Study on EU Positioning: An Analysis of the International Positioning of the EU Using Revealed Comparative Advantages and the Control of Key Technologies

Final Report

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Directorate-General for Research & Innovation
Research, Innovation and Science Policy Experts High Level Group

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EXECUTIVE SUMMARY

Background and purpose

In view of the year 2020 the overall framework conditions for research and innovation are changing. The international positioning of the EU in terms of trade and influence are challenged by the sustained competition with the USA and the rise of China and other countries as global economic players. Processes of digitalisation in the world economies are accelerating, thereby enhancing globalisation of research and innovation. Disruptive innovation addressing societal grand challenges (SGCs) and global markets may likely emerge. Against this background the purpose of this study is to provide an assessment of the international positioning of the EU in the year 2020 with respect to research and innovation in each of the thematic areas funded in Horizon 2020. This includes an elaboration of strengths and weaknesses of the EU, an analysis of the comparative advantage of the EU today, an identification of the key enabling technologies for the 21st century, an identification of centres of excellence in the areas of Horizon 2020, an assessment of the EU's competitive position in 2020, and an assessment of possible impact of major EU initiatives for research and innovation.

Methodology, approach

The approach of the study comprises three levels of analysis: the current situation with respect to the European competitive position in the thematic areas of Horizon 2020, trend analyses towards 2020, and a critical debate and recommendations. We use a combination of qualitative and quantitative methods. The diagnosis of the current competitive position of Europe is based on a literature review and more than 30 expert interviews which also revealed foresight variables, possible game changers and centres of excellence. The quantitative assessment firstly provides an overview of the comparative advantage of Europe in 2015. This is based on the analysis of scientific publications using data from Thomson Reuter's Web of Science database. In addition, patent analyses using the EPO Worldwide Statistical Database (PATSTAT) were carried out. Data on BERD, value added, import and export were collected from the OECD STAN database, complemented by EUROSTAT data. In the trend analyses scenarios for the position and comparative advantage of Europe in the year 2020 were elaborated. For that purpose a structural prediction model relating R&D expenditures, scientific specialisation, technological specialisation, and economic specialisation to measures of economic success (trade balance and share of world production) in each of the KETs and SGCs was built. Results of the qualitative, quantitative and scenario analyses were critically debated at a stakeholder workshop.

Results

The **present position** of the EU in the SGCs of transport, climate and energy is very favourable. These SGCs are strongly correlated to the KETs advanced manufacturing technologies, Internet of Things, space, biotechnology and nanotechnology. Europe presents a good positioning in the first three of these KETs, while in the latter two the European position is not as strong. Since also other KETs contribute to SGCs, we conclude that public research activities in all KETs fields are important for achieving advances in dealing with SGCs.

The most important **trend** from the **KETs** perspective is the increasing merging of ICT with other KETs and the rising diffusion of ICT in almost all economic sectors. This will lead to an acceleration of innovation dynamics in most sectors. Concurrently, the trend towards diffusion of ICT to many sectors will also enable new e-services, offering additional opportunities for user-oriented business models. Managing risks of cyber attacks and insuring safe and secure data handling are key requirements for this trend. In **SGC** areas the most important overarching trends comprise an increasing interlinkage between different SGCs, a stronger consideration of user needs and expectations, a growing demand for individualised and customised solutions, arising impact of societal and environmental issues and a clear need for implementing sustainable solutions in all sectors. European diversity in terms of market characteristics, consumer preferences or environmental conditions is considered as an asset for dealing with these trends and challenges since it offers opportunities to explore and test innovative approaches in variable environments. Accordingly, Europe is well positioned for mastering these new modes of innovation.

The concept of **centres of excellence** needs some reconsideration. There is a clear trend towards networking and cooperation. This trend implies that the ability to set up and operate networks of excellent research sites is an important asset for European competitiveness. Instead of large and static centres, smaller, flexible and agile units are becoming more important. Including a value chain perspective in setting up such networks will provide additional future opportunities.

Looking at the **European position in 2020**, a forecast of specialisation indicators based on **trend extrapolations** indicates improvements of the input (R&D) and throughput (publications, patents) variables for Europe. However, this does not translate into an enhancement of output values such as exports or Revealed Comparative Advantage. Although considering the time lag between input in terms of R&D investment and research activities and output as indicated by improved economic performance, the forecast illustrates that Europe most likely will not succeed in improving its competitive position in a sustained manner if business as usual will continue. Considering recent activities in China and other competing regions aiming at boosting their competitive positions in KETs and SGCs, reinforces this observation.

The **scenario analysis** confirms the observation that there is a risk of erosion of the current good position of Europe in a mid to long term due to the upcoming of new technology-oriented players such as China, Korea and other East Asian countries and the prominent role of the US in the route towards the digital revolution. The excellent position of Europe in some areas such as advanced manufacturing technologies might also diminish due to increased efforts in other countries, namely China and Japan but also the USA. All these countries have set up and partially implemented dedicated policies in the context of advanced manufacturing technologies. In the energy area the scenario analysis indicates that it may become harder for Europe to strengthen its current outstanding position. Although Europe will remain a strong player in absolute terms, a slight weakening of the relative European position seems likely. On the other hand, there is also an opportunity for Europe to further increase its strengths and effectively using its first mover advantage. Continuity in terms of ambitious energy and climate policies is an important influencing factor for the realisation of this positive outlook.

In addition to the relative perspective which was the main focus of this analysis, an absolute perspective is also appropriate. Since the worldwide **market** and also the European market in the analysed areas will be growing over the coming years even a decline in the relative European position in these growing markets will not lead to a detoriation of absolute levels, rather even raising absolute positions is possible, thereby securing or even creating new jobs in Europe. Europe is still the largest science conducting region in the world both in KETs and in SGCs. Similar trends can be identified in terms of exports, while R&D and also patents seem to stagnate also in absolute terms leading to decreasing shares. Dynamics of these indicators take place in other regions of the world. Accordingly, there is a risk that in a mid- to long-term perspective the European position might also erode in absolute terms.

Conclusions and recommendations

Currently, Europe benefits from an overall good position in many of the KETs and SGCs. Our scenario analysis indicate that the increasing competition from South-East Asia will most likely imply a decline of Europe's relative position in KETs and SGCs because scientific, technological and competitive strengths will become globally dispersed in a multipolar world. This increasing **global dispersion** requires that Europe specialises in core strengths in order to remain competitive because it will be impossible for Europe to be excellent in all areas.

A prerequisite for effective **specialisation** is the identification of the core technologies and societal demands of the future. Therefore, we recommend to **strengthen ongoing foresight processes** and to institutionalise an exchange process with industry in order to make available the required **strategic intelligence**. Specialisation also implies that collaboration with countries in other world regions for sourcing the necessary knowledge inputs in particular in those KETs and SGCs where other regions are stronger is important. Accordingly, we recommend **fostering precompetitive collaboration** between Europe and those regions.

Specialisation also occurs inside Europe because competences are heterogeneously distributed across European countries. It is recommended to harness the heterogeneity as a source of technology and knowledge diversity. Such a **diversity-oriented policy approach** can both combine excellence and cohesion as it addresses top research, but also basic research and absorption capacities European-wide. This implies that future policies should complement the current excellence focussed funding approach with policies that are able to **exploit regional strengths by creating seedbeds** of specialised, dynamic and geographically dispersed actors in KETs and SGCs. By empowering such regional actors policy-making also contributes to establishing Europe-wide hubs and networks of excellence which not only provide technological and scientific **excellence**, but also contribute to **cohesion** across Europe.

RESUME

Formation et objectif

Compte tenu de 2020, le cadre général des conditions de recherche et d'innovation sont en train de changer. Le positionnement international de l'UE en matière de commerce et d'influence est continuellement contesté par la concurrence des États-Unis, la montée en puissance de la Chine ainsi que par d'autres pays agissant économiquement sur un niveau mondial. La numérisation des économies mondiales s'accélère, améliorant ainsi la mondialisation de la recherche et de l'innovation. L'innovation de rupture s'adressant aux défis sociétaux et aux marchés globaux, émergera probablement. Dans ce contexte, l'objet de cette étude est de fournir une évaluation du positionnement international de l'UE en 2020 concernant la recherche et l'innovation dans chacune des domaines thématiques financées par Horizon 2020. Cela comprend l'élaboration des qualités et faiblesses de l'UE, une analyse de l'avantage comparatif de l'UE actuelle, une identification des technologies principales habilitantes pour le XXIème siècle, une identification des centres d'excellence dans les domaines d'Horizon 2020, une estimation de la position concurrentielle de l'UE en 2020 tant qu'une évaluation de l'impact possible des initiatives majeures de l'UE pour la recherche et l'innovation.

Méthodologie, conception

L'approche de l'étude comprend trois niveaux d'analyse : la situation actuelle concernant la position concurrentielle européenne dans les domaines thématiques d'Horizon 2020, l'analyse des tendances pour 2020, un débat critique et des recommandations. Une combinaison de méthodes qualitatives et quantitatives est utilisée. Le diagnostic de la compétitivité actuelle de l'Europe est élaboré sur la base d'un aperçue de la littérature cruciale et plus de trente interviews d'experts ce qui révéla également des variables de prévisions, des possibles *game changers* et des centres d'excellence. L'évaluation quantitative de niveau 2 fournit premièrement un aperçu de l'avantage comparatif en Europe pour 2015. Elle est basée sur l'analyse des publications scientifiques se servant des informations de la base de données de Thomson Reuters's Web of Science. En outre, des analyses de brevet d'invention ayant recours à la base de données EPO Worldwide Statistical (PATSTAT) ont été effectuées. A partir de la base de données STAN de l'OCDE des données sur les DIRDE ainsi que la valeur ajoutée au même titre que les données sur l'importation et l'exportation ont été collectées et complétées par des données d'EUROSTAT. Des scénarios concernant la position et l'avantage comparatif de l'Europe en 2020 ont été élaborés dans l'analyse des tendances. A cet effet, un modèle prévisionnel de structure concernant les dépenses en R&D, la spécialisation scientifique, la technologique et l'économique pour mesurer le succès économique (balance commerciale et part de la production mondiale) dans chacun des KETs et SGCs a été construit. Les résultats des analyses qualitatives, quantitatives et de scénario ont été discutés de manière critique lors d'un atelier avec les parties prenantes (stakeholder workshop).

Résultats

La position actuelle de l'UE dans les SGCs du transport, du climat et de l'énergie est très favorable. Ces SGCs sont fortement corrélées aux technologies de fabrication de pointe KETs, l'Internet des objets, l'espace, la biotechnologie et la nanotechnologie. L'Europe représente un bon positionnement dans les trois premières des KETs, alors que dans les deux dernières, la position de l'Europe n'est pas aussi forte. Puisque d'autres KETs contribuent aussi aux SGCs, nous concluons que les activités de recherche publique dans tous les domaines de KETs a un impact positif sur les SGCs.

La **tendance** la plus importante concernant la perspective des **KETs** est la fusion croissante de l'ICT avec d'autres KETs et la diffusion montante de l'ICT dans presque tous les secteurs économiques. Cela conduira à une accélération de la dynamique de l'innovation dans la plupart des secteurs. Simultanément, cette tendance pourra également autoriser les nouveaux e-services, offrant des opportunités supplémentaires pour les modèles d'af-

faires axés sur l'utilisateur. Les exigences clés de cette tendance sont de gérer les risques de cyber-attaques et d'assurer la manipulation sûre et sécurisée des données. Dans le domaine des **SGCs**, les tendances globales les plus importantes comprennent une inter-dépendance croissante entre différents SGCs, une meilleure prise en compte des besoins et des attentes des utilisateurs, une demande croissante pour des solutions individualisées et personnalisées, résultant de l'impact des enjeux sociétaux et environnementaux et d'un besoin évident de mettre en œuvre des solutions durables dans tous les secteurs. La diversité européenne est considérée comme un atout pour faire face à ces tendances et défis puisqu' elle offre la possibilité d'explorer et de tester des approches novatrices dans des environnements variables. Par conséquent, l'Europe est bien placée pour maîtriser ces nouveaux modes d'innovation.

Le concept de **centres d'excellence** nécessite quelques reconsidérations. Il existe aujourd'hui une tendance visible envers la mise en réseau et la coopération. Cela implique que les capacités de mise en place et de mise en œuvre de sites de recherche d'excellence sont un atout important pour la compétitivité européenne. En comparaison avec des centres larges et à durée permanente, des petites unités plus flexibles et agiles deviendront de plus en plus important. De plus, l'inclusion du concept de chaine de valeur dans la mise en place de ces réseaux apportera des opportunités additionnelles à l'avenir.

En perspective de **la position Européenne en 2020**, les prévisions d'indicateurs de spécialisation basés sur des **extrapolations de tendances** indiquent des améliorations des variables d'input (R&D) et du throughput (publications, brevets) pour l'Europe. Cependant, ceci ne se traduit pas par une amélioration des valeurs de résultat (output) telles que les exportations ou des avantages comparatives relevés. Même en tenant compte du décalage entre l'input (mesuré en termes d'investissements en R&D et d'activité de recherche) et les résultats (output) (mesuré par une croissance économique améliorée), les prévisions indiquent que l'Europe ne pourra probablement pas améliorer sa compétitivité d'une manière soutenable si le statu quo est maintenu. Ces observations sont renforcées notamment prenant en compte les activités récentes en Chine et dans autres régions concurrentes ayant l'objective d'accroitre leur position compétitive en matière de KET et SGCs.

L'analyse des scénarios confirme l'observation selon laquelle il existe un risque d'érosion de la bonne position actuelle de l'Europe sur une moyenne et longue durée. Cela est dû à la montée des nouveaux acteurs, orientés envers la technologie, tels que la Chine, la Corée ou autre pays de l'Asie de l'Est ainsi qu'au rôle dominant des Etats-Unis sur le chemin de la révolution numérique. L'excellente position de l'Europe dans quelques domaines telles que les technologies de fabrication avancées pourrai également diminuée en raison d'efforts augmentés d'autre pays, en particulier la Chine, le Japon et les E.U. Tous ces pays ont mis en place des politiques spécifiques dans les domaines des technologies de fabrication avancées et sont en train de les mettre en œuvre. En matière d'énergie, l'analyse des scénarios montre qu'il est de plus en plus difficile pour l'Europe de consolider sa position actuelle exceptionnelle. Bien que l'Europe reste un acteur puissant en terme absolu, un léger affaiblissement de sa position relative semble probable. Néanmoins, l'Europe pourra continuer à augmenter sa position de force et de faire usage de son avantage au premier entrant. Sa continuité en matière de politiques ambitieuse dans les domaines de l'énergie et du changement climatique est également un facteur important et d'influence qui contribue à une perspective positive.

Le focus de cette analyse étant une perspective relative, une perspective de l'absolu semble également apropriée. Prenant en compte que le **marché mondial** ainsi que le marché Européen dans les domaines en question sera en croissance dans les prochaines années, un déclin de la position relative de l'Europe n'absolutisera pas dans une détérioration en terme absolu. Au contraire, une augmentation en terme absolu est probable, entrainant une sécurisation ou même une création de nouveaux emplois en Europe. L'Europe reste la région mondiale avec la plus grande production scientifique en termes de KET et SGC. De similaires tendances sont identifiées pour les exportations. Cependant, la R&D et les brevets d'invention semblent de stagner en termes absolus entrainant un déclin de quoteparts, faute d'une dynamique dans d'autres régions du monde. Par conséquent, il existe un risque que la position Européenne puisse corroder en terme absolu.

Conclusions et recommandations

L'Europe bénéficie actuellement d'une bonne position dans beaucoup de KET et SGC. Notre analyse des scénarios indique que la compétition croissante de l'Asie du sud-est implique très probablement un déclin de la position relative de l'Europe dans les domaines de KET et SGC en raison d'un étalement de ses atouts scientifiques, technologiques et de compétitivité dans un monde multipolaire. Afin de rester compétitive dans un **monde devenant de plus en plus dispersé**, l'Europe sera forcée de se spécialiser sur ces points forts centraux, car il sera impossible d'être excellent dans tous les domaines.

Une des conditions préalable à une **spécialisation** efficace est l'identification des technologies fondamentales ainsi que des exigences sociétales de l'avenir. Nous recommandons de consolider le **processus de prospection** en cours ainsi que d'institutionnaliser un processus d'échange avec l'industrie afin de mettre à disposition **l'intelligence stratégique** nécessaire. Se spécialiser implique également de collaborer avec des pays dans d'autres régions du monde afin de s'approvisionner du savoir-faire nécessaire, en particulier relatif aux KET et SGC dans lesquels d'autres régions sont plus puissantes. Nous recommandant également de **favoriser la collaboration dans un stade précompétitif** entre l'Europe et les régions en question.

Une spécialisation à également lieu au sein de l'Europe dû au fait que ces compétences sont distribuées de manière hétérogène sur les différents pays Européens. Nous recommandons d'exploiter cette hétérogénéité et de puiser dans la diversité de connaissances, de savoir-faire et des technologies émergentes. Une telle **approche politique basée sur la diversité** est susceptible de combiner l'excellence et la cohésion. Afin d'éviter une concentration régionale, les politiques choisies ne devront pas seulement suivre une approche visant l'excellence lors de la distribution du financement pour la recherche. Il est plutôt recommander d'exploiter les atouts régionaux en créant des viviers d'acteurs spécialisés, dynamiques et géographiquement dispersés dans le domaine des KET et SGC. Renforcer les pouvoir des acteurs politiques régionaux contribuera également à créer des plateformes et réseaux **d'excellence** qui ne contribueront pas seulement à une base technologique et scientifique renforcée, mais également à la **cohésion** au sein de l'Europe.

1. INTRODUCTION: BACKGROUND AND PURPOSE

As pointed out in the specifications for this study, in view of 2020 the overall framework conditions for research and innovation are changing. In particular three global trends which are closely interrelated are emphasised:

- The sustained competition with the USA and the rise of China and other BRICS countries as global economic players are expected to challenge the international positioning of the EU in terms of trade and influence.
- Digitalisation of world economies is accelerating, thereby enhancing globalisation of research and innovation. In consequence, risk financing of innovative firms and start-ups, corporate investment decisions, centres of excellence (CoE) and global mobility of researchers are affected by this trend considerably.
- Disruptive innovation addressing societal challenges and global markets may likely emerge. It could be expected that such changes affect entire social systems, for example, transport systems, energy systems, production systems, systems for health and aging. In consequence, structural change may be induced with new firms breaking up incumbent firm structures.

Against this background the main objective of this study is to provide an assessment of the international positioning of the EU in the year 2020 with respect to research and innovation in each of the thematic areas funded in Horizon 2020. In order to achieve this overall aim, the following objectives are pursued:

- Elaboration of strengths and weaknesses of the EU in research and innovation in each of the thematic areas funded in Horizon 2020.
- Analysis of the comparative advantages of the EU today.
- Identification of the Key Enabling Technologies (KETs) for the 21st century and specification of those KETs that the EU controls and that confer a strategic advantage to the EU.
- Identification on a global basis of the CoE in each of the areas of Horizon 2020.
- Analysis and assessment of the EU's comparative advantage and competitive position in 2020.
- Identification of likely locations of poles of excellence in 2020 with respect to the key thematic areas of Horizon 2020.
- Assessment of the possible impact of major EU initiatives for research and innovation.
- Based on the assessment of the international positioning of the EU in 2020 recommendations are elaborated on which countries and on which sectors the EU should cooperate in basic research and in close-to-market activities.

The geographic scope of the study concerns the European research area as a whole as well as the 28 EU Member States individually. The European situation is compared to the USA, Japan and the BRICS countries (Brazil, Russia, China, India, China, South Africa). In addition, South Korea as an emerging Asian economy is considered.

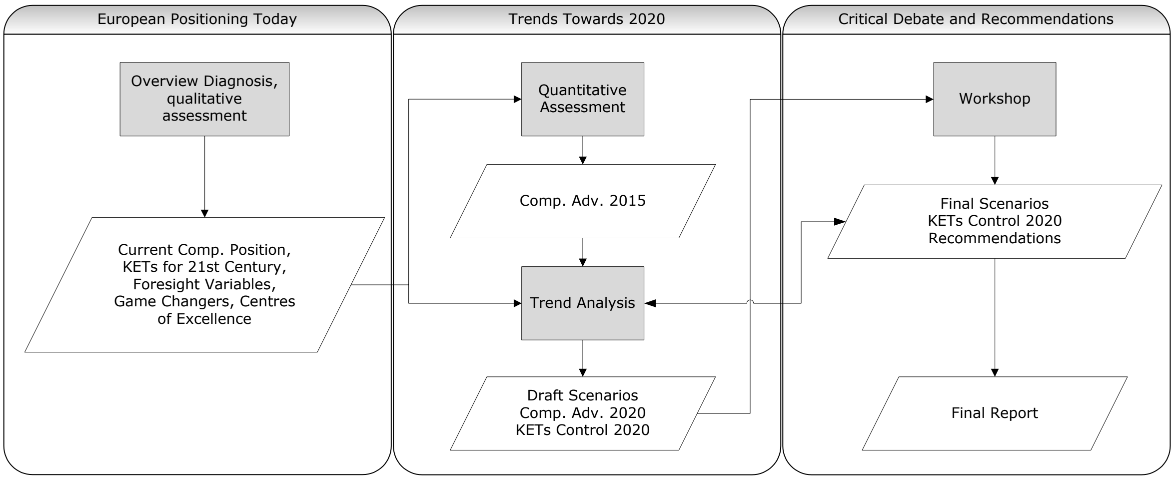
The thematic scope of the study is defined by the major societal challenges and the industrial technology areas mentioned in Horizon 2020 (LEIT). LEITs include the Key Enabling Technologies (KETs), nanotechnology, advanced materials, advanced manufacturing and possessing, micro- and nanoelectronics and photonics as well as space research and innovation and information and communication technologies (including components and systems, advanced computing, future Internet, content technologies and information management, robotics, Internet of Things, human-centric digital age, cross-cutting topics addressing cyber security).

2. METHODOLOGY, APPROACH

The general approach of the study comprises three levels of analysis (Figure 2-1):

1. The current situation with respect to the European competitive position in the thematic areas of Horizon 2020.
2. Trend analyses towards 2020.
3. Critical debate and recommendations.

Figure 2-1: Overall approach for the study on EU positioning



A combination of qualitative and quantitative methods is used. At level 1 a diagnosis of the current competitive position of Europe is elaborated based on a literature review and in particular expert interviews. As a result of these analyses foresight variables, possible game changers and CoE are identified. At level 2 firstly a quantitative assessment of Europe's positioning is carried out, providing and analysis of the comparative advantage of Europe in 2015. Together with the results of the qualitative analysis at level 1 this forms the basis for the following trend analysis. In the trend analysis scenarios for the position and comparative advantage of Europe in the year 2020 are elaborated. At level 3 results of qualitative, quantitative and scenario analyses are critically debated at a stakeholder workshop. Results of the workshop feed into the elaboration of recommendations.

Qualitative analysis

The qualitative analysis is based on in-depth interviews with experts and stakeholders. Interviewees were selected in a way that all thematic areas of Horizon 2020 (societal challenges and LEITs) were covered. In total, 31 interviews were carried out by phone. Interviews were structured by an interview guide covering the following main topics: general trends in each area; influencing factors and among these possible disruptive innovation and game changers; existence, location and role of CoE; strengths and weaknesses of Europe in the different areas and expected changes; potential for cooperation in basic research and close to market activities, focussing on most promising sectors and countries; framework conditions guiding future cooperation.

Quantitative analysis

The data used for the study were collected from various sources, which will be described in more detail below.

Patents

The necessary patent data for the study were extracted from the "EPO Worldwide Patent Statistical Database" (PATSTAT), which covers patent information from more than 80 patent offices worldwide.

The definitions for the KETs, LEITs and SGCs originate from different sources. In case of KETs, we resorted to the definition of the KETs Observatory (IDEA Consult et al. 2015). In the case of SGCs, a definition developed by Fraunhofer ISI within a project for the JRC-IPTS ("Collection and analysis of private R&D investment and patent data in different sectors, thematic areas and societal challenges" (JRC/BRU/2014/J.6/0015/OC)) was applied (Frietsch et al. 2016). In the case of LEITs, technology experts at the Fraunhofer ISI developed a definition based on classes of the International Patent Classification (IPC) in combination with keywords that were searched in the title and abstract of the patents.

All the patents used for the analysis were counted according to their year of worldwide first filing, what is commonly called the priority year. This is the earliest registered date in the patent process and is therefore closest to the date of invention. The assignment of patents to countries is based on the address of the inventor.

We further followed the concept of "transnational patents" suggested by Frietsch and Schmoch (2010). In detail, all filings at the World Intellectual Property Organisation (WIPO) under the Patent Cooperation Treaty (PCT) and all direct filings at the European Patent Office (EPO) without precursor PCT filing are counted. This excludes double counting of transferred PCT filings to the EPO. Put more simply, all patent families with at least a PCT filing or an EPO filing are taken into account. This approach is able to overcome the home advantage and unequal market orientations of domestic applicants, so that a comparison of technological strengths and weaknesses between countries becomes possible.

In addition to the number of transnational filings, the average family size of patent applications was calculated. A patent's family size is determined by the number of distinct patent offices at which a patent has been filed. The average family size can thus be seen as an indicator of the breadth of the market coverage of a patent, but it can also be linked to the quality of a patent as it can be assumed that a patent is filed more frequently in foreign countries if the patented invention is assumed to be of high quality (Harhoff et al. 2003; Putnam 1996; Van Zeebroeck 2011).

Scientific Publications

The scientific publications within the dataset were collected from Thomson Reuter's Web of Science (WoS) database. Hereby, data from the Science Citation Index (SCI), the Science Citation Index Expanded (SCIE) as well as the Social Science Citation Index (SSCI) were used. Taken together, this forms a multi-disciplinary database with a broad coverage of fields. The searches refer to the natural and engineering sciences, and the medical and life sciences as well as the social sciences. However, the WoS primarily covers English language expert journals, implying that journals in other languages are not included. In general, the SCI, SCIE and the SSCI cover highly cited journals, i.e. journals with high visibility where already the fact of placing a publication in these indexed journals can be considered as a first quality indicator.

To classify publications by fields, we resorted to an existing list of 27 scientific disciplines based on the subject categories provided by Thomson Reuters. For KETs, LEITs and SGCs, combinations of subject categories and keyword searches were applied.

BERD, value added and imports/exports

The data on BERD (2005-2012), value added (2004-2014) and import/exports (1990-2014) by sectors (NACE Rev. 2) were collected from the OECD STAN database and complemented by EUROSTAT data to fill some of the gaps in the time series. In order to fill the remaining gaps, several imputation methods were applied, e.g. use of the average value in t-1 and t+1 in case of a missing value in t or carry forward the value of t at the end of a time series where a value for t+1 does not exist.

Conversion of sectoral data to technology fields (KETs, LEITs, SGCs)

One of the major challenges within this project was to estimate BERD, value added and imports/exports by KETs, LEITs and SGCs, as these indicators are only available at the sectoral (NACE 2-3 digit) level. To do this, we resorted to a matrix of (transnational) patent filings by NACE sectors and KETs/LEITs/SGCs that has been generated by linking the *2013 EU Industrial R&D Investment Scoreboard* with PATSTAT at the level of companies/patent applicants. Based on this matched dataset, we were able to generate probabilistic concordance schemes based on the shares of patents by sectors in each of the technology fields. This matrices of patent shares was then applied to relocate the BERD, value added and import/export data by KETs, LEITs and SGCs. If, for example, the patent shares show that patent filings from one sector are split up by 50% to LEIT1, 30% to LEIT2 and 20% to LEIT3, the BERD, value added and import/export data were split up accordingly. This leads to a final panel dataset where all indicators, i.e. patents, publications, BERD, value added and imports/exports are available for the KETs, LEITs and SGCs by country and year. This dataset was used for all further analyses.

Scenarios

For the scenarios we have built a structural prediction model relating R&D expenditures (BERD), scientific specialisation (RLA), technological specialisation (RPA) and economic specialisation (RCA) to measures of economic success (in particular the trade balance and the share of world production) in each of the KETs and the SGCs.

In order to link these variables in a structural model, we propose using a three-step sequential model. On the first level we determine how the RCA, RPA, and RLA depend on BERD. In a second step, we allow the RCA to depend on the RPA and RLA. In a third step we model the share of world production and the trade balance as function of RLA, RPA, RCA, and BERD. A schematic representation is contained in Annex 2. Based on the empirical dataset we have estimated this model by panel regression-techniques, which determine both the direction and the strength of association represented by each of the links. The regression tables and a more formal description of the methodology can be found in Annex 2.

The coefficients resulting from the regressions are summarised in Table 2-1. These coefficients will be used to assess the likely future impacts of different scenarios for the development of the core variables RCA, RPA, RLA, and BERD on the two outcome variables, i.e. the trade balance and the share of world value added in the scenario analysis.

Table 2-1: Summary of the effects for the total model

Effect from to	Trade Balance	Share world market (value added)	RCA	RPA	RLA
RCA	1% increase leads to 2.3675% increase	No effect			
RPA			1% increase leads to 0.003% increase		
RLA			1% increase leads to 0.007% increase		
BERD	1% increase leads to 0.6671% increase	1% increase leads to 0.1527% increase	1% increase in BERD increases RCA 0.023%	No effect	No effect

3. RESULTS

3.1 Current position of EU in KETs and SGCs

The position of the EU is assessed on the basis of comparative advantages. This implies a relative perspective on the position, taking also into account the developments worldwide. Comparative advantage also means that Europe might realise economies of scale and scope and especially takes high market shares, be it in terms of technologies (patents), science (publications), input (R&D expenditures) or output (value added or exports). The theoretical and empirical literature shows that areas of competitive advantage are persistent over time and that it is much harder for competitors to enter markets with strong actors or to take market shares from them.

To measure the comparative advantages, we build on established specialisation ratios which have a long tradition in science and technology analysis (Grupp 1998, Schubert and Grupp 2011) and the calculation of the Revealed Comparative Advantage (Balassa 1963) in conjunction.

Indicators of trade specialisation build on the concept of comparative advantage, which states that trade and production specialisation is the result of relative productivity differences between countries. This idea was first popularised by Ricardo (1817) and since then has remained a fundamental concept in international trade theory. The first to introduce an indicator of comparative advantage was Balassa (1965)[1] who proposed a measure that he called Revealed Comparative Advantage (RCA).

The comparative advantage refers to the relative costs of one product in terms of another in one country vis-à-vis another country. While early economists believed that absolute advantage in a certain product category would be a necessary condition for trade (implying that one country is more productive than another or alternatively has lower costs in producing a certain product), it was Ricardo (1817) who showed that international trade is mutually beneficial under the weaker condition of comparative advantage (meaning that productivity of one good relative to another differs between countries).

3.1.1 Comparative advantage: statistical data

Figure 3-1 shows the **R&D specialisation** of Europe in individual KETs and SGCs. While in the case of SGCs a balanced pattern with positive values for climate, transport, energy and below average specialisation for security, food and health becomes apparent, the situation in KETs is less positive. In space and advanced manufacturing we see a positive specialisation. Internet of Things, photonics, and advanced materials are close to the worldwide average, while others are clearly below zero, with – for example – content technologies or biotechnology strongly negative. In these fields R&D is more intensively conducted in other parts of the world than in Europe.

While the deductions from the interviews and scenarios presented in section 3.3 provide information on the results in 2020 according to worldwide trends in KETs and SGCs, we present in this section also rather simple time series analyses extrapolated until 2020. The forecast of the specialisation ratios is based on a one-step trend extrapolation until 2020, where the forecast length depends on the year of the last available data. If the last observation year, for e.g. exports is 2014, the forecast for the RTA in 2020 is based on calculating the average growth factors between 2008 and 2014 for all underlying time series and applying the growth factors to the levels in 2014. The resulting forecasted values for 2020 for each time series are then used to calculate the respective specialisation ratios.

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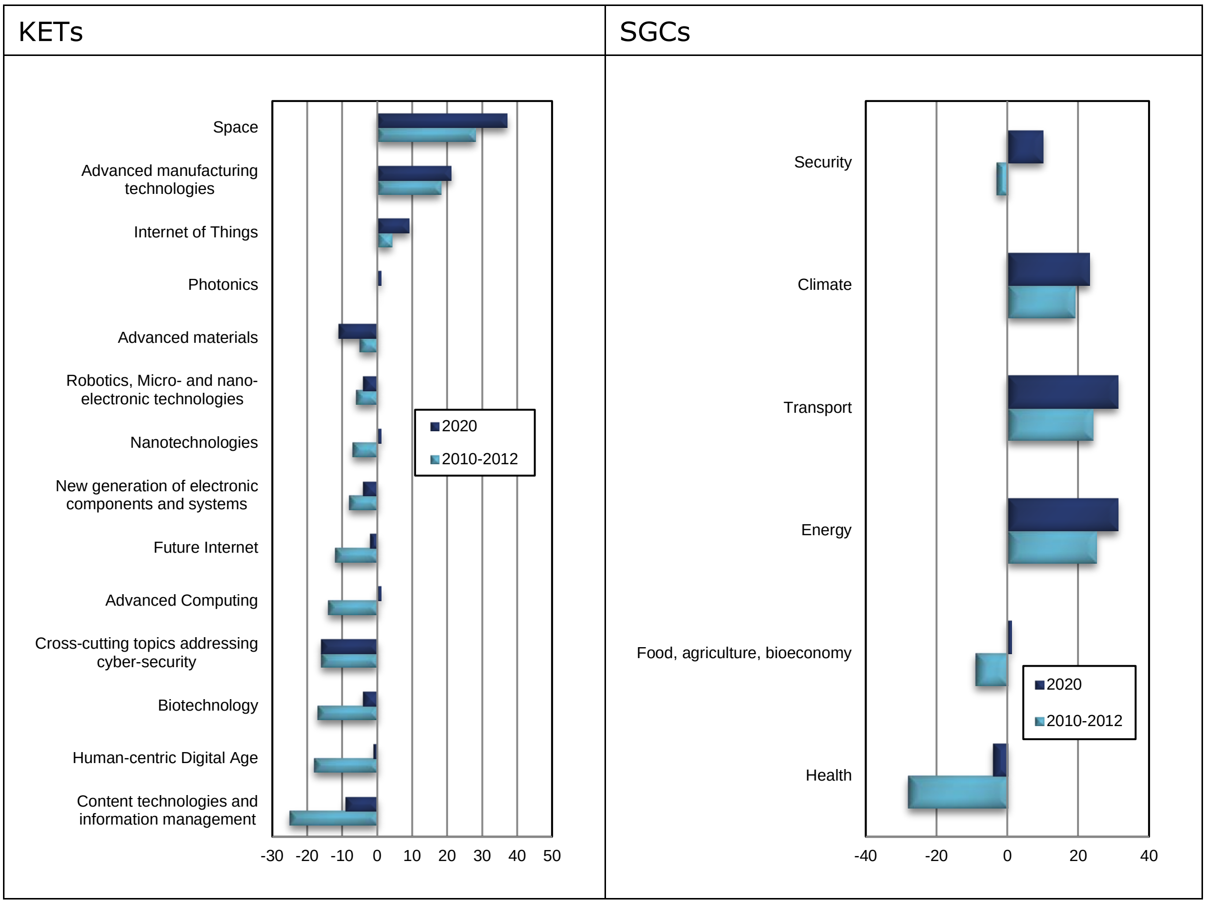
[1] Balassa, B. (1965): Trade Liberalisation and Revealed Comparative Advantage. In: The Manchester School of Economics and Social Sciences, 33, S. 99-123.

The respective data is also depicted in Figure 3-1, indicated by the dark blue bars. The data results from changes in the specialisation indices of the past seven years and extrapolates these to the year 2020. In the case of R&D expenditures we see that the relative positioning of the EU-28 countries improves in most areas. Only the field advanced materials loses ground and in cyber security there is hardly any change. Given that the past trends continue in the future, Europe is able to considerably improve its already good position in space and also in AMT and IoT. In the case of the other fields Europe will be able to catch up with the worldwide average and reach specialisation indices close to zero (which indicates the world average). For all six Societal Grand Challenges under analysis here we also see an improvement of the R&D specialisation index. Food and health will be close to the world average as well as security that will bill slightly above the average, while the already positively specialised fields of climate, energy and transport will be even more outstanding by 2020.

Figure 3-1: Europe's current R&D (BERD) specialisation in 2010-2012 in KETs and SGCs and the extrapolation for 2020



While R&D expenditures represent the input in the innovation process, publications and patents can be interpreted as intermediate or throughput indicators, reflecting the competitiveness of the science system in the case of publications and the technological competitiveness mainly of the industrial system in the case of patents. Figure 3-2 depicts the Revealed Literature Advantage (RLA), which is the **specialisation of the science system**. Europe hardly has many advantages here, but is in several cases close to the worldwide average – for example in space, advanced computing or also in health or climate. Interesting to note is that content technologies, which were at the lower end in the case of R&D expenditures, are at the higher end in terms of scientific publications. Advanced manufacturing technologies, on the other hand, clearly show negative specialisation values here. Also photonics, biotechnology, advanced materials or nanotechnologies do not belong to the explicit scientific strengths of Europe.

Again, using simple trend extrapolations of the past years to the future years up to 2020 results in considerable changes compared to the current situation (see dark blue bars in Figure 3-2). In the already positively specialised fields like content technologies and advanced computing the European position will further improve. In a number of fields, among them space, digital age, future Internet, advanced materials or AMT there is hardly any change, while in the other fields a considerable decrease is forecasted. This relates to IoT, photonics, robotics, nanotechnologies and new components. In the case of SGCs changes are hardly visible, except for climate and transport, where positive changes might occur worth mentioning.

Figure 3-2: The scientific basis – current scientific publications in 2010-2014 in KETs and SGCs and the extrapolation for 2020

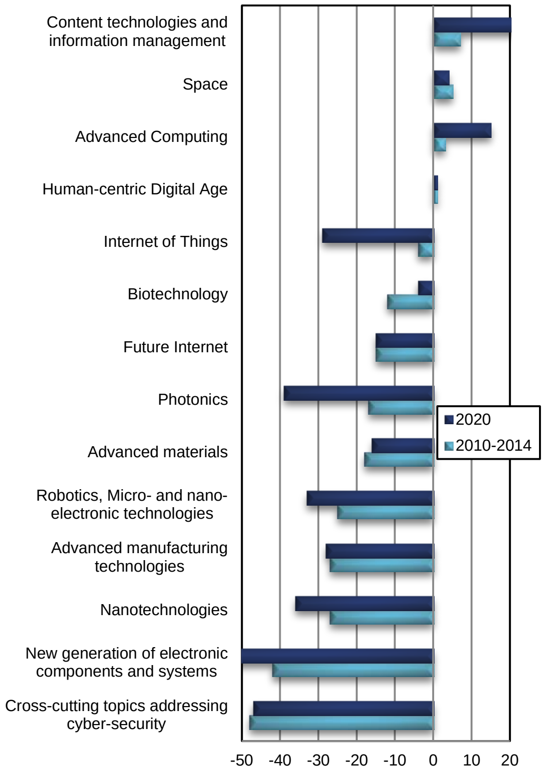
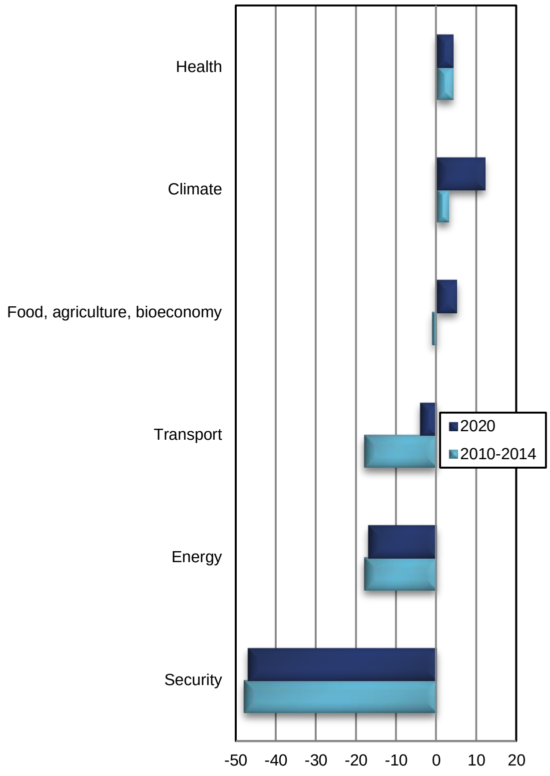
KETs	SGCs
	

Figure 3-3 depicts the **Revealed Technological Advantage** (RTA), based on patents. Here the positions are rather negative in the case of KETs, with the clear exceptions of advanced manufacturing and – interestingly – also of Internet of Things (IoT). In the case of SGCs, however, the situation is much better, indicating comparative advantages in transport, climate, food and also energy. In security, the European position is similar to the worldwide activities. Only in health a clearly negative value indicates a comparative disadvantage – or to put it in other words, comparative advantages in other parts of the world, mainly in the USA.

The extrapolations of the specialisation indices in each of the fields in the EU are displayed by the dark blue bars in Figure 3-3. According to this data, Europe will be able to improve its position in space, photonics, biotechnology and also in nanotechnologies. Hardly any changes occur, according to this trend analysis, in the fields of AMT, robotics and new components. However, in most of the KETs fields a decrease of the European position is forecasted based on this, mainly in IoT, advanced computing or also in the field of digital age. When it comes to the patent applications in the Societal Grand Challenges improvements can be expected in almost all fields except for health, where a slight decrease, but still an index value close to the worldwide average is forecasted.

So far, only input and throughput indicators were analysed. The output perspective, however, is of particular interest, not only because this is where the economic competitiveness can directly be assessed, but also because this is where the value and the jobs are created, which are the main aim of the Innovation Union Strategy and the reason for political intervention and support. In so far it completes the picture and shows who makes best (or at least good) out of the input and the throughput advantages.

Figure 3-3: The technological basis – current patent applications in 2009-2013 in KETs and SGCs and the extrapolation for 2020

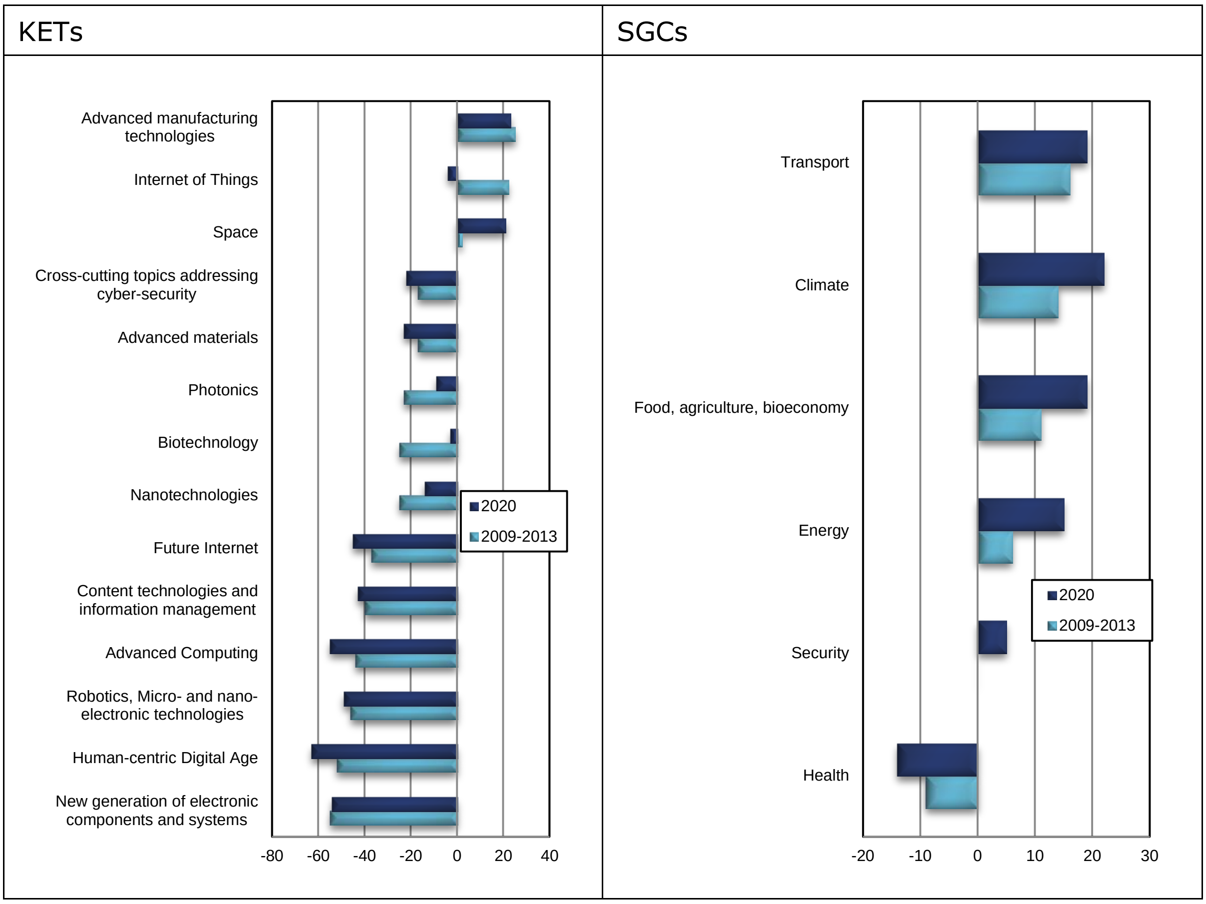


Figure 3-4 shows the **export specialisation** – and thereby the revealed trade advantage – of Europe in KETs and SGCs.[2] While in the case of KETs (left panel) the export specialisation is rather similar to the input and throughput indicators, the situation is slightly deviating from the input/throughput pattern, when looking at the SGCs. Europe has comparative advantages in biotechnology, advanced manufacturing, and also space, but is close to the worldwide average here. One reason for this is the inclusion of the intra EU trade and the fact that about one quarter of worldwide high-tech exports is trade within Europe. When looking at the right-hand panel, where the export specialisation of SGCs is depicted, surprisingly health is at the top. In all the other indicators health did not belong to the fields of particular strength. The explanations are at least twofold. There are strong pharmaceutical companies in Europe that serve the world market, but mainly also the European market, which is one of the most important health markets in the world. Second, the non-European companies as well as the European companies have their hubs for distribution within Europe, for example in the UK, the Netherlands or Belgium,

2 This data includes intra-EU trade, which accounts for almost 25% of worldwide trade in high-tech goods (see Schubert et al. 2014). An alternative analysis excluding intra-EU trade, both for export specialisation (RTA) and export-import specialisation (RCA) are provided in Annex 3.

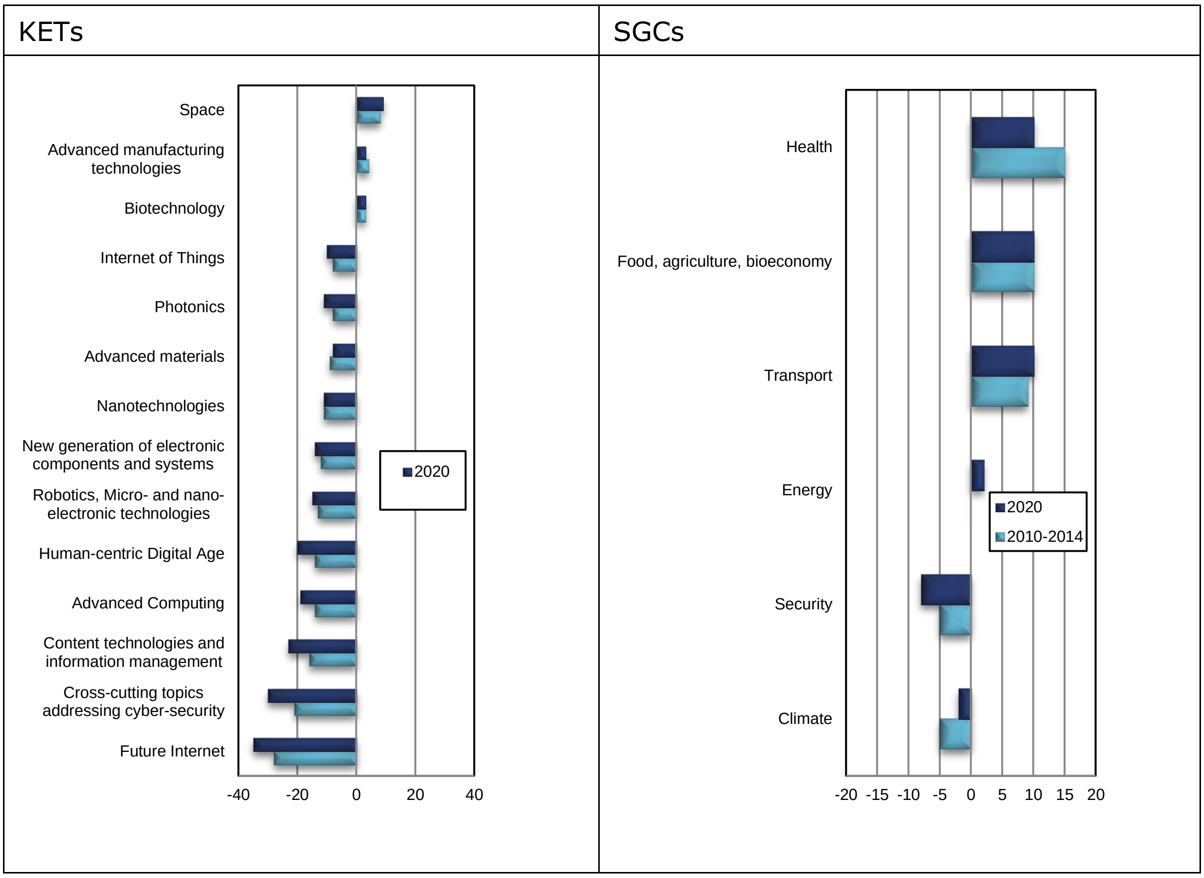
which adds to the intra-EU trade. The distribution within Europe is accounting to the exports of Europe.

Further SGCs with positive export specialisation values are food and transport, while energy is at an average level. Security and climate do not belong to the European export strengths in relative terms, but are still close to the average.

When looking at the forecasts for 2020, indicated by the dark blue bars in Figure 3-4, we hardly see any expected improvements of the positioning of the EU-28 countries in the case of KETs. Space and also advanced materials slightly increase, biotechnology and nanotechnologies are stable, but all others decrease. However, the effects estimated by the time trend analysis does not project massive changes in the relative export positions – neither in the positive nor in the negative direction. Stronger effects are forecasted for the SGCs. In health and security the EU-28 are expected to lose some of its current position, while in transport, energy and also climate positive developments are to be expected.

This data includes intra-EU trade, which is an appropriate and relevant perspective here. This allows the assessment of the worldwide trade flows and the contributions of the EU-28 to these worldwide flows. It needs to be taken into account that the majority of international trade, especially in high-tech goods, takes place within economic areas/continents and not so much between them. In addition, indirect intercontinental effects might arise from intra-EU trade of input goods, which would be neglected if excluding intra EU-trade.

Figure 3-4: The output perspective – current exports (world trade specialisation, RTA) in 2010-2014 and the extrapolation for 2020



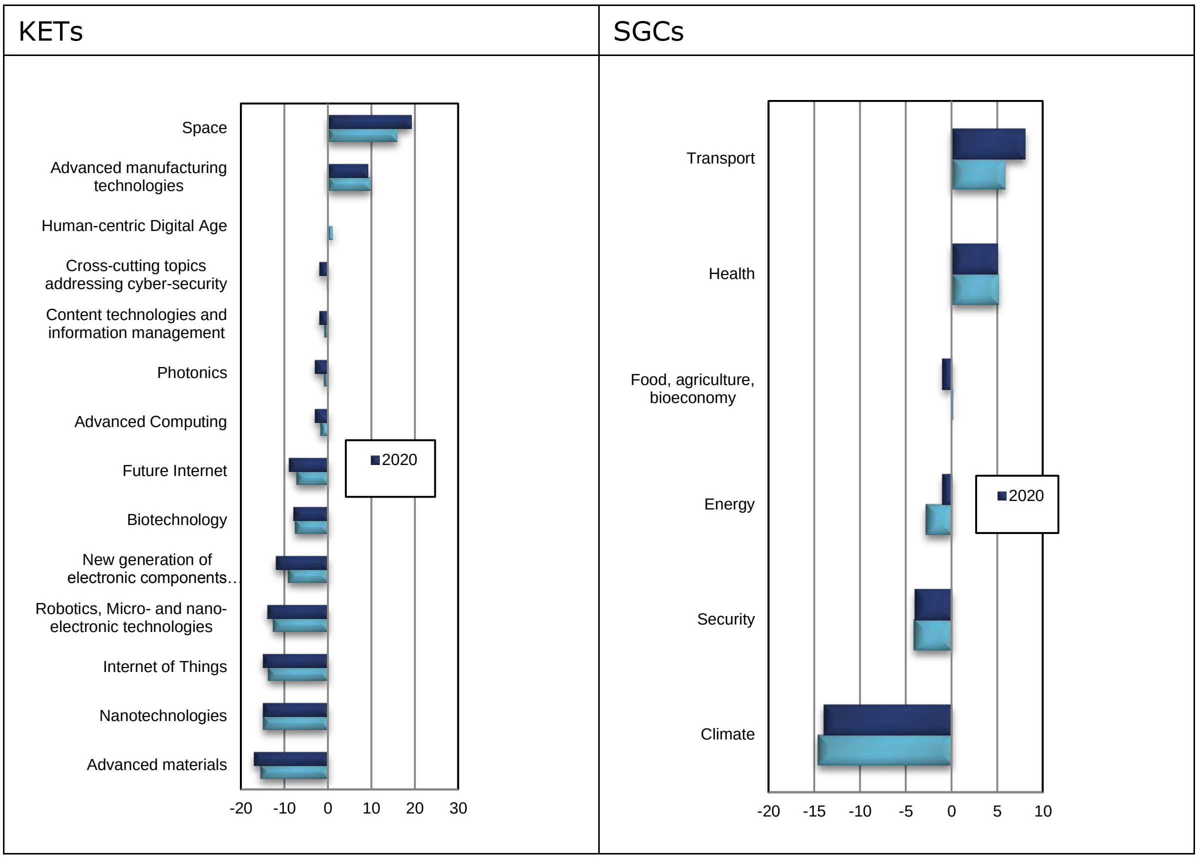
The export-import relation, amalgamated in the **Revealed Comparative Advantage** (RCA), is depicted in Figure 3-5. The export portfolio showed particular areas of European specialisation in space and to a lesser extent in AMT and biotechnology. The RCA shows positive values in similar fields, namely in space and AMT, while biotechnology reaches a negative value here. This means that in these areas the shares of exports are much higher than the imports. In another perspective on these data the European companies are able to assert themselves against the international competition. They are more competitive – at least on the national market – and show a comparative advantage.

In the case of SGCs it is again transport and health that show positive values. Food is at an average level concerning this indicator and security and climate are below the average. The explanations for the poor performance in climate are many imports of solar panels from China, which were especially increasing at the beginning of this decade. Europe – in particular Germany – accounted for a very large share of worldwide demand in photovoltaics in this period and this was mainly supplied by Chinese producers due to the quick decline in prices (also due to over-capacities in China) and a high demand, which European producers were not always able to supply.

The forecasts are depicted by the blue bars in Figure 3-5. Again, similar to the trade specialisation (RTA) described in the previous paragraphs, we hardly find any improvements of the relative positioning of the EU-28 countries as a group. Only space is expected to further improve its positioning in the case of export-import-relations (RCA). The index values of all other fields will decrease according to the simple forecast based on the past trend analyses. However, the expected changes are only small in value and some of them will even keep their relative position, among them nanotechnologies, but also AMT more or less. In the case of SGCs, we mainly see improvements, especially in transport, but also energy. Health will be stable and also security will more or less reach the same relative value.

All the forecasts presented in this section are simple trend extrapolations, assuming that the future will develop exactly in the same way as the (recent) past did. This assumption, however, does not take into account that current science and innovation policy in Europe – but also elsewhere in the world – is meant to change the past trends and make them more beneficial for Europe and the European aims in science and innovation. Therefore the interviews and the scenarios presented in section 3.3 will suggest reasonable deviations from these simple trend forecasts.

Figure 3-5: The output perspective – Revealed Comparative Advantage (export-import)



3.1.2 Strengths and weaknesses

At first sight, the European positions seem not extraordinary advantageous, especially in KETs. However, as a matter of fact and also as a matter of theory, not every country (group of countries) can and should specialise in everything. The basic idea of Revealed Comparative Advantages is that of advantages by specialisation or by focussing on certain areas of particular strengths, mainly to be able to realise economies of scale and scope in scientific, technical and productivity terms. In other words, countries should focus on what they can do relatively best.

For Europe this means that strengths and areas of particular interest should be in the focus. As was seen in the previous chapter, Europe is in a rather good position in most SGCs. So these are the areas to strengthen the strengths. However, certain KETs are also in the focus. In addition, and this is subject to the following empirical analysis, certain KETs can be seen as input or a precondition for certain SGCs. These are the KETs where Europe might have an outstanding interest to be able to keep its advantageous positions in SGCs also in the future. In the following, we analyse the **shares of patents in each SGC that can also be assigned to one of the KETs**. In addition, we discuss the correlations across all countries of patent applications in individual KETs and SGCs, indicating synergies of competences.

Table 3-1 shows the share of overlap of patent applications between KETs and SGCs. As a matter of definition and a matter of fact, KETs can be seen as enabling technologies for other fields. In this case we analyse their impact or enabling character for the SGCs. For example, 13.1% of the patent applications in the Grand Challenge food can also be assigned to biotechnology. 12.1% of the patent applications in energy stem from microelectronics. Advanced computing plays an outstanding role in security, but also in transport and even health, compared to other KETs. Microelectronics are particularly relevant for energy. Advanced materials are co-classified with food, climate, but also energy. Cyber security, of course, is important for security in general and overlaps with about 15% of the patents filed within this SGC. For this, also future Internet technologies are of particular relevance, so that the European strength in security is mainly based on the three IT-based KETs of advanced computing, cyber security and future Internet.

The total overlap can be seen in the last row. In the case of security, almost 86% of the patent applications are also classified in one of the KETs fields. In transport and energy the shares are well beyond 50%, while in health and climate the total shares are much lower, but still considerable at levels of 12% or 18%, respectively.

Table 3-1: Heatmap of overlap between KETs/LEITs and SGCs based on shares within SGCs

	Health	Food	Energy	Transport	Climate	Security
Biotechnology	2.8%	13.1%	2.4%	3.2%	4.3%	4.5%
Nanotechnologies	0.6%	0.8%	1.2%	0.1%	0.6%	0.6%
Microelectronics	0.2%	1.3%	12.1%	0.7%	0.4%	1.0%
Photonics	0.6%	1.0%	3.5%	1.0%	0.5%	2.8%
Advanced materials	1.1%	7.9%	4.6%	1.8%	9.3%	0.6%
AMT	0.9%	1.1%	2.4%	5.5%	2.2%	3.9%
Components	0.2%	0.2%	12.0%	0.6%	0.4%	0.8%
Advanced computing	3.5%	1.1%	4.3%	16.4%	0.4%	26.9%
Future Internet	0.8%	0.5%	6.3%	4.8%	0.1%	17.9%
Content technologies	0.3%	0.1%	0.3%	10.2%	0.0%	1.9%
Cyber security	0.0%	0.0%	0.1%	0.4%	0.0%	15.4%
IoT	0.0%	0.0%	0.1%	0.1%	0.0%	0.1%
Digital age	0.9%	0.1%	0.8%	6.0%	0.1%	8.5%
Space	0.0%	0.1%	0.3%	2.8%	0.0%	0.5%
Total overlap	12.1%	27.3%	50.5%	53.6%	18.3%	85.5%

To define the role the individual KETs play for the SGCs, it is also meaningful looking at the correlations across countries. Table 3-2 contains the bivariate correlation coefficients across all individual countries under analysis here. The high general coefficients indicate that – also dependent on size effects – activities in one field come along with activities in the other fields. The differences in the coefficients, however, show the areas of particular correlation. The darker green the cells are, the higher is the correlation. Biotechnology, for example, is highly correlated to all Grand Challenges, but especially to health and interestingly also to security. Nanotechnologies also qualify as a group of cross-cutting technologies, being relevant in all Grand Challenges, but particularly in health and security again. Also advanced manufacturing technologies (AMT) qualify as a cross-cutting technology field, being highly correlated to the technological performance in food, energy, transport, and climate, while it is less correlated to security and health. Internet of Things (IoT) and interestingly also space qualify as cross-cutting technologies in this respect, correlating outstandingly high with four out of the six Grand Challenges.

Table 3-2: Heatmap of correlations between patent filings in KETs and SGCs across all countries, 2013

	Health	Food	Energy	Transport	Climate	Security
Biotechtechnology	0.990	0.988	0.985	0.981	0.983	0.990
Nanotechnologies	0.994	0.984	0.974	0.972	0.975	0.994
Microelectronics	0.901	0.929	0.957	0.938	0.941	0.911
Photonics	0.914	0.954	0.978	0.965	0.968	0.932
Advanced materials	0.912	0.950	0.972	0.960	0.962	0.925
AMT	0.955	0.993	0.993	0.998	0.996	0.973
Components	0.891	0.917	0.946	0.926	0.929	0.900
Advanced computing	0.985	0.966	0.963	0.955	0.958	0.982
Future Internet	0.949	0.949	0.960	0.947	0.950	0.959
Content technologies	0.982	0.952	0.943	0.937	0.939	0.977
Cyber security	0.991	0.976	0.969	0.965	0.968	0.993
Internet of Things	0.932	0.973	0.987	0.984	0.981	0.952
Digital age	0.977	0.948	0.945	0.934	0.938	0.972
Space	0.972	0.995	0.997	0.997	0.997	0.983

3.2 Centres of excellence

An overview of centres of excellence (CoE) in the thematic areas of Horizon 2020 based on expert assessments during the interviews and the workshop is presented in the following table 3-3.

In most thematic areas CoE have been identified in different EU countries mainly located in Central and Northern Europe. In addition, in several thematic fields, for example health, individual research institutes at universities or public research centres are mentioned as important research sites. They are not considered as CoE due to lacking critical mass.

In total only few CoE have been flagged out by the experts, indicating that CoE are not perceived as key elements driving European competitiveness in all thematic areas. However, in some areas CoE are playing an important role. This is in particular the case where large and expensive equipment and infrastructure is needed. Nanoelectronics with the centres IMEC or MINATEC is an example. Other cases concern areas where it is crucial to combine different science and technology topics and skills at one location. The Wageningen Research Centre represents an example for such a case in the agricultural and food area. This CoE covers the whole agro-food production chain including recycling. It combines health and nutrition issues with trends towards personalisation and also offers education, research and consulting at one location. Thereby a comprehensive approach along the whole food chain can be implemented.

The analysis of CoE reveals some overarching **trends** implying that the concept of CoE needs some reconsideration. There is a clear trend towards networking and cooperation not least stimulated by European policy initiatives such as EIT and KICs. This trend implies that the ability to set up and operate networks of excellent research sites can be an important asset for European competitiveness. In some areas, for example transport and mobility, industry is playing a key role in CoE. Cooperation between industry and public research institutes is becoming more important in such areas. The dynamics in science, technology and innovation is growing rapidly. CoE need to take account of this trend. Instead of large and static centres, smaller, flexible and agile units are becoming more important. Finally, the value chain perspective in the different thematic areas has important implications for the concept of CoE. CoE are playing different roles in different parts of the value chain. At early stages of the value chain which are fuelled by excellent science, there is no need for large research units. Rather, small creative and flexible units are important. At later stages (and higher TRL levels), critical mass is becoming fundamental for mastering technology implementation.

Within the scope of this study a detailed analysis of collaborative networks of excellence was not possible. However, some promising areas with high potential to expand or create such networks in 2020 could be identified. A general observation is that most of these networks either have a national dimension or range over countries which share a common language or a common cultural heritage. These are considered as two important supporting factors for fruitful and efficient collaboration.

Within **KETs** industrial **lasers** are a promising field with Germany as a strong player and the potential to become an innovation hub of this technology. Cross-national collaboration with France would be interesting since there are many SME active in **photonics** which could contribute to future laser technologies. In **robotics** collaborative networks between Germany and the Netherlands have a great potential. **Advanced materials** is an area where pan-European networks offer potential. In particular advanced materials for low carbon energy and energy efficiency technologies based on the already existing EMIRI[3] network are promising. This is also an example of a network organised along the whole **value chain**. In **ICT** and **cyber security** a Scandinavian network including Finland, Denmark, Sweden and Estonia has potential to become a strong international player in 2020. Cyber security networks benefit from collocation with strong economic centres, for example, in logistics or finance. In this field a network in the Rhine-Main region between Frankfurt and Darmstadt in Germany combining cyber security expertise mainly located in Darmstadt with the economic competences in the financing and logistic sector around Frankfurt is emerging.

In the **health** area a first example of a network of excellence concerns medical imaging technologies which has a lot of potential in Germany with strong players like Fraunhofer and Max Planck. Cross national collaboration with research organisations in the Netherlands such as the Erasmus Medical Center in Rotterdam and between industrial players of both countries could contribute to the further development of this network. A second example pertains to big data analytics in health. In Ireland a network of four centres each with additonal associated partner organisations is spanning across the country.

In the food area the Öresund region between Malmoe and Copenhagen already comprises a strong network today with additional potential for 2020. There is a strong push from the private sector in this field complemented by policy initiatives. Another network embraces Wageningen University in the Netherlands where collaboration potentials with universities in Leuven and Ghent in Belgium are seen, thereby combining the strength of Wageningen in the whole agri-food chain with the strong biotech experience in Belgium. Finally the planned KIC on food will add a powerful pan-European network dimension to the food area.

In the **energy** area collaborative networks in general have a strong national dimension. However, there is potential for expanding such networks on a global scale. Two examples illustrate this trend. In biofuels technological excellence is available in a number of Euro-

3 http://emiri.eu/

pean countries such as Germany and Denmark with strong players in enzymes and microorganisms. A combination with the profound experience of Brazil in bioethanol would have potential. In renewables there is a powerful network of universities in the United Kingdom. Collaboration on a global scale with California and in particular the University of Berkeley would be promising since the European expertise in research could be combined with excellent research, entrepreneurship and innovative regulation in California.

These examples illustrate some promising areas for future networks of excellence in KETs and social challenges. An in-depth analysis of this new concept with a particular focus on the question to which extent such networks are organised already along value chains would be worthwhile.

At a global level, in particular some of the Asian regions are expected to establish new or expand existing CoE. Examples include Singapore or South Korea in climate and resources, nanotechnology in China or microelectronics in Taiwan and China with strong influence on advanced manufacturing.

Table 3-3: Centres of excellence

Theme	Europe			Outside Europe		
	Name	City	Country	Name	City	Country
Nanotechnology	MINATEC	Grenoble	FR	Stanford University	Stanford	US
	IMEC	Leuven	BE	MIT	Boston	US
Photonics	Munich Centre for Advanced Photonics	Munich	DE	National Institute of Aerospace	Hampton	US
				University of Central Florida	Orlando	US
Advanced manufacturing	Integrative Production Technologies	Aachen	DE	Industrial Technology Research Institute	Chutung, Hsinchu	TW
	TU Dortmund	Dortmund	DE	MIT	Boston	US
	Ghent University	Ghent	BE			
ICT, cyber security	CASED	Darmstadt	DE			
Health	CEA/LET	Grenoble	FR	Boston Medical Center	Boston	US
	Trinity College	Dublin	IE	John Hopkins	Baltimore	US
	Kings College	London	GB	Texas medical Center	Houston	US
	Institute of Bioengineering	Barcelone	ES			
	Erasmus University Medical Centre	Rotterdam	NL			
Food, agriculture, forestry	Leuven Food Science and Nutrition Research Centre	Leuven	BE	EMBRAPA Brazilian Agricultural Research Corporation	Brasilia	BR
	Wageningen University	Wageningen	NL	Several Land Grant Universities		US
	Teagasc Moorepark Research Centre	Fermoy	IE	Chinese Academy of Agricultural Sciences		CN
	Ghent University	Ghent	NL			
	FiBL	Frick	CH			
	Aarhus University	Aarhus	DK			

Theme	Europe			Outside Europe		
	Name	City	Country	Name	City	Country
Energy	DSM	Heerlen	NL	UC Berkley	Berkley	US
	Novozymes	Bagsvaerd	DK			
	Clariant Biotechnology Group	Planegg	DE			
Transport	KTH Royal Institute of Technology	Stockholm	SE	UC Berkley	Berkley	US
	Automotive Companies	Various	DE	Silicon Valley		US
	Fraunhofer Institutes	Various	DE			
Climate, resources	EAWAG	Duebendorf	CH			
	SINTEF	Trondheim	NO			
	Potsdam Climate Institute	Potsdam	DE			
	KWR Water Cycle Research Institute	Nieuwegein	NL			

3.3 Position in 2020: Trend analysis

3.3.1 Trends

General

In the **short term** at a global level budget constraints for innovation are expected to rise (Table 3-4). In addition, a growing competition for knowledge production is taking place which will lead to a global dispersion of knowledge. This trend together with the increasing complexity of knowledge creates additional uncertainties with respect to credibility of knowledge. The reorientation of innovation towards user, society and environment and in consequence the importance of responsible research and innovation will intensify.

In the **long term** the funding landscape will be influenced by private funders such as large foundations which will gain importance. The relationship between innovation and employment is another important long-term trend. This trend is closely related to an increasing automisation and digitalisation in many industrial sectors which might lead to job losses thereby having severe impact on the buying power of the middle class. Stronger involvement of the civil society into innovation activities is expected. Not least due to demographic change, additional stress on social care systems is anticipated challenging their sustainability.

Table 3-4: General trends

Short term	Long term
Constraints for innovation funding	Private funders upcoming (e.g. large foundations)
Growing competition for knowledge production	Innovation and employment
Global dispension of knowledge	Growing stress on social care systems
Uncertainty of knowledge credibility	Stronger involvement of civil society in innovation
Reorientation of innovation towards user, society, environment	
RRI getting more important	

KETs

In **nanotechnology** three main trends until 2020 and beyond have been identified. Firstly, **new construction principles** are emerging. Nanotechnology will enable bottom up construction using self-recognition and self-assembly characteristics of nanoparts. This will lead to a new paradigm of producing goods. Secondly, **nanomaterials with new functionalities** will become available. Examples include graphene and other single layer two dimensional materials. These materials are characterised by unique properties such as low weight, mechanical strengths, electrical and thermal conductivity, flexibility, and transparency, which so far have not been available as functional combinations in one type of material. Metamaterials defined as materials with properties not found in nature are other examples. The unique features of such materials do not depend on their chemical composition but on their structures. Specific nanostructures can influence, for example, electromagnetic waves or sound and be used to construct noise absorbing surfaces. Thirdly, nanotechnology is expected to enable new **medical applications**. These include scaffolds for regenerative medicine, new devices for drug delivery, which could be used, for example, to target cancer cells, and new means to treat individual cells or even to manipulate single molecules such as DNA, RNA or proteins.

In **advanced materials** a closer **linkage** between raw materials (e.g. metals) and advanced materials will be established requiring new approaches for the direct conversion of raw materials into advanced materials. In construction and buildings **materials for improving energy efficiency and recyclability** will develop. Examples include thinner and more efficient insulation material. Advanced materials of high environmental performance are expected to transform buildings into "banks of materials" which will be part of urban mining systems. Finally, advanced materials will be used in various forms for electricity storage systems not only for mobile use in vehicles but also for stationary use, for example, in buildings.

Digitalisation will be a key trend in **AMT**. Internet of Things, cyber physical systems, smart manufacturing, and increasing automation are important elements of this trend. 5G communication technologies will further accelerate the digitalisation in AMT. Digitalisation also includes new ways of human machine interactions.

New **production technologies** are another trend in AMT. These embrace **additive manufacturing** and smart **robotics**. Robotics is also expected to become more pervasive in the **health** sector. Robotics connected to smart infrastructures and smart devices will facilitate personalised and contextualised interaction in home care or day-to-day life.

AMT also concerns **chemical production**. Batch processes increasingly will be replaced by continuous processes. This requires more efficient process control and optimisation. In chemical process industry carbon capture and utilisation (CCU) approaches will allow the use of CO_2 emissions as feedstock. A prerequisite is the availability of point CO_2 sources, for example, from steel plants at the production sites. This calls for the creation of industrial ecosystems, comprising the required activities in a symbiotic way.

Finally AMT extends to **construction**. An industrialisation of the manufacturing of prefabricated modules for buildings and construction is expected. In addition renewable energy production will be integrated into buildings.

Photonics will benefit from new materials such as **graphene**. Breakthroughs in **energy** technologies based on photonics such as more efficient solar cells and longer lasting batteries are expected. An increasing use of sensors which are getting smaller and cheaper and a general trend towards **miniaturisation** are other important developments in photonics. Photonics is also expected to lead to new applications in **imaging**. Using high computing power will enable the creation of images indirectly from data.

Microelectronics will increasingly be applied to construction in the form of building information modelling systems.

In **biotechnology** new **tools** are available now which will be applied increasingly by 2020. These include rRNA technologies and in particular **gene editing**. The latter allows precise, fast and cheap manipulation of DNA in an unprecedented manner. Besides medical applications, which are already being discussed and developed intensively, gene editing can also be used in plant and animal breeding or for new environmental applications.

High-speed approaches for the complete analysis of components of living organisms ("omics technologies") are other important emerging tools. Applied to microorganisms the "microbiome" will become available meaning the complete genome information of microorganisms in plants, animals or in the human digestion system. Environmental applications would reveal the "ecobiome" – genome information of all microorganisms of a given ecosystems. Currently already structural information of microbiomes and ecobiomes is available. In the future this will be complemented by functional information.

Energy applications of biotechnology include new generations of biofuels using non-food sources such as waste, cellulosic material or algae as feed stock. Cheap enzymes and microorganisms are considered as breakthrough for this trend.

Not least due to environmental concerns alternative **proteins sources** are searched for replacing animal proteins. This creates an increasing pressure on developing and using plants as protein sources.

In addition to these specific trends, there are comprehensive trends affecting almost all KETs. Most important is the growing role of **ICT** which is developing continuously from short to long term. ICT is expected to get even more pervasive, thereby influencing considerably the future competitive position of Europe. In particular the speed of innovation will accelerate significantly due to the growing use of ICT. This also affects traditional sectors such as automotive, construction or chemistry.

ICT will provide a number of **tools** for applications in different sectors. **Big data and big data analytics** are one of these. Important applications include, for example, the **health sector**. Data mining of patient data which are stored by health care organisations will provide new insight into health issues. Open platforms for pharmaceutical research have already been established such as the "Open PHACTS"[4] platform. Other application areas include nutrition and food.

In the transport sector vehicles increasingly are equipped with **sensors** which in total are generating a huge amount of data. One of the question is which new business models out of such mobility data could be generated. For example, value added business intelligence about data which are independent of location, time and hardware would be interesting.

Advanced positioning systems are another important trend of ICT. This includes on the one hand GPS tracking systems far below the current price of 3.000 US dollars. On the other hand new tracking technologies for indoor applications based for example on WiFi or Bluetooth are developed.

Cloud computing is already changing the game. Computing power will no more be a limiting factor, it will become a commodity. Beyond cloud computing **fog computing** is emerging. Fog computing means decentralised computing structured at the edge of the cloud instead of inside the cloud. The goal of fog computing is to improve efficiency and reduce the amount of data that needs to be transported into the cloud for data processing, analysis and storage. Thereby efficiency increases are expected. Currently fog computing is not seen as a big market. However, the European position is considered as favourable so that in the future interesting market positions could be expected. Fog computing can also be considered in the context of integrated computing. The elimination of expensive equipment by the integration into devices is seen as a radical innovation.

[4] https://www.openphacts.org/

In the long run ICT will lead to a **digitalisation** of many industrial sectors and many parts of social life. One of the consequences of digitalisation is a growing use of **artificial intelligence**. Due to a pressure to become faster, decision making is increasingly becoming autonomous performed by artificial intelligence systems. This includes, for example, also technologies that are attacking or defending cyber infrastructures autonomously. This means that algorithms would be available which are able to learn independently about cyber security. One of the questions is how to implement artificial intelligence without replacing people. Further, a direct relation to **robotics** is obvious. In this understanding autonomous vehicles could be seen as a first artificial intelligence robot.

A prerequisite for all these applications is the **safe and secure use and handling of data**. Currently there is a perception that big data is controlled mainly by American companies. Finally big data statistics alone in certain circumstances are not sufficient. Rather, a combination with small data meaning qualitative case studies like analysis for understanding big data statistics is required.

The availability of high performance **digital infrastructure** is a key prerequisite for this trend. ICT will also have a strong influence on the administration and service domain. Various e-services will be expanding and merging. New forms of e-government and e-services are expected. These will be based among others on the combination of different sets of information which are handled separately so far.

The increasing complexity of ICT and related services and the growing interconnectedness bear a risk of large incidents such as cyber attacks. In addition, the regulatory framework for safe and secure data handling needs to be developed in parallel.

Societal challenges

The main trends in societal challenges are summarised in Table 3-5. In **health, demographic change and well-being** mastering chronic diseases is a continuous short and long term trend. More efficient technologies for high-speed analyses of genomes or proteins but also for non-invasive diagnosis will become available widely in the short term. In addition, remote care systems facilitating patient home care will spread. Prevention will remain a key trend in health care. In the long term, patient-centred care, telemedicine and mobile care will become more important. In addition, technology-driven trends are expected such as companion diagnostics, regenereative medicine or new means for treating the causes of diseases.

Table 3-5: Trends in societal challenges

	Short term	Long term
Health	Chronic diseases, high speed analysis and diagnosis, remote care systems, prevention	Chronic diseases, patient control and mobile care
Food agriculture, bioeconomy	Sustainable food-chain, health and nutrition	Consumer trends, personalisation, health
Energy	Electricity storage, zero-energy buildings, demand side management, improved energy efficiency in all sectors, decarbonisation in the electricity sector, harmonisation of energy markets	Electricity and hydrogen-based economy, organic PV, carbon capture and storage (CCS)
Transport	Autonomous vehicles, mobility as service	Smart infrastructures, new role of transport
Climate, environment, resources	Integrated water management, recycling	Circular economy, need for critical materials

In **food, agriculture, bioeconomy** a key short-term trend is the need to establish sustainable food chains. The interdependency between nutrition, life style and health is another important short-term trend, implying that the impact of food and nutrition on health will gain importance. Personal expectations and requirements are additional elements of this trend. In the long term, mainly consumer trends are considered as most important. Consumer interest in personalisation and health issues will have considerable impact on the demand side of the agrifood chain.

In **energy** improved electricity storage systems are needed already in the short term. Zero energy buildings, demand side management improved energy efficiencies, decarbonisation in the electricity sector, and the harmonisation of energy markets are other short-term trends. In the long run a transformation of the economy from a fossil based economy to an electricity and hydrogen based economy, the application of organic photovoltaics and the introduction of carbon capture and utilisation technologies are expected. The harmonisation of the European energy market will be a continuous trend providing framework conditions for future sustainable energy supply concepts.

In the **transport** domain autonomous vehicles are an important short-term trend, raising not only technological challenges but also requiring new political and legal provisions related to insurance, liability, safety, security. Mobility increasingly will be perceived as a service aggregating different means for achieving transport. In the long term, smart infrastructures will become essential, having considerable impact on urban planning and urban space. This includes, for example, the replacement of technical infrastructures along roads by demand-specific devices which are integrated into vehicles. New mobility concepts in the long term will also change the role of transport. Transport will no longer be a means for moving from one location to another. Rather it will become part of other work and leisure activities.

In the **climate, environment and resources** domain integrated water management concepts are important short-term trends, meaning that the currently separate tasks of water management will be integrated into a whole water management system. Recycling is another short-term trend. Closed loop and circular processes are needed in all application areas. In the long term the circular economy will play a key role. On the resources side a growing need for critical raw materials is expected due to an expanding use of portable electronics, the electrification of vehicles or low carbon energy technologies.

3.3.2 Influencing factors

Main influencing factors for the future positioning of Europe are summarised in Table 3-6. In addition, more detailed factors for each thematic area are presented in Annex 1.

Main **driving forces at a general level** are demographic change, climate change, the trend towards a circular economy and globalisation. Globalisation will lead to a growing need of sharing knowledge which can stimulate the generation of new ideas for innovation. At the policy level, a more strategic orientation of innovation policy is considered as a driving force. The identification of strategic areas and the concentration of forces will exert a positive influence on the future positioning. A general **impeding factor** is an expected increasing pressure on budgets for innovation. In the course of globalisation, access to global networks is crucial, implying that lacking or low-efficient communication networks will be hindering. The fear of global crime is another impeding factor in this context. Globalisation could also lead to a stronger concentration of innovation capacities and economic competence at a few innovation poles. For those not participating in such a multipolar world innovation activities will become more difficult with negative consequences for their competitive position. Finally, a collapse of social care systems in a number of Member States not least due to demographic change would increase the already expected pressure on innovation budgets.

A key **driving force** relevant for all **societal challenges** is the growing digitalisation. Also improved, more precise and cheap positioning and location systems will have a strong influence on a number of economic sectors and services. Extended life expectancies will be important for the healthcare system, but also for food and agricultural, energy or transport. In particular in the climate and energy area, regulation and standards are playing an important role as driving factors. The growth of megacities in terms of number and size will have important implications for transport, healthcare and water management, offering new opportunities for mobility concepts or water management systems. In some areas (over)regulation is considered as an **impeding factor** (e.g. health) and lacking standards can hinder future developments (e.g. mobility).

Table 3-6: Influencing factors

	Driving	Impeding
General	Demographic change	Pressure on innovation budgets
	Climate change	
	Trend towards circular economy	
	Globalisation - Sharing knowledge	Globalisation - Access to global networks, availability of communication networks - Global crime - Multipolar world: concentration of innovation and economic competence on few global poles
	Innovation policy becoming more strategic: identify strategic areas and concentrate forces	Collapse of social care systems?
Societal challenges	Growing digitalisation	Growing influence of large global IT companies
	Better positioning/location systems	Inconsistent policies
	Extended life expectancies	Path dependencies
	Regulation, standards related to environment and energy (e.g. decarbonisation)	Regulation, lacking standards
	Megacities growing (number and size) - Transport, water management healthcare...	
LEIT	Availability of new materials (graphene, metamaterials)	Job losses due to automation
	Better energy storage technologies	
	Digitalisation - Introduction of 5G communication - IoT, additive manufacturing, robotics - Automation of manufacturing and decision making (algorithms) (!)	
	Carbon capture and utilisation	

In some areas inconsistent policies are considered as hampering factors. For example, in the transport domain urban transport infrastructure is owned and managed by cities while new mobility concepts are developed by the private sector, both acting under different and partially inconsistent governance systems. Path dependency and tradition in some domains such as water management add additional bottlenecks to innovations.

In **KETs** new materials with improved properties and new combinations of functions (e.g. graphene or metamaterials) are considered as **driving forces** for a number of applications. The need for better energy storage systems is another driver for the application of different KETs. Digitalisation will strongly influence advanced manufacturing. This also implies that algorithms will become more important and even be integrated in decision making. Carbon capture and utilisation (CCU) is another driving force for future production systems. A main **impeding factor** in the LEIT domain is the fear of job losses due to increased digitalisation and automation.

Some of these influencing factors can also be considered as **game changers**. These include, in particular, the following:

- The control of healthcare by large private IT companies.
- The access to high performance computing capabilities and cloud technologies.
- Decision-taking algorithms and artificial intelligence diffusing into all societal challenges domains.
- The concentration of innovation and economic competences on a few global poles (multipolar world).
- The collapse of social care systems.
- The implementation of CCU.

EU policy initiatives

EU initiatives for R&I are playing an important role for the current and future position of the EU in KETs and SGCs. In particular, **Horizon2020** is perceived as a very good instrument facilitating cooperation in KETs and SGCs. Public private partnerships (PPP) provide a good means to signal industry that there is support for R&I in industry-relevant areas. The existing and upcoming KICs provide important incentives for the upstream part of R&I. They have improved significantly the innovation climate in the EU, especially in areas that had been lagging behind, for example, innovation in the food area. It is expected that the upcoming KIC on food will be an important catalyst for improving knowledge and technology transfer between countries. COST Actions are also playing a useful role in bringing together different actors across the EU. Joint Programming Initiatives are perceived as helpful instruments for aligning cross-national research agendas.

Considering the crucial role of digitalisation in all KETs and SGC related markets and the identified bottlenecks (fragmentation, lacking harmonisation, weak IT infrastructures, lacking business models for the data economy, safety and security issues), it is self-evident that the **Digital Single Market Strategy** for Europe has an essential role for the positioning of the EU in 2020 and beyond.

The expert interviews also highlighted areas calling for **additional European initiatives** for R&I. These can be grouped into three categories:

- Broadening of existing initiatives,
- Improvement of existing initiatives,
- New initiatives.

Suggestions for the **broadening of existing initiatives** firstly concern the involvement of new groups of players. A stronger integration of citizens as active stakeholders, for example, in living labs or as "researchers", providing empirical evidence and personal experience about environmental quality (e.g. water or air) in projects dealing with resources would be desirable. In specific fields, for example security, the UN is considered as an additional stakeholder to be involved more intensively into R&I activities. Secondly, expansion also relates to the geographic dimension. Applying the COST instrument at a global level is one of the suggested actions. In order to enhance global collaboration, joint research institutes between the EU and the US would be another option. A third target for broadening existing instruments would be a shift at the TRL scale. For example, KICs for higher TRL levels have been proposed.

A first proposition for **improving existing initiatives** refers to exchange programmes for researchers within the EU. A better coordination of such activities is considered as helpful. A general issue concerns support activities for SME to join European initiatives. This could be stimulated, for example, by focusing on higher TRL levels, by supporting the last steps before market introduction or by providing additional incentives for industry to focus on societal and environmental demand issues. In general new initiatives for supporting a closer interaction between science and industry, following practises of the NSF (US), are considered as fruitful. Supporting long-term relations between R&I partners beyond a time frame of individual projects is considered as another worthwhile target.

New initiatives are needed for speeding up the current mechanisms of EU R&I subsidies. Considering the whole process starting from consultations about important R&I directions, elaborating calls, writing and evaluating proposals, conducting research activities and finally achieving results, it takes many years until results driving future innovation are available. Currently, it may last up to ten years between idea and innovation. Accordingly, it might be worthwhile to consider complementary fast track mechanisms addressing in particular higher TRL level, where competition for markets is becoming fierce and speed is playing a decisive role deciding between success and failure. One suggestion made by the experts was to provide structural or block funds to excellent RTOs and leave it their responsibility to decide about the specific research activity. Such a system would need to be combined with regular evaluation and control.

Experts also were in favour of the ongoing activities of the EC for reinforcing the policy framework for **public procurement of innovative solutions**[5]. Green procurement or procurement focusing on innovative services instead of products and processes are suggested.

Standardisation and regulation could be another topic where new initiatives are asked for. This includes, for example, harmonisation issues between the American FDA and the European EMA for facilitating market access of new drugs and medical devices. Finally, a still unsolved problem in the European context is the low availability of venture capital compared to the United States. New initiatives for mobilising private capital are considered as helpful.

3.3.3 Scenarios

As lined out in the previous chapter the results from the interviews with the experts suggest that there are several ongoing trends until 2020. Some of them occur on the general level affecting all KETs and SGCs. Other trends are relevant only for some of the fields. Based on interview information we have devised six different scenarios. The first scenario is a baseline scenario which simply takes the empirically observable changes from 2009 to 2014 and applies them for the period 2015-2020. The baseline scenario therefore can be interpreted as a status-quo forecast which would result if trends of the last five years would continue for the period 2015 to 2020. Two further scenarios reflect general trends that apply for all fields. The first is a dilution scenario reflecting the trend that formerly peripheral countries become increasingly active in the KETs and SGCs. The second represents a digitalisation scenario, which highlights in particular the risk that Europe looses ground because its economy is not generally at the forefront of digitalisation process. Two further scenarios represent alternatives for the fields of advanced manufacturing technologies (AMT). Although most interview partner mostly agreed on general trends the assessment of the future developments in ATM did show some divergence. Some experts assumed that China at the expense of Europe would become stronger in field. Others regarded an even further strengthening of the European position in ATM as the more likely scenario. We have thus decided to design two different scenarios, one in which China becomes increasingly dominant and one in which Europe keeps its competitive edge. Finally we consider a scenario for future developments in the field of energy.

Further note, that for all but the baseline scenario we calculate a bandwidth ranging between lower and upper limits of reasonably assumable changes in the core variables. Also note that all scenarios should be interpreted relative to the baseline scenario.

5 https://ec.europa.eu/digital-single-market/en/news/eu-policy-initiatives-pcp-and-ppi

Scenario 1: Baseline

In the baseline scenario which uses past trends to update the expected values for the next five years until 2020 we assume that BERD share and the patent specialisation in KETs/SGCS will drop by 2%, while the RCA will drop by 1%. The RLA as a measure of scientific specialisation will increase by 2%. Based on the coefficients found in Table 2-1, the scenario results show that we expect a decline in the European trade balance and in the share of world production by 3.7% and 0.3%, respectively (compare Table 3-7). Thus, if past trends simply extend to the future, Europe will – although mildly – lose ground in KETs/SGCs. It should be noted however that baseline scenario is purely backward looking because it is based on events in the past. The results from the expert interviews are, however, forward looking in the sense that the experts' assessments takes into account future events not completely or even not all visible in past trends.

Scenario 2: Dilution

Starting with the general scenarios, an expectation shared by many of the experts is that research and economic activities in the KETs/SGCs will become more globalised with new players becoming increasingly important. Thus, higher competition will lead to a despecialisation of Europe. For our first scenario – which we label Dilution – we assume that until 2020 Europe's RPA and RLA will drop by between 5% (lower limit) and 10% (upper limit) and BERD will drop by between 1% (lower limit) and 2% (upper limit). We assume that at least in the short-run the RCA is not affected, because effects trickling down from science and technology generation usually need time to materialise in trade measures. In Table 3-7 we find these assumptions in the column labelled scenario change for EU countries. Because the dilution scenario is one that predicts a declining importance of Europe the **effects** both on the trade-balance and the world-share of production in KETs/SGCs are negative. Nonetheless, they are relatively modest in particular compared to the baseline scenario reflecting what can be expected if current trends continue. We find that at the upper limit the trade balance will experience a further decline by 1.5% while the share of world production would drop by 0.3%. The relatively small decline is due to the fact that dilution is assumed to take place on the scientific and technology side but will not – at least in the short-run – affect the specialisation in trade. It is however likely that in the long-run dilution will also affect the RCA implying that the effects may become more pronounced. In that respect, the scenario shows that the emergence of new competitors may in the short-run have only limited effects, while in the long-run the effects for Europe may be more severe.

Scenario 3: Digitalisation

A second trend that was prominently described by many experts relates to the role of digitalisation. In particular, it was highlighted that increasingly large private players like Google or Apple perform R&D in the fields linked to KETs/SGCs. The experts highlighted that these players are most frequently located outside Europe, implying that a further strengthening of their position would result both in a decline of European R&D shares as well as subsequently a decline of patenting specialisation (RPA) and comparative advantage (RCA) of European firms. Based on these insights our second scenario (Digitalisation) assumes that BERD shares decrease by between 5% and 10% in Europe while the RCA and the RPA drop by between 2% and 5%. The **effects** on the trade balance in the KETs/SGCs amount to a drop between 8.0% (lower limit) and 18.5% (upper limit) while the effect on the share of world production would amount to a drop between 0.8% and 1.5%, respectively. These figures highlight that the majority of the experts saw the reinforcing trends towards digitalisation in many fields as a threat for the European position in the KETs/SGCs because large private players primarily driving these processes are mostly located outside Europe.

Scenario 4 and 5: AMT-China grows; AMT-Europe grows

As concerns advanced manufacturing technologies (AMT) the expert opinions were more ambiguous. Some expected that, despite a currently strong position of the European countries in this field, China will strongly move into these fields, again leading to a flattening of the European specialisation patterns. Thus, until 2020 some experts expected that Europe would lose its competitive edge in AMT. Contrary to that negative outlook other experts tended to assume that in particular several countries in Northern and Central Europe (Sweden, Denmark, Germany, the Netherland) would manage to cope effectively with the new players from South-East Asia, potentially even leading to a strengthening of the European position in the field of ATM. Because of these contradictory opinions we devised two scenarios.

In the first we assume that the **growth of China** would lead to a decline between 5% and 10% in BERD and RPA. An even stronger decline of between 10% and 15% would be expected for the RLA, because China's upgrading was based on a science-push strategy, where increases in the scientific performance precede increases in the economic/technological performance. Contrary to that the change in the RCA would be with a 1-2% decline more modest. In total the changes would lead to a decline between 5.9% and 11.7% in Europe's trade balance and decline of about 0.8% and 1.5% in the share of world production in AMT held by European firms. The size of these effects, however, strongly depends on how strongly the changes in BERD, the technological specialisation and the scientific specialisation eventually also affect economic specialisation as measured by the RCA. Should also the comparative advantages deteriorate as a result of the declining specialisation in science and technology (which is a likely outcome in the long run), the losses with respect to the European position in AMT would be much more severe.

Many experts however were less pessimistic about Europe's ability to cope with the intensifying Chinese competition. If **Europe** turns out to be more resilient and **maintains its competitive edge** in AMT (scenario assumptions: 5%-10% increase in BERD, 1%-5% increase in RPA and RLA, 5%-10% increase in RCA), the economic effects would be much more favourable. In this case the trade balance would increase by between 15.2% and 30.5% while the share of world production in AMT would increase by about 0.8% and 1.5%

Scenario 6: Energy

Finally we consider a scenario for the energy sector. Currently, Europe is among the best performing regions in the world, but in particular regions from Asia have been catching up fast. Thus, it may become hard for Europe to further strengthen its position. Although Europe will remain a strong player in absolute terms, a negative outlook would imply a slight weakening of the European position (BERD: -1%, RPA, RLA, RCA: -2%), implying a decline in the trade balance of 5.5% and a decline in the world production share of 0.2%. Some experts however regarded it as possible that Europe even manages to further increase its strength reaping economies of scale in the field and effectively using its first-mover advantage. In this positive outcome (BERD: +2%, RPA, RLA, RCA: +4%), the middle-term developments may be much more positive. Under these more optimistic premises, which largely build on the assumption that the performance increases in science and technologies would strengthen the firm's BERD investments, the trade-balance would increase by 10.9% while the share of world production would increase by 0.3%. This positive scenario is assessed as more realistic if Europe would build on continuity in terms of ambitious energy and climate policies. This refers in particular to providing stable investment conditions for low carbon technologies like renewables and energy efficiency. Furthermore, user-producer interactions are needed for relatively new technologies like wind offshore. Therefore it is very policy dependent whether the negative or the positive outlook materialises.

Table 3-7: The scenarios

Scenario	Variable	Scenario change (lower limit)	Scenario change (upper limit)	Effect: trade balance (lower limit)	Effect: share world produc-tion (low-er limit)	Effect: trade balance (upper limit)	Effect: share world produc-tion (upper limit)
Dilution	BERD	-1,00%	-2,00%	-0,67%	-0,15%	-1,33%	-0,31%
	RPA	-5,00%	-10,00%	-0,04%		-0,07%	
	RLA	-5,00%	-10,00%	-0,08%		-0,17%	
	RCA	0,00%	0,00%	0,00%		0,00%	
Sum				-0,79%	-0,15%	-1,57%	-0,31%
Digitalisation	BERD	-5,00%	-10,00%	-3,34%	-0,76%	-6,67%	-1,53%
	RPA	-2,00%	-5,00%	-0,01%		-0,04%	
	RLA	0,00%	0,00%	0,00%		0,00%	
	RCA	-2,00%	-5,00%	-4,74%		-11,84%	
Sum				-8,08%	-0,76%	-18,54%	-1,53%
AMT-China grows	China						
	BERD	-5,00%	-10,00%	-3,34%	-0,76%	-6,67%	-1,53%
	RPA	-5,00%	-10,00%	-0,04%		-0,07%	
	RLA	-10,00%	-15,00%	-0,17%		-0,25%	
	RCA	-1,00%	-2,00%	-2,37%		-4,74%	
Sum				-5,90%	-0,76%	-11,73%	-1,53%
AMT-Europe grows	BERD	5,00%	10,00%	3,34%	0,76%	6,67%	1,53%
	RPA	1,00%	5,00%	0,01%		0,04%	
	RLA	1,00%	5,00%	0,02%		0,08%	
	RCA	5,00%	10,00%	11,84%		23,68%	
Sum				15,20%	0,76%	30,46%	1,53%
Energy	BERD	-1,00%	2,00%	-0,67%	-0,15%	1,33%	0,31%
	RPA	-2,00%	4,00%	-0,01%		0,03%	
	RLA	-2,00%	4,00%	-0,03%		0,07%	
	RCA	-2,00%	4,00%	-4,74%		9,47%	
Sum				-5,45%	-0,15%	10,90%	0,31%
Baseline	BERD	-2,00%		-1,33%	-0,31%		
	RPA	-2,00%		-0,01%			
	RLA	2,00%		0,03%			
	RCA	-1,00%		-2,37%			
Sum				-3,68%	-0,31%		

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 What is the position of EU today and in 2020?

Currently, we see good or even outstanding positions of the EU-28 countries in the SGCs of transport, climate and energy. These are particularly interrelated and correlated with the KETs advanced manufacturing technologies (AMT), Internet of Things (IoT) and space, as well as biotechnology and nanotechnologies, where in the former three Europe also shows a good positioning, while in the latter two Europe is not able to achieve an outstanding position. However, also other KETs contribute to SGCs like photonics, advanced materials, or digital age. This means that it is indeed legitimate to conduct (public) research in all KETs fields, but that it is also to be expected and acceptable to follow niche strategies, focusing on certain parts within the KETs, namely those that contribute to the good position in SGCs. Europe cannot and should not focus on all KETs and all SGCs with the same intensity. The forecast of specialisation indicators based on trend extrapolations assuming that the developments over the past few years will continue without change results in improvements of the input (R&D) and throughput (publications, patents) variables. However, this does not translate into an enhancement of the output values (exports, RCA). Although considering the time lag between input in terms of R&D investment and research activities and output as indicated by improved exports or RCAs, this comparison indicates that Europe most likely will not succeed in improving its competitive position in a sustained manner if business as usual will continue. Considering recent activities in China and other competing regions aiming at boosting their competitive positions in KETs or SGCs reinforces this conclusion.

Table 4-1 summarises the indicators analysed in this report and indicates positive values of European specialisation.

Table 4-1: Summary of specialisation indicators (latest available year/forecast 2020)

	R&D	Publications	Patents	Exports	RCA
	Key Enabling Technologies				
Biotechnology				+/+	
Nanotechnologies					
Microelectronics					
Photonics					
Advanced materials					
AMT	+/++		++/++	+/	+/+
Components					
Advanced computing		+/+			
Future Internet					
Content technologies		+/++			
Cyber security					
IoT	+/+		++/		
Digital age					
Space	++/++	+/+	/++	+/+	+/+
	Societal Grand Challenges				
Health		+/+		+/+	+/+
Food			+/+	+/+	
Energy	++/++	/+	+/+		
Transport	++/++		+/+	+/+	+/+
Climate	+/++	+/+	+/++		
Security	/++				

Legend: + = index values between 5 and 20, indicating a moderate specialisation
++ = index values above 20, indicating a strong specialisation

4.2 Which are the main trends?

The European position is still good in most areas, but erodes in a mid- to long-term perspective, due to the upcoming of **new technology-oriented players**, especially China, Korea and other East-Asian countries and the prominent role of the US towards the digital revolution. The excellent European position in some areas (e.g. AMT) might also diminish due to increased efforts in other countries, namely China and Japan, but also the USA. All of these countries have set up and partially implemented their own policies in the context of AMT – for example in China the "Made in China 2025" and in the USA the "Advanced Manufacturing Partnership". However, next to a relative perspective, which was the main task of the analyses underlying this report, an absolute perspective is also appropriate.

The worldwide **market** and also the European market in the analysed areas will be growing over the coming years. Even though the relative position in these growing markets might decline, the absolute level might further grow and thereby keep or even add new jobs in Europe. Europe is still the largest science conducting region in the world, both in KETs and in SGCs and was even able to increase its head-start to the USA, while Asian countries caught up. Similar trends can be identified in terms of exports, while R&D and also patents seem to stagnate also in absolute numbers, leading to decreasing shares. The dynamics in these indicators takes place in other regions of the world. As these indicators cover input and throughput, it might be derived that in a mid- to long-term perspective the European position might further erode – and then not only in relative, but maybe also in absolute terms.

From a **KETs perspective** the most important and all-embracing trend is the increasing merging of ICT with other KETs and the rising diffusion of ICT into almost all economic sectors. This will lead to an acceleration of innovation dynamics in most sectors. Concurrently this trend will enable new e-services, for example in health, transport, energy, public administration and government, which offer opportunities for new service and user oriented business models. Managing risks of cyber attacks and ensuring safe and secure data handling are key requirements evolving simultaneously.

SGC areas will face important overarching trends. These include an increasing interlinkage between different areas (e.g. food, nutrition, health and environment), stronger consideration of user needs (e.g. remote patient care) and expectations, growing demand for individualised and customised solutions, rising impact of societal and environmental issues, and finally a clear need for implementing sustainable solutions in all sectors.

When dealing with these trends and challenges **Europe can take advantage of its diversity** which offers opportunities to explore and test innovative approaches in variable environments and also constitutes a supportive climate for innovation. Accordingly, Europe is well positioned for mastering these new modes of innovation and generating the required future oriented business models.

4.3 Where are the future opportunities?

SGCs are the current and future areas of strong European positions, where jobs and growth seem possible. Areas of absolute growth are of particular interest (bigger pie); while a decreasing relative position has to be accepted. Taking a value chain perspective this implies that KETs supporting SGCs are particularly important. Considering the current competitive position of Europe, a selective strategy with **specialisation on highly valuable parts of the value chain** (high-tech, not low price) in areas of revealed advantage seems promising. From the selective approach a **cooperation strategy** directly evolves, which needs to take into account make or buy decisions. Cooperation is crucial also from another perspective. In order to master the global challenges, joint efforts are required (e.g. joint rules and approaches to counteract cyber crime and cyber attacks, global strategies for coping with infectious diseases). Accordingly, there is a huge potential for cooperation in the precompetitive domain. Considering specific European strengths, AMT is a field where cooperation with China, Korea and the USA seem promising; in the Energy domain potential is seen among others in China. It is important to note that cooperation could serve two different strategic goals, safeguarding and strengthening Europe's position at the European market, and improving Europe's position on the world market. In Horizon 2020 third countries are expected to bring in their own matching funds. These provisions create different incentives for collaboration which might lead to more interest driven peer-level collaborative operations.

4.4 What should policy do?

Currently Europe benefits from an overall good position in many of the KETs/SGCs. However, the rise of catching-up and industrialised countries in particular in South-East Asia will increasingly challenge Europe. In particular the dilution scenario has confirmed that the increasing competition from South-East Asia will most likely imply a decline of Europe's relative position in KETs/SGCs, because scientific, technological, and competitive strengths will more than in the past be globally dispersed in a multipolar world. The increasing global dispersion requires that Europe specialises in core strengths in order to remain competitive, because it will be impossible for Europe to be excellent in all areas. A prerequisite for effective specialisation is the implementation of **forward looking processes of monitoring and strategic intelligence** in order to identify the core technologies and societal demands of the future. It is therefore necessary to strengthen e.g. ongoing foresight processes, but also to institutionalise an exchange process with industry. Specialisation will, however, also imply that Europe has to collaborate with countries in other world regions in order to source the necessary knowledge inputs in particular as concerns KETs/SGCs where other regions are stronger. **Fostering pre-competitive collaboration** should therefore be an important goal of European STI policy. Furthermore, specialisation will also occur inside Europe because competences are heterogeneously distributed across European countries. Europe's policy-making should however, instead of regarding heterogeneity of competences as a potential threat to cohesion, harness the heterogeneity as a source of technology and knowledge diversity. Such a **diversity-oriented policy approach** can both combine excellence and cohesion as it addresses top research, but also basic research and absorption capacities European-wide. This implies that future policies should complement the current excellence focussed funding approach with policies that are able to **exploit regional strengths by creating seedbeds** of specialised, dynamic and geographically dispersed actors in KETs and SGCs. By empowering such regional actors policy-making also contributes to establishing Europe-wide hubs and networks of excellence which not only provide technological and scientific **excellence**, but also contribute to **cohesion** across Europe.

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