitusch (KIT-IWW)

Contents

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- Silvain de Munck (TNO)
- Ursula Huws (Analytica research)

The final sector report for the electrical and optical equipment sector builds on the results of various tasks in Europe INNOVA Sectoral Innovation Watch:

Broek, van den T. and A. van der Giessen (2010) *Sectoral Innovation Performance in the Electrical and Optical Equipment Sector*, Final Report Task 1, Europe INNOVA Sectoral Innovation Watch, for DG Enterprise and Industry, European Commission, June 2010

Broek, van den T. and A. van der Giessen (2010 *Sectoral Innovation Foresight - Electrical and Optical Equipment Sector*, Final Report Task 2, Europe INNOVA Sectoral Innovation Watch, for DG Enterprise and Industry, European Commission, December 2010

Montalvo, C., K. Pihor and T. van den Broek (2011) Analysis of market and regulatory factors influencing sector innovation patterns – Electrical and Optical Equipment Sector, Final Report Task 3, Europe INNOVA Sectoral Innovation Watch, for DG Enterprise and Industry, European Commission, December 2011

H. Grupp†, D. Fornahl, C.A.Tran, J. Stohr, T. Schubert, F. Malerba, Montobbio F., L. Cusmano, E. Bacchiocchi, F. Puzone, (2010) *National Specialisation and Innovation Performance*, Final Report Task 4 Horizontal Report 1, Europe INNOVA Sectoral Innovation Watch, for DG Enterprise and Industry, European Commission, March 2010

Rubalcaba, L, J. Gallego, C. Hipp, and M. Gotsch (2010) *Organisational innovation in Services*, Final Report Task 4, Horizontal Report 2, Europe INNOVA Sectoral Innovation Watch, for DG Enterprise and Industry, European Commission, February 2010

Dachs, B., I. Wanzenböck, M. Weber, J. Hyvönen and H. Toivanen (2011) *Lead Markets*, Final Report Task 4, Horizontal Report 3, for DG Enterprise and Industry, European Commission, March 2011

Montalvo, C., Diaz Lopez F.J., and F. Brandes, (2011) *Potential for eco-innovation in nine sectors of the European economy*, Final Report Task 4, Horizontal Report 4, Europe INNOVA Sectoral Innovation Watch, DG Enterprise and Industry, European Commission, December 2011

Mitusch K. and A. Schimke (2011) *Gazelles – High-Growth Companies*, Final Report Task 4, Horizontal Report 5, Europe INNOVA Sectoral Innovation Watch, for DG Enterprise and Industry, European Commission, January 2011

Executive summary

The electrical and optical equipment sector is a high-tech manufacturing sector. It is one of the most innovative sectors in Europe with investments and advances in fundamental research, applied R&D and innovation in the actual use of equipment. This sector is also one of the most global sectors with competition between Europe, US, Japan, China and other regions, and global players having spread their business activities (R&D, marketing, production, assembling, etc.) across different parts of the world.

The sector encompasses stastically four segments:

- Computers and office equipment
- Electrical machinery and equipment
- Radio, TV & communication equipment (electronics), which includes i.e. the semi-conductor industry
- Instrument engineering (optical equipment), which includes medical equipment and photonics.

Electrical and optical equipment is used by consumers but more so by a range of private and public sectors such as automobile, retail, aeronautics and space, health, education and government. Electrical and optical equipment is perceived a general purpose technology or Key Enabling Technology: the development, provisioning and use of ICT are crucial for the competitiveness of firms, sectors and regions, and for addressing societal challenges such as scarcity of energy and water, ageing and security.

The electrical and optical equipment sector is truly dynamic

Innovation at full speed: innovation takes place at a very rapid pace, and markets applying the E&O equipment are very dynamic. Product cycles are extremely short and consequently production operations are continuously under transition. Important obstacles in timely integration of new sciences and technologies are the lack of standards and regulatory guidelines for using the new technologies as well as the lack of indicators for confirming the efficacy of the new technologies.

Globalization: In the last few decades, globalization (and in specific the rise of BRIC countries) put pressure on the competitiveness of firms. Low-cost production and segmentation of the value chain increasingly force European firms to focus on innovation as their core competence.

Collaboration on R&D is important: In the context of the debate on fragmentation of R&D in Europe - and possibly duplication of efforts, lack of scale and excellence - the data confirms that progress can still be made. European programmes such as the 6th Framework Programme are perceived relevant by large firms and forms from West and Northern Europe. The relevance by other firms, in other countries is substantially lower. Furthermore, 40% of firms collaborate with national universities, government or research institutes, whereas only 9% collaborates with international universities, government or research institutes. This indicates that steps can be made towards the European Research Area.

SMEs active in R&D: Compared to other sectors, a large number of SMEs is active in R&D and innovation. No less than 75% of SMEs in engaged in intramural R&D. To some extent, this is stimulated by policy, albeit the relevance of European policy is different for SMEs than for large firms. The latest data indicates that SMEs participate more actively in regional programmes than in national and - especially - European programmes. In addition to pragmatic considerations, this can be related to widely debated factors such as the 'SME friendliness' of the content and procedures of national and European programmes. Additionally, a large number of firms introduce new products and a large part of their revenues comes from new products. This clearly indicates that innovation actually is translated into competitiveness and economic growth.

Products converge into services: Remarkably, service innovation is important to the sector. For example, 37% of all computer & office equipment manufactures introduced a new or improved service on the market. This insight is also relevant input for scientific, statistical and policy debates on the overlap or even convergence between manufacturing and services sectors.

A sector driven by demand: the electrical & optical equipment is crucial for addressing societal challenges such as scarcity of energy (e.g. smart grids, energy efficiency, storage systems). Additionally, consumer markets are still highly relevant. New digital media services - via the internet or otherwise - will stimulate the development and sales of new equipment (and vice versa).

Public funding is an important financial source the sector: There are vivid partnerships between academia, large firms and SMEs in European Technology Platforms which are essential for innovation. Furthermore, open innovation (i.e. with users or suppliers) is getting more attention. However, little data is available on public procurement and its role in the sector, although government is an important user of electrical & optical equipment. It is recommended to gather more data, also to see if procurement is an effective policy instrument to stimulate innovation. Next, the communication on Strategic Key Enabling Technologies from the European Commission indicates important policy measures to stimulate innovative new business[1]. European policy could drive innovation by for example measures on skills, knowledge transfer, publicly supported research programmes, consolidation of research activities and (consistent with the recommendations in the Electra report) large-scale demonstration projects.

Skilled labour force: As a high-tech sector, the electrical & optical equipment sector depends on high skilled human resources. On average there is a trend from low-skilled labour towards high-skilled labour in the sector in all European regions. The most important future skills are up-to-date technical knowledge (preferably combined with business knowledge), entrepreneurship, creativity, the ability to work in multi-disciplinary and cross-sectoral environments, supply chain management knowledge, knowledge of regulation and e-skills. Up-to-date technical knowledge with understanding of business

[1] European Commission (2009), Preparing for our future: Developing a common strategy for key enabling technologies in the EU, COM(2009) 512 final, 30.09.2009, Brussels

is needed at the same time. For example extensive knowledge of optics and the generation and processing of images will be very important to compete in the Medical equipment industry.

The future of the electrical and optical equipment sector is steered by society

On the other hand technology drivers make new applications possible. Technology trends include long term trajectories such as miniaturisation (even beyond Moore's law), ambient intelligence, embedding of technologies, ubiquitous connection, interaction, but also robotisation and the convergence of ICT, nano, biotech and other technologies.

The application of these future technological trends in the electrical & optical equipment sector will be steered by future societal demand and challenges. Important future challenges relevant to this sector are an ageing population, globalization, urbanization, energy and materials scarcity, climate change, security concerns, a mature network society and increased personalisation and customisation of products and services.

The combination of technology and societal demand drivers lead to five important innovation themes:

Smart buildings: the application of ambient intelligence in buildings. Electrical & optical equipment can make buildings more sustainable, living and tele-working more intelligent and can assist the elderly with independent living.

Smart health care systems: the patient will really become the centre of attention in providing personalised health care, empowering the patient and enabling the provision of effective health care targeting the individual patient.

Smart transportation systems: integrated traffic management systems will regulate safe, fast reliable and flexible transportation by co-ordinating the mix of transportation modes available and reducing congestion and reducing the environmental burden.

Smart energy supply systems and green equipment: energy supply systems for energy consumption, creation, management and storing will be needed that are reliable and continuing, while at the same time energy efficient as well as environmental friendly.

Smart security systems: increased interoperability and seamless connectivity of security systems and devices, intelligent surveillance systems and devices, as well as enhanced scanning and detecting techniques and efficient and effective tracking and tracing systems.

Important future lead customer markets, in which these innovation themes will be applied, are:

- Trans-European networks, transportation, infrastructure and telematics, which makes i.e. use of infrastructural technologies and sensors.
- E-health infrastructure and nano-diagnostics, which makes use of mix of smart cards, mobile computing and RFID.

- Energy generation, transmission and distribution, which makes use of smart grids, high voltage direct current, renewables, low-carbon technologies and storage systems.
- Civil protection, security, defence, urging the need for data storage, sensors, RFID, etc.
- Building, intelligent living, ambient assisted living, access, detection and control technologies.
- Automation, industrial IT, relying on web based technologies and RFID.
- Digital radio & TV, HDTV, which need access and common interface technologies.

Policy implications

The electrical and optical equipment sector requires policy and regulation to prepare for future challenges (e.g. demand, globalization, and rapid innovation cycles). The following policy implications should be considered:

Stimulate service innovation: to further acknowledge the complexity of the sector - and its challenges - the link between manufacturing and services must be stressed. Increasingly, the manufacturing of electrical & optical equipment is linked to services such as maintenance, remote servicing, upgrades, leasing, etc. This further increases the relevance of the sector for economic, societal and environmental challenges. It also increases the challenges for innovation.

Promote solutions for grand societal challenges: Societal challenges are complex issues, in need for systemic solutions, multidisciplinary approaches and the involvement of stakeholders. Policy should strongly stimulate and support the development of these solutions with public procurement, institutional changes, infrastructural decisions, as well as other incentives.

Support eco-innovation: the challenge of energy scarcity and global warming is probably one of the most important grand challenges for the electrical & optical equipment sector. The ELECTRA report suggests that ICT-enabled eco-innovations promise to deliver most of the energy efficient solutions with applications in a number of areas. However, the adoption rates of eco-innovation still lack behind. Policy and regulation should help to stimulate eco-innovation, for example by means of public-private partnerships, public procurement or incentives for consumers.

Align research efforts to increase efficiency: Research efforts and policy efforts to support R&D are often fragmented in Europe, resulting in a lack of synergies and economies of scale and scope. Policy should focus on better coordination of research and policy efforts to accelerate development, avoid duplications and to reach sufficient critical mass.

Improve capitalisation on R&D results: Radical innovation require sufficient resources for fundamental and interdisciplinary research, creative and fresh approaches and support for capitalising on R&D results. Policy should focus on emphasising the need for technology transfer, translation of R&D to the market and support links between research institutions and SMEs. Policy should gather stakeholders, support pilots and stimulate best practice exchange.

Support SMEs and stimulate financial investment in the sector: Policy should focus on stimulating financial investment in high-tech industries for R&D prototyping, manufacturing and infrastructure. Policy should stimulate the development of public loan and financing facilities for SMEs. Policy should stimulate venture capital funds specialised in early stage investment.

Support standardisation: The converging, interactive and interconnected electrical & optical equipment will be integrated and applied in existing systems in downstream sectors such as health care. Policy should focus on taking the lead in standardisation, support the development of industry standards and translate these standards into legislation where appropriate.

Remove regulatory barriers: Policy should focus on identifying and removing the potential regulatory barriers to innovation and adoption of innovative electrical & optical equipment. Moreover, policy should focus on harmonising differences in regulation of the European market and considering the long-term total costs and benefits of new technologies that require substantial investments.

Foster skills: Europe lacks sufficient skilled labour and improved skills are necessary at all occupational levels in the sector. Policy could focus on attracting more students in the technical and multi-disciplinary fields. In the short and medium term, policy could focus on attracting highly-educated foreign nationals to Europe.

Raise awareness and enhance trust, privacy and security: Policy should focus on safeguarding privacy and security of citizens and consumers, by appropriate safety and privacy regulation, but also by stimulating and support sector agreements including users. Acceptance can be supported by raising awareness, showing the value of these new technologies and stimulating the user friendliness and interoperability of new technologies.

On policy level, electrical & optical equipment, such as nanotechnogy, electronics and photonics, is seen as a Key Enabling Technology (KET) by the European Commission. The current policy debate recognizes the importance of KETs for the competitiveness of the European industry, but there are still no compromises which technologies should be included. The European Commission, however, aims to develop a common strategy to bundle R&D efforts along these technologies. The policy analysis of this report highly stresses the importance of this development.

1 Patterns and performance of sectoral innovation

The electrical and optical equipment sector is a truly innovative sector. New products, and increasingly services, are developed and brought to the market at a very rapid pace. The sector highly contributes to European R&D spending and has, consequently, a large share in European patents. For example, large multi national companies (MNCs), such as Nokia and Siemens, are dominating the top 10 of the European R&D scoreboard. Additionally, a high percentage of SMEs shows innovative activities. Although it represents about 10.4% of the total revenue in the manufacturing industry, the E&O equipment sector is crucial for innovation in Europe, with investments and advances in fundamental research, applied R&D and innovation in the actual use of equipment. Electrical & optical equipment, which largely consists of ICT manufacturing, is a strong driver for innovation in other sectors. Electrical & optical equipment is used by consumers, but even more so by sectors such as automobile, retail, aeronautics and space, health, education and government. For example, intelligent transport infrastructures (e.g. intelligent roads) are enabled by the development of ICT systems. Therefore, electrical & optical equipment is recognized by the European Commission as a Key Enabling Technology: the development, provisioning and use of ICT are crucial for the competitiveness of firms, sectors and regions, and for addressing societal challenges such as scarcity of energy and water, ageing and security.

The sector is also one of the most global sectors with competition and collaboration between Europe, US, Japan, China and other regions, and global players having spread their business activities (R&D, marketing, production, assembling, etc.) across different parts of the world. Currently, the European industry faces a major competitiveness challenge. Production of equipment in Europe, for example solar panels in Germany, is largely replaced to the low-cost countries. Production is just the beginning. As the level of education is increasing in low-cost countries, R&D is increasingly distributed around the globe. The consequence is a complex value chain, in which European companies are forced to rethink their added value in the sector and adjust their strategies. On sector level, countries should bundle their R&D efforts, which urges for standardization, regulation, specialization (technically and geographically), harmonize research efforts, etc. Moreover, global challenges such as energy scarcity, ageing and urbanization, place a responsibility on electrical & optical equipment to provide the essential building blocks for smart solutions. For example, the use of sensor networks in Health can help to reduce the medical costs caused by ageing. Governments have different policy and regulation options to tackle the current barriers and meet future requirements.

The goal of this study is to analyse the current and future state of innovation in the electrical & optical equipment and provide the European Commission with policy recommendations.

This final sector report is based on earlier tasks conducted by the consortium. It analyses and wraps up the results of the Sectoral Innovation Performance analysis (Task 1), Sectoral Innovation Foresight

(Task 2), the analysis of market and regulation factors affecting patterns of innovation and the horizontal reports, covering cross-sectoral themes such as eco-innovation and high-growth firms.

These will parts be presented in six main chapters. Chapter 1 starts with a (statistical) introduction of the sector, a general profile and a quantitative overview of the Sectoral Innovation Performance based on analysis of the SIW database. Chapter 2 discusses the carriers of innovation: who is innovating, what is the workforce and how does innovation currently takes place. Next, chapter 3 provides an overview of the future developments in the E&O equipment sector. Both technological and societal drivers are presented and combined in innovation themes. The innovation themes are discussed in the light of three scenarios, which lead to future requirements for innovation and future policy directions. Chapter 4 describes the most important drivers and barriers in the sector today. The sectoral consequences of several horizontal themes are discussed in chapter 5. Finally, chapter 6 draws up conclusions based on the earlier chapters and sums up the most important policy implications.

1.1 Statistical definition of the sector and sector-specific indicators

The electrical & optical equipment sector includes *“manufacturers of a diverse range of goods that can be classified as either being consumer goods (for example, telephones, radios, televisions and watches), capital goods (for example, computers and transmission equipment) or intermediate goods (for example, electronic components such as conductors and wiring) that are used by other sectors of the economy”* (Eurostat, 2008a).

Four subsectors are discerned in Eurostat’s European Business: facts and figures 2007 edition (Eurostat, 2008a):

- Computers and office equipment
- Electrical machinery and equipment
- Radio, TV & communication equipment (electronics), which includes i.e. the semi-conductor industry
- Instrument engineering (optical equipment), which includes medical equipment and photonics.

Statistically, the sector encompasses four NACE groups in the Eurostat databases. Table 1.1 gives an overview of the statistical classification in NACE rev. 1.1 and NACE rev 2.

Table 1.1 Classification of activities: the electrical and optical equipment sector

	NACE rev 1.1		NACE rev. 2
30	**Manufacture of office machinery and computers**		
30.0	Manufacture of office machinery and computers	28.2	Manufacture of other general-purpose machinery
		26.20	Manufacture of computers and peripheral equipment
31	**Manufacture of electrical machinery and apparatus n.e.c.**	**27**	**Manufacture of electrical equipment**
31.1	Manufacture of electric motors, generators and transformers	27.1	Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus
31.2	Manufacture of electricity distribution and control apparatus	27.1	Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus
31.3	Manufacture of insulated wire and cable	27.3	Manufacture of wiring and wiring devices
31.4	Manufacture of accumulators, primary cells and primary batteries	27.2	Manufacture of batteries and accumulators
31.5	Manufacture of lighting equipment and electric lamps	27.4	Manufacture of electric lighting equipment
31.6	Manufacture of electrical equipment n.e.c.	27.9	Manufacture of other electrical equipment
32	**Manufacture of radio, television and communication equipment and apparatus**	**26**	**Manufacture of computer, electronic and optical products**
32.1	Manufacture of electronic valves and tubes and other electronic components	26.1	Manufacture of electronic components and boards
32.2	Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy	26.3	Manufacture of communication equipment
		26.4	Manufacture of consumer Electronics
32.3	Manufacture of television and radio receivers, sound or video recording or reproducing apparatus and associated goods	26.4	Manufacture of consumer Electronics
33	**Manufacture of medical, precision and optical instruments, watches and clocks**	**26**	**Manufacture of computer, electronic and optical products**
33.1	Manufacture of medical and surgical equipment and orthopaedic appliances	26.6	Manufacture of irradiation, electro medical and electrotherapeutic equipment
		32.5	Manufacture of medical and dental instruments and supplies
33.2	Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment	26.5	Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks
33.4	Manufacture of optical instruments and photographic equipment	26.7	Manufacture of optical instruments and photographic equipment
		26.8	Manufacture of magnetic and optical media
33.5	Manufacture of watches and clocks	26.5	Manufacture of instruments and appliances for measuring, testing and navigation; watches and clocks

Source: Eurostat database

In terms of turnover the electrical & optical equipment industry counts for about 10.4% of total manufacturing in Europe (see table 1.2). In 2005 the sector employed approximately 3,664,000 persons in more than 205,000 enterprises which make an average of 15 persons per enterprise. The share of the sector's value added (11.6%) is a bit higher than other structural business indicators from Eurostat.

Table 1.2 Structural business indicators

Scope: EU27 *Year: 2005*	***Manufacturing of Electrical & Optical equipment***	***Total Manufacturing***	***Share (%) of E&O equipment in manufacturing***
Number of enterprises	*205,760*	*2,322,295*	*8.9%*
Number of persons employed (in 1000)	*3,664*	*34,644*	*10.6%*
Productivity (in thousands EUR per employee)	*51.8*	*47*	
Turnover (in million EUR)	*€ 657,705*	*€ 6,328,885*	*10.4%*
Value added (in million EUR)	*€ 189,793*	*€ 1,629,874*	*11.6%*

Source: Eurostat database

In the electrical & optical equipment sector large companies are more important than small and medium-sized enterprises (SMEs) compared to other sector. Large firms count with 64% for most of the value added within the EU27 in 2004. In all subsectors except the optical equipment sector large companies play a more important role than SMEs. For example, the share of value added coming from large enterprises was particularly high in the computer and office equipment and electronics subsector. So, scale and scope appear to be crucial in these subsectors.

The electrical machinery subsector is by far the largest subsector and counts for approximately 254,000 million euro turnover in 2005. The electronics (206,000 million EUR) and optical equipment subsector (138,000 million EUR) come next. Computer and office equipment is by far the smallest subsector with a turnover around 60,000 million EUR in 2005. Figure 1.1 indicates the importance of large companies in the electrical & optical equipment sector and some differences in subsectors. Looking at the number of companies, the differences become even clearer: although the optical equipment sector is third in ranking in terms of turnover, it has with distance the largest amount of companies (93800 in 2005). It shows clearly the importance of high-tech SMEs (i.e. start-ups and gazelles) in the optical equipment subsector.

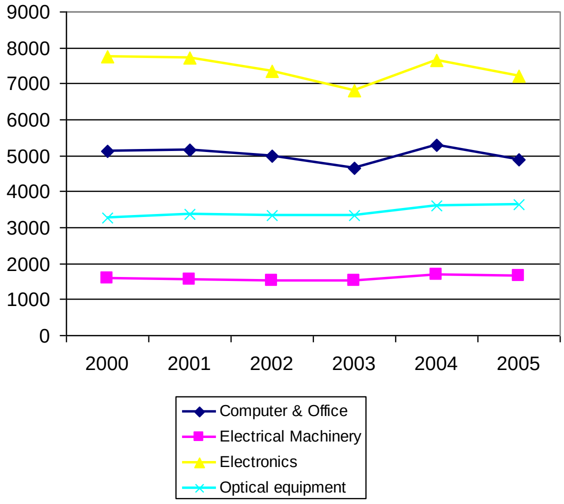
1.2 Characterisation of the sectors

1.2.1 Classification

In general, the electrical & optical equipment sector qualifies as a high-technology sector (OECD, 2005). This sector is one of the most innovative sectors in Europe. Three subsectors (1) computers and office equipment (2) electronics and (3) optical equipment belong to High Technology industry (Eurostat, 2008a) and show very high innovation intensity (Peneder, 2008). Electrical machinery and equipment sector is typically part of the Medium High Technology industry and show high innovation intensity (Peneder, 2008). So, the electrical & optical equipment sector is on average a High Technology industry. The electrical & optical equipment sector includes ICT manufacturing, but excludes ICT services.

The electrical & optical equipment sector has both characteristics of a *science-based* and a *specialised suppliers* sector (Pavitt, 1984). On one hand, the subsectors “office & computer” and “electronics” are generally *science-based* sectors, which are characterized by a high rate of product and process innovations, internal R&D and scientific research (See also Malerba, 2004). Figure 1.1 gives an overview of the patent applications registered at the European Patent Office between 2000 and 2005. It is an important indication for the innovativeness of the different subsectors.

Figure 1.1 EPO applications subsectors



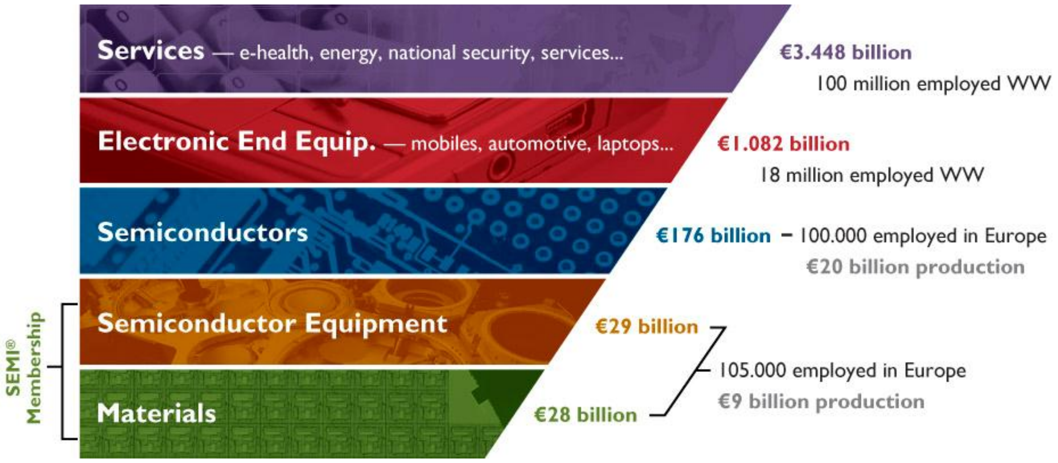
Source: Eurostat data from 2007

As these sectors are highly knowledge-intensive, and innovation is key for competition in the sector, intellectual property is protected by various means, such as short lead-times, patents, trademarks, product complexity and secrecy (Wintjes & Dunnewijk, 2008). On the other hand, the subsectors “electrical machinery” and “optical equipment” can be characterised as specialised supplier sectors that produce equipment for other industries. In specialised supplier sectors innovation is strongly user-oriented, focusing on performance improvement, reliability, and customization. Engineering skills and profound knowledge of the users, obtained by user-supplier interaction, are important sources for innovation. Patents, local knowledge, i.e. of the users, and the interactive nature of this knowledge are important means of appropriation. Pavitt’s (1984) taxonomy does not apply strictly and static: i.e. scientific research is very important for the Optical equipment subsector and the Electronics subsector is getting more user-centred (FISTERA, 2005). Furthermore, large manufacturers, like Siemens, IBM and HP, increasingly integrate their products with services (European Commission, 2006a).

1.2.2 Electrical & optical equipment as a general purpose technology and key enabling technology

The electrical & optical equipment sector and more narrowly defined ICT manufacturing, produces a *General Purpose Technology (GPT)* and is a net source of technology and innovation for other sectors (Scherer, 1982; Robson et al, 1988; Malerba, 2004; Guerrieri et al., 2006). Hence, the electrical & optical equipment sector has an impact on the whole economy: it drives product, process and organisational innovation and indirectly boosts productivity and service quality (Guerrieri et al, 2006; FMEC, 2007). Sectors that depend on high-technology input from the electrical & optical equipment sector are for example mechanical engineering, transport, health, chemicals, aerospace and ICT services. Key elements of GPT sectors are *pervasiveness* (like electronic circuits), *technological dynamism* (manifested in short lead-times) and *innovation complementarities* with other forms of technological progress (Guerrieri et al, 2006). Indicative figures on the global semiconductor market, provided by industry association SEMI, illustrate the role of this sector as a *technology enabler*: The European semiconductor industry represented EUR 176 billion in 2009, which enabled some EUR 1,082 billion in electronics systems business and approximately EUR 3,448 billion in services worldwide. Figure 1.2 shows a rough estimation of the economic impact of the Semiconductor and electronics sector (SEMI, 2009).

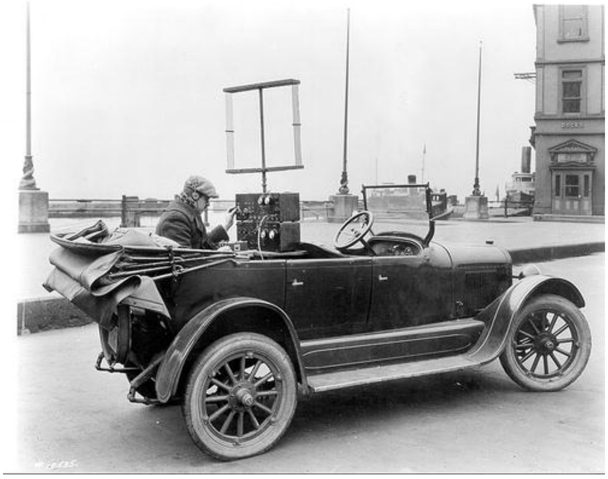
Figure 1.2 Rough estimation of the economic impact



Source: SEMI, 2009

ICT hardware evolved towards a GPT over the past century. Over the years, ICT components became smaller and smaller. *Miniaturization* enables the wide range application of ICT components. As Figure 1.3 shows, it was almost impossible to integrate mobile phone technologies in cars early 19th century. Nowadays, cars cannot drive without electronics.

Figure 1.3 An ancient car phone

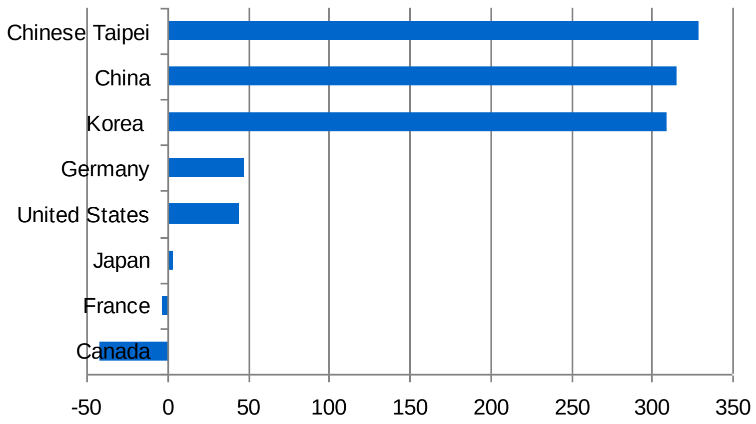


The European Commission recognizes the importance of electrical & optical equipment as a GPT. The Communication "Preparing for our future: Developing a common strategy for key enabling technologies in the EU" (European Commission, 2009b) defines electronics (e.g. semiconductors), nanotechnology and photonics as a Key Enabling Technologies. The Commission defines KETs as technologies that are *“knowledge intensive and associated with high R&D intensity, rapid innovation cycles, high capital expenditure and highly-skilled employment. They enable process, goods and service innovation throughout the economy and are of systemic relevance. They are multidisciplinary, cutting across many technology areas with a trend towards convergence and integration.”* European Commission, 2009c)

1.2.3 Europe’s declining competitive advantage

Europe’s position in the global electrical & optical equipment market has been getting more difficult during the last decade (Wintjes & Dunnewijk, 2008; ELECTRA, 2008, ESIA, 2006; European Commission, 2006a). Overall, Europe has a large trade deficit in the electrical & optical equipment market. The sector has competitive disadvantages compared to manufacturers in Asia and the USA. According to the Competitiveness Report 2006 (European Commission, 2006a), this does not only apply to standardised products, but also to innovative products. Several sources report that manufacturers in Asia and the USA have higher productivity, net income and R&D expenditure.

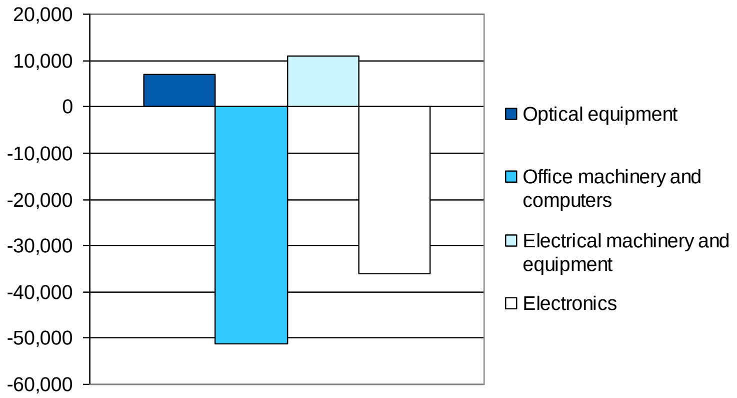
Figure 1.4 Growth of R&D expenditure of top ICT firms between 2000 and 2006 in percentage



Source: OECD (2008a)

Data from Eurostat (2008a) shows that the most strongly IT related subsectors electronics (trade-deficit over EUR 35 billion) and computer & office machinery (trade-deficit over 50 billion EUR) have a weak position compared to upcoming countries like China, India, Taiwan, South-Korea and Russia (ELECTRA, 2008). Between 1990 and 2002 the combined share of EU-15, Japan and USA in the IT related subsectors decreased with 20 percent points: from 80% to 60%; specifically at the benefit of China (OECD, 2005 and 2008a).

Figure 1.5 Trade balance in 2006 (in millions EUR)

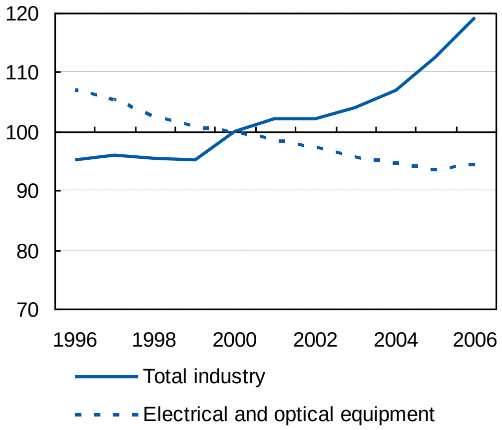


Source: Eurostat

1.2.4 Coping with the dynamic and fast changing sector

The developments in the sector take place at a very rapid pace, and markets applying the electrical & optical equipment are very dynamic. Moreover, product cycles are extremely short. Production operations are continuously under transition, because of short product life cycles and high product obsolesce frequency (Graedel and Howard-Greenville 2005). Important obstacles in timely integration of new science and technologies are the lack of standards and regulatory guidelines for using the new technologies as well as the lack of indicators for confirming the efficacy of the new technologies (Wintjes & Dunnewijk, 2008; EITO, 2007; ELECTRA, 2008; European Commission, 2006b; Van Eecke et al, 2007). Market surveillance is needed both on the internal market as well as at the border of the European Union (ELECTRA, 2008). Intellectual Property Rights regulation protects European firms from trademark piracy, counterfeiting and other attacks on intellectual property, but regulation is highly dependent on enforcement of intellectual property regulation in emerging economies (ELECTRA, 2008).

Figure 1.6 Index of domestic output prices from 1996-2006



Source: Eurostat

1.2.5 Globalisation of the whole supply chain

The sector has a maximum exposure to fierce international competition, which increases the pressure on the sector to innovate, especially in lead markets (i.e. Wintjes & Dunnewijk, 2008). Both production and research & design are getting more dispersed over the globe. Global issues, increased mobility (i.e. by cheap transport and ICT technologies), the urge for cost-efficiency, and the dismantling of the value chain in the Electrical & optical equipment sector lead towards the trend that R&D is increasingly undertaken on an international level (OECD, 2008b; European Commission, 2008). Firms' innovation strategies increasingly depend on globalization of R&D to sense new market and technology trends worldwide (OECD, 2008b). Globalization is an important opportunity for Europe: European enterprises can cooperate globally to increase their scale and reduce production costs for example in emerging countries such as India and China. In this sense, access to a worldwide network of knowledge, research infrastructures and resources will strengthen innovation in the European ICT sector (European Commission, 2008).

1.2.6 Convergence of products into services and solutions

According to the OECD (2008a) Information Technology Outlook 2008, growth in the ICT sector is especially driven by growth in ICT services. ICT services account for more than two-thirds of the total ICT sector value added and it is growing. Also, the share of ICT services in employment is growing. ICT equipment and services are becoming increasingly integrated, not only in the end product to the customer (a product that comes along with a service and v.v.), but also in the development of the product and its components. Moreover, ICT equipment is increasingly sold as a service, rather than a single product with a service attached. The amalgamation of products and services is not only relevant for ICT goods. The convergence of products into services and solutions requires interdisciplinary, cross-functional and cross-sectoral approaches to designing new products and services. This interdisciplinary collaboration is an important challenge and requires the development of interdisciplinary studies, but also the establishment of research centres that support and stimulate multidisciplinary research. Special attention should be paid to the issue of intellectual property, as multidisciplinary collaboration is expected to use increasingly ‘open-source’ science in which IP is owned by the collaborating parties or society. Interdisciplinary collaboration is further stimulated by locating research centres and manufacturing facilities in close proximity. This can create effective networks of knowledge transfer and attract qualified human capital minimising delay and expediting knowledge transfer (National Research Council Canada, 2005; European Commission, 2006c).

1.2.7 Convergence and linkages with downstream sectors

Electrical & optical equipment is used in many different markets that are increasingly converging. Digital convergence brings together computing, communications, contents and consumer electronics. Moreover it will increasingly follow the convergence of various technologies, brining together ICT, biotechnology, nanotechnology and cognitive sciences. This results in a wealth of opportunities, but is also blurring the traditional boundaries between market sectors and technology domains. One combined global market for electrical & optical equipment and digital services will emerge. The electrical & optical sector will become less identifiable as a discrete sector and borders between the various actors in the value chain will disappear. Firms will increasingly be defined by their role, e.g. as system developer, content provider, assembler, rather than by traditional market segment or technology domain. Moreover, the production process will further modularise, fragmenting the value chain and requiring increased re-organisation of the production processes and chains at the international level (ISTAG, 2006).

1.3 Common set of indicators

This section will delve deeper into the innovation performance per subsector. This statistical analysis will be mainly based on Eurostat’s fourth Community Innovation Survey (CIS4) which categorizes in the industrial code NACE revision 1.1.

1.3.1 General innovation activity

The electrical & optical equipment sector is a R&D intensive sector: 77.5% of the firms are engaged in intramural R&D. This is substantially more than in average for all sectors (21.5%). When considering the four subsectors, the computer & office equipment is most active in R&D (85.8%), followed by the electronics (81.95), the optical equipment (77.9%) and the electrical machinery subsector (74.1%). In average, firms in the sector spend almost 8% of their turnover on R&D activities; while for all sectors this share is much lower (3.7%). Companies in the electronics subsector spend the largest share of their turnover on R&D: 10.7%. Companies in the electrical machinery subsector spend the least: 5.6% of their turnover in 2004. The companies in the electrical and optical equipment do not only invest relatively large amounts in R&D, but more than 60% of the firms arrange training for their employees, compared to almost half of the companies in the average for all sectors.

Table 1.3 also shows that companies in the electrical & optical equipment sector are more than average engaged in the market introduction of innovations (42.7% compared to 33.6%). About 36% of the firms introduced a new or significantly improved product on the market and almost 20% introduced a new service. A new production method was introduced by 26% of the firms. The firms in the computer and office equipment subsector are the most active in introducing new products, services and processes. This subsector introduced mainly new products (54.2% of the companies), followed by services (37.1%) and processes (32.8%). The electrical machinery subsector is least engaged in innovation activities; only 14% of the firms in this subsector introduced a new service and 29.3% introduced a new product. The subsectors electronics and optical equipment are somewhere in between: about 42% introduced a new product, 25% a new service, and 27% a new production method.

Table 1.3 General innovation activity in the electrical & optical equipment sector, per subsector

	Computer & Office[1)]	Electrical machinery[2)]	Electronics[3)]	Optical[4)]	E&O AVG[5)]	TOTAL AVG[6)]	GAP[7)]
General innovation activity (goods. services and process)	65.4%	42.0%	52.2%	53.1%	48.1%	n/a	n/a
Introduced onto the market a new or significantly improved good	54.2%	29.3%	42.6%	42.0%	36.3%	n/a	n/a
Introduced onto the market a new or significantly improved service	37.1%	14.0%	25.5%	23.7%	19.9%	n/a	n/a
Introduced onto the market a new or significantly improved method of production	32.8%	24.2%	27.9%	26.5%	26.0%	n/a	n/a
Engagement in intramural R&D	85.8%	74.1%	81.9%	77.9%	77.5%	21.5%	360%
Total R&D expenditure / Total turnover in 2004	9.0%	5.6%	10.7%	8.8%	7.8%	3.7%	211%
Engagement in training	56.6%	61.1%	65.8%	61.5%	61.9%	48.6%	127%
Engagement in market introduction of innovation	42.2%	36.0%	41.9%	51.6%	42.7%	33.6%	127%
Engagement in acquisition of machinery	72.6%	77.7%	77.3%	67.1%	73.8%	75.8%	-2.0%

Notes: 1) Computer & Office Machinery: NACE 30; 2) Electrical machinery: NACE 31; 3) Electronics: NACE 32; 4) Optical equipment: NACE 33; 5) Average for the whole E&O equipment sector; 6) Average for all sectors; 7) Gap in percentage points between E&O AVG and TOTAL AVG
Source: Eurostat CIS 4

Introduction of new products

More than half of the companies in the electrical & optical equipment sector introduced a product which is new to the market (57.5%) or which is new to the firm (59.2%). This is substantially higher than the average for all sectors (11.2% and 12.5% respectively). The computer and office equipment subsector is the most active (62.5% and 67.5%). The electronics and optical equipment subsector are equally active in introducing products new to the market, while the electrical machinery subsector lags somewhat behind (52.1%). Nevertheless, somewhat more companies in the electrical machinery subsector than in the optical equipment subsector introduced a product new to the firm (58.7% compared to 56.3%). Table 1.4 presents the results for the various subsectors.

Although the companies in the electrical & optical equipment sector are substantially more active in R&D and innovation than the average for all sectors, this does not result in substantially more turnover than in average coming from these innovations. Two third of the turnover comes from existing products and one third of the turnover from new, which is relatively high. About 15% of the turnover of the companies in the sector comes from products that are new to the market, compared to 11.2% in average for all sectors. About 13% of the turnover in the sector comes from products that are new to the firm, which is only slightly higher than in average for all sectors. The computer and office equipment subsector realises the highest share of turnover from products new to the market: 18.7%, followed by the electronics (17.7%) and at some distance by optical equipment (13.9%) and the electrical machinery (13.4%). The electronics subsector realises the highest share from products new to the firm: 15.7%, followed by optical equipment (13.1%), computer and office equipment (12%) and electrical machinery (11%).

Table 1.4 Introduction of new products in the E&O equipment sector, per subsector

	Computer & Office	**Electrical machinery**	**Electronics**	**Optical**	**E&O AVG**	**TOTAL AVG**	**GAP**
Did the enterprise introduce a product new to the market	62.5%	52.1%	60.5%	61.6%	57.5%	11.2%	46.3%
Did the enterprise introduce a product new to the firm	67.5%	58.7%	63.0%	56.3%	59.2%	12.5%	46.7%
Export (EU or outside EU)	8.5%	11.8%	8.6%	8.6%	9.9%	n/a	n/a
% of turnover in new or improved products introduced during 2002-2004 that were new to the market	18.7%	13.4%	17.7%	13.9%	14.7%	11.2%	3.5%
% of turnover in unchanged or marginally modified products during 2002-2004 that were new to the firm	12.0%	11.0%	15.7%	13.1%	12.7%	12.5%	0.2%
% of turnover in unchanged or marginally modified products during 2002-2004	65.4%	68.6%	62.2%	68.5%	67.2%	72.9%	-5.8%

Source: Eurostat CIS 4

Intellectual Property Rights

In average, 35% of the companies in the electrical & optical equipment sector secure their intellectual property rights, for example by applying for a patent. About 40% of the companies in the optical equipment subsector secure their intellectual property rights, followed by almost 38% of the companies in the electronics, 35% of the companies active in computer & office equipment, and 31% of the companies in electrical machinery. In average, a quarter of the companies in the sector apply for a patent. This is more common in the optical equipment subsector (29.6%) and less widely spread in the computer & office equipment subsector (18.2%). The companies in this last subsector seem to prefer registering a trademark (23.3%). This is also chosen by companies in the optical equipment (23.7%) and the electronics (23.1%). Registering an industrial design is relatively more important to companies in the electrical machinery. Claiming copyright is the least favourite method to secure intellectual property rights in all subsectors. Table 1.5 presents the finding for the various subsectors.

Table 1.5 Protecting intellectual property rights in the E&O equipment sector, per subsector

	Computer & Office	Electrical machinery	Electronics	Optical	E&O AVG	TOTAL AVG	GAP
General intellectual property rights	34.9%	30.7%	37.7%	38.9%	35.1%	n/a	n/a
Applied for a patent	18.2%	21.6%	24.4%	29.6%	24.7%	15.9%	8.8%
Claimed copyright	9.0%	2.6%	6.0%	3.6%	4.0%	4.5%	-0.5%
Registered an industrial design	10.2%	14.7%	10.6%	15.8%	14.1%	17.4%	-3.3%
Register a trademark	23.3%	13.9%	23.1%	23.7%	19.5%	16.0%	3.5%

Source: Eurostat CIS 4

Cooperation

In average, one third (33.8%) of the companies in the electrical & optical equipment sector collaborates with partners in their innovation activities. This is somewhat higher than the average for all sectors (25.1%). National collaborations are very popular: 90.3% of the firms in the sector cooperate with national partners, which is substantially more than the average for all sectors (23%). Slightly more than 50% of the companies collaborate with international partners in the same sector and slightly less than 50% collaborate with international partners from other sectors. Both types of collaborations are far more present in this sector than in other sectors. Cooperation with other enterprises within the enterprise group is also important: one third of the companies have this type of collaborations, compared to 8.7% in average for all sectors. Almost 40% of the companies collaborate with national universities and research organisations, while international collaborations are less present with only 8.8%.

Collaboration in innovation is popular amongst companies in the electronics subsector (40.7%), but less in the computer and office equipment subsector (27.3%). When collaborating in innovation, in all subsectors about 90% of these companies cooperate with national partners. International collaborations are somewhat less present in the computer and office equipment than in the other subsectors. Cooperation with other enterprises within the enterprise group is popular for companies in the electrical machinery (43.4%), but substantially less present in the computer and office equipment subsector (21.5%). Half of the companies in the electronics cooperate with national universities and research organisations, while in the computer and office equipment subsector about 32% of the companies cooperate with national research institutes. Examples of these conglomerates are IMEC in Belgium and the cluster around Grenoble including the CEA-LETI institute. Although companies in the Electrical machinery are very much in favour of collaborating with international partners (57 to 60% of the collaborations), this does not hold for cooperating with international universities and research organisations (6.8%, compared to 43% for national research institutes).

Table 1.6 presents the findings for the various sub-sectors. This may imply that research collaboration with global suppliers and customers is more important than with research institutes.

Table 1.6 Cooperation in the electrical & optical equipment sector, per subsector

	Computer & Office	Electrical machinery	Electronics	Optical	E&O AVG	TOTAL AVG	GAP
Cooperation arrangements on innovation activities	27.3%	28.9%	40.7%	36.9%	33.8%	25.1%	8.7%
National cooperation	89.0%	87.8%	92.7%	91.3%	90.3%	23.0%	67.3%
International cooperation	44.9%	60.5%	58.0%	58.7%	51.9%	11.8%	40.0%
International cooperation outside company group	41.5%	57.5%	57.8%	54.7%	48.7%	5.1%	43.6%
Cooperation with other enterprises within enterprise group	21.5%	43.4%	32.2%	31.6%	31.9%	8.7%	23.1%
Cooperation with National Universities / Government or research institutes	31.6%	43.1%	50.0%	46.9%	39.8%	n/a	n/a
Cooperation with International Universities / Government or research institutes	7.8%	6.8%	12.6%	13.8%	8.8%	n/a	n/a
Cooperation National Market	77.7%	68.7%	71.4%	78.7%	65.8%	n/a	n/a

Source: Eurostat CIS 4

Public funding

About 55% of the companies in the electrical & optical equipment sector use public funding; this is twice as much as in average for all sectors. Around 60% of the companies in the electronics and optical equipment subsectors use public funding. Somewhat less companies in the electrical machinery (49.5%) and the computer and office equipment (40.8%) use public funding. Public funding from the central government is the most popular; 22% of the companies in the sector use this type of funding. Regional funding follows with 19.3% of the companies using this. For companies in the computer and office equipment and the electrical machinery subsectors, regional funding is somewhat more important than funding from the central government. For companies in the electronics and optical equipment subsectors it is the other way around. Public funding from the EU and from the European Framework Programmes (6% and 7.9% respectively) is less important to the companies in the sector than national and regional funding. Still, EU funding is more important for the sector than other manufacturing sectors. Public funding from the EU and the European Framework Programmes is used by more companies in the electronics and optical equipment subsectors than in the other two subsectors. Table 1.7 presents the findings for the various subsectors.

Table 1.7 Public funding in the electrical & optical equipment sector, per subsector

	Computer & Office	Electrical machinery	Electronics	Optical	E&O AVG	TOTAL AVG	GAP
Any public funding	40.8%	49.5%	63.8%	60.0%	55.3%	28.9%	26.3%
Public funding from local or regional authorities	16.5%	20.4%	16.5%	19.9%	19.3%	15.5%	3.8%
Public funding from central government	12.3%	18.1%	29.5%	24.0%	22.0%	15.4%	6.6%
Public funding from the EU	4.2%	3.4%	8.6%	8.0%	6.0%	5.8%	0.2%
Funding from EU's 5th or 6th RTD	3.7%	3.6%	11.2%	11.9%	7.9%	2.6%	5.2%

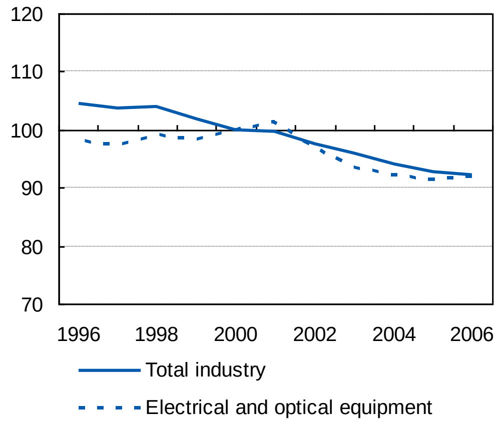
Source: Eurostat CIS 4

2 Carriers of innovation

2.1 People

The electrical & optical equipment sector employs over 3.6 million workers in EU27 (Eurostat SBS data, 2004). This is approximately 10.6% of all European working in the manufacturing sector. The largest number (almost 1.7 million) is working in the electrical machinery subsector followed by the optical equipment subsector (1 million persons in 2005). Over the years the total number of employees in the sector has been declining: between 1996 and 2006 it shrunk with nearly 6.5%. However, the decrease in employees was a bit smaller than the total industry development in employees (see figure 2.1).

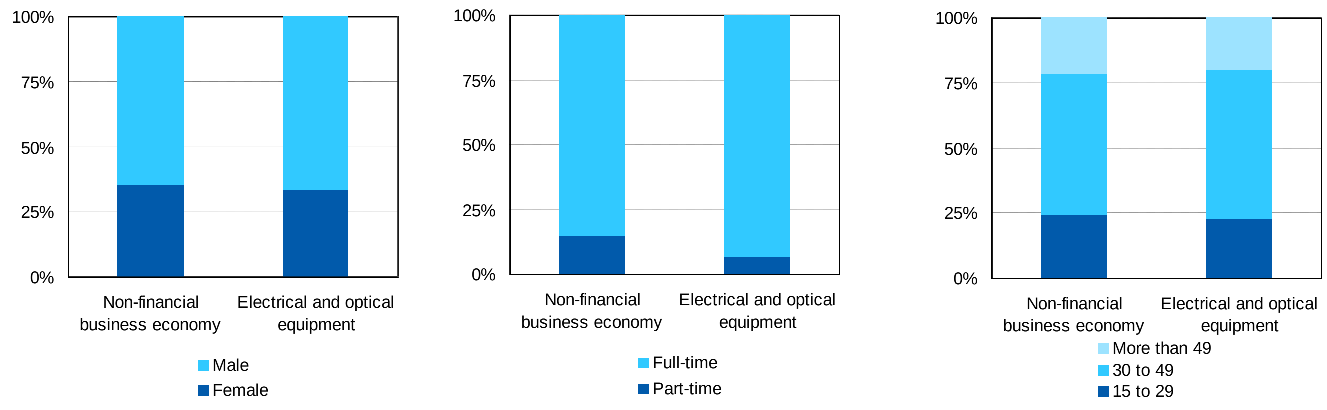
Figure 2.1 Index of employment between 1996-200



Source: Eurostat (2008)

In 2005 more than half of the 3.6 million people works in three countries: (1) Germany (1.0 million), (2) France (0.43 million) and (3) Italy (0.42 million). However, the electrical & optical equipment sector is the most important for employment in Slovakia. About 6.8 % of Slovakian employees work in the sector, followed by Hungary (6.0 %) and Finland (5.4 %). These countries are most specialised in manufacturing electrical & optical equipment. About 64% of all employees in the sector work for a large company (250 or more employees). Eurostat data in Figure 2.2 demonstrates that the average employee is male (approximately 64 percent), works on a full-time basis (over 90 percent) and about 80 percent is younger than 49, which is a bit younger than other non-financial business sectors.

Figure 2.2 Distribution of gender, contract and age



Source: Eurostat (2008)

The electrical & optical equipment is a high-tech sector: global and fast-changing markets, high degree of competitiveness and R&D intensive. Therefore, the share of engineers is by far the largest of jobs in the sector followed by assembling and business. Employment is dominated by medium educated employees; this is true for the EU15 (47%), but specifically for Central and East Europe (CEE)[2] (71%). Low educated workers, with a share of 17% in the EU15 and only 9% in the CEE, lost ground; decreases in both the EU15 and CEE amounted to 5% points over the last 7 years. The CEE has considerably more assemblers, machinery workers and mechanics than the EU15, whereas the EU15 has more engineers, professionals and office clerks than the CEE. The skills paragraph will delve deeper into the differences. Changes in the CEE show more marked shifts, e.g. in the category other professionals and labourers (both minus 5% points), engineers and assemblers (up 4% and 5% points, respectively) and computing professionals (up by 3% points) (Van der Zee et al., 2009).

Table 2.1 Global trends in employment

Electrical & optical equipment sector (excluding electrical machinery)				
	Employment growth (in %)	***Change in share of employment manufacturing total (in %)***	***Value added growth (in %)***	***Value added growth per employee (in %)***
Europe (EU-15)	-4.6	-0.4	62.1	69.9
United States[1]	-31.2	-2.18	-7.5	34.3
Japan	-32.6	-1.71	-24.2	12.5
Emerging economies				
Brazil[2]	9.2	0.3	-2.4	-10.6
Russia[3]	24.0	1.9	188.8	64.5
India	-10.5	-0.71	23.6	38.2
China[4]	125.4	8.25	650.8	N.A.

Source:<TNO Research, based on data of UNIDO (ISIC Rev. 3), van der Zee et al. (2009)
[1] USA: does not contain data on 'Watches and Clocks' (NACE 33.3))
[2] Brazil: 1996-2005, Russia: 2001-2005; India: 1998-2004
[3] Russia: 'Total' does not contain data on 'Watches and Clocks' (NACE 33.3)
[4] Data for China based on ISIC Rev 2

[2] Central and East Europe are Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, and Slovenia (joined on 1 May 2004) and Bulgaria and Romania (joined on 1 January 2007).

Table 2.1 adds a global perspective of employment. Data from the United Nations Industrial development organisation reveals how movements in employability on a global scale. Between 1995 and 2005 a clear pattern is visible: the traditional countries dominating the electrical & optical equipment sector are losing terrain in terms of employability. The number of employees decreased more severe in United States and Japan, both with more than 30%. In the contrary, an emerging country like China is rapidly growing: between 1995 and 2005, the number of Chinese employees in the sector grew with more than 125% and in Russia with almost 24 percent. Likewise the shift from CEE to EU15, this data shows a clear shift from Europe, United States and Japan towards Emerging economies, like China and Russia.

Productivity

According to Eurostat data from 2005 the average productivity (calculated as the gross value added per employee) within the sector (51.8k EUR) is a bit higher than the industry average[3] (47k EUR) which is not surprising, because of the combination of a capital intensive and science-based nature. The most ICT manufacturing related subsectors: computer & office (65k EUR) and electronics (62.5k EUR) had the highest productivity averages in 2005. However, there are huge differences between countries in EU27. In all subsectors, Ireland has the highest labour productivity. EU15 countries have significantly higher labour productivity rates than CEE. For example, Latvia is on of the countries with the lowest labour productivity among all subsectors. This reflects the role of Central and East Europe, which is due to lower wages more specialised in labour-intensive activities, such as assembling.

Table 2.2 Country and productivity per subsector

Computer & Office		**Electrical machinery**		**Electronics**		**Optical equipment**	
EU average	65	EU average	44.4	EU average	62.5	EU average	53.5
Highest productivity		*Highest productivity*		*Highest productivity*		*Highest productivity*	
Ireland	156.1	Ireland	90	Ireland	207.5	Ireland	113
Germany	89.6	Netherlands	67.6	Finland	145.2	Denmark	82
Denmark	83.7	Austria	66.5	Sweden	125.4	Sweden	78.9
Lowest productivity		*Lowest productivity*		*Lowest productivity*		*Lowest productivity*	
Greece	5.5	Romania	4.8	Latvia	5.8	Bulgaria	4.3
Bulgaria	6.6	Latvia	5.5	Slovakia	8.2	Romania	9.6
Latvia	8.4	Bulgaria	7.3	Estonia	11.1	Latvia	10.6

Source: Eurostat, data from 2005

Skills

High-skilled human resources are important for the electrical & optical equipment sector. The short innovation cycles require skills to adapt quickly to the competitive environment. Trends in production (i.e. lean manufacturing); supply chain management, investment and innovation should be reflected by the skills of the whole workforce in the sector (from operational to strategic level in the organisation). The UK based Electronics Sector Strategy Group pointed out that strategic management, design skills and entrepreneurship are important for innovation in the sector. Many sources mention that a lack in highly skilled and educated human resources can slow down innovation in the sector (Wintjes & Dunnewijk, 2008; EITO, 2007; European Commission, 2006a; European Commission, 2006b;

[3] NACE category D

Eucomed, 2007). The shortage mainly regards 'hard skills'. The British Sector Skills Council for Science, Engineering and Manufacturing Technologies (SEMTA) reports a skill gap in the British Electrical & Optical equipment sector: there is a lack of employees with technical engineering and (machinery) programming skills. The same holds for the Electrical machinery sub sector. Another more specific example arises in the optical equipment subsector, in which there is a shortage of medical engineers, such as Medical Informatics specialists (Eucomed, 2007).

The 'Comprehensive Sectoral Analysis of Emerging Competences and Economic Activities in the European Union' for the European Commission (DG Employment) gives a complete overview of the emerging skills, competences and economic activities in the electrical & optical equipment sector (Van der Zee et al., 2009). However, the electrical machinery subsector was not taken into account in this analysis. The division of occupations in the sector gives an overview of the skills and competences. Table 2.3 gives an overview of the current situation. It shows the job functions, descriptions and trends and the figures for the EU15, CEE and EU27.

Table 2.3 Most common job functions in the electrical & optical equipment sector

Job functions	Characterization and trends	EU15	CEE	EU27
Managers	Corporate and specialist managers covering all firm functions. Increasingly high educated	10%	5%	9%
Computing professionals	ICT professionals developing and designing systems and programmes, as well as applying embedded software. Increasing their share and mainly mid and high educated.	8%	6%	8%
Engineers	R&D and production engineers, respectively developing new products and processes and applying and supporting systems used in production. Increasing their share, mainly mid and high educated.	21%	13%	19%
Business and other professionals	Accounting & Finance, Sales and Marketing, Supply chain Management. Stable share, mainly mid educated.	16%	12%	14%
Office clerks and secretaries	Office clerks, administrative functions. Decreasing in share and lower and mid educated, but improving.	10%	7%	10%
Metal machinery workers. Blacksmiths	Metal moulders, welders, sheet-metal workers, blacksmiths, and tool-makers. Stable in share and lower / mid educated	4%	7%	5%
Electric and -equipment mech. fitters	Electrical and electronic equipment mechanics, fitters and servicers. Decreasing in share and lower / mid educated, but improving	7%	10%	7%
Precision, handicraft, craft printing	Precision workers in metal and related materials, precision-instrument makers and repairers, photographic workers. Stable in share.	8%	6%	8%
Assemblers	Electrical and electronic equipment assemblers. From lower to mid educated. Decreasing in EU15.	8%	23%	11%
Labourers & operators	Manufacturing labourers, quality control workers. Decreasing in share and lower to mid educated.	9%	11%	9%

Source: Van der Zee et al. (2009)

Table 2.3 shows a picture consistent with the differences found in the productivity data. The EU15 countries have more highly educated engineers and secondary functions, i.e. managers, office clerks and professionals and the CEE have more lower educated technical jobs (such as machinery workers) and assemblers of electrical and electronic equipment. Overall, a general trend of up-skilling can be observed in the EU computer, electronic and optical products sector, meaning a move to a higher –

predominantly middle and high - educated workforce, with a consequent decrease of the low educated workforce.

2.2 Organisations

2.2.1 The largest R&D spending firms

As explained in the introduction section of this report, large companies are dominating the electrical & optical equipment sector. We present the largest R&D spending manufacturers of the sector using two sources:

- The EU Industrial R&D Scoreboard (release date: October 2008) ranking about 1000 European companies on the R&D expenditure.
- The number of patent applications at the European Patent Office in 2007.

Table 2.4 shows the top 15 of European firms with the highest R&D expenditure according to the R&D Scoreboard. Although Nokia (Finland) is in terms of sales and employees way smaller than Siemens (Germany) it is by far the biggest R&D spender in Europe with 5.28 billion Euros. The top 10 is dominated by companies from the electronics subsector: 7 out of 10 companies of the largest companies are from this sector. However, it must be said that large multi nationals such as Alcatel-Lucent (France), Philips (The Netherlands) of Siemens are much broader than the subsector in this study or the category of the scoreboard they are assigned to. For example, Philips produces both consumer electronics (which is part of the electronics subsector), Lighting equipment (which is part of the Electrical machinery subsector) and has a vivid medical equipment division (which is part of the optical equipment sector) as well.

Table 2.4 Top R&D spending European and non-European firms

#	*Company*	*Country*	*Subsector*	*R&D expenditure (Million euro)*	*Net sales (Million euro)*	*Employees*
1	Nokia	Finland	Electronics	5,281.00	51,058	100,534
	Samsung	*Korea*	*Electronics*	*4,691.00*	*n/a*	*n/a*
	IBM	*USA*	*Computer & Office equipment*	*4,475.00*	*n/a*	*n/a*
	Intel	*USA*	*Electronics*	*4,145.00*	*n/a*	*n/a*
	Panasonic	*Japan*	*Electronics*	*3,570.00*	*n/a*	*n/a*
2	Alcatel-Lucent	France	Electronics	3,368.00	18,005	76,410
3	Siemens	Germany	Electrical machinery	3,366.00	90,348	398,200
	Sony	*Japan*	*Electronics*	*3,359.00*	*n/a*	*n/a*
	Cisco systems	*USA*	*Computer & Office equipment*	*3,272.00*	*n/a*	*n/a*
	Motorola	*USA*	*Electronics*	*3,221.00*	*n/a*	*n/a*
4	Philips Electronics	The Netherlands	Electronics	1,604.00	27,037	125,656
5	Infineon Technologies	Germany	Electronics	1,169.00	7,682	42,549
6	STMicroelectronics	The Netherlands	Electronics	1,166.16	6,816	52,180
7	NXP	The Netherlands	Electronics	1,058.00	4,629	37,627
8	Schneider	France	Electrical machinery	675.00	17,309	119,340
9	ASML	The Netherlands	Electronics	488.96	3,809	6,191
10	Carl Zeiss	Germany	Optical equipment	290.00	2,604	11,936
11	Océ	The Netherlands	Computer & Office equipment	218.75	3,098	23,798
12	Agfa-Gevaert	Belgium	Electrical equipment	200.00	3,283	13,553
13	Fresenius	Germany	Optical equipment	184.00	11,358	108,262
14	Legrand	France	Electrical machinery	175.90	4,129	32,355
15	Essilor International	France	Optical equipment	137.67	2,908	29,272
16	Invensys	UK	Electrical machinery	136.15	3,427	26,002
15	BioMerieux	France	Optical equipment	131.80	1,063	5,749

Source: R&D scoreboard 2008 (OECD, 2008a)[4]

[4] The OECD data on R&D expenditure is collected in the year 2007. The amounts of R&D expenditure are converted from USD to EUR with the average exchange rate in 2008 (EUR: USD = 1.37)

The OECD IT outlook 2008 gives an overview of the patent applications at EPO in 2007. This regards mainly ICT manufacturing related applications, so it covers only a part of all applications that has been registered in the E&O equipment sector. Table 2.5 demonstrates the resulting top 10 of global companies registering patents at EPO. It does not reflect a different picture than the figures of the Scoreboard. The largest European companies are Philips, Siemens, Nokia and NXP. Unsurprisingly, the other companies are large producers from Asia, such as Samsung (South-Korea) and Matsushita (Japan) and LG Electronics (South Korea).

Table 2.5 Top 10 firms registering EPO applications

Ranking	***Enterprise***	***Country***	***Number of applications (2007)***
1	Philips	Netherlands	3222
2	Samsung	South Korea	2478
3	Siemens	Germany	1850
4	Matsushita	Japan	1395
5	LG Electronics	South Korea	1080
6	Sony	Japan	929
7	Nokia	Finland	873
8	Fujitsu	Japan	819
9	Hitachi	Japan	755
10	NXP	Netherlands	670

2.2.2 Industry organisations and initiatives

This paragraph will give an overview of the most important industry organisations. It includes industry associations, initiatives and standardizing bodies.

The European Electronics Component manufacturer's Association (EECA) represents the European-based manufacturers of semiconductor devices. It includes a part on passive components (EPCIA) and semiconductors (ESIA). National associations linked to ESIA are AETIC (Spain), AGORIA (Belgium), ANIE (Italy), FEEI (Austria), HSIA (Greece), NMI (United Kingdom), SITELESC (France) and ZVEI (Germany). The most important research institute is CEA-TETI in France.

DigitalEurope was founded as the European Information & Communication Technology Association (EICTA) in 1999 and represents 56 multinational companies and 36 national associations within the European digital technology industry. In total, more than 10.000 companies with approximately 2 million employees are represented by DigitalEurope. Although it includes manufacturers, this association is much broader covering software and services (such as consultancy) as well.

The International Technology Roadmap for Semiconductors (ITRS) is the fifteen-year assessment of the future technology developments and requirements in the semiconductor industry. ITRS is sponsored by the semiconductor industry associations from Europe, Japan, Chinese Taipei, Korea and the United States. Teams of global chip manufacturers, equipment suppliers, and research communities identify the innovation challenges and develop the roadmaps, which describe very precisely the technology requirements for the future (www.itrs.net).

SEMATECH is an international strategic and applied research and development consortium of 18 global companies and a university (Albany, Texas). SEMATECH started as a US initiative, supported by the US government, but it has become a global consortium since the mid 1990s. SEMATECH aims to accelerate the adoption of new technologies and innovation in the semiconductor manufacturing. Although the consortium itself includes only semiconductor production firms, it collaborates also with equipment and material suppliers, universities, research institutes, start-up companies and governments. SEMATECH has three subsidiaries: the Advanced Technology Development Facility (ATDF), the Advanced Materials Research Center (AMRC) and the International SEMATECH Manufacturing Initiative (ISMI) (http://www.sematech.org/). The International Imaging Industry Association (I3A) is a global consortium of imaging companies and aims to develop and promote the adoption of open industry standards, to solve interoperability challenges, and to resolve infrastructure issues (http://www.i3a.org).

Another industrial consortium is the International Electronics Manufacturing Initiative (iNEMI), which includes 70 electronics manufacturers, suppliers, associations, government agencies and universities. iNEMI aims to identify the needs and priorities of the global electronics industry, the technology and infrastructure gaps and helps to bridge these gaps by accelerating the adoption of new technologies, developing industry infrastructure, disseminating business practices, and stimulating industry standards. iNEMI provides a forum for companies to collaborate and to share expertise (http://www.inemi.org/cms/).

Apart from the Photonics21 technology platform, European Optical equipment manufacturers are united in the European Photonics Industrial Consortium (EPIC). This consortium groups all major players, both from academia and industry.

Another industry organisation is Eucomed. It represents 4500 European designers, manufacturers and suppliers of medical technology used in the diagnosis, prevention, treatment and amelioration of disease and disability. Eucomed members include national trade and pan-European product associations and internationally active manufacturers of all types of medical technology. The mission of Eucomed is to improve patient and clinician access to modern, innovative and reliable medical technology.

CENELEC, the European Committee for Electrotechnical Standardization, was created in 1973 and is a non-profit technical organization composed of the National Electrotechnical Committees of 30 European countries. CENELEC’s mission is to prepare voluntary electro technical standards that help develop the Single European Market/European Economic Area for electrical and electronic goods and services removing barriers to trade, creating new markets and cutting compliance costs.

ETSI, the European Telecommunications Standards Institute, produces ICT standards as well. It is an official European Union standardization organization that produces globally-applicable standards for fixed, mobile, radio, converged, broadcast and internet technologies. Currently, ETSI has 700 ETSI member organizations from 62 countries across 5 continents world-wide.

ELECTRA is a joint initiative by the EU's electrical and electronic engineering industry and the European Commission. It aims at addressing the EU's policy objectives on climate change and the creation of more growth and better jobs, whilst proving that the electrical and electronic engineering industry in Europe is strong, vibrant and innovative. ELECTRA deals with all questions relating to the competitiveness of the European electrical and electronics engineering industry.

2.2.3 Research institutes

There are large research institutes linked to the electrical & optical equipment sector. Large research institutes are located in Germany (i.e. Fraunhofer), France (i.e. CEA-LETI), Benelux (i.e. IMEC) and Spain (i.e. UMLC), (CATRENE, 2009), but for the optical branch also in Scotland, Ireland and Poland. The ICT sector and its academia face several challenges (see for example European Commission, 2009a; EIT, 2009):

- Fragmentation: the EU's higher education and research systems are too fragmented, leading to dispersed innovation efforts.
- Only a few world-class universities
- Not enough business involved in education and research
- Education and research are too slow in responding to changes in needs. Lack of entrepreneurship.
- Europe is not able to attract or keep top-class research talent
- Need for user-driven innovation and more attention to lead markets
- Insufficient private funding for education and R&D compared with other world regions

The European Institute of Innovation and Technology (EIT) is an initiative by the European Commission to tackle those challenges on research, i.e. the fragmented landscape of research in Europe. It aims to foster excellence in European innovation by pooling the expertise of universities, research bodies and businesses. Initially it received a funding of 300 million and it was opened in September 2008 in Budapest. EIT embeds the business dimension in all knowledge activities and in turn makes knowledge outputs from universities and research more accessible to businesses. Its instruments to foster innovation will be trans- and interdisciplinary strategic research and education in areas of important economic or societal interest and exploitation of its knowledge outcomes for the benefit of the citizens. It will build a 'critical mass' of human and physical resources, attracting and retaining private sector investment in innovation, education and R&D (EIT, 2009). It works with Knowledge Intensive Communities, working on specific areas. Two of them are very relevant to the E&O sector: (1) Next generation ICTs and (2) Renewable energies.

2.2.4 Financial organisations

External financing from (1) shares (2) private equity (venture capital and later stage) investments from private equity funds and investment banks are important for the innovation in the sector. Wintjes & Dunnewijk (2008) point out that private equity has become increasingly important for SMEs and start-up companies in the ICT sector. According to their research, the ICT sector has attracted the largest share of private equity investment in the EU-25 between 1997 and 2005. The total investment of private equity in this sector was about 11,000 million EUR in 2005.

The largest financial stakeholder in private equity funding is the European Investment Fund. In 2008 financial guarantees for SMEs totalled about 12,000 million EUR which is about 50% more than in 2005 (European Investment Fund, 2009). ICT and Biotech SMEs have the largest share in these guarantees.

Apart from private equity and shares, funding from the public sector is an important financial source for innovation as well. CIS4 data revealed that over 55.3 percent of the responding firms received any public funding (local, regional, national or European).

2.3 Clusters and networks

2.3.1 European Technology Platforms

In Europe, but also worldwide, companies, universities and other research organisations collaborate in dedicated R&D collaborations and networks. European Technology platforms (ETPs) are the most important examples of collaborative networks in the E&O equipment sector. ETPs help the industry and academic research institutes to co-ordinate their research in specific technology fields (i.e. micro-electronics). All ETPs set up a common strategy, a Strategic Research Agenda (SRA), and aim to build partnerships to share risk, pools of resources and team up to compete worldwide. Accordingly, their objective is to speed up innovation by sharing knowledge and experience and build consensus around technology development strategies and other measures needed to turn R&D into marketable products (ISTAG, 2006). They are important input for the Framework Programme 7 (FP7).

The technological fields of the ETPs vary from solar energy technologies to robotics. CATRENE is, for example, a pan-European programme for co-operative R&D in microelectronics, initiated by the industry and funded within the framework of EUREKA. CATRENE started in January 2008 and builds on previous EUREKA programmes JESSI, MEDEA, and MEDEA+. This four-year programme focuses on R&D in nano electronics.

Two of the ETPs, ENIAC and ARTEMIS, are Joint Technology Initiatives (JTI). A JTI is a Joint Undertaking by industry and academics under a special treaty of the FP7, focusing on one specific industrial area, having a well defined objective, addressing a market failure and funded by a combination of private and public investments.'

The functioning of the ETPs was evaluated in August 2008 by Ideaconsult. The results of an extensive online survey, case studies and interviews among all relevant stakeholders revealed that the ETPs are successful in mobilising industry and academia and creating a momentum on industrial and political level. The study concludes that ETPs are generally considered to be sufficiently open and transparent and successfully involve and represent a broad range of EU-wide stakeholders in their activities. Most stakeholders are satisfied with the strategic work of the ETPs and the coordination role they have resulting in significant synergy effects between industry and academia. Concerning the goal of mobilisation of resources stakeholders indicate positive effects in relation to the increase of EU funding, national funding and also industrial (private) funding in certain R&D areas. Concerning effects on the improvement of framework conditions and the enhancement of a high-skilled workforce, there are positive effects as well. However, the study reveals that ETPs have difficulties in providing evidence about their activities and the results achieved. Despite of this, it seems that innovation performance benefits from these platforms.

2.3.2 Clusters

As a high-tech sector the electrical & optical equipment sector depends on research and highly skilled human resources. Therefore, regional concentration mostly depends on a research friendly environment and the availability of a highly skilled workforce (Wintjes & Dunnewijk, 2008). Organisations participating in a cluster enjoy several economic benefits, including access to specialised human resources and suppliers, knowledge spill overs, pressure for higher performance in head-to-head competition and learning from the close interaction with specialised customers and suppliers.

The cluster analysis of the previous Sectoral Innovation Watch revealed the following clusters for ICT manufacturing (which excludes the electrical machinery subsector): Stockholm (Sweden), two Finnish regions (North and South Finland), Ile de France (France), Oberbayern (Germany), Hampshire and Isle of Wight (UK), Dresden (Germany), Vienna (Austria), Surrey and East and West Sussex (UK).

Based on these three dimensions, clusters are rated with one to three stars (with tree stars being most important).

Table 2.6 gives an overview of the most important clusters. Over half of all clusters are located in Germany. For example, the whole top 5 of analytical instruments clusters is German.

Table 2.6 Top 5 clusters for each cluster category[5]

Top 5 lighting and electrical equipment clusters					
Cluster	*Employees*	*Size*	*Spec.*	*Focus*	*Stars*
Lombardia (Milan), IT	27 599	5.34%	2.40	0.68%	**
Rhône-Alpes (Lyon), FR	15 971	3.09%	2.95	0.83%	**
Arnsberg (Dortmund), DE	15 523	3.01%	5.09	1.43%	**
Stuttgart, DE	9 944	1.93%	2.43	0.68%	**
Detmold, DE	7 060	1.37%	3.80	1.07%	**
Top 5 medical equipment clusters					

[5] The European Cluster Observatory (www.clusterobservatory.eu) contains a database with 259 regions, 38 industrial cluster categories resulting in 10.000 clusters in 32 countries. These clusters are assessed on three dimensions:

- **Size:** if employment reaches a sufficient share of total European employment, it is more likely that meaningful economic effects of clusters will be present.
- **Specialisation:** if a region is more presented in a certain cluster than in the overall economy, this will indicate the economic importance of the regional cluster.
- **Focus:** if a cluster accounts for a larger share of a region's overall employment, it is more likely that spill-over effects and linkages will actually occur instead of being drowned in the economic interaction of other parts of the regional economy.

Ireland, IE	17 509	3.92%	4.53	1.10%	**
Freiburg, DE	13 026	2.92%	7.74	1.88%	**
Emilia-Romagna (Bologna), IT	11 601	2.60%	2.68	0.65%	**
Karlsruhe, DE	8 501	1.90%	3.69	0.89%	**
Tübingen, DE	6 765	1.52%	4.75	1.15%	**
Top 5 communication equipment clusters					
Vest (Timisoara), RO	36 431	4.57%	14.10	6.10%	***
Zapadne Slovensko (Nitra), SK	25 022	3.14%	7.78	3.37%	***
Pohjois-Suomi (Oulu), FI	7 725	0.97%	7.40	3.21%	***
Etelä-Suomi (Helsinki), FI	18 465	2.32%	3.60	1.56%	**
Düsseldorf, DE	17 989	2.26%	2.51	1.09%	**
Top 5 information technology clusters					
Berks, Bucks and Oxon (Oxford), UK	45 071	2.19%	3.68	4.10%	***
Oberbayern (München), DE	45 026	2.19%	2.56	2.85%	***
Karlsruhe, DE	36 164	1.76%	3.41	3.81%	***
Stockholm, SE	34 633	1.69%	3.21	3.59%	***
Zürich, CH	23 685	1.15%	2.80	3.12%	***
Top 5 analytical instruments clusters					
Oberbayern (München), DE	21 339	3.99%	4.65	1.35%	**
Darmstadt (Frankfurt am Main), DE	19 466	3.64%	4.79	1.39%	**
Karlsruhe, DE	18 037	3.37%	6.53	1.90%	**
Freiburg, DE	17 315	3.24%	8.59	2.50%	**
Stuttgart, DE	15 738	2.94%	3.71	1.08%	**

The most important optics and photonics clusters are bayern photonics e.V., Hanse Photonik e.V., Photonics Cluster UK, Optics Valley France, Optec-Berlin-Brandenburg e.V., Optence e.V. , OpTech-Net e.V.; Duisburg, OptecNet Deutschland e.V., OptoNet e.V., Photonic Net, Photonic BW, PhotonAIX e.V., Scottish Optoelectronics Association, South East Photonics Network (SEPNET) and The Welsh Opto-electronics Forum.

According to the mapping of cluster policies in Europe, all countries have cluster programmes on a national and/or regional level by January 2008 (INNOVA, 2008). However, cluster policy is still at an early stage in many countries. Around half the countries in the survey first started applying cluster policy after 1999.

Table 2.7 gives three examples of clusters in the E&O equipment sector: OptecBB in Germany, Grenoble cluster in France and the Vilnius cluster in Lithuania.

Table 2.7 Examples of clusters in the electrical & optical equipment sector

Cluster	***Focus***	***Description***
OptecBB (Germany)	Photonics	OptecBB is one of the 9 optics clusters / competence networks in Germany. It is part of the OptecNet association and is an important photonics cluster in the area of Berlin-Brandenburg (Germany). It clearly shows the science-based nature of the Optical equipment subsector. In 2002, it consisted of over 260 companies and about 40 research centres. The OptecBB cluster had a total turnover of 1,800 million EUR and employs about 7,400 people in 2002. As in many Optical equipment clusters, SMEs have an important share: about 90% of the companies are small (up to 49 persons) and 5 percent of the firms is large. Remarkable, these large companies are less active in developing the OptecBB cluster than small clusters. Research institutes include Humboldt University in Berlin, the university of Potsdam, several Fraunhofer institutes and the Max-Born-Institute; ranging from fundamental to applied research. *Source: ACM Research, Developing Photonics Clusters: Commonalities, Contrasts and Contradictions, April 2007; www.OptecBB.de*
Grenoble (France)	Nano- and microelectronics	The Grenoble area (France) is known for its large nano- and microelectronics cluster. In 2006 this high-tech cluster employed about 25.000 jobs directly related to microelectronics and almost 40.000 when IT related industry is counted as well. The entire value chain of microelectronics is present: from R&D to clean rooms and it brings innovation stakeholders from industry, academics and government together. About 500 companies are in the cluster. Examples are ST Microelectronics (The Netherlands), NXP (The Netherlands and Motorola (USA) and fast-growing start-ups like Soitec (France). There are many research facilities in the Grenoble area: about 15 percent of the people working in the Grenoble area are researchers. They work in large research institutes such as CEA-LETI – boosting about 1500 researchers and 115 laboratories and covering themes like biotechnology, renewable energies (i.e. solar power) and nanomaterials. In addition, it has an incubator role for high-tech start-ups. *Source: INNOVA cluster case studies*
Vilnius (Lithuania)	Laser technology and optical components	Although being a small cluster, the laser technology cluster in the area of Vilnius (Lithuania) is an example of an East European cluster in the Electrical & Optical equipment sector. About 10 companies produce laser machines for the industry, medical sector and research. Furthermore, it produces instruments based on laser technology and optical components like sensors and detectors. The origin of the cluster is the scientific work for the Soviet Defence industry. Laser technology companies are exporting to the European Union, US, Japan, Switzerland and other countries. The total sales network covers nearly 100 countries. Nevertheless, the turnover is small (15 M € in 2003) as the market is predominantly scientific. A large part of the lasers are used in the area of scientific research at foreign universities, institutes, including Japanese and Israeli nuclear re-search centres, and laboratories of large companies. The largest companies in the cluster are UAB Eksma, UAB Ekspla and UAB Šviesos konversija and the most important research institutes are the Laser Research Centre at Vilnius University, the Vilnius University Institute of Material Science and Applied Research, the Laboratory of Indirect Optics and Spectroscopy of the Institute of Physics and the Opto-electronics Laboratory at the Institute of Semiconductor Physics. *Source: INNOVA cluster case studies*

3 Sectoral Innovation Futures

3.1 Emerging and future drivers of innovation between S&T and demand

3.1.1 Science & technology drivers

This section aims at giving an overview of the most important science & technology (S&T) drivers in the electrical and optical equipment sector. Most drivers are cross-subsector (e.g. optical, electronics, electrical machinery, etc.) and are not exclusive for the electrical & optical equipment sector (e.g. miniaturization), emphasising the fact that this sector can be classified as a General Purpose Technology producing sector. At the end of this section, an analysis is made of how the science & technology drivers are embedded in the FP7 – ICT programme.

Science & Technology drivers in the electrical & optical equipment sector can be distinguished on two phases of the value chain:

1. The production side of electrical & optical equipment, which encompasses materials, machinery and the production of equipment (e.g. semiconductors).
2. The application phase of electrical & optical equipment, which encompasses integration, hardware, software and services.

The S&T drivers on the production and application side enable each other and the S&T drivers on both the production and application side are influenced by demand drivers (section 3.2). The next sections describe the S&T trends on the production and application side. Table 3.1 gives an overview of the S&T drivers that will be discussed in the next paragraphs.

Table 3.1 Technology trends in the electrical & optical equipment sector

Technology trends	***Description***
Miniaturisation	Electronic components, such as micro- and nano-electronics or fibre optics, need to become smaller to increase power and capacity.
Moore’s law	The processing power of micro-electronics doubles approximately every 18-24 months.
Disk law	The amount of storage capacity doubles every 9 months.
Butter’s law	Data coming out of a fibre cable doubles every 9 months
Metcalfe’s law	The value of a network increases by the square of the number of devices connected to the network.
Community’s law	The content of a community increases by $2^{\text{number of members}}$
More than Moore’s law	Moore’s Law will increasingly be combined with “More than Moore”. “More than Moore” reflects the development of technologies and applications that go beyond the boundaries of conventional semiconductors.
Flexibility in shape	Electrical and optical equipment is getting more diverse in appearance.
Energy-efficiency	Technologies are getting more efficient in producing, using and specifically storing energy. This enables autonomy for even the smallest electronics
Convergence of technologies	Technologies are getting increasingly combined in innovation: i.e. the combination of optics, mechanics and electrical engineering and the convergence of Biotechnology, Nanotechnology, Information technology and Cognitive sciences.
Ubiquitous connectivity	Networks and the Internet will become omnipresent.
Embedded	Electrical and optical equipment will disappear in our daily environment.
Intelligent	Electronics are becoming more autonomous.
Rich and sensitised interaction	Electronics will interact in a more content-rich, interactive and experiential way.

Miniaturisation

There are several common technology laws on the production side of the electrical & optical equipment sector (Singapore Foresight, 2007). The most known example is Moore's law: the processing power of microelectronics doubles approximately every 18-24 months. These laws are incorporated in the Information & Communication Technology Techno-Economic paradigm (Perez, 2002) and have been applied since the seventies. These technology laws imply *miniaturization* of technology, as micro- and nano-electronics or fibre optics need to become smaller to increase power and capacity. *The number of devices* is rapidly increasing as well. Figure 3.2 shows the trend line of miniaturization and the increasing number of devices on logarithmic scales. The huge mainframe computers from the seventies evolve towards a System in Package (SiP) chips, in which all chips are packed on each other, and a Push-Pin. However, in the future there may be limits to miniaturization. This possible scenario is denoted as "Beyond Moore's law", which urges the industry to find new technological solutions for advancements, such as Quantum computing.

Advancements in materials

Advancements in materials, such as organic materials, polymers, etc., allow electrical & optical equipment to get smaller (e.g. on nano scale), stronger, flexible, thinner, lighter or with very specific functionalities (e.g. resistant to extreme temperatures) (Leis, Butter and Van der Molen, 2007). Smart integration and smart materials enable the production of, not only components on all kind of surfaces, but whole systems; e.g. Smart Plastics or Smart organic systems (e.g. biological disposable) systems (VDMA, 2006). Figure 3.1 gives an example; in the near future it will be possible to produce intelligent systems on foil. The ability to integrate E&O equipment into other materials is an important boost realising embedded technologies.

Figure 3.1 Systems in foil

Source: TNO (2008)

Advancements in material science have major implications on the different subsectors of the electrical & optical equipment sector: optical equipment will further adapt to different shapes and electrical equipment can become more flexible, organic, flat, etc. It boosts upcoming markets in the electrical machinery subsector, such as lighting solutions, like ultra thin OLED displays, or photovoltaic cells for power generation. Last but not least, material science stimulates cheaper production of electrical & optical equipment and alternatives for scarce materials.

Convergence of science and technologies

Integration of technology for different science domains like mechanics, optical science and electrical engineering will push forward the integration of optics, electronics and machinery (e.g. optoelectronics, mechatronics or even opto-mechatronics). This integration enables new applications, like robotisation. The integration of nano-, bio-, information- and cogno technologies (known as NBIC convergence) will drive new applications such as bio-inspired ICT systems or DNA-chips. However, Leis, Butter and Van der Molen (2007) point out that this is not the only convergence taking place. Natural sciences, social sciences, humanities and ethics are also increasingly included. For example, a better understanding of complex ecological or geographical systems, such as weather or ocean flows, can inspire high-tech developments.

Ubiquitous networks

By 2015, it is estimated that the world is covered by a network of high capacity optical fibre, connected to low-cost wireless access nodes enabling anywhere, anytime connectivity (Singapore ICT foresight, 2007). Combining computing and communication networks with increasing bandwidth, and full interconnection and interoperability will permit seamless delivery of high volumes of data and services at any place and anytime. Connectivity is ubiquitous, mobile and always on. Data will be transferred secure and basic service enablers like presence, location, billing and authentication support the rapid creation of value-added services. High speed networks are always connected to ubiquitously available high power and low cost processors, making real-time grid computing a reality (ISTAG, 2006).

Embedded technologies

According to IDA (2005) and FISTERA (2005), embedding electronics in our environment will make ICT invisible and lead to the complete disappearance of the Personal Computer as we know it today. Consequently, electrical & optical equipment can be embedded in all kinds of products: cars, buildings, energy networks, house appliances, etc. Such an environment allows an invisible technical infrastructure for human action (IPTS 2003, Nordman, 2004; FMER, 2007). Technologies such as low-cost sensors, sensor and actuator networks and RFID enable data collection and control across massively distributed systems (e.g. autonomous sensor networks). Linking these sensors to geographical information (by e.g. GPS or ‘geotagging’) makes it easier to track objects

Increase of intelligence

Electrical & optical equipment will become more intelligent in the near future (ISTAG, 2006). Two factors will add to this important S&T driver (FMER, 2007; Grunwald, 2007; ISTAG, 2006). First, E&O equipment will become more sophisticated, both in computational power and visual form. Second, advancements in Artificial Intelligence (combination of ICT and cognitive sciences) will increase autonomy of electrical & optical equipment. Apart from raw processing power and storage, intelligent systems will use an array of cognitive functions that make them much more adaptive to impulses from their environment (FMER, 2007).

Rich and sensitised interaction

In the near future, interaction with technology will be much more content-rich, interactive and experiential (ISTAG, 2006). Systems will increasingly become visual and content-rich, using new visual techniques and 3-dimensional interfaces for searching, retrieving and consuming digital content. Systems will combine real and virtual worlds and include sensory interfaces, offering highly realistic, personalised and interactive experiences and enhancing intuitive man-machine interaction.

Robotisation

Many trends mentioned in the previous paragraphs, such as miniaturization, increase of intelligence, convergence of sciences & technology and rich and sensitised interaction are stimulating more autonomous (for example sensitised robots for to accompany elderly people) and smaller robots (e.g. nanobots that can monitor health within the body). Reduction in production costs and the wide array of applications will boost the number of robots. Robotisation will be an important driver for several innovation themes in the electrical & optical equipment sector, for example healthcare, production and logistics, entertainment, buildings & active ageing, and space exploration. Figure 3.2 gives an example of a robotisation: modular robots can form flexible networked robots able to perform autonomous tasks. In the future, these networked robots can cooperate to perform complex tasks.

Figure 3.2 A networked robot

Source: Kumar et al, 2006

3.1.2 Demand drivers

Electrical & optical equipment has an enormous scope and reach within our society and economy. Therefore, the future of electrical & optical equipment is steered by global challenges. The METRIS report on “Emerging Trends in Socio-economic Sciences and Humanities in Europe” (published in 2009) and a study on mega trends for innovation (TNO, 2008b) show the following demand-side drivers as important for the electrical & optical equipment sector.

Ageing society

Europeans have a better health than 50 years ago. The life expectancy rate has increased by 10 years in total, due to improved social-economic and environmental conditions, as well as better medical treatment and care (World Health Organisation, 2008; European Commission, 2004). Consequently, Europe's population is ageing rapidly. The ageing society has important socio-economic implications. On the one hand, it will lead to changing demands and needs for products and services, and, on the other hand, an ageing society leads to an ageing and also declining labour force. An ageing society demands new and other types of health and social care: new types of diagnostics and treatments for new geriatric and complex combinations of diseases. Also health care and social services that can be provided at home are required, enabling the elderly to stay at home longer independently. In addition, the ageing society has implications for the user-friendliness and accessibility of products and services, including user interfaces adapted to the specific requirements of older people. Lifelong learning facilities are necessary to enable older people being active both socially and economically.

Urbanisation

Although urbanisation in the western world has slowed down, the growth of urban areas is still an important future trend (METRIS, 2009). For example, about half the world population lives in urban areas. Urbanisation brings new economic, sustainability, social and cultural challenges, because living in dense areas boosts complexity of how people live together. It urges for example the need to solve traffic congestion with smart transportation systems or diminish pollution by stimulating a sustainable lifestyle or to make infrastructures more energy-efficient. In addition, an increased urban environment puts the role of construction and housing more central. Apart from raising challenges, urbanisation offers opportunities to stimulate energy efficiency and sustainability (METRIS, 2009).

Globalisation and migration

In the next 15 years, geographical and conceptual borders between societies will increasingly fade (TNO, 2008b). The blurring of borders increases the interaction on multiple levels: individual, organisational and societal. This will increase the complexity and interdependencies within and between societies and economies. Migration has been growing for the last few decades; according to the United Nations, about 3 percent of the Earth's population is a migrant. Migration can both be seen as to be restrictive or as a productive activity for (knowledge-intensive) sectors. Globalisation and migration urges the need for intercultural versatility, flexibility and the ability to quickly adapt to new environments. It has vast consequences for mobility, logistics and transportation, sustainability and production.

Environmental sustainability

There is a growing concern for environmental sustainability[6], shown by the attention for climate change and energy-efficiency. Environmental sustainability encompasses sustainable products, scarcity in natural resources, energy efficiency and climate change. The growing interest in making products more environmentally friendly and energy efficient has contributed much to innovation and

[6] According to the United Nations (1987) sustainability refers to "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

the development of new products and product categories (TNO, 2008b). Environmental sustainability impacts many sectors of our economy, such as transportation, utilities and construction. Environmental stability is increasingly embedded in European policy and regulation, and customers' preferences are getting more sustainable. These forces stimulate firms to rethink their products, services, production processes and supply chain. The call for more energy efficiency, alternative energies and new materials has led to new innovation potentials and the support for emerging technologies as well.

Security

Security is increasingly an important topic for European citizens. The number of incidents and attacks is increasing and (the perception of) security is threatened by terrorist attacks, illegal migration and major incidents (in sports and culture, but also events at the G-8 summits), but also by natural, financial and health crisis (e.g. pandemia). The call for more security is strong and is expected to become even stronger. On the individual level security is getting more important to enhance and protect privacy and trust in technology and is therefore of growing importance for the acceptance of innovations in the E&O Equipment sector. Increased security and privacy concerns impact the requirements for products and services in several sectors, such as health, transportation and construction.

The network society

ICT advancements enabled the development of a network society (Castells, 1996). Nowadays, people are increasingly connected and can use networks to gather, exchange, and exploit knowledge, information and skills. The Internet connects humans to each other as well as humans to (computer) technology. It enables action and contact, instant global communication, and increased information intensity, to serve niche interests for targeted online communities. The future of the network society will enable people to create and exchange knowledge instantly, independent of space and time. People will be able to create their own social networks, make (virtual) connections with friends, customers, family and employees. The network society already has and will increasingly impact product and service innovation, for example in health, entertainment, interpersonal communication and life long learning. For example, seamless two-way communication with the external world will become very important in construction and transportation sectors.

Personalisation and empowerment

A cross-cutting demand driver is the increasing need for personalisation and empowerment. Consumers are increasingly involved in the production and innovation of products. Identifying yourself with products and services is important in the current "experience economy" (Pine & Gilmore, 1999). Open innovation of products and services, in which lead users support the design and development of new concepts, is an example of empowerment. In the public sector this trend is present as well: citizens increasingly demand citizen-centric services and they use social web technologies to increasingly participate in decision-making processes. The need for personalisation and empowerment has an important effect on the health market. Customers demand personalised health system, which support self-monitoring and diagnosis. It has a profound effect on shopping, entertainment and learning systems as well.

3.2 Sector scenarios

The two key drivers with high uncertainty shaping the future of the electrical and optical equipment sector are:

- **Role of government (passive versus active)**
  In the future, the electrical & optical equipment sector plays a role in tackling large global trends: climate change, energy and material scarcity, an ageing population, increasing mobility within and between continents, and safety and security trends. The macro level of the trends and the decisions related to them need an active role of the government. The political climate will determine whether government senses the urgency of these megatrends and how much effort in terms of policy, regulation, and investment will be done to overcome these challenges. This scenario analysis will show that both an active and passive role of the government has its pro's and con's.
- **Level of risk taking in innovation (low versus high)**
  The technology laws (like Moore's law) predict a clear line of fast and incremental innovation regarding electronics. In the future, it is not unlikely that incremental innovation will no longer be sufficient, because of the upcoming need for disruptive, radical innovations, currently denoted by the Semiconductor industry as "more than Moore's law". However, radical innovation by businesses (SME and large firms), academia and governments needs a more risk seeking mind-set than incremental innovation, which tends to follow strict dependency paths. Whether the global challenges, described in the previous chapter will be met, partly depends on the level of risk taking in innovation.

The two key drivers are used to construct three scenarios. The major opportunities and risks, potentially associated with the scenario will be assessed.

3.2.1 Proven technology serving society (Scenario 1)

In this scenario the electrical and optical equipment sector offers low-cost products based on proven technologies. The sector serves societal demands with mainly non-technological solutions in which services and maintenance are important elements. Most of the technologies are imported from outside Europe (i.e. Asia). This scenario is characterised by an important role of the (national) government in the innovation process for addressing major societal challenges. The sector has an active social responsibility, but is also rather risk averse, resulting in incremental and highly-planned innovation.

Risks and opportunities

The main risks of the scenario are:

- Europe loses its worldwide competitive position in production and R&D of electrical & optical equipment;

- Dependency on imported technology;
- Problems that are driven by megatrends, for example climate change, can not be fully addressed, because critical technologies (resulting from radical innovation) are not available;
- High degree of control, rather than creativity.

The main opportunities of the scenario are:

- Europe becomes a champion in services and service innovation;
- Technological, financial and societal stability, because R&D investments are only in proven technologies and solutions;
- ICT fully focussed on benefiting society, including national healthcare, transport, security, and logistics;
- Stakeholders in the E&O Equipment sector are aware of sustainability (climate and social).

3.2.2 Innovative social society (Scenario 2)

In this scenario the electrical & optical equipment sector invests extensively in developing advanced technological solutions. The sector is willing to take risks needed for integrative, intelligent and convergent radical innovations. The government plays an active role and uses a mission oriented approach (‘Man on the Moon’) to stimulate radical solutions addressing the major societal challenges.

Risks and opportunities

The main risks of this scenario are:

- Radical innovation can only address a few mega challenges;
- Inefficiency of investments;
- Despite the high degree of specialisation and focus, the electrical & optical equipment sector will be still in heavy international competition;
- Financial instability;
- Strong ethical debate can limit technological progress.

The main opportunities of this scenario are:

- Europe will have competitive advantage in some technological domains of the electrical & optical equipment sector;
- Some global issues, i.e. climate change, can be effectively addressed;
- Potential positive impact of technology can be higher;
- High degree of corporate social responsibility.

3.2.3 Market forces dominate with radical innovation (Scenario 3)

In this scenario the electrical & optical equipment sector focuses on short-term radical and creative solutions with innovative business models, and fast adaptation to consumer demand and personalisation. European competitive position will increasingly depend on the disruptive innovations produced by SMEs. Market forces and the ‘democratic power’ of the consumers dominate this scenario and the government has a rather passive role not only in stimulating innovation, but also in addressing societal challenges and safeguarding social responsibilities and ethical issues.

Risks and opportunities

The main risks of this scenario are:

- Less attention for social issues which need government intervention;
- Inefficient innovation spending (e.g. duplication, low take-up rates, etc.) due to high level of risk taking and lack of coordination;
- Ethical issues (such as privacy or identity) are of less concern;
- Financial and social instability.

The main opportunities of this scenario are:

- Strong position of Europe in innovative services, e.g. in entertainment and shopping;
- Radical breakthroughs in technologies and services;
- High degree of creativity and entrepreneurship;
- Global knowledge economy can give a boost to labour market of the E&O Equipment sector.

3.3 Future innovation themes and corresponding linkages with other sectors

3.3.1 Overview of innovation themes

The main science and technology drivers as identified in section 3.1 will have important implications for many different societal issues and market demands, as specified in section 3.2. Superposing the science and technology drivers with the demand-side drivers, results in various innovation themes for the electrical and optical equipment sector. This section presents five innovation themes. The innovation themes present opportunities for innovation in electrical & optical equipment, addressing major societal challenges and market demands. The innovation themes clearly show that innovation in the electrical & optical equipment sector often results from the joint development of equipment or hardware on the one hand and software and services on the other hand.

The following innovation themes have been identified:

Smart buildings: increasing energy consumption, changes in demographics (ageing society, growing number of singles) and more intensive use of houses (both for living and work) boost the demand for the application of ambient intelligence in buildings. ICT can make buildings more sustainable, living and tele-working more intelligent and can assist the elderly with independent living.

Smart health care systems: one of the main innovation areas for health care will be the personalisation of health care. The patient will really become the centre of attention in providing health care, empowering the patient and enabling the provision of effective health care targeting the individual patient. Personalisation will also be a main driver for improving the quality and efficiency of health care.

Smart transportation systems: the increasing demand for faster, safer, reliable en flexible transport requires integrated traffic management systems, co-ordinating the mix of transportation modes available, while reducing congestion and reducing the environmental burden.

Smart energy supply systems and green equipment: the main challenge for the future energy supply will be the development of an energy supply system that is *reliable and continuing*, while at the same time *energy efficient* as well as *environmental friendly*. Energy-efficient energy supply systems include a broad category of activities: consumption, creation, management, storing, and balancing production and use.

Smart security systems: an important societal trend is that people are feeling less safe and secure due to an increasing number of incidents and attacks and the threat of terrorism. The increasing demand for higher security in all parts of daily life activities requires increased *interoperability and seamless connectivity* of security systems and devices, *intelligent surveillance* systems and devices, as well as *enhanced scanning and detecting* techniques and efficient and effective *tracking and tracing* systems.

3.3.2 Relation with scenarios

Although all described innovation themes are relevant to some extent in every scenario context, they differ in certain ways with respect to their:

- market opportunities
- competitive position
- societal implications.

Table 3.2 discusses the importance of the different innovation themes for the three scenarios.

Table 3.2 Overview of scenarios, innovation themes, markets, competitive position and societal implications

Scenario	Specific Innovation Themes	Markets	Competitiveness	Societal implications
Proven technology serving society	• Smart living	• Driven by government initiatives • Smart living concepts in national public sector • Low export, high import	• Low risk attitude and low funding levels threaten competitive position of Europe. Position is taken over by BRIC-countries. Europe becoming dependent on other countries for critical technologies.	• Mainly experimental and focused on (semi) public activities: only gradual access for people
	• Smart health care systems	• National public markets • Cost focus • Only marginal personalisation of healthcare • Complex market: High entry barriers, especially for SMEs • Import of critical technologies	• More incremental than radical innovation will erode Europe's strong knowledge base and competitive position in medical technology	• No real answer to major societal challenges in healthcare • Unequal access to high-tech health care • Privacy concerns and ethical considerations lead to stringent regulation, hindering innovation
	• Smart transportation systems	• Main opportunities on national public market for public transportation • Driven by mobility problems and eco-innovation • Complexity of mobility issues is barrier	• Smart combinations of existing technologies, more incremental • Low risk attitude and low funding levels threaten competitive position of Europe. Europe becoming dependent on other countries for critical technologies.	• Without clear government support and political will to address major mobility and sustainability issues, it will be very difficult to deal with complexity of systems integration and innovation • Privacy concerns and ethical considerations lead to stringent regulation, hindering innovation
	• Smart energy supply systems and green equipment	• Driven by need for energy-efficient and sustainable economy • National public market for energy supply systems, but active role of government is needed to stimulate demand for smart energy supply systems	• Europe has strong competitive position in energy and eco-innovation, but radical solutions are needed to improve technologies: energy storage, generation and to reduce dependency on scarce materials • Less competitive in green entrepreneurship or in solar energy	• Government can stimulate public attitude towards eco-innovation and sustainability, but more substantial investments in R&D are needed to come to real solutions • Privacy concerns and ethical considerations lead to stringent regulation, hindering innovation
	• Smart security systems	• Both public and private market • Public market more nationally oriented, because of national interests. Private market more international	• Smart combinations of low-cost solutions with proven technologies • Low government support for R&D can result in higher dependency on critical technologies from abroad	• Smart security systems address the rising security concerns in society • Privacy concerns and ethical considerations lead to stringent regulation, hindering innovation
Innovative social society	• Smart living	• Government stimulate both public and private sectors • Extensive renewal of the housing market, reforming public health care • High export, low import	• Active role government in renewing housing market, smart living concepts for elderly and sustainable living, and removing obstacles in regulation and reforming public health care systems supports innovation and implementation	• Strong government support for radical solutions boosts development and adoption of smart living concepts • Privacy and legal issues actively and effectively addressed
	• Smart health care systems	• Large national and European market • Opportunities on the global market: emerging economies • Radical solutions in public market as test bed for private market	• Strong government support and high risk taking support maintaining and advancing Europe's knowledge base and competitive position in medical technology	• Addressing major societal challenges in healthcare: more efficient, personalised, available to everyone • Privacy, legal issues and ethical considerations are actively addresses, but not limiting radical solutions
	• Smart transportation systems	• Strong public market, but also strong private market for personalised and eco-friendly transportation solutions • European orientation, global export opportunities, especially in BRIC countries as these are developing their public transport system and because of growing middle class	• Smart combinations of existing technologies combined with radical new transportation solutions • Europe's strong position in automotive sector offers opportunities for strong position in smart, eco-friendly cars, integrating E&O Equipment technologies	• Active role by the government and the political will to find radical solutions will support major mobility and sustainability issues at an European level • Privacy and legal issues actively and effectively addressed

			• Strong and coordinated government support for radical innovation can support competitive position and export opportunities	
	• Smart energy supply systems and green equipment	• Driven by government initiatives, needed for radical solutions in both public and private applications: investing in infrastructure, stimulating demand by subsidies and regulation • Large public and private market • International orientation, export opportunities, especially to BRIC countries	• Future investments essential to maintain strong knowledge position, resulting in export potential • Less competitive in green entrepreneurship or in solar energy. Government could support this with strong investments in research and infrastructure, but also by stimulating demand through subsidies and regulation	• Active role by the government and the political will to find radical solutions will support major eco-efficiency and sustainability issues at an European level • Active government stimulates public attitude towards eco-innovation and sustainability
	• Smart security systems	• Strong government role in stimulating radical solutions and independence on critical security technologies • Large national, public market for radical security solutions	• Despite substantial investments in R&D uncertain to what extent the sector can translate their expertise abroad. Security is often national issue.	• Smart security systems address the rising security concerns in society • Privacy and legal issues actively and effectively addressed
Market forces dominate with radical innovation	• Smart living	• Doubtful whether market forces will be strong enough for important semi-public sector • Lack of resources for radical innovation • Opportunities mainly from individual consumer applications	• Specialisation in niches supports strengthening competitive position in these niches • Based on consumer demands. Doubtful whether strong enough for realising radical and creative solutions	• Passive role for government, lack of effective regulation addressing legal and privacy issues • Societal groups can be excluded from having access to the networked society
	• Smart health care systems	• Large national and European market • Opportunities on the global market: increasing middle class in emerging economies stimulating demand for innovative health products • Personalised and private health care	• Focus on applications for private markets not sufficient to address major societal challenges in health care, endangering Europe's knowledge base	• Unequal access to healthcare • Lack of effective regulation addressing privacy concerns, ethical considerations and legal issues.
	• Smart transportation systems	• Strong public market requires active role of government. Lack of governmental action results in less promising market perspectives. Private market may be less promising	• Competitive position in specific niches, build on demand from private markets. Doubtful whether this will be enough for addressing societal challenges	• Passive role for government does not support mobility and sustainability issues, which are high on the social agenda for Europe • Lack of effective regulation addressing privacy concerns, ethical considerations and legal issues.
	• Smart energy supply systems and green equipment	• Government support is lacking to stimulate demand at the private and public market to transfer to smart energy systems and green equipment	• Focus on private market applications • Lack of resources for substantial investments in R&D hinders the development of essential technologies, such as for energy storage and generation. This endangers Europe's knowledge position.	• Passive role for government does not support societal challenges of energy-efficiency and sustainability • Lack of effective regulation addressing privacy concerns, important in e.g. smart meters • Active role for government in stimulating public attitude towards sustainability necessary for stimulating the market
	• Smart security systems	• Focus on private market, opportunities for consumer-oriented solutions • Both national and international markets, because national interests are less important • Integrating existing security components into customised security systems offers niche market for SMEs	• Europe has strong position in niche market of home security systems • Focus consumer-oriented solutions could strengthen sector's competitive position in private security market	• Private security market will become more important. Security will increasingly become a private issue, more than a public issue. • Lack of effective regulation addressing privacy concerns, ethical considerations and legal issues.

3.4 New requirements for sectoral innovation

This section will discuss the potential barriers and requirements for innovation themes to develop into successful markets. Often newly emerging markets require changes in the physical infrastructure, the institutional setting, and knowledge structures to become successful. Most barriers and requirements are of cross-cutting nature and to a large extent relevant for all innovation themes and at least to some degree for all three scenarios.

3.4.1 Knowledge and skills requirements

Need for a multidisciplinary approach: The increasing convergence of technologies as well as of markets, but also the convergence of technologies and services into one offer require interdisciplinary, cross-functional and cross-sectoral approaches to designing new products and services. This requires on the one hand interdisciplinary studies to train students and on the other hand the establishment of interdisciplinary research centres stimulation of interdisciplinary R&D projects.

Need for a systems approach: Solutions to customers increasingly provide a total package, more than just components. Hence, the focus will be more on designing and integrating systems, requiring more knowledge of for example the inter-operability of systems and the whole value chain in a specific market.

Need for a global perspective: The supply chain will further globalise. This results in an increasing need for supply chain managers, who have good knowledge of trade regulations, taxes, tariffs, judicial issues, as well as of financial tools. In addition, they should be able to work with intercultural differences. Furthermore, employees will need to be able to understand their customers' needs; spotting market trends and needs into product and service specifications.

3.4.2 Networks and linkages with other sectors

Different functions, products and services will converge into solutions addressing various market needs. The various identified innovation themes for the E&O Equipment sector show strong linkages between markets and between sectors. For all identified innovation themes cross-sectoral linkages and collaborations between the various parties in the value chain are needed to support the development of breakthrough solutions and adoption by the society. This is especially relevant in scenario 2 which has a focus on radical solutions addressing multidisciplinary societal challenges. In scenario 3, radical innovations occur in loosely organised networks or 'swarms' of SMEs. In all identified innovation themes and mainly in scenario 1 and 2, the public market is very important. Public private partnerships would be a good model to stimulate knowledge transfer, innovation and implementation in addressing the major societal challenges such as mobility, energy efficiency and the ageing society. Bringing various actors in the value chain together and fostering linkages between them could be supported by locating them close to each other, forming a regional cluster.

3.4.3 Organisational innovation and firm strategies

Current and future innovation in the electrical & optical equipment sector instantly changes the market structures and how (networks of) firms organize innovation.

Networked and open innovation: Firms will be more specialised than before, which influences their R&D and innovation strategy. They will focus on a few core topics, while also acquiring technology from external resources. Further specialisation in R&D offers SMEs the opportunity to pin point a specific topic in R&D. Vertical teams will develop critical new technologies, while sharing the costs (Pfahl and McElroy, 2007; FISTERA, 2006; Photonics21, 2006). R&D is becoming more decentralised and organised in networks of companies, universities and other research organisations. Innovation is increasingly the combination of cross-sectoral basic research results from specialised outsiders with corporate knowledge about the applications and market needs, as well as the needs of lead-users (Pfahl and McElroy, 2007; FISTERA, 2006; Photonics21, 2006

Globalisation and modularisation of R&D: R&D is increasingly organised in locations around the world. Research communities and coalitions, including virtual forms of R&D organisation and distributed innovation are emerging. Innovation will be the product of networks rather than single enterprises. This requires better communication between the companies and other partners in the network about technology developments, for example through road-mapping.

Convergence of technologies and markets: The traditional boundaries between market sectors and technology domains are blurring. Consequently, the sector will become less identifiable as a discrete sector and border between the various actors in the value chain will disappear. Firms will increasingly be defined by their role than by traditional market segments or technology domains Moreover, modular R&D and production approaches will increase flexibility and shorten the product cycle, but will also place burden on the producers of components and modules (Pfahl and McElroy, 2007) and require increased re-organisation of the production processes and chains (ISTAG, 2006). Realising future innovation themes will require new design and manufacturing technologies (Pfahl and McElroy, 2007).

Service innovation: Growth in the ICT sector is especially driven by ICT services (OECD, 2008a). In the period 1996-2006 ICT services grew faster than total business services, driving the growth of the ICT sector. Although ICT manufacturing grew fast until 2000, over the period 1995-2006 ICT manufacturing grew less than manufacturing as a whole. Electrical & optical equipment and services will become increasingly integrated, not only in the final offer to the customer, but also in the design phase. This trend of service innovation will offer high-tech SMEs the opportunity to specialize themselves in specific customized services.

3.4.4 Institutional change and regulatory issues

Future developments in the electrical & optical equipment sector are likely to be hampered by institutes.

Fragmentation and standardisation: Important obstacles in timely integration of new science and technologies are the lack of standards and regulatory guidelines for using the new technologies, as well as the lack of indicators for confirming the efficacy of the new technologies. Governments have problems coping with the fast changing environment as well. Consequently, firms and governments should be well informed by foresight information about future developments in science and technology as well as trends in the sector (National Research Council Canada, 2005; European Commission, 2006a). The convergence of technologies makes standardisation an extra complex endeavour.

Flexibility of international labour market: European countries need to take flexibility in job mobility into account. The decrease in technical specialists in Europe makes attracting a talented workforce from abroad even more important in the future. Currently, it is still not easy and attractive for technical talent to move to Europe with their families. As the success of the high-tech innovation themes highly depends on the availability of the right knowledge and skills, this is an urgent issue. The international orientation and the focus on radical innovation in

Increased importance of trust and privacy for consumer acceptance: Although science and technology can amaze people, at the same time, people can also become very frightened by these developments. Education and showing the value of science for society is needed to reduce the fears. Consumer acceptance is heavily related to issues of trust, security and privacy, especially in a networked society. This can raise the concern of privacy infringements by firms or governments. It will require appropriate privacy regulation as well as regulation and sector agreements on network security with identification and authentication. Users should be convinced of the value of the new products and services for addressing their needs and it should be very convenient to use these new products and services.

Complexity of societal transitions: Electrical & optical equipment is essential for many societal transitions or system innovations. Involving all relevant stakeholders for a breakthrough innovation (i.e. system innovations in mobility or healthcare) is very complex. Government should act quickly with all stakeholders to create the right regulation and financial incentives to boost such. Governments need to incorporate the innovation themes in their strategic planning.

Financing breakthrough innovations: Often, breakthrough innovations and transformations are not foreseen and come from unexpected angles. This requires that science and technology have enough freedom to develop their own path without a lot of steering on specific applications. Hence, this requires sufficient resources for more fundamental and interdisciplinary research. Instead of only supporting the traditional disciplines and established research groups, more support must become available to new and interdisciplinary disciplines and research groups (National Research Council

Canada, 2005). An important challenge in funding research on European level is to find the right balance between radical innovation and incremental innovation. Long and extensive procedures for co-funded research can hamper agile and creative innovation, especially for SME's.

3.5 Sectoral innovation policy in a scenario framework

The previous sections on the innovation themes and requirements for innovation revealed several areas for policy intervention. These are not isolated policy issues; various studies on the electrical and optical equipment sector point at similar areas where policy intervention could make a difference (for example ELECTRA, 2008; EC, 2009b). In order to foster the innovation themes, policy and policy strategies should aim to meet the emerging requirements. The following recommendations can be made for each scenario:

Scenario 1 'Proven technologies serve society': in this scenario low-cost products based on proven technologies are offered. The sector serves societal demands with mainly non-technological solutions in which services and maintenance are important elements. This scenario is characterized by an important role of government in the innovation process for addressing major societal challenges. The sector has an active social responsibility, but is also rather risk averse, resulting in incremental and highly-planned innovation.
Policy options: focus should be on the promotion of grand societal challenges, support standardisation and remove regulatory barriers.

Scenario 2 'Innovative 'Innovative social society': in this scenario the sector invests extensively in developing advanced technological solutions. The sector is willing to take risks needed for integrative, intelligent and convergent radical innovations. The government plays an active role and uses a mission oriented approach ('Man on the Moon') to stimulate radical solutions addressing the major societal challenges.
Policy options: focus should be on support for breakthrough innovations that address grand societal challenges, stimulation of knowledge transfer, and raising awareness and enhance trust.

Scenario 3 'Market forces dominate with radical innovation': this scenario focuses on short-term radical and creative solutions with innovative business models, and fast adaptation to consumer demand and personalisation. European competitive position will increasingly depend on the disruptive innovations produced by SMEs. Market forces and the 'democratic power' of the consumers dominate this scenario and the government has a passive role.
Policy options: this scenario requires less policy initiatives, except stimulation of breakthrough innovation, support to SMEs and capitalization on R&D.

Chapter 6 (Policy options and conclusions) will discuss general policy implications for the electrical & optical equipment sector.

4 Barriers to innovation

An analysis of market and regulatory factors influencing sector innovation patterns provided a more fine grained analysis of the factors influencing innovation in the electrical & optical equipment sector. General and sector-specific literature was studied to define what (1) market factors and (2) regulatory factors hamper or stimulate innovation in the sector. These factors were operationalised and measured by using CIS4 micro-data and a complementary survey conducted by the SIW-II consortium. Almost 800 firms indicated what market and regulatory factors influenced their innovation activities and innovation outcome. Finally, the literature on drivers and barriers is confronted with the outcomes of the CIS4 analysis and the SIW-II survey to draw up conclusions for the electrical and optical equipment sector.

4.1 Market factors affecting innovation

High labour costs and scarcity in labour skills can hamper innovation: Comparatively high labour costs in the EU are an incentive for firms in the electrical and optical equipment sector to transfer their production to countries with lower wage levels. This affects in particular areas of the industry which have a lower technology component or a lower net product. It is only by having employed staff with relevant knowledge that allows companies to develop high quality, technologically sophisticated products and manufacture and market these (Eucomed, 2007; European Commission, 2003; Thumm, 2000). Employment compared to production is relatively higher in Europe vis-à-vis the United States and Japan, therefore Europe faces a productivity challenge which is largely due to fewer annual working hours and product mix (ELECTRA, 2008). A lack of highly skilled and educated human resources can slow down innovation in the E&O Equipment Sector (Wintjes & Dunnewijk, 2008; EITO, 2007; European Commission, 2006a; European Commission, 2006b; Eucomed, 2007). Among the skills that are mentioned as necessary, are: engineering, science, technology management, project management and business management. Specifically, strong academic skills and knowledge on core engineering studies is needed. In the Optical subsector, there is a shortage of medical engineers, such as medical Informatics specialists (Eucomed, 2007).

Fragmented ICT research: Several sources report that European ICT research lacks coordination, cooperation, technology transfers to businesses and funding (see i.e. EITO, 2007; Wintjes & Dunnewijk, 2008, ESIA, 2006; European Commission, 2009b). For example, coordination should reduce overlap in national research programmes. European Technology platforms, Joint Technology Initiatives and joint national programmes aim at the (further) development of European centres of excellence, such as the European Institute of Technology. In the European Semiconductor industry, R&D programmes and co-operation fall short of a coherent and consistent concept for stimulating R&D investment (ESIA, 2006). Coherent and consistent funding of ICT research is necessary given the fact that countries such as China and South-Korea are increasingly developing their R&D activities, which weaken the competitive advantage of Europe, even in innovative products and R&D.

Segmentation in the optical equipment subsector: The majority the products in the subsector optical equipment, medical devices specifically, are tailored for specific target groups (e.g. illnesses or uses). Markets are therefore highly segmented and national markets are often too small for extensive R&D investments to be worthwhile, for efficient, capital-intensive production techniques to be implemented and for the necessary turnovers to be achieved (Thumm, 2000).

Globalization of the value chain: The production of computer & office equipment and electronics is increasingly taking place in Asia (Brandes et al., 2007). Comparative advantages and technological developments have facilitated a fragmentation of production processes, which allows distributing the value chain over different locations in the world. In this respect, the growing share of parts and components in world trade has given rise to an increased re-organisation of production process at international level (European Commission, 2006a). European firms are forced to focus on their core competences (e.g. R&D) and as the share of added value in production is descending (European Commission, 2007). However, R&D is increasingly transferred to Asia as well (OECD, 2008b). Cost-efficiency optimisation as a result of globalization is certainly a strong driver in the E&O equipment sector: the internationalisation of a firm's R&D promises substantial benefits, such as a more cost-efficient innovation process, better ability to learn about R&D conducted by others, a quicker road to commercialisation and a positive impact on the firm's own innovation capacity (ESIA, 2006; OECD, 2008b).

Lack of capitalization on R&D investment: The technological cycle in the electrical and optical equipment sector is very short. Innovative products which may become mature and being produced low-cost countries locations (European Commission, 2006a). This makes it hard for firms to capitalize on their R&D investments. The semiconductor industry is an example of an industry that has been affected by the dramatic changes in the conditions of global competitiveness (ELECTRA, 2008; ESIA, 2006).

Market concentration consolidation stimulates innovation: The trend towards larger company units and market concentration is very important in the electrical and optical equipment sector'. Another characteristic feature of most of subsectors in the electrical and optical equipment sector is its high R&D intensity. Both factors are positively associated with innovation (ESIA, 2006; Thumm, 2000).

Collaboration increases the impact of innovation and reduces risks related to innovation: The proximity of research centres and manufacturing facilities stimulates technology transfer, as it minimises delay between research and market, and it expedites the knowledge transfer. The development of technology clusters has a significant macroeconomic impact in terms of innovation, productivity and competitiveness (European Commission, 2006b). For example, Europe has greatly benefited from the proximity between locally based semiconductor manufacturers and end-user equipment manufacturers' applications in industry segments such as wired and wireless communications, automotive, consumer and industrial equipment goods, computer and electronics (European Commission, 2006b). Open innovation is an emerging driver in the electrical and optical equipment sector. Suppliers and lead users can help to develop radical and incremental innovation

(Lettl et al., 2008). Even Open Innovation with competitors is an option. The European semiconductor industry found ways to actively cooperate on the process technology development, while remaining competitors on product development (European Commission, 2006b).

Grand challenges drive the innovation agenda: The electrical & optical equipment sector is highly affected by grand societal problems. For example, in the healthcare sector the demand is in particular fuelled by shifts in consumer preferences due to ageing, not only expressed by increasing demand for health care, care and living for elderly, but also in leisure goods and services (Brandes et al., 2007). Medical technology products must increasingly satisfy the criteria of cost efficiency in addition to the demands on technology and function (Thumm, 2000). The demand drivers energy-efficiency and climate change stimulate the development of new technologies leading to a significant shift in energy consumption, such as changing fuel mixes, developing clean fuel technologies, carbon sequestration or storage solutions (ELECTRA, 2008). Nowadays, electrical and optical equipment are pervasive to the benefit of business (B2B, B2C), consumer choice (product availability, quality improvement) and further customisation, education (e-learning), health (e-health, tele-medicine) and the overall quality of life (Brandes et al., 2007).

Convergence is main technological driver: Digital convergence (i.e. the coming together of computing, communications, content and consumer electronics) is unleashing a wealth of opportunities, blurring the boundaries between market sectors, and proving a powerful driver for innovation and change (ISTAG, 2006). Major technological drivers of digital convergence are embeddedness, cost-effective computing, miniaturization, ubiquitous communication, and advanced materials and sensing devices, communication networks convergence, and the increasing standardisation and interconnectivity of various devices (European Commission, 2006a). Although the level of international outsourcing is still much lower in market services than in the manufacturing sector, imported intermediates in services sectors have become more important. Although the overall effect on innovation may be positive (e.g. organisational and process innovation), the effects will be mixed for specific regions, firms and employees (OECD, 2008a).

4.2 Regulation and innovation

Environmental regulation can both stimulate and hamper innovation: On one hand, regulation regarding environmental sustainability is strong driver for (eco-) innovation in the sector (ELECTRA, 2008). For example, the Directive 2005/32/EC on Eco-Design of Energy Using Products establishes a framework for harmonised eco-design requirements in products. Regulation can be a barrier as well. According to the European Directive 2002/96/EC, the costs of processing historical waste have to be financed by all producers that are in the market. Therefore, new market entrants have to pay for waste that is caused by the large existing manufacturers. In this way, there is criticism that this Directive creates incentives for large manufactures to produce excessively in order to discourage entrance, and to spread the costs among existing and new producers (Mock and Perino, 2008).

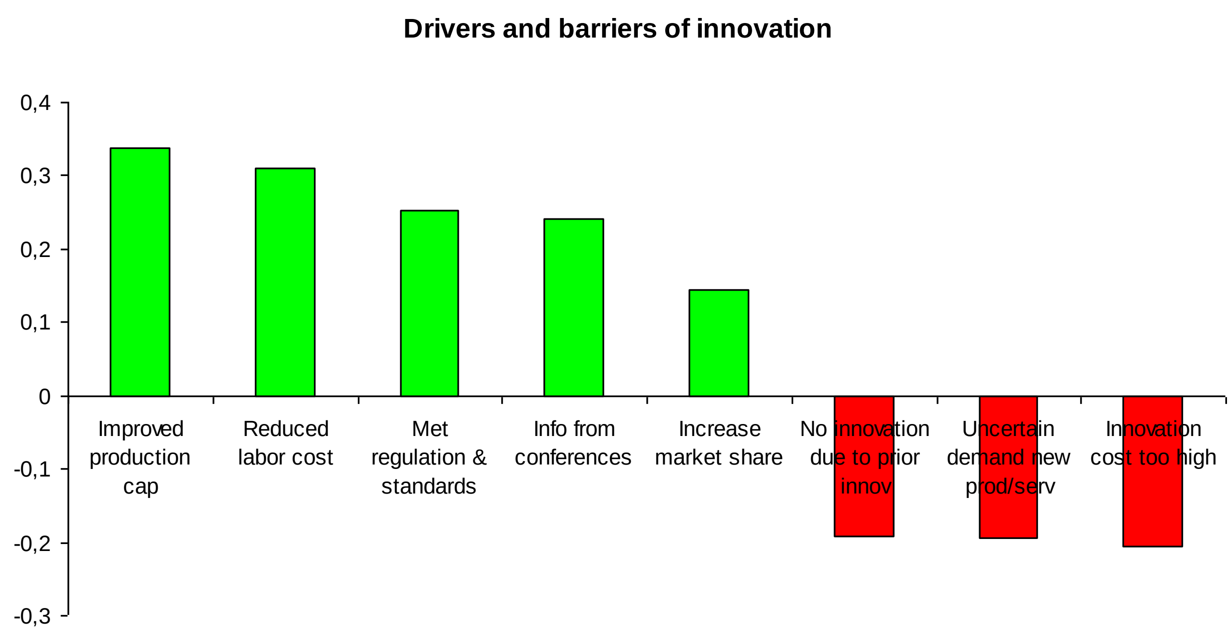
Safety regulation offers economies of scale and flexibility: The Directive 2006/95/EC Low Voltage ensures that electrical equipment within certain voltage limits provides (1) a high level of protection for European citizens and (2) enjoys the benefits of a Single European Market. The Directive 90/385 EEC Active Implantable Devices and the Directive 93/42 EEC Medical Devices are limited to essential requirements to protect the safety and health of patients and users. This means that regulation offers technological flexibility for innovation. The Directive 2004/108/EC on Electromagnetic Compatibility (EMC) governs the electromagnetic emissions of this equipment in order to ensure that, in its intended use, such equipment does not disturb radio and telecommunication as well as other equipment.

Fiscal regulation hampers semiconductor industry: Europe's R&D tax environment does not help to overcome the gap in R&D intensity vis-à-vis the United States and Japan. Thus government initiatives could implement a generalised tax credit system for R&D spending for all semiconductor companies in any geographical area in Europe (ESIA, 2006).

Standardisation: Finally, standardisation needs to be close to industry. In particular, concentration of the market, protection of intellectual property rights, average size of companies are factors that define the way a sector contributes to and uses voluntary standards. The principles and rules of the European standardisation system have to remain applicable to all the sectors but it should provide the necessary flexibility to address the different needs of the each sector. (ELECTRA, 2008)

4.3 Systemic failures

Figure 4.1 Drivers and barriers of innovation



The analysis (see figure 4.1) shows three major barriers for innovation in the electrical and optical equipment sector: the innovation costs are too high, uncertain demand for new products and services, and no innovation due to the existence of a prior innovation that has not been exploited sufficiently.

Surprisingly, regulation and standardization factors are more perceived as drivers than barriers to innovation. In addition, the in-depth frequency and correlation analysis shows a few more hampering factors. Regarding regulation, it seems that fiscal and taxation regulation is the most hampering factor. This is not a surprise due to the costs and complexity of this regulation. On the market side, factors that increase costs of R&D or decrease the funding for R&D are the most important hampering factors. These factors are labour costs, input and component prices and the availability of (public) funds for R&D. Last, open innovation with competitors seems to be difficult in the electrical and optical equipment sector.

All three 'market failures' identified with the CIS-4 factor analysis are related to two essential aspects of the electrical and optical equipment industry: high investments in R&D and uncertainty due to changes in demand and competition. It clearly shows the fierce competition that firms in the electrical and optical equipment sector face with firms from US, Japan and more recently China, Taiwan and South Korea. This competition is putting pressure on the return on investments of R&D in the European electrical and optical equipment sector. This confirms many sector-specific barriers described in the second chapter: due to the rapid technological cycle, products which are innovative may become mature and being produced in low-cost countries locations. In addition to production, innovation activities are increasingly off-shored to R&D facilities in low-cost countries (OECD, 2008b). This reduces the innovation cycles for firms, urges for more radical innovation (which can increase the uncertainty of demand) and increases the negative consequences of legacy innovations; the vintage effect. A highly-skilled labour force, attractive fiscal regulation for R&D, availability of public funding for R&D with sufficient IPR protection can further overcome the barriers.

Based on this analysis, we can draw up the following conclusions:

Regulation and standardization should focus on 'grand societal challenges': The electrical and optical equipment produces a *General Purpose Technology or Key Enabling Technology (European Commission, 2009a)*, which is often an important input for downstream sectors (e.g. automotive). This means that the electrical and optical equipment sector is driven by demand drivers. Regulation regarding these societal issues is perceived as an important driver for innovation by European firms. Perhaps, regulation, e.g. regarding energy efficiency of equipment, is easier for European firms to comply with than their counterparts in low-cost countries. Important measures to realise this include public procurement, institutional changes, infrastructural decisions, as well as other incentives. The survey shows that standardization is an important driver for innovation. Standards are essential for securing the market opportunities for European industry. Setting standards, e.g. in medical equipment, can give a competitive advantage to European firms.

Importance of highly-skilled labour force: The fierce international competition puts pressure on European firms to innovate. This emphasizes the role of the government to assure that the electrical and optical equipment sector is supplied with a high-skilled labour force that can compensate the comparatively high labour costs in Europe. European policy should focus on attracting engineering students, increase the interdisciplinary capabilities of students and employees and integrate new technologies in vocational training. Europe needs to be an attractive workplace for highly-educated foreign employees (European Commission, 2008b).

Increased importance of lead users for innovation: The downside of fierce competition is that firms perceive collaboration on R&D with competitors as negative for their innovation performance. However, they do value innovation with suppliers, lead users and universities. This stresses the importance of knowledge transfer within the value chain and within high-tech clusters, where universities and RTO's participate in innovation. The survey shows the importance of lead users for innovation in particular. Policy can focus on fostering the participation of lead users in the development and execution of large, European demonstration projects and the exchange of best practices.

Reducing the risks of R&D investments: The electrical and optical equipment sector is highly capital-intensive, especially the electronics subsector. The survey and the literature show that market and regulation factors that decrease either the initial investments of innovations or the uncertainty of the investments made will foster innovation in the sector. Policy and regulation could aim to reduce fiscal and taxation burden for firms, stabilize prices of energy and (input) components and the availability of public funding for radical innovation. Radical innovation makes the capitalisation on R&D investments more uncertain. Policy should focus on emphasising the need for technology transfer and translating R&D results into marketable products. Policy should support strengthening the technology transfer process and assure that firms, in particular SME's, are able to join long-term research projects.

5 Horizontal issues relevant to the sector

In the present chapter, the main issues of five horizontal reports relevant to the electrical & optical equipment sector are presented and discussed.

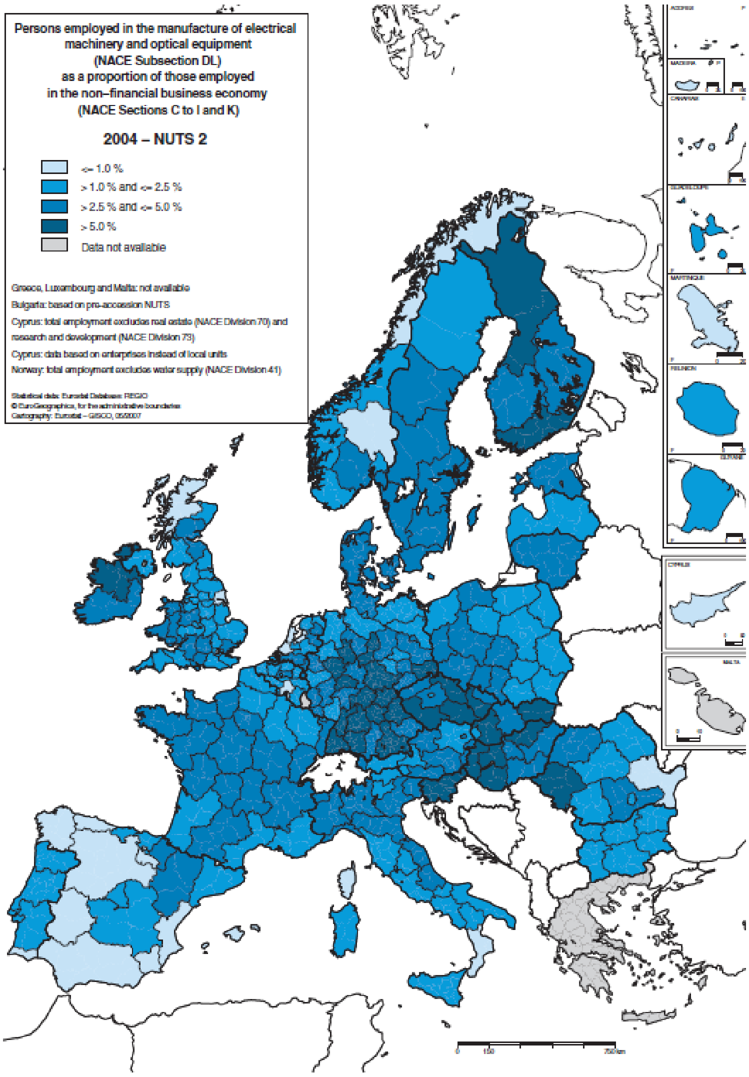
5.1 Impact of national specialisation on economic performance

Some countries are more specialised in the electrical & optical equipment sector. An interesting indicator for national specialisation is the relative share of the sector's employment and value added in the national economy. Eurostat (2008) provides a map with the concentration of the sector across Europe (see figure 5.1). It shows perfectly the areas in Europe that are specialised in the sector. For the whole sector, Hungary is most specialised in manufacturing electrical & optical equipment. The sector counts for about 10.2% of its total value added and nearly 6% of the Hungarians work in the sector. In Slovakia the highest share of employees works in the sector: nearly 7% in 2004. Other countries in which the E&O equipment sector is important are Finland, Germany and Czech Republic.

Zooming in to the different subsectors, specialisation among European countries becomes clearer. Germany is the most in optical equipment specialised sector in Europe. This is not surprising as Germany has regions like around Jena and Berlin-Brandenburg, with strong science-based optical equipment industries, the largest optical equipment companies, and industry networks like OptecNet (see www.optecnet.be). Germany employs relatively speaking almost 2 times as much people in the optical equipment sector than the EU average and the value added is about 1.6 times as high. Other countries specialised in optical equipment are Sweden and Slovenia.

Hungary is with distance the most specialised country in computer and office equipment: the value added originating from this subsector is almost 5 times more important for Hungary than for other countries. Additionally, the share of people working in the computer and office equipment subsector is 2.5 times larger than the EU27 average. Other specialised countries (in terms of employees and value added) are Germany, United Kingdom and Czech Republic.

Figure 5.1 Concentration of electrical & optical equipment in Europe



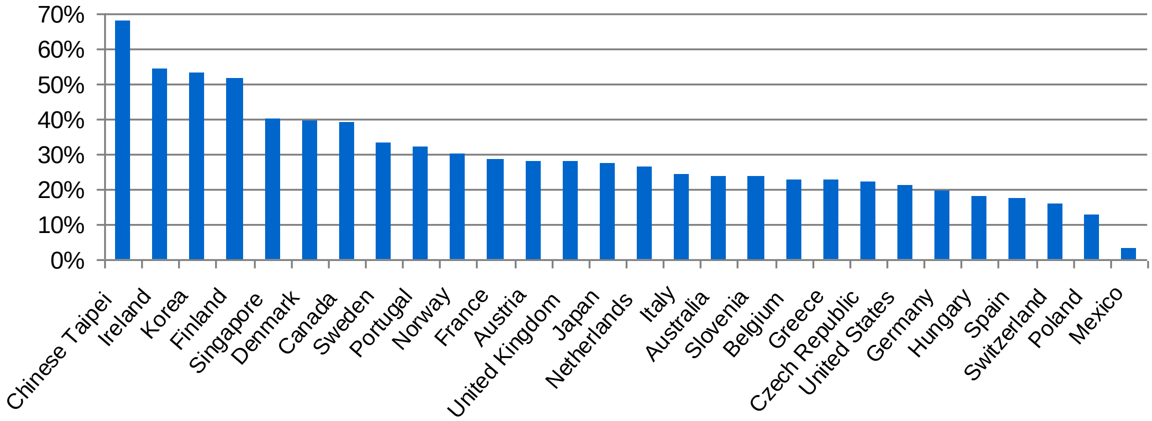
Source: Eurostat (2008)

Although Germany is in absolute figures the largest producer of electrical machinery & equipment, Slovakia is the most specialised country in Europe. The value added from this subsector is about 2 times more important for Slovakia than the average European country and the share of employees is almost 3.5 times larger. Other specialised countries are Hungary, Czech Republic and Germany.

Finland (with Nokia weighting heavily) is the most specialised European country in the electronics subsector. The value added from this subsector contributes over 7 times more in this Nordic country than average European countries. In addition, the electronics subsector provides Finland with many jobs: the share of people working in the electronics sector is about 4.5 times larger than the EU27 average.

These figures count for the whole value chain: from R&D to production and sales and distribution. However, OECD data (OECD, 2008a) allows us to show which countries are most specialised in ICT research. Figure 5.2 shows a ranking of countries on the share of ICT researchers in the total number of researchers. Although research on ICT services is included, it gives us some idea of the specialisation. European research is not as radically specialised as Chinese Taipei, where almost 70% of the researchers are ICT related. The European countries with most researchers in ICT are Ireland (54.2%), Finland (51.5%) and Denmark (almost 40%). Remarkably, the CEE are specifically specialised in production instead of research: Hungary and Czech Republic, which were among the top specialised countries according to Eurostat data, have relatively low shares of ICT researchers (both around 20%). This difference in specialisation makes the R&D versus producing / assembling division between CEE and EU15 clearer. A similar picture emerges from the IPTS rapport “Mapping R&D Investment by the European ICT Business Sector” (Lindmark et al, 2008). Most ICT R&D takes place in Finland and Sweden. In general, North Europe shows a higher concentration of ICT research than South Europe. Additionally, the R&D intensity is higher in West Europe than East Europe.

Figure 5.2 Share of ICT R&D researchers in total R&D researchers in 2006



Source: OECD (2008a)

The national specialisation analysis of the SIW project reveals that Finland, Sweden, Ireland and the Netherlands have a comparative technological advantage in E&O equipment. However, other members of the EU experience a process of de-specialisation. The most important reason is the current leadership of US and Japan, and the recent emergence of the electrical & optical equipment sector in China, Chinese Taipei and Korea. The electrical and optical equipment sector shows a strong trend to strengthen collaboration activities. Especially, Germany (not specifically specialised in E&O equipment) show strong ties with the United States.

Furthermore, the national specialisation analysis suggests that Belgium, Finland, France, the Netherlands, and the UK are the countries with the best framework conditions for lead markets evolution in the electrical and optical industry (see table below). In addition, the patent analysis (Grupp et al. 2010) also finds that Estonia has gained competitive advantages in recent decades.

Table 5.1 Lead market potentials of EU-25 countries in the E&O equipment sector

Country	Advantage				
	Price [PPP Statistics]	Demand [PPP Statistics]	Export [Trade Statistics]	Transfer [FDI]	Market Structure [Entry Rate]
Austria	+	-	+	-	NA
Belgium	+	+	+	NA	NA
Cyprus	-	+	-	NA	NA
Czech Republic	-	-	-	-	-
Denmark	+	-	+	NA	NA
Estonia	-	+	-	NA	+
Finland	+	+	-	+	+
France	+	+	+	+	+
Germany	+	-	+	-	-
Greece	-	-	-	NA	NA
Hungary	-	+	-	NA	+
Ireland	+	-	-	NA	NA
Italy	-	+	+	NA	-
Latvia	-	-	-	NA	+
Lithuania	-	+	-	NA	+
Luxembourg	-	-	-	NA	+
Malta	-	+	-	NA	NA
Netherlands	+	-	+	NA	+
Poland	-	-	-	-	NA
Portugal	-	-	-	-	-
Slovakia	-	-	-	NA	-
Slovenia	-	-	-	NA	-
Spain	-	-	-	NA	+
Sweden	+	+	+	NA	-
United Kingdom	+	+	+	-	+

Note: +: above average advantage; -: below average advantage; NA: Not Available
Source: Cleff et al (2007, p. 107)

5.2 Impact of innovation on high-growth companies

High-growth companies, so-called gazelles, are important for economic competitiveness and development, and are increasingly recognised by policy-makers. Although innovative SMEs are essential for innovation in the electrical & optical equipment sector, most R&D investments are undertaken by large companies (e.g. MNCs) rather than by SMEs (Wintjes & Dunnewijk, 2008; ELECTRA, 2008; EITO, 2007). For example, IDC/MERIT (2007) found that only 42% of the SMEs in the ICT sector (which corresponds to the computer and electronics subsector) invest more than 5 percent of turnover to R&D. Obstacles for SMEs are the complexity and amount of effort (e.g. time) needed for raising funds for R&D investments or applying for patents (Wintjes & Dunnewijk, 2008). Globalisation can also be a challenge for ICT SMEs. Wintjes and Dunnewijk (2008) argue that ICT SMEs must deal with increasing international competition, keep up with the technological innovation pace and adapt to the reorganisation of world supply chains. In addition, they argue that ICT SMEs cannot afford to focus only on local markets, as globalization is increasing trade openness, forcing greater specialisation and the elimination of less efficient firms. High-growth SMEs are more important in the Optical equipment subsector, where SMEs focus on different niches.

According to the cross-sectoral analysis of high-growth SMEs, other bottlenecks for high-growth SMEs are compliance to regulation (which heightens the entry barriers) and fierce competition due to increased globalization.

5.3 Impact of organisational innovation

Cooperation with different stakeholders, such as users (both end-users and downstream sectors), research institutes (such as the European Institute of Technology), public and private sector, is important for innovation in the electrical & optical equipment sector. Fierce competition, a high degree of technological complexity and high R&D investments urge firms to start partnerships in which the industry interacts in regional clusters. These regional clusters (whether they are located in Asia, Europe or the USA) consist of large firms, SMEs, research institutes, government agencies and financial organisations, such as venture capitalists. Remarkably, large firms innovate more openly than SMEs. This has probably two reasons: (1) SMEs have limited resources to deploy innovation activities more broadly and (2) large companies operate more in public funded research projects. Apart from the importance of regional clusters of innovation, Europe should bundle and scale-up all the efforts on the European level (i.e. with centres of excellence) to ensure coordination and effective cooperation between clusters.

5.4 Impact of eco-innovation

The global challenge to reach the Kyoto priorities places a great responsibility on the electrical & optical equipment sector. Apart from making the sectors itself more energy efficient, ICT as a General Purpose Technology should help other sectors such as construction, transport and power distribution, become more energy efficient and decrease CO2 emissions (Bio Intelligence, 2008). The need for energy efficiency is an important demand driver, but is not the only force pushing eco-innovation; it is influenced by Institutions as well. An established legislative framework on issues like energy labelling, eco-design, waste or product safety is in place in Europe. Although regulation in general is not more important than it is in other sectors (Cleff et al, 2007), it impacts the firms and their strategies. Energy directives put pressure on companies to innovate and i.e. make sustainable products that are built to last, repair and recycle / reuse. On one hand, directives stimulate product and process innovation, but on the other hand directives such as WEEE can heighten entry barriers for the market, giving large companies a competitive advantage (Mock and Perino, 2008).

Some of the most evident environmental sustainability concerns in the E&O equipment sector are related to the emission of greenhouse gas, material/resource loss, use of chemicals associated with the production process and in the end product, e-waste, energy consumption and water use.[7]

[7] Greenpeace campaigns concerned with the use of toxic chemicals in electronics, e-waste dumping and exports and the greening of ICT are some of the expressions of the growing environmental concerns about this sector

Table 5.2 Eco-innovation opportunities in electrical and optical equipment

Eco-innovation	Brief description	Example
Smart grid	A smart grid system consists of advanced grid components, smart devices, integrated communication technologies, programmes for decision support and human interfaces, and advanced control systems. The application of smart grids with local energy generation seems to favour some technologies. For example, micro CHP (combined heat and power) got a lot of attention during the development of smart power systems. But also other forms of distributed power generations have a lot of potential for the coming years, such as on-site photovoltaic cells and wind turbines.	• SASensor and Virtual private network Technology from Dutch Locamation • Gridstream components from Swiss Landis+Gyr
Smart metering	Smart metering is a part of energy infrastructure which allows end users to measure energy and water consumption on an individual level and transfers the data to the energy and water provider for monitoring.	• ZONOS metering platform from German Cuculus
Smart lighting systems	This category encompasses optical components (e.g., LEDs) and optical equipment (entire lighting systems) which contribute to energy efficiency and generation.	• Smart control lighting system and LED luminaires from UK-based Thorlux Lighting
ICT-based transportation & logistic systems	In addition to widely available navigation and driving assistance systems, this category includes solutions for traffic control to optimise vehicle flows, electronic reservation systems or vehicle detection systems to organise urban traffic more efficiently.	• Intelligent transport software from UK-based Zircon
High capacity PV	This category includes innovations in the generation and storage of environmental-friendly energy. In general photovoltaic refers to the use of panels to convert solar radiation into electricity. Panels contain a semiconductor material that exhibit a photovoltaic effect, such as some silicon derivatives. In principle, high capacity photovoltaic cells offer less material use per unit, less embodied energy, higher energy density, better cost efficiency and sometimes even higher recyclability rates.	• Lightweight, low-embodied energy, high capacity PV technology from British WhitfiedSolar • Organic photovoltaic panels from German Heliatek
Advanced batteries and charging systems	Advanced batteries includes a variety of forms of energy storage devices, ranging from lithium/high temperature, advanced lead/acid, Ni/MH, Ni/Zn, enzyme catalysed batteries, battery/super-capacitor hybrids, etc. It may also include systems for battery management and charging systems.	• Effpower LIC™ lead/acid bipolar battery from Swedish-Austrian venture Effpower and Banner Batteries • EV fast-charging technology from Dutch Epyon
E-waste recycling technologies and collection systems	This category includes recycling technologies for particular waste streams vis-à-vis with the automation and optimisation of production systems is the recycling of electronic and optical equipment. It also includes recycling systems explicitly designed to help firms and consumers to meet WEEE requirements.	• Engitec's CX® lead-acid batteries recycling and lead production system from Italian Engitec • Recolight collection scheme in the UK
Advanced materials	Advanced materials allow the production of smaller and lighter electrical and optical equipment, using less material, less toxic components and higher rates of material recycling and degradation. These innovations aim at replacing traditional raw materials with alternative organic materials, aiming to alleviate material scarcity and e-waste generation.	• Ultra-low super-conducting electronics • linear polyphenylene sulphide (PPS)
Radio-frequency identification chips	Patented since 1973 but only available at the commercial scale since early 2000s, RFID chips can increase supply chain performance through real-time monitoring and processing of products. In this way, the concept of just-in-time, which is already widely used in large assembly operations, could be applied to almost every sector. The indirect environmental side effect of this would be lower energy consumption because of fewer and/or optimised storage facilities.	• EBM energy reduction technology incorporated into wireless radio frequency sensors from German Nanotron
Automation and optimisation of production systems	Automation is often defined as the technology by which a process or procedure is accomplished without the intervention of humans. It is basically composed by a programme of instructions and a control system that executes the former. New developments in ICT have boosted automation as a source of large eco-efficiency potential	• Extended Automation System for a fully automated bio-ethanol production from ABB
Sensors	Detection and/or monitoring devices that combine a … optical or chemical component applied to generic optical detection principles for chemicals/pollutants detection Examples for such ICT solutions are electrochemical sensors and nano-carbon tubes. These can be applied to process monitoring or smart grids.	• Wave-Phire™ ultrahigh temperature sensors in renewable energy generation from British OxSensis
Inspection robots	Developing and manufacturing electronic and optical components is often accompanied by large amounts of defects. Advances in miniaturisation of electronics add even more to this development. Here, inspection robots can be a remedy to the above problem to achieve higher yield enhancement. A new are of application are inspection robots in renewable power generation (e.g. off-shore wind turbines)	• RIWEA turbine inspection robot from Fraunhofer

Since a number of environmental concerns in this sector are associated to energy consumption, material use and e-waste a large share of eco-innovation focus on tackling these problems. The table above presents 12 eco-innovation areas. Examples are highly energy-efficient devices and development of new organic materials, which can be even bio degradable. When looking on the ICT side of the E&O sector, innovations in process optimisation and logistics (e.g. RFID chips) contribute to (direct or indirect) reduced energy and material consumption. Finally, innovations associated with electrical grid systems, which can transfer electricity in two ways, support the development of home-made energy solutions. It is important to note that eco-innovations aiming to improve the overall environmental efficiency of the sector (e.g. use of chemicals or process efficiency) are not discussed in this short review.

A number of recent studies have signposted a number of opportunity areas that are expected to drive eco-innovation in this sector. The ELECTRA study suggested that ICT-enabled eco-innovations promise to deliver most of the energy efficient solutions with applications in a number of areas. Intelligence is called to be an important driver for the ICT challenge for environmental sustainability and energy efficiency. An example linking ICT and automation is an ambient-intelligent interactive monitoring system for energy use optimisation that can be used in manufacturing SMEs, stores and warehouses. Nonetheless, the ELECTRA study reported that in spite of their savings potential, the adoption rate of some of these eco-innovations (e.g. motors, drives, lighting systems) has not been as speedy as anticipated (ELECTRA 2008).

5.5 Impact of innovation on new lead markets

The electrical & optical equipment firms face in general fierce competition by US, Japan, South-Korea and increasingly the emerging economies. Therefore, deliberately chosen lead markets are important for the global position of Europe’s sector. These markets are subject to some requirements: they should be relevant to citizens, driven by need and not by technology (so-called demand pull instead of technology push), should be essential for Europe’s competitiveness, of the industry’s interest and potential barriers should identifiable and removable (European Commission (2007). According to ELECTRA (2008), traditional lead markets for the E&O equipment sector are telecommunication equipment (e.g. Nokia, Ericsson and Alcatel-Lucent), medical equipment (e.g. Siemens Medical, Philips Medical and Draeger).

Table 5.3 shows the growth potential of current European lead markets based on data from the German Electrical & Electronic Manufacturers’ association ZVEI. The electrical machinery & equipment for industrial automation is by far the largest growth market (58 billion euro market value in 2005), followed by the digital radio and TV (25 billion market value in 2005) and the energy markets (22 billion market value in 2005). No data was available for the transportation sector which is an important growth market as well.

Table 5.3 Market value and growth potential of lead markets

Lead market	***Market value (in billion EURO)***	***Annual growth potential***
Automation	58	2.5%
Digital radio & (HD)TV	25	6%
Energy	22	3%
Security	14	4%
Health	13	7%

Source: ELECTRA (2008)

Data from ZVEI and ELECTRA does not take the optical equipment sector into account. According to Phtonics21 (2005), important current lead markets for Europe (having a global market share between 25 and 45%) are lighting, measurement and automated vision, production technology, medical technology, life sciences, defence photonics and optical components and systems. Having a closer look at the Semiconductor industry, which is in the heart of the E&O equipment industry, Europe's industry has a leading stand in markets specialised in chips for cars, wireless devices and industrial applications (ESIA, 2008).

Furthermore, McKinsey (2008) identified four markets in which ICT could be more systematically applied: (1) Industrial motors and automation (estimated savings about €68,000 million) (2) Logistics (estimated energy savings about €208,000 million) (3) Buildings (1.68 GtCO2e, worth €216,000 million) and (4) Grid technologies (estimated value about €79,000 million).

Important future lead customer markets of the sector are (ELECTRA, 2008):

- Trans-European networks, transportation, infrastructure and telematics, which makes i.e. use of infrastructural technologies and sensors.
- E-health infrastructure and nano-diagnostics, which makes use of mix of smart cards, mobile computing and RFID.
- Energy generation, transmission and distribution, which makes use of smart grids, high voltage direct current, renewables, low-carbon technologies and storage systems.
- Civil protection, security, defence, urging the need for data storage, sensors, RFID, etc.
- Building, intelligent living, ambient assisted living, access, detection and control technologies.
- Automation, industrial IT, relying on web based technologies and RFID.
- Digital radio & TV, HDTV, which need access and common interface technologies.

6 Policy analysis and conclusions

The electrical and optical equipment sector is a high-tech manufacturing sector. It is one of the most innovative sectors in Europe with investments and advances in fundamental research, applied R&D and innovation in the actual use of equipment. This sector is also one of the most global sectors with competition between Europe, US, Japan, China and other regions, and global players having spread their business activities (R&D, marketing, production, assembling, etc.) across different parts of the world. Electrical and optical equipment is used by consumers but more so by a range of private and public sectors such as automobile, retail, aeronautics and space, health, education and government. Electrical and optical equipment is perceived a general purpose technology or Key Enabling Technology: the development, provisioning and use of ICT are crucial for the competitiveness of firms, sectors and regions, and for addressing societal challenges such as scarcity of energy and water, ageing and security. For example, the European Commission see that ICTs have a catalytic impact in three key areas:

- productivity and innovation, by facilitating creativity and management;
- modernisation of public services, such as health, education and transport;
- advances in science and technology, by supporting cooperation and access to information

The European electrical & optical equipment sector faces some major challenges. In the last few decades, globalization (and in specific the rise of BRIC countries) put pressure on the competitiveness of firms. Low-cost production and segmentation of the value chain increasingly force European firms to focus on innovation as their core competence. The foresight (chapter 3), barriers to innovation analysis (chapter 4) and horizontal analysis point out the following policy implications that stimulate the competitiveness of the E&O equipment sector:

Stimulate service innovation: to further acknowledge the complexity of the sector - and its challenges - the link between manufacturing and services must be stressed. Increasingly, the manufacturing of electrical & optical equipment is linked to services such as maintenance, remote servicing, upgrades, leasing, etc. This further increases the relevance of the sector for economic, societal and environmental challenges. It also increases the challenges for innovation.

Promote solutions for grand societal challenges: Societal challenges are complex issues, in need for systemic solutions, multidisciplinary approaches and the involvement of stakeholders. Policy should strongly stimulate and support the development of these solutions with public procurement, institutional changes, infrastructural decisions, as well as other incentives.

Support eco-innovation: the challenge of energy scarcity and global warming is probably one of the most important grand challenges for the electrical & optical equipment sector. The ELECTRA report suggests that ICT-enabled eco-innovations promise to deliver most of the energy efficient solutions with applications in a number of areas. However, the adoption rates of eco-innovation still lack behind. Policy and regulation should help to stimulate eco-innovation, for example by means of public-private partnerships, public procurement or incentives for consumers.

Align research efforts to increase efficiency: Research efforts and policy efforts to support R&D are often fragmented in Europe, resulting in a lack of synergies and economies of scale and scope. Policy should focus on better coordination of research and policy efforts to accelerate development, avoid duplications and to reach sufficient critical mass.

Improve capitalisation on R&D results: Radical innovation require sufficient resources for fundamental and interdisciplinary research, creative and fresh approaches and support for capitalising on R&D results. Policy should focus on emphasising the need for technology transfer, translation of R&D to the market and support links between research institutions and SMEs. Policy should gather stakeholders, support pilots and stimulate best practice exchange.

Support SMEs and stimulate financial investment in the sector: Policy should focus on stimulating financial investment in high-tech industries for R&D prototyping, manufacturing and infrastructure. Policy should stimulate the development of public loan and financing facilities for SMEs. Policy should stimulate venture capital funds specialised in early stage investment.

Support standardisation: The converging, interactive and interconnected electrical & optical equipment will be integrated and applied in existing systems in downstream sectors such as health care. Policy should focus on taking the lead in standardisation, support the development of industry standards and translate these standards into legislation where appropriate.

Remove regulatory barriers: Policy should focus on identifying and removing the potential regulatory barriers to innovation and adoption of innovative electrical & optical equipment. Moreover, policy should focus on harmonising differences in regulation of the European market and considering the long-term total costs and benefits of new technologies that require substantial investments.

Foster skills: Europe lacks sufficient skilled labour and improved skills are necessary at all occupational levels in the sector. Policy could focus on attracting more students in the technical and multi-disciplinary fields. In the short and medium term, policy could focus on attracting highly-educated foreign nationals to Europe.

Raise awareness and enhance trust, privacy and security: Policy should focus on safeguarding privacy and security of citizens and consumers, by appropriate safety and privacy regulation, but also by stimulating and support sector agreements including users. Acceptance can be supported by raising awareness, showing the value of these new technologies and stimulating the user friendliness and interoperability of new technologies.

On policy level, electrical & optical equipment, such as nanotechnogy, electronics and photonics, is seen as a Key Enabling Technology (KET) by the European Commission (European Commission 2009b, European Commission, 2009c). The current policy debate recognizes the importance of KETs for the competitiveness of the European industry, but there is still no compromises which technologies should be included. The European Commission, however, aims to develop a common strategy to bundle R&D efforts along these technologies. The policy analysis of this report highly stresses the importance of this development.

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Annex – Overview SIW deliverables

Overview of the deliverables from the Europe INNOVA Sectoral Innovation Watch

Deliverables can be downloaded from www.europe-innova.eu

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