A Report on Swedish Innovative Optics & Photonics in Life Sciences & Health

1 Introduction

You wake up with an intense toothache. You take a painkiller and call your dentist. At the dentist surgery an x-ray examination is performed, concluding caries. The dentist uses a dental laser to remove the caries, and after placing some composite material in the "drilled" hole in your tooth, the composite material is cured by exposing it to ultraviolet light. All these, the x-ray examination, the dental laser "drilling", and the ultraviolet light curing, are examples of applications of optics and photonics technologies within the field of life sciences and health, often referred to as *biophotonics*.

But what about the painkiller? In pharmaceutical and biotechnology research laboratories many analysis instruments are based on optics and photonics technologies, and the pharmaceutical manufacturing process is often monitored and optimised by means of optics and photonics, in order to optimise the manufacturing process and to guarantee optimal quality of the products – biophotonics!

Your pain is gone and your tooth is remediated. To celebrate, you prepare a tasty tortillas dinner. You open the package of ready-made tortilla breads, bought at your local food shop. All the pieces of bread are nicely circular in shape and almost equal in size – thanks to the automatic vision inspection systems, again optics/photonics, in the manufacturer's production lines, systems that identify and remove pieces of abnormal shape or size. Also, there is no reason to worry about damaging your tooth repair by crunching onto some hard piece of contamination in the bread, since the breads have all been x-rayed in the packaging line as well. And all the pieces of bread are made out of wheat flour made of grains, guaranteed to have high quality due to spectroscopic grain analysis – biophotonics…

As you realise, biophotonics share in some way the everyday life of almost every person living in Sweden in the year of 2013!

But what exactly is *photonics*? The magazine *Photonics Spectra* has provided the following definition at the top of page 5 in every issue since March 2009 and up to day October 2013:

> *"Photonics: The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation to detection to communications and information processing."*

Biophotonics is the field where photonics is used in life sciences and health applications.

The photon, the "light particle", is the quantum unit of all electromagnetic radiation (ordered from long to short wavelengths): radio signals, microwaves, terahertz radiation, infrared light, visual light, ultraviolet light, x-rays, and gamma radiation. There is no strict definition of photonics with regard to wavelengths of the applied electromagnetic radiation, but there are non-specific boundaries of what regions of the electromagnetic spectrum to be included. The applications of infrared light, visual light, and ultraviolet light are generally included; sometimes the field of terahertz radiation is included; and sometimes x-rays are included, especially in biophotonics, where the common use of medical x-rays are influential. Radio signals, microwaves, and gamma radiation are in general not included.

The present report considers applications of infrared light, visual light, ultraviolet light, and x-rays in the fields of life sciences and health.

2 Summary

In life sciences and health, photonics constitutes an important toolbox for applications within medical diagnostics, medical therapy, biotechnology, pharmaceutics, food technology, agriculture and other fields. The current status of innovative Swedish life science and health optics and photonics has been investigated and possible futures have been analysed. An inventory of the actors of today was performed and evaluated, and a SWOT (”Strengths”, ”Weaknesses”, ”Opportunities”, ”Threats”) analysis was carried out. Conclusions were established based on the results, and recommendations for the future were appointed.

In total 68 actors were identified, whereof 45 actors where innovative biophotonics constitutes a major part of the total activities (*Primary Actors*) and 23 actors where biophotonics constitutes a minor part of the total activities (*Secondary Actors*). The total annual turnover (used for enterprises) and budget (used for academies and authorities) figures for the actors were 20637 MSEK, whereof 3029 MSEK for the *Primary Actors* and 17608 MSEK for the *Secondary Actors*. The corresponding values for number of employees (in Sweden) were 1681 in *Primary Actors*, 7069 in *Secondary Actors*, and 8750 in total. More than 3 billion SEK are annually converted within companies and academies employing almost 1700 people, just within the focus field of Swedish innovative life science and health photonics, and additionally 17.6 billion SEK and more than 7000 employees are strongly dependent on the Swedish biophotonics research and development in their daily business. A qualified guess gives that the total part of the *Secondary Actors'* business that is directly innovative life science and health photonics, is of about the same size as the total sum for the *Primary Actors*. That is, the total Swedish innovative optics and photonics in life sciences and health is estimated to employ approximately 3500 people and has a yearly turnover/budget of the order of 6 billion SEK. Considering that the world biophotonics market is expected to grow very fast within the next years, Sweden has great opportunities to progress in the biophotonics field of business, supposing optimal strategies are developed and executed.

From the statistical analysis of the inventory data, and from the SWOT analysis, some important conclusions were reached regarding the Swedish innovative life science and health photonics:

- With regard to turnover and number of employees, the total contribution from large enterprises and SME companies (10 times more in numbers) are of equal size among the *Primary Actors*.
- Industrial research and development is of great importance in the field and many of these R&D companies have started as a spin-off from academic research.
- Early-stage R&D companies in the field are vulnerable on their way to reach the stage of commercialisation.
- It is both important to stimulate the academic life science and health photonics, in order to spin off in R&D companies, as well as supporting the early-stage R&D companies on their way to commercialisation.
- There are great opportunities for Swedish innovative enterprises in biophotonics to flourish, once they have reached the state of commercialisation.
- The Stockholm-Uppsala-Mälaren region and Skåne are today the Swedish geographical main players among *Primary Actors* in the field.
- Solitarily niched photonic life science companies can become very successful also located outside the university and metropolitan areas.

Based on the present study, conclusions were drawn and concrete recommendations were suggested. In order to alleviate existing obstacles and promote the progress and growth of Swedish innovative biophotonics, we propose an increase of *interaction* at all levels: between actors, between sectors, between academy, industry, and the public sector, and between system levels. Interaction interfaces create synergies, such as new ideas, new solutions, new collaborations, new funding, new businesses, new market, and new job opportunities. This will require support, for example governmental support, in order to create new interaction infrastructures, as well as incitements that do not require short-term commercial results, for interdisciplinary interaction between industry, academy, and the public sector.

3 Background

Horizon 2020 is the European Union's next framework programme for research and development, and the European Commission has determined photonics as one of six *Key Enabling Technologies* (KETs) for *Horizon 2020*. Hence, photonics is considered a particular important technology for the future and increased resources will be focused to innovations in photonics (and the other KETs) during the period 2014 to 2020. Related to the framework programme for research and development is *Smart Specialisation* or *RIS3* (*Research and Innovation Strategies for Smart Specialisation*), that is a strategic approach to economic development through targeted support for research and innovation. The concept of *Smart Specialisation* is to boost regional innovation by enabling regions to focus on their strengths.

In order to facilitate work and adequate decisions regarding *Smart Specialisation* related to the *Key Enabling Technology* photonics in Sweden and in Europe, basic data is of great importance concerning the current status of Swedish optics and photonics, regarding current strengths, weaknesses, opportunities, and threats, and about current trends and future potentials. PhotonicSweden has undertaken responsibility, vis-a-vis Photonics[21] (a European technology platform of photonics) and VINNOVA (*Swedish Governmental Agency for Innovation Systems*), to investigate the status of the Swedish field of photonics and work out a strategic research and innovation agenda for Swedish optics and photonics.

The work with the strategic research and innovation agenda is carried out by the seven work groups (WGs) of PhotonicSweden: WG1: Information and Communication; WG2: Industrial Manufacturing and Quality; WG3: Life Sciences and Health; WG4: Lighting, Displays, and Photovoltaics; WG5: Security, Metrology, and Sensors; WG6: Optical Components and Systems; WG7: Research, Training, and Education. Each of the seven work groups investigates their special field and report on that field. Thereafter one national Swedish strategic innovations agenda will be worked out based on the work by the seven groups. The national Swedish strategic innovations agenda will finally serve as input material for Photonics[21] in working out future European photonics strategies.

The present report is the report from work group 3 *Life Sciences & Health*.

4 Inventory – Current Status

4.1 Actors in Swedish Optics & Photonics within Life Sciences & Health

An inventory of Swedish optics & photonics actors within the field of life sciences and health identified a total number of 68 actors.

In order to be an included actor the following two inclusion criteria must be fulfilled:

- The actor is an enterprise, an academic institution or centre, or a public authority with *prominent innovative activities* (research, development, or consultancy) in *optics/photonics* within the field of *life sciences and/or health*.
- One of the following:
  - The actor has that kind of *prominent innovative activities* located in *Sweden*.
  - The actor has *not* that kind of *prominent innovative activities* located in *Sweden*, but has *manufacturing and/or sales of own products* in *Sweden*, including *prominent focus* in this *manufacturing and/or sales*, on *optics/photonics* within the field of *life sciences and/or health*.

After identifying the actors, the actors were divided into two groups:

1) *Primary Actors* where the *optics/photonics* within the field of *life sciences and/or health* constitutes a *major part* of the *total activities* of the actor. (*Table 1*.)
2) *Secondary Actors* where the *optics/photonics* within the field of *life sciences and/or health* constitutes a *minor part* of the *total activities* of the actor. (*Table 2*.)

A typical example of a *Primary Actor* is an academic research group with a research focus in biophotonics, or an SME R&D company centred around one photonic technology applied to one or a few life science applications. A typical example of a *Secondary Actor* is an academic centre with prominent research within biophotonics, but to a minor extent of the total activities, or a large or medium sized enterprise R&D company with a wide range of activities whereof only a minor part, such as one or a few of many products or one or a few of many R&D groups, are centred around photonic technologies within life sciences and health.

The actors and information about the actors are presented in *Table 1* (*Primary Actors*) and *Table 2* (*Secondary Actors*).

Regarding "Turnover/Budget", turnover has been used for companies (research institutes, large enterprises and SMEs) and budget for academies and governmental authorities. Most figures for "Turnover/Budget" and "Number of Employees" of companies originates from the latest publicly available annual reports (as of June 2013), with data typically about one year old. Data were collected from www.allabolag.se, from the actors' websites, and/or by personal contacts with the actors.

The definition of *SME* used is the official definition that took effect within the European Union the first of January 2005 (Commission Recommendation 2003/361/EC, "concerning the definition of micro, small and medium-sized enterprises", annex, article 2, paragraph 1):

> "*The category of micro, small and medium-sized enterprises (SMEs) is made up of enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million.*"

A *company* that does not fulfil the definition of an SME is categorised as a "Large Enterprise" in the table category "Enterprise Type".

Regarding "Type of Activities (in Sweden)", "Sweden" is mentioned within parentheses, in order to emphasis that only the activities located to Sweden are considered in the report. Some of the actors are large international companies with only some part of their business in Sweden. In those cases only the activities in Sweden are analysed.

Table 1: Primary Actors *are presented in the table. 45 identified actors fulfil the criteria of innovative Swedish optics and photonics actors within life sciences and health and categorised as an actor where the optics/photonics within the field of life sciences and/or health constitutes a* major *part of the total activities of the actor.*

Name	Website	Turnover/Budget (MSEK)	Number of Employees	Enterprise Type	Activities (in Sweden)	Geographic Location
Acreo Swedish ICT AB, biophotonics part	http://www.acreo.se/	44	30	SME	Research Institute	Kista/Hudiksvall/Norrköping/Göteborg
Biolin Scientific AB	http://www.biolinscientific.com/	99	22	SME	Industrial R&D, Manufacturing, and Sales	Västra Frölunda
Biological Physics, Applied Physics, Chalmers University of Technology	http://www.chalmers.se/ap/EN/research/biophysics	21	21	Academy	Academic Research	Göteborg
Biomedical & X-Ray Physics, Department of Applied Physics, School of Engineering Sciences, KTH	http://www.biox.kth.se/	25	25	Academy	Academic Research	Stockholm
Biomedical Instrumentation, IMT – Department of Biomedical Engineering, Linköping University	http://www.imt.liu.se/bit	16	16	Academy	Academic Research	Linköping
BioOptico AB	http://www.biooptico.com/	0.4	1	SME	Industrial R&D, Manufacturing, and Sales	Linköping
Biophysics and Biophotonics Group, Biological Physics, Department of Physics, Umeå University	http://www.physics.umu.se/english/research/biological-physics/the-optical-tweezers-center/	17	17	Academy	Academic Research	Umeå
BNP – Division of Bionanophotonics, Applied Physics, Chalmers University of Technology	http://www.chalmers.se/ap/EN/research/bionanophotonics	15	15	Academy	Academic Research	Göteborg
Cell Physics, Department of Applied Physics, School of Engineering Sciences, KTH	http://www.cellphysics.kth.se/	20	20	Academy	Academic Research	Stockholm
CellaVision AB	http://www.cellavision.com/	170	64	SME	Industrial R&D, Manufacturing, and Sales	Lund
Clinical Laserthermia Systems AB	http://www.clinicallaser.se/	0.35	1	SME	Industrial R&D	Lund
Cobolt AB	http://www.cobolt.se/	54	26	SME	Industrial R&D, Manufacturing, and Sales	Solna
Complex Systems and Biophysics, Department of Physics, University of Gothenburg	http://www.physics.gu.se/forskning/komplexa-system	14	14	Academy	Academic Research	Göteborg
DDD North AB (Derma Diagnostic Development)	http://www.dddnorth.se/	0	0	SME	Industrial R&D	Umeå
Demetech AB	http://www.demetech.com/	1.5	2	SME	Industrial R&D, Manufacturing, and Sales	Täby
Experimental Biomolecular Physics, Department of Applied Physics, School of Engineering Sciences, KTH	http://www.biomolphysics.kth.se/	10	10	Academy	Academic Research	Stockholm
Foss Analytical AB	http://www.foss.dk/	683	168	Large Enterprise	Industrial R&D, Manufacturing, and Sales	Höganäs
GasPorOx AB	http://www.gasporox.se/	0.38	5	SME	Industrial R&D, Manufacturing, and Sales	Lund
Gyros AB	http://www.gyros.com/	75	58	SME	Industrial R&D and Manufacturing	Uppsala
HemoCue AB	http://www.hemocue.com/	569	303	Large Enterprise	Industrial R&D, Manufacturing, and Sales	Ängelholm
Höks Instrument AB	http://www.hokinstrument.se/	8.9	8	SME	Industrial R&D	Västerås
Lund Medical Laser Centre	http://www.mlc.lu.se/	17	17	Academy	Academic Research	Lund
LVI Low Vision International AB	http://www.lvi.se/	56	32	SME	Industrial R&D, Manufacturing, and Sales	Växjö
Masimo Sweden AB (previously Phasein)	http://www.phasein.se/	52	33	SME	Industrial R&D, Manufacturing, and Sales	Danderyd
Micro and Nanosystems, School of Electrical Engineering, KTH, biophotonics part	http://www.kth.se/ees/omskolan/organisation/avdelningar/mst	5	5	Academy	Academic Research	Stockholm
Mindray Medical Sweden AB (previously Artema Medical AB)	http://www.mindray.com/artema	131	28	SME	Industrial R&D, Manufacturing, and Sales	Sundbyberg
Optilia Instruments AB	http://www.optilia.eu/	12	7	SME	Industrial R&D, Manufacturing, and Sales	Sollentuna
Perimed AB	http://www.perimed-instruments.com/	73	69	SME	Industrial R&D, Manufacturing, and Sales	Järfälla
Phase Holographic Imaging PHI AB	http://www.phiab.se/	2.2	6	SME	Industrial R&D, Manufacturing, and Sales	Lund
Physics of Medical Imaging, Department of Physics, School of Engineering Sciences, KTH	http://www.mi.physics.kth.se/	11	11	Academy	Academic Research	Stockholm
ProstaLund AB	http://www.prostalund.com/	6.6	2	SME	Industrial R&D, Manufacturing, and Sales	Lund
Q-linea AB	http://www.qlinea.com/	4.5	13	SME	Industrial R&D, Manufacturing, and Sales	Uppsala
Redsense Medical AB	http://www.redsensemedical.com/	7.3	4	SME	Industrial R&D and Manufacturing	Halmstad
ScandiDos AB	http://www.scandidos.se/	38	22	SME	Industrial R&D, Manufacturing, and Sales	Uppsala
Scint-X AB	http://www.scint-x.com/	0.6	5	SME	Industrial R&D, Manufacturing, and Sales	Kista
SenseAir AB	http://www.senseair.se/	111	73	SME	Industrial R&D, Manufacturing, and Sales	Delsbo
Serstech AB	http://www.serstech.com/	2.4	2	SME	Industrial R&D, Manufacturing, and Sales	Lund
Servotek AB	http://www.servotek.se/	3.4	5	SME	Industrial R&D	Arlöv
Silex Microsystems AB	http://www.silexmicrosystems.com/	219	165	SME	Industrial R&D, Manufacturing, and Sales	Järfälla
SpectraCure AB	http://www.spectracure.com/	4.5	3	SME	Industrial R&D	Lund
Spectro Analytic Irradia AB (Irradia Sverige AB)	http://www.irradia.com/	11	9	SME	Industrial R&D, Manufacturing, and Sales	Stockholm
Tobii Technology AB	http://www.tobii.com/	340	309	Large Enterprise	Industrial R&D, Manufacturing, and Sales	Danderyd
UmBio AB	http://www.umbio.com/	5.4	10	SME	Industrial R&D, Manufacturing, and Sales	Umeå
WheelsBridge AB	http://www.wheelsbridge.se/	0.5	0	SME	Industrial R&D, Manufacturing, and Sales	Linköping
Xcounter AB	http://www.xcounter.se/	72	25	SME	Industrial R&D, Manufacturing, and Sales	Danderyd

Table 2: Secondary Actors *are presented in the table. 23 identified actors fulfil the criteria of innovative Swedish optics and photonics actors within life sciences and health and categorised as an actor where the optics/photonics within the field of life sciences and/or health constitutes a* minor *part of the total activities of the actor.*

Name	Website	Turnover/Budget (MSEK)	Number of Employees	Enterprise Type	Activities (in Sweden)	Geographic Location
Aerocrine AB	http://www.aerocrine.com/	157	107	SME	Industrial R&D, Manufacturing, and Sales	Solna
Autoliv Electronics AB	http://www.autoliv.com/	818	293	Large Enterprise	Industrial R&D, Manufacturing, and Sales	Motala
Biotage Sweden AB	http://www.biotage.com/	291	58	SME	Industrial R&D, Manufacturing, and Sales	Uppsala
CMTF – Centre for Biomedical Engineering and Physics	http://www.cmtf.umu.se/	28	28	Academy	Academic Research	Umeå/Luleå
Department of Medical Cell Biology, Uppsala University	http://www.mcb.uu.se/	75	104	Academy	Academic Research	Uppsala
Elekta AB	http://www.elekta.com/	9290	3162	Large Enterprise	Industrial R&D, Manufacturing, and Sales	Stockholm
Elekta Instrument AB	http://www.elekta.com/	1444	228	Large Enterprise	Industrial R&D, Manufacturing, and Sales	Stockholm
Fibertronix AB	http://www.fibertronix.com/	3	0	SME	Industrial R&D and Manufacturing	Hudiksvall
FLIR Systems AB	http://www.flir.com/se	1308	394	Large Enterprise	Industrial R&D and Manufacturing	Täby
GE Healthcare Bio-Sciences AB	http://www.gehealthcare.com/sesv	600	1200	Large Enterprise	Industrial R&D, Manufacturing, and Sales	Uppsala
Hamamatsu Photonics Norden AB	http://sales.hamamatsu.com/	409	20	SME	Sales	Kista
Maquet Critical Care AB	http://www.maquet.com/	1554	376	Large Enterprise	Industrial R&D and Manufacturing	Solna
Maquet Nordic AB	http://www.maquet.com/	134	27	SME	Manufacturing and Sales	Solna
MAX-lab	http://www.maxlab.lu.se/	85	129	Academy	Academic Research	Lund
Olink AB	http://www.olink.com/	32	29	SME	Industrial R&D, Manufacturing, and Sales	Uppsala
Optronic Partner dp AB	http://www.optronic.se/	38	20	SME	Consulting	Skellefteå/Stockholm/Göteborg
Optronic Partner pr AB	http://www.optronic.se/	149	53	SME	Manufacturing	Skellefteå
Perten Instruments AB	http://www.perten.com/	266	62	SME	Industrial R&D, Manufacturing, and Sales	Hägersten
Qualisys AB	http://www.qualisys.com/	52	18	SME	Industrial R&D, Manufacturing, and Sales	Göteborg
RTI Electronics AB	http://www.rti.se/	49	35	SME	Industrial R&D, Manufacturing, and Sales	Mölndal
SciLifeLab	http://www.scilifelab.se/	400	400	Academy	Academic Research	Stockholm/Uppsala
Swedish Radiation Safety Authority	http://www.stralsakerhetsmyndigheten.se/	400	300	Governmental Authority	Governmental Authority (incl. research)	Solna
Uppsala Berzelii Technology Centre for Neurodiagnostics, Uppsala University	http://www.berzelii.uu.se/	26	26	Academy	Academic Research	Uppsala

Considering the activity of research the report makes a distinction between "Academic Research" (*i.e.* university research), "Research Institute" (*i.e.* a company providing research as its business), "Governmental Authority (incl. research)" (*i.e.* a governmental authority that includes research in its activities), and "Industrial R&D" (*i.e.* a business oriented company carrying out research and/or development within its own business).

Note that the companies have been divided into separate groups depending on if they (in Sweden) have all three activities of "Industrial R&D, Manufacturing, *and* Sales", just two "Industrial R&D *and* Manufacturing" or "Manufacturing *and* Sales", or solely "Industrial R&D", "Manufacturing", "Sales", "Consulting", or is a "Research Institute". Hence, for example, "Industrial R&D" is mentioned in no less than three types of activity categories. Consequently, in order to calculate the total number of "Industrial R&D" companies, data for all these three categories must be added together.

In *Table 1* and *Table 2* "Geographic Location" for each actor is presented. In the later statistical analysis (see the following two sections), the locations were divided into "Geographical Regions" based on the identified actors main locations in Sweden. The "Geographical Regions" are specified as follow:

"Skåne": *The province Skåne.*

"West Coast Region": *The west coastal region ranging from the Skåne border in south to the Norway border in north (containing Gothenburg).*

"Småland": *The province Småland.*

"Eastern Gothia": *The province Eastern Gothia ("Östergötland").*

"Stockholm-Uppsala-Mälaren Region": *The region containing Stockholm, Uppsala, and the Mälaren Valley ("Mälardalen").*

"South Northern Sweden Coast Region": *The coastal region of the Northern Sweden ranging from Gävle in the south to Sundsvall in the north.*

"North Northern Sweden Coast Region": *The coastal region of the Northern Sweden north of Sundsvall.*

There are several geographical parts of Sweden that are not included at all, due to the fact that no actors were identified in other regions.

Statistical analyses of the collected data are presented in the two following sections. The statistics is divided based on the actors belonging to the *Primary* and *Secondary Actors* groups, respectively.

4.2 Primary Actors – Statistical Results

Statistics were created based on data collected in the work with the inventory of innovative Swedish optics and photonics actors within the field of life sciences and health. The statistics for the *Primary Actors* (*Table 1*) are presented as pie charts in *Figure 1* to *3* in this section.

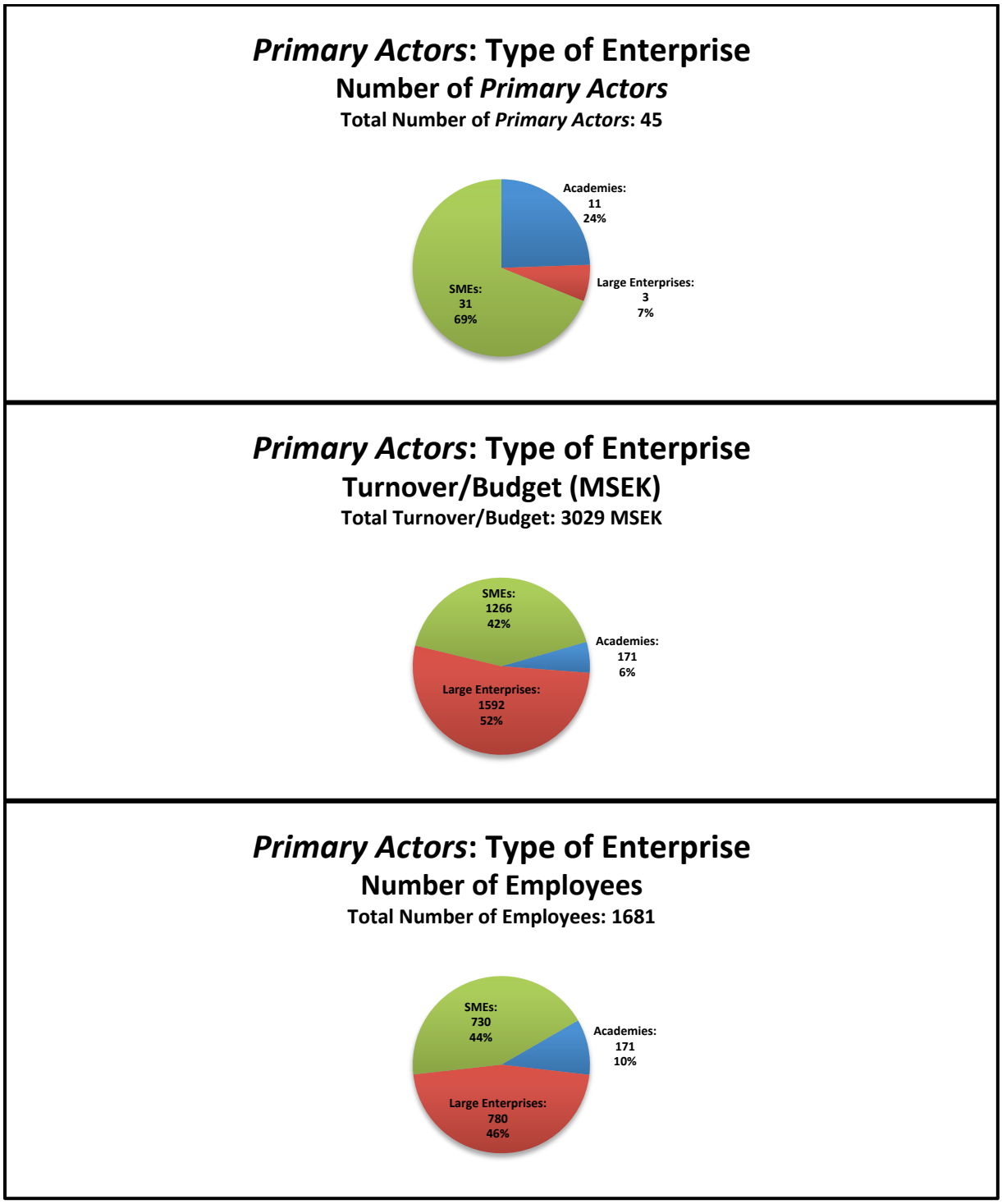

***Figure 1**: The three diagrams above presents the 45 identified* Primary Actors *divided into groups depending on "Type of Enterprise": "Academies", "Large Enterprises", and "SMEs". The uppermost diagram, "Number of* Primary Actors*", shows the distribution of the 45* Primary Actors *in the different types of enterprise. The diagram in the middle, "Turnover/Budget (MSEK)", shows the distribution of the total annual turnover (used for research institutes, large enterprises, and SMEs) or budget (used for academies) of the different types of enterprise. The lowermost diagram, "Number of Employees", shows the distribution of the total number of employees of the different types of enterprise.*

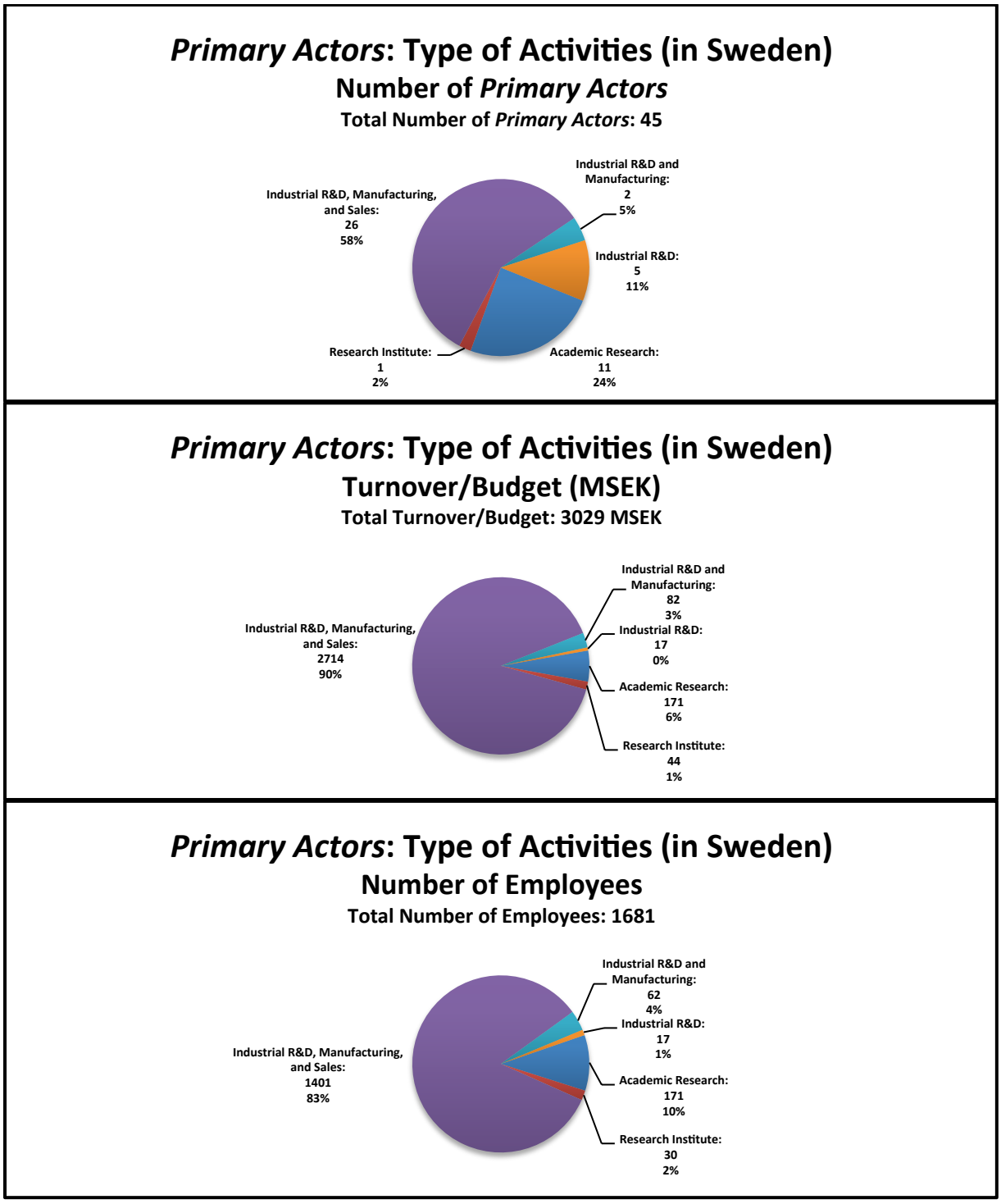

***Figure 2**: The three diagrams above presents the 45 identified* Primary Actors *divided into groups depending on "Type of Activities (in Sweden)": "Academic Research", "Research Institute", "Industrial R&D, Manufacturing, and Sales", "Industrial R&D and Manufacturing", and "Industrial R&D". The uppermost diagram, "Number of* Primary Actors*", shows the distribution of the 45* Primary Actors *in the different types of activities. The diagram in the middle, "Turnover/Budget (MSEK)", shows the distribution of the total annual turnover (used for research institutes, large enterprises, and SMEs) or budget (used for academies) of the different types of activities. The lowermost diagram, "Number of Employees", shows the distribution of the total number of employees of the different types of activities.*

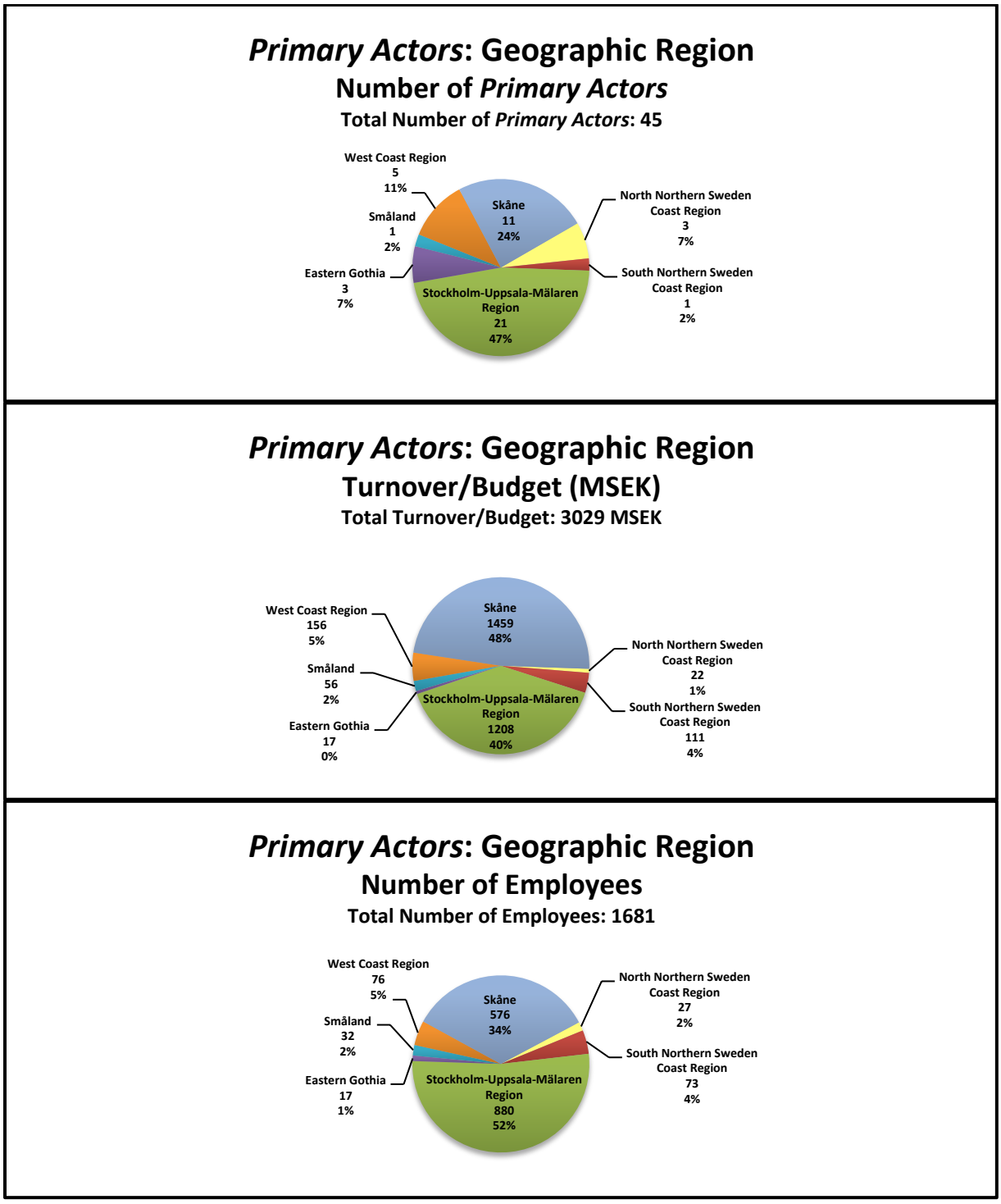

***Figure 3**: The three diagrams above presents the 45 identified* Primary Actors *divided into groups depending on "Geographic Region": "North Northern Sweden Coast Region", "South Northern Sweden Coast Region", "Stockholm-Uppsala-Mälaren Region", "Eastern Gothia", "Småland", "West Coast Region", and "Skåne". (No other geographic regions were represented.) The uppermost diagram, "Number of* Primary Actors*", shows the distribution of the 45* Primary Actors *in the different geographic regions. The diagram in the middle, "Turnover/Budget (MSEK)", shows the distribution of the total annual turnover (used for research institutes, large enterprises, and SMEs) or budget (used for academies) of the different geographic regions. The lowermost diagram, "Number of Employees", shows the distribution of the total number of employees of the different geographic regions.*

4.3 Secondary Actors – Statistical Results

Statistics were created based on data collected in the work with the inventory of innovative Swedish optics and photonics actors within the field of life sciences and health. The statistics for the *Secondary Actors* (*Table 2*) are presented as pie charts in *Figure 4* to *6* in this section.

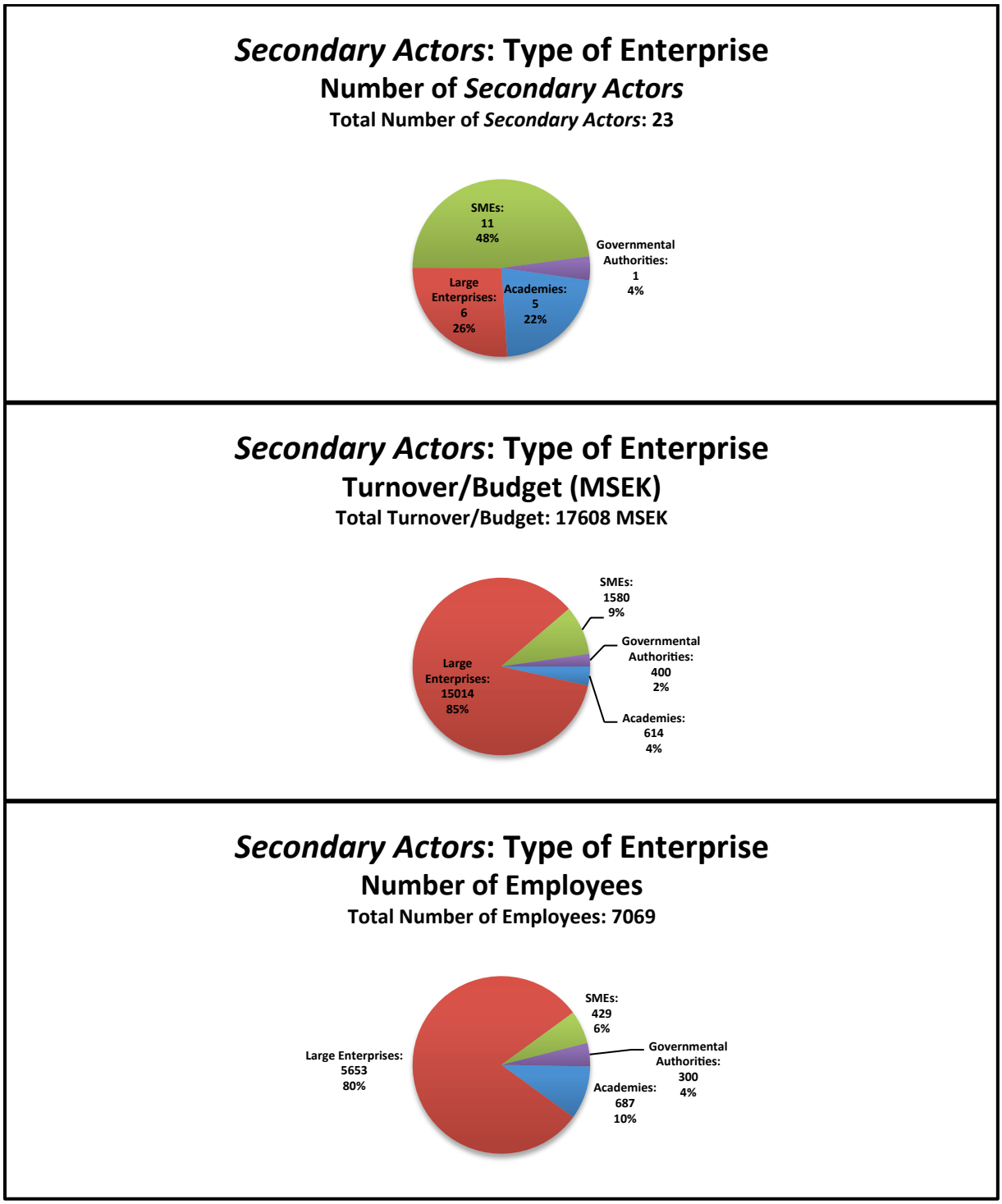

***Figure 4**: The three diagrams above presents the 23 identified* Secondary Actors *divided into groups depending on "Type of Enterprise": "Academies", "Large Enterprises", "SMEs", and "Governmental Authorities". The uppermost diagram, "Number of* Secondary Actors*", shows the distribution of the 23* Secondary Actors *in the different types of enterprise. The diagram in the middle, "Turnover/Budget (MSEK)", shows the distribution of the total annual turnover (used for large enterprises and SMEs) or budget (used for academies and governmental authorities) of the different types of enterprise. The lowermost diagram, "Number of Employees", shows the distribution of the total number of employees of the different types of enterprise.*

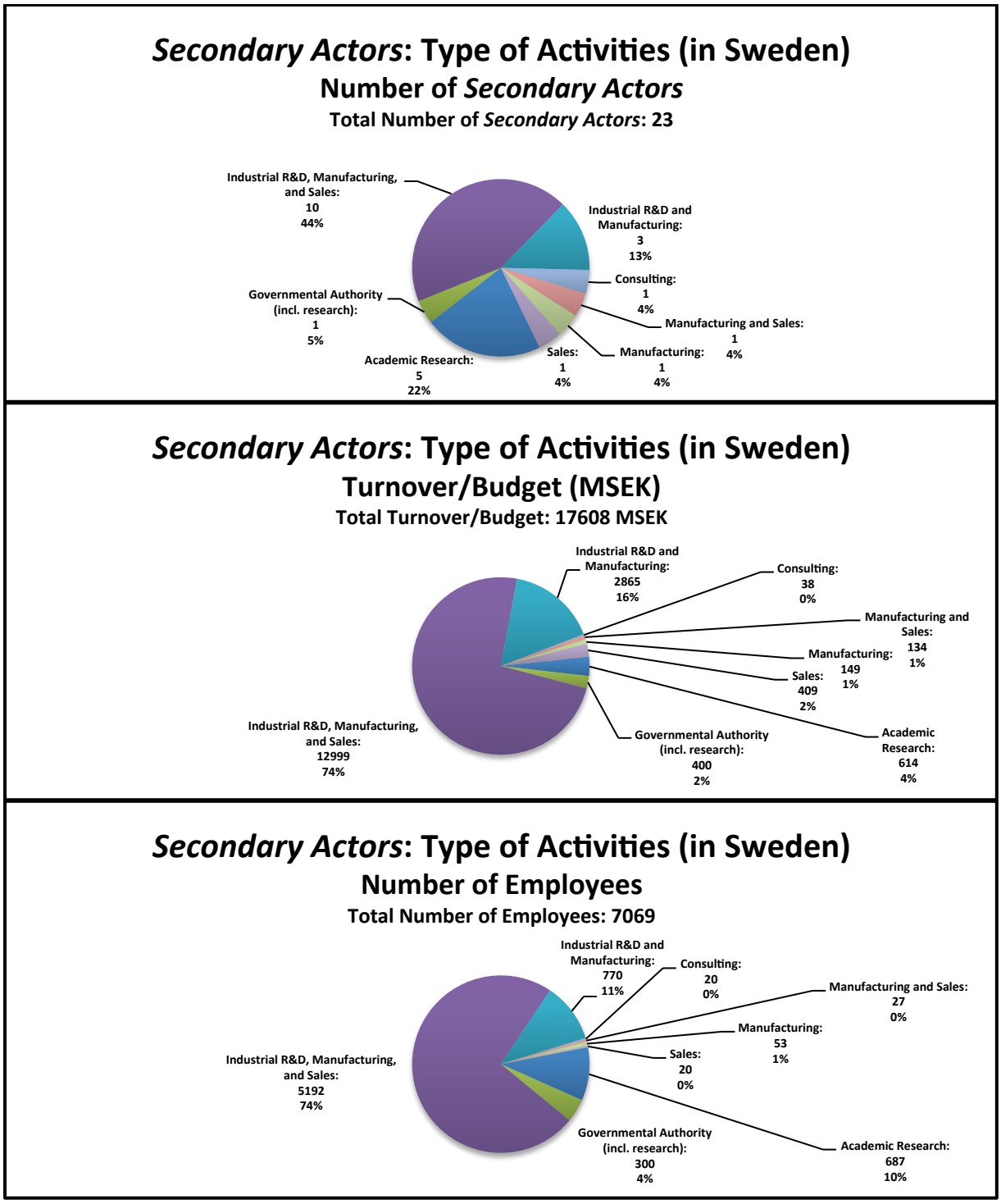

***Figure 5**: The three diagrams above presents the 23 identified* Secondary Actors *divided into groups depending on "Type of Activities (in Sweden)": "Academic Research", "Governmental Authority (incl. research)", "Industrial R&D, Manufacturing, and Sales", "Industrial R&D and Manufacturing", "Consulting", "Manufacturing and Sales", "Manufacturing", and "Sales". The uppermost diagram, "Number of* Secondary Actors*", shows the distribution of the 23* Secondary Actors *in the different types of activities. The diagram in the middle, "Turnover/Budget (MSEK)", shows the distribution of the total annual turnover (used for large enterprises and SMEs) or budget (used for academies and governmental authorities) of the different types of activities. The lowermost diagram, "Number of Employees", shows the distribution of the total number of employees of the different types of activities.*

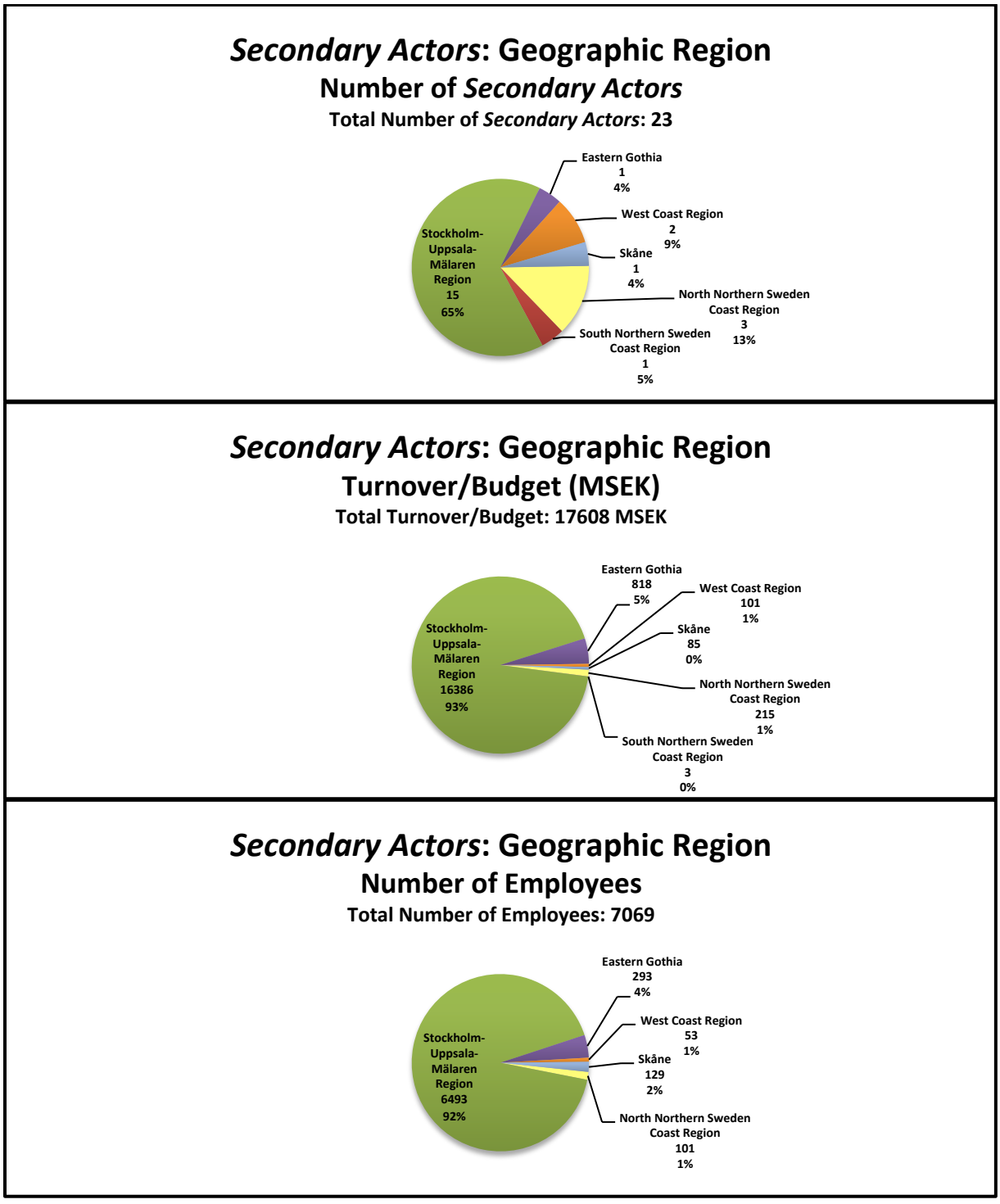

***Figure 6**: The three diagrams above presents the 23 identified* Secondary Actors *divided into groups depending on "Geographic Region": "North Northern Sweden Coast Region", "South Northern Sweden Coast Region", "Stockholm-Uppsala-Mälaren Region", "Eastern Gothia", "West Coast Region", and "Skåne". (No other geographic regions were represented.) The uppermost diagram, "Number of* Secondary Actors*", shows the distribution of the 23* Secondary Actors *in the different geographic regions. The diagram in the middle, "Turnover/Budget (MSEK)", shows the distribution of the total annual turnover (used for large enterprises and SMEs) or budget (used for academies and governmental authorities) of the different geographic regions. The lowermost diagram, "Number of Employees", shows the distribution of the total number of employees of the different geographic regions. (The one actor from "South Northern Sweden Coast Region" is not present in the lowermost diagram because the actor has zero employees.)*

4.4 Discussion of the Results

First of all it should be noted that the inventory lists of actors are not comprehensive. A comprehensive approach to identify the complete set of innovative Swedish actors in the photonics life science and health field is not feasible. Moreover, the distinction if an identified possible actor was included as an identified actor, and if an identified actor was mapped into the group of *Primary Actors* or the group of *Secondary Actors*, is somewhat arbitrary – though the inclusion criteria were followed as far as reasonable. Consequently, the lists are biased by the knowledge of the people involved in the agenda work, as well as by the limitations of available information from possible actors' webpages, the website www.allabolag.se, and other sources of information. This implies that some actors may not have been identified or not been included, and a few included actors might be close to the limits of the inclusion criteria, and a few included actors may actually better fit in the other group (*Primary Actors* or *Secondary Actors*) than they have been placed in. However, the summaries of the results, the statistics of the total data, are considered to be reliable.

Secondly, for "Type of Activities (in Sweden)" it should be noted that regarding the activity "Manufacturing", there is a risk to overemphasis the importance of Swedish manufacturing in the field considered. In most cases information about where actual manufacturing occurs, in Sweden or abroad, of the commercialised innovative enterprises is not easily accessible. Consequently, including the term "Manufacturing" does not necessarily mean that all the corresponding companies do carry out manufacturing of their products in Sweden. Rather it means that this "Industrial R&D" company located in Sweden does have manufacturing of their own products, independent of if the manufacturing actually takes place in Sweden or abroad. Though, in most cases where information has been available, these companies have at least some of their manufacturing located in Sweden, such as manufacturing of part of their products or the final production (calibration of optical measurement instruments manufactured in a foreign country, for example).

In total 68 actors were identified, whereof 45 *Primary Actors* and 23 *Secondary Actors*. The total annual turnover and budget figures for the actors were 20637 MSEK, whereof 3029 MSEK for the *Primary Actors* and 17608 MSEK for the *Secondary Actors*. The corresponding values for number of employees (in Sweden) were 1681 in *Primary Actors*, 7069 in *Secondary Actors*, and 8750 in total. More than 3 billion SEK are annually converted within companies and academies employing almost 1700 people, just within the focus field of Swedish innovative life science and health photonics, and additionally 17.6 billion SEK in turnover/budget and more than 7000 employees are strongly dependent on the Swedish biophotonics research and development in their daily business. A qualified guess gives that the total part of the *Secondary Actors'* business that is directly innovative life science and health photonics, is of about the same size as the total sum for the *Primary Actors*. That is, the total Swedish innovative optics and photonics in life sciences and health is estimated to employ approximately 3500 people and has a yearly turnover/budget of the order of 6 billion SEK.

It should be noted that especially one corporation among the *Secondary Actors* is very dominant in the statistics. The Elekta corporate group (the two companies Elekta AB and Elekta Instrument AB) represent no less than 48% of the total work force and stand for 61% of the total turnover/budget of the *Secondary Actors*. This is the main explanation why the sectors "Large Enterprises", "Industrial R&D, Manufacturing, and Sales", and "Stockholm-Uppsala-Mälaren Region", in the charts for *Secondary Actors* are very dominating when regarding "Turnover/Budget" and "Number of Employees". It should also be emphasised that, depending on definition of *photonics*, the part of Elekta's technology that is biophotonics vary considerably. Most of Elekta's technology platforms deals with or are related to gamma radiation generated by radioactive substances. Indeed this radiation is high energetic (short wavelength) photons, but this is not considered as photonics. However, one of their technology platforms is based on linear accelerators creating very high energetic ionising therapeutic x-rays, and in this report on biophotonics we have included x-rays in the definition of photonics. From this point-of-view probably a few percent of Elekta's business is biophotonics. That is a small amount, but considering the full size of the workforce and turnover of the corporation, this contribution is still of the same order as the large *Primary Actors*.

Among *Primary Actors* the number of "SMEs" is ten times the number of "Large Enterprises", at the same time as the total turnover as well as the total number of employees for the two groups are roughly of the same size. That is, among *Primary Actors*, the total contribution of large enterprises and SME companies are equally important in the photonics life science field.

Analysing the pie charts for "Type of Activities (in Sweden)" of the *Primary Actors* the domination of "Industrial R&D, Manufacturing, and Sales" is striking. Some possible explanations may be indicated. First, industrial research and development is of great importance and may indicate a strong potential of growth in the field. It is known that many of these enterprises have their origin from university research, and they have started as R&D companies spun off from the academic results. However, the number of industrial *Primary Actors* at earlier stage, such as in the activity category "Industrial R&D" (with no manufacturing or sales) is comparatively small. This may point out the importance for the young R&D companies to reach the stage of commercialisation. It is reasonable to believe that many of the young industrial R&D companies goes bankrupt or becomes incorporated into bigger enterprises (in many cases foreign), prior to finishing development of their first products and bringing them to the market. From this we conclude that it is both important to stimulate the academic life science and health photonics, in order to spin off in R&D companies, as well as supporting the early-stage R&D companies on their way to commercialisation, where there is a great opportunity for Swedish innovative enterprises in life science and health photonics to stand by themselves on solid ground with activities of research and development, manufacturing (in Sweden or abroad), and sales to the market.

For *Primary Actors* the "Stockholm-Uppsala-Mälaren Region" is largest with regard to number of *Primary Actors* and number of employees, with "Skåne" at second place. However, regarding yearly turnover/budget the value is actually higher for "Skåne" than for the "Stockholm-Uppsala-Mälaren Region". (Note that "Skåne" has approximately 1.2 million inhabitants, as compared to about 3 million inhabitants in the "Stockholm-Uppsala-Mälaren Region".)

Of the totally 68 identified actors, 58 (85%) are geographically located in the areas close to major universities (Umeå, Uppsala, Stockholm, Linköping, Gothenburg, Lund). For the *Primary Actors* the figures are 39 of 45 (87%) and for the *Secondary Actors* it is 19 of 23 (83%). Part of the explanation is that the academic actors are located at the major universities, but it is also obvious that there is a strong correlation between the presence of universities with relevant education and research, and the presence of innovative companies in the high-tech field of photonics and optics within life sciences and health. However, it is also very interesting to note that among the *Primary Actors*, three out of the seven biggest actors, are actually companies located to smaller cities (the Swedish part of the Danish company Foss Analytical AB in Höganäs, HemoCue AB in Ängelholm, and SenseAir AB in Delsbo). Apparently solitarily niched photonics life science companies can become very successful also located outside the university and metropolitan areas.

Finally, as a possible measure of academic spin-off into industrial research and development within Swedish life science photonics, let us compare the number of identified academic *Primary Actors* with the number of identified *Primary Actor* companies in the six Swedish city areas with major universities, see *Table 3*.

***Table 3**: Number of identified academic and company* Primary Actors *in the Swedish city areas with major universities.*

University City	Number of Academic *Primary Actors*	Number of Company *Primary Actors*
Umeå	1	2
Uppsala	0	2
Stockholm	5	12
Linköping	1	2
Gothenburg	3	1
Lund	1	8

The results from two of the areas distinguished from the other, the results from Stockholm and Lund. In both the Stockholm area and the Lund area the number of company *Primary Actors* clearly exceeds the number of academic *Primary Actors*, which might be interpreted as a successful high rate of giving birth to new photonics life science companies. In these two areas also two important academic *Secondary Actors* are located, SciLifeLab in Stockholm/Uppsala and MAX-lab in Lund. Together this may be a reasonable argument that these two regions are suitable for *Smart Specialisation* or *RIS3 – Research and Innovation Strategies for Smart Specialisation* – in life science and health photonics.

In the Uppsala area zero academic *Primary Actors* and two company *Primary Actors* were identified. However, there are several large *Secondary Actors*, both in the academy (largest the Uppsala location of SciLifeLab and the Department of Medical Cell Biology at Uppsala University) and in the industry (most notably GE Healthcare Bio-Sciences AB). Consequently, the total business of biophotonics in the Uppsala area may well be comparable to for example the Lund area, but there appears to be more small biophotonics R&D companies spun off from the academy in Lund than in Uppsala.

5 SWOT

5.1 SWOT Analysis

A SWOT (”Strengths”, ”Weaknesses”, ”Opportunities”, ”Threats”) analysis based on collected knowledge about historical situation, current status, and future trends was carried out. The SWOT diagram is presented in *Figure 7* and details about the analysis are provided in the succeeding section.

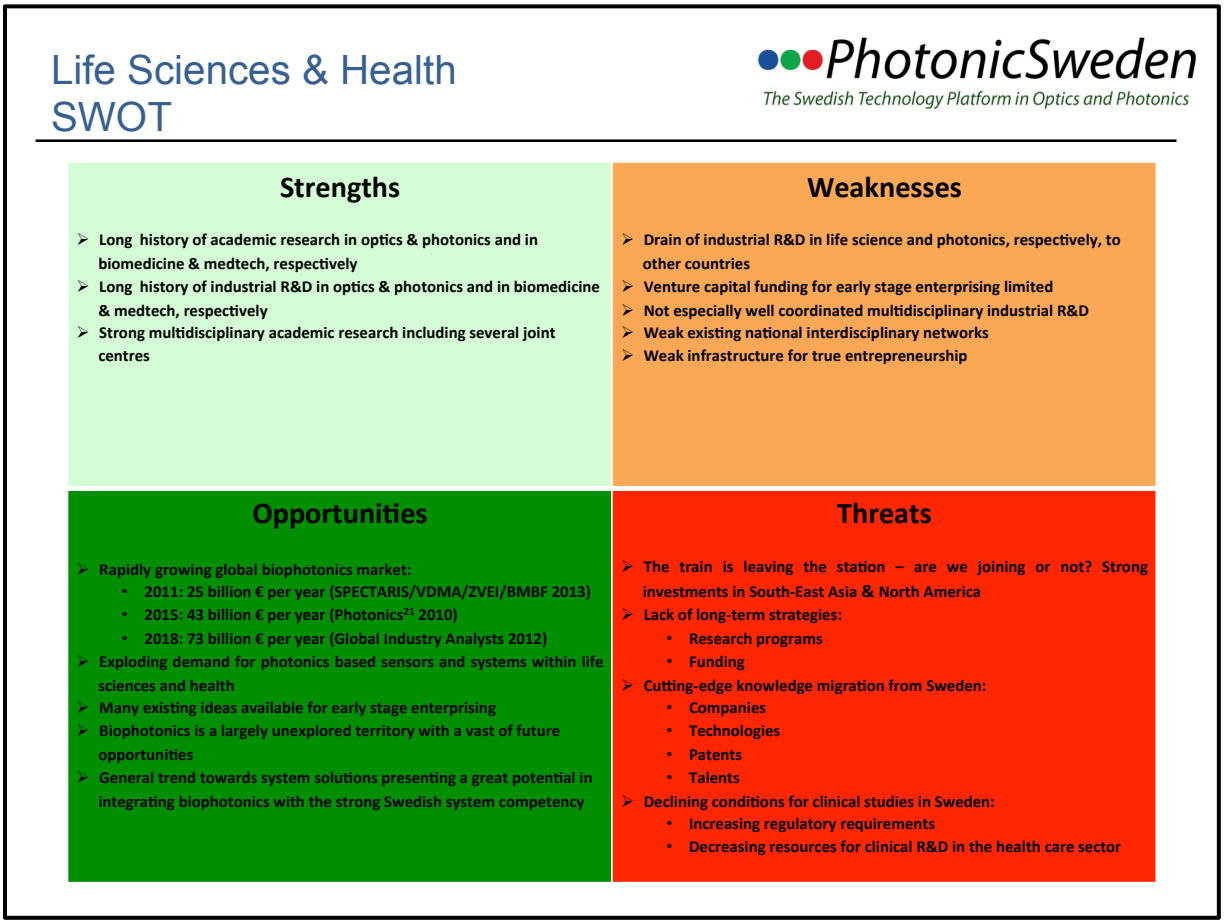

***Figure 7**: SWOT analysis of Swedish innovative optics & photonics in life sciences and health.*

5.2 SWOT Details

Strengths

Looking back at the past century, it is safe to say that the R&D within the area of optics and photonics is, and has been, strong in Sweden. This is true both for academia and industry with a long history of successful companies within the area backed up by world-class university-based research. The same holds for R&D within biomedicine and medical technology where Swedish progress has had a large and worldwide impact on a number of areas in the field.

This long history of efforts and progress within the respective fields is a very strong basis for interdisciplinary R&D where optics and photonics is used as basis for progress in biomedicine and medical technology, both as enabling technology for new and improved process and analysis methods to simplify the research itself, and as part of new innovative solutions for end user problems.

There are already a few interdisciplinary academic research centres up and running (CMTF – Centre for Biomedical Engineering and Physics – in Umeå/Luleå, SciLifeLab in Stockholm/Uppsala, Lund Medical Laser Centre, and MAX-lab in Lund) that are carrying out research in the intersection

between optics/photonics and biomedicine/medical technology. Resources like these are important for further work on strengthening the interaction between the research fields.

Weaknesses

Photonics for life sciences and health experience the same problems as many other research areas regarding drain of industrial R&D to other countries and the lack of venture capital for early-stage enterprise funding.

On top of these general weaknesses, photonics for life sciences and health also suffers from rather weak national interdisciplinary networks and a multidisciplinary industrial R&D that is not especially well coordinated. The few interdisciplinary research centres that do exist are mainly run by universities with a comparably small industrial involvement. While there are strong R&D efforts and industrial interests within each field, the interdisciplinary combination of the fields is much less exploited.

Opportunities

An exploding demand for photonic-based sensors and systems within life sciences and health is experienced today both in Sweden and worldwide. The yearly world biophotonics market is expected to grow very fast:

- 25 billion Euros in 2011 (actual figures from "Photonik – Branchenreport 2013", SPECTARIS, VDMA, ZVEI, and BMBF – the German Ministry of Education and Research, 2013).
- 43 billion Euros in 2015 (prognosis from "Lighting the way ahead – Second Strategic Research Agenda in Photonics", Photonics[21], 2010).
- 73 billion Euros in 2018 (prognosis from "Biophotonics – Global Strategic Business Report", Global Industry Analysts, 2012).

Even though the past decades have seen an ever-increasing activity on R&D within biophotonics and adjacent areas, this interdisciplinary field is still largely unexplored. At the same time, there are many new ideas that seek resources and funding, both for early enterprising and widening the knowledge and understanding of the science itself.

These facts along with a general trend towards system solutions open for a future of vast opportunities where the strong Swedish system competence is used to integrate photonics in innovative solutions within the life sciences and health area. Given the right support in terms of funding and networking and interaction arenas, all components for successful R&D and business building are already present to give the future activities in this area a major boost.

Threats

Most of the threats to the future of Swedish photonics in life sciences and health are closely connected to the listed weaknesses. Strong investments in, for example, South-East Asia and North America implicate a risk that Swedish biophotonics is left behind, and feed the migration of companies, technologies, patents, and cutting-edge knowledge out of Sweden. Additionally, clinical studies are crucial to medical technology and biomedicine R&D, but due to increasing regulatory requirements and decreasing resources for clinical R&D in the Swedish health care sector, clinical studies are too migrating from Sweden, complicating for Swedish life sciences and health research and development.

6 Conclusion & Vision

Based on the results from the inventory of the current status (statistics and discussion) and the SWOT analysis, we strongly believe that the best way to alleviate existing obstacles and promote the progress and growth of optics and photonics in Swedish life sciences and health can be summarized in one single, but very important, word: ***interaction***. Specifically, we need more:

- interaction between actors within each sector;
- interaction between sectors (photonics, electronics, medical technology, biomedicine, clinical science, …);
- interaction between academia, SMEs, large enterprises, and the public sector;
- interaction between system levels (components, modules, part systems, full systems, system owners/managers).

Interaction interfaces create synergies: new ideas, new solutions, new collaborations, new funding, new businesses, new market, new job opportunities…

In order to realise this, it is important to have strategies and funding for clusters, joint centres and a networking infrastructure *without demanding a tangible short-term outcome for the single actors at every step*. At the same time it is important to facilitate smaller scale interdisciplinary projects, capable to focus on well-defined aims and with a flexibility that is difficult to obtain in large centre constellations. Taking action today will hopefully result in a substantial national outcome stimulated and supplemented by *Horizon 2020*.

7 Recommendations

How can the need for interaction be addressed in more specific terms? As the former sections show, there are many companies involved in photonic-based life science in one way or another, many of which are rather young and small. These are usually strongly focused on one or a very limited number of ideas that are transformed to a product or service. While this work is important and contributes to the development in the area, there are very limited muscles available for more general R&D or networking. It is therefore important that future programmes related to photonics for life science include:

- Improved support for collaboration within groups of few but complementary actors that have the potential to develop technical platforms that can serve as a basis for further development into specific products. This could, for example, be sensor platforms for diagnosis or monitoring, or service platforms for communication between care providers and care takers, it could be vertical collaborations between component and system actors, horizontal collaborations between actors of different disciplines, or combinations thereof.
- Incitements and funding for interdisciplinary interaction between commercial and academic actors as well as the public sector that *do not* require short-term commercial results. Instead, success may be measured in, for example, definition of future joint development projects that in turn can result in new products and commercialisations.
- Funding for basic national networking within the area, where the success is measured, for example, by created interaction interfaces (workshops, match-making and/or pitch session events, and so forth).
- Increased funding for SMEs to work with research institutes and research centres in relevant areas, as well as increased funding for these bodies to bridge the gap between promising research results and commercialised products.
- Support to interdisciplinary research and/or development projects and *Triple Helix* joint centres with technical/photonics partners working together with clinical partners, possibly matching/strengthening and encouraging support provided by regional counties responsible for the healthcare.
- Directed support to relevant geographical regions such as the creation of *Smart Specialisations* and directed support to relevant interdisciplinary single actors.

8 Contributors

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All contributions are very appreciated – thank you!

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