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# Technologies of the future for Germany: The country is well placed in many areas but some need readjustment

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Which technologies will move the German economy in the coming decade? Where will (sustainable) growth come from? What strengths can Germany build on and where do we need to play catch up? What adjustments do we need to make today? KfW Research has commissioned a study to identify technologies of the future from a German perspective. The focus lies on technologies that may already achieve high market relevance in the medium term.

The identified technologies of the future cover a broad range of fields. They include technologies involving motor vehicles, as well as information, the environment and climate. Technologies associated with the production of medicines also come into play. Germany already possesses a high level of competency in many of these technologies and in others it has yet to develop them.

German companies are well-positioned in automotive technologies such as hybrid electric mobility, battery technology, electric traction motors, lightweight automotive construction and autonomous driving. These technologies build on traditional German strengths. But further research is necessary, particularly with the aim of building expertise in electric mobility.

Information technologies represent a challenge for Germany. They are becoming increasingly important in many other technological fields but Germany's technological competences here are only mid-range. As it appears quite unrealistic for the country to catch up with other countries in these technologies within a few years merely by ramping up research and development, a particular focus should be placed on building skills in their application – especially in manufacturing technologies.

Environmental and climate technologies directly address social needs. In order for these technologies to be profitable for companies already in the short term it is important to create a reliable framework for their use, such as a carbon tax. The incentives for investing in environmental and climate technology must be strengthened on a broad front.

Manufacturing technologies are among Germany's traditional strengths. A particular challenge for German businesses is the new market for additive manufacturing and the integration of information technology.

Future medical technologies include, for example, novel vaccines which were long deemed to have limited economic attractiveness. Vaccines have gained new importance with the coronavirus pandemic. As new viruses that pose a similar threat will emerge time and again in the coming years, considerable growth potential can be assumed.

For Germany as a technological nation it is particularly important to create growth through innovation, technological progress and competitiveness in key technological areas. It is the only way to create future-proof jobs and secure and increase prosperity in Germany. The growing orientation of Germany's economic policy towards social needs and, thus, the promotion of relevant technological fields mirrors this importance.[1]

The coronavirus crisis will ultimately leave a deep mark on the economy and state finances. The government will remain under increasing pressure to take efficient action. In particular, more public support measures will have to be directed into areas that are as future-oriented as possible.

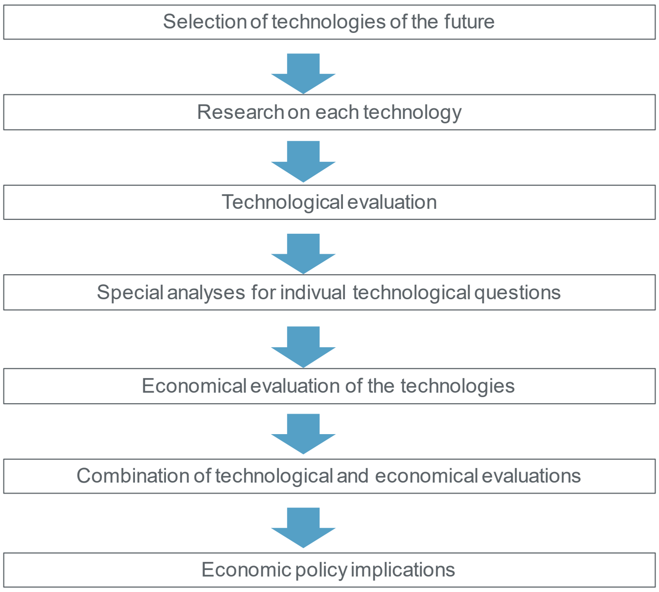
KfW Research has therefore commissioned a study with the Fraunhofer Institute for System and Innovation Research (ISI) to identify technologies of the future from a German perspective. The main criterion for their identification was that they gain high market relevance in the medium term, in other words in roughly five to ten years. That means technologies that are already being used commercially and have significant growth potential. The study also aimed to take into account Germany's existing technological profile, societal challenges such as climate change, the situation of small and medium-sized enterprises (SMEs) with regard to these technologies and the current debate on technological sovereignty. The most important findings of the study are summarised below.[2]

**Identifying technologies of the future based on Germany's technological position and their market value from a German perspective**

The preselection of potential technologies of the future from a German perspective was based on a range of German and international studies on technologies of the future and societal challenges. External experts and experts of the Fraunhofer Institute for System and Innovation Research were also interviewed. On that basis, a list of just over 30 technologies was compiled that relate to the areas of information technology, manufacturing technology, materials, health, transport, environment / climate and energy. The list covers a broad range of technologies.[3]

Research strategies for patents, publications and trademarks were developed for these technologies. This formed the basis for identifying a set of indicators on Germany's technological position for each technology. These indicators were combined into a composite indicator to enable the technologies to be ranked. In addition, the economic relevance of a technology was identified on the basis of its current market value from a German perspective (see box on methodology at the end). On that basis, the technologies were evaluated and conclusions drawn for economic policy (Figure 1).

### Figure 1: How the study was carried out




Source: Schmoch et al. (2021)

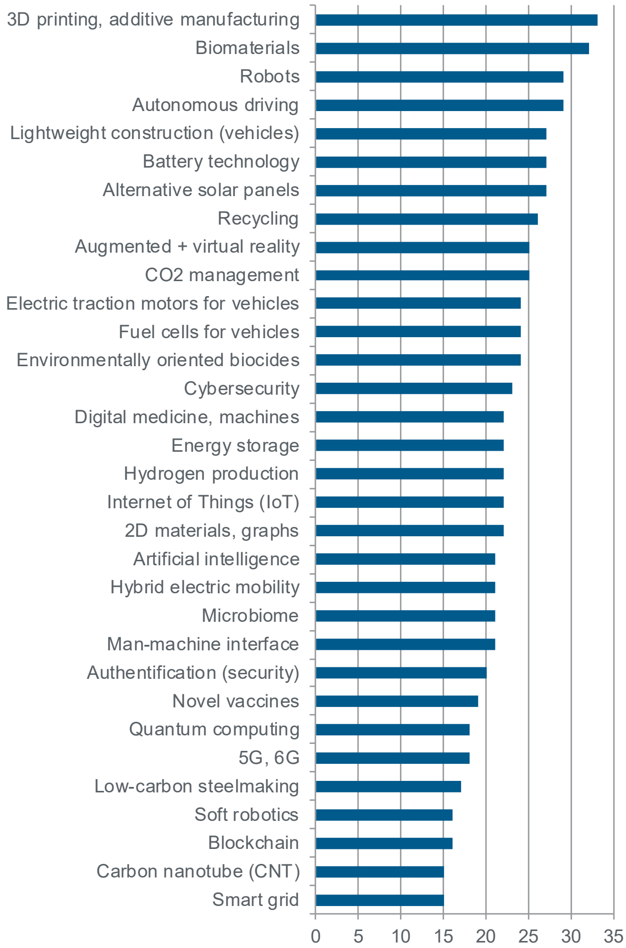
## Additive manufacturing, biomaterials and automotive technologies top the list

In assessing the technological position from a mid-term perspective, it became evident that additive manufacturing and biomaterials occupy the top ranks (Figure 2). Additive manufacturing or 3-D printing is the generic term for all manufacturing processes in which materials are deposited layer upon layer to create three-dimensional objects. These processes are particularly well-suited for the manufacturing of high-precision parts with high geometric complexity in small series. Biomaterials are important because they can mitigate the problem of dwindling conventional raw materials as they are derived from renewable resources.

They are followed by autonomous driving and lightweight automotive construction. The good position in battery technology, which some experts already declared as lost for Germany given the strength of some Asian countries, deserves to be mentioned. German manufacturers have caught up well in battery technology. They possess strengths regarding alternatives to lithium, high capacities and recyclability. In the transition to electric mobility it will be important to leverage these strengths in the market.

### Figure 2: Ranking of future technologies by technological indicators from a German perspective

In index points




Source: Schmoch et al. (2021)

Finally, the low position in blockchain technology, which many studies on the future identify as a key technology of the future, is striking. Key figures such as German specialisation, number of German contributions and size of patent family are low in patent, publication and trademark indicators. However, the indicators that refer to the development trend for this technology have high values.

Alternatively, a ranking was determined when additionally taking into account the position of SMEs in a technology. To this end, the share of patents applied for by SMEs was included in the calculation. But that does not materially alter the ranking of the technologies. Noticeable shifts occur only in individual technologies such as recycling (then rank 4), $CO_2$ management (then rank 5) and energy storage (then rank 9).

## Wide range of market values

The wide spread of market values is noteworthy (Figure 3). Hybrid electric vehicles and hydrogen production show very high values, while robotics and electric traction motors show medium values. Augmented and virtual reality lie at the transition between these two fields. Novel vaccine to microbiome technologies exhibit very low values.

Hydrogen is important as it can serve as an energy source to considerably help bring down carbon emissions. Virtual reality can be applied in many fields of manufacturing, for example to create virtual prototypes, in production planning, for virtual training and for ergonomic assessments. Augmented reality enables additional information to be made available in real time. The microbiome and its variations correlate with a number of diseases. Influencing it is believed to have great medical potential.

The top-ranking technology of hybrid electric vehicles builds on Germany's traditional strength in automotive engineering. Three technologies that are embedded in the context of societal challenges – recycling, biomaterials and hydrogen production – are also at the top of the list and often not mentioned in conventional futures studies. Among the information technologies, the internet of things and augmented and virtual reality play an important role. 5G / 6G, cybersecurity and artificial intelligence are still in the mid-value range but as they grow in the years ahead they could gain more importance. This applies in particular to artificial intelligence, which is deemed to play a key role in the future development of productivity.

Most of the technologies in the low value range are still in a very early stage. They are unlikely to make a major contribution to value creation in Germany in the medium-term perspective examined here. But the futures studies consulted emphasise that these technologies will also gain significantly more weight in the long term.

### Technological and economic strength coincide often but not always

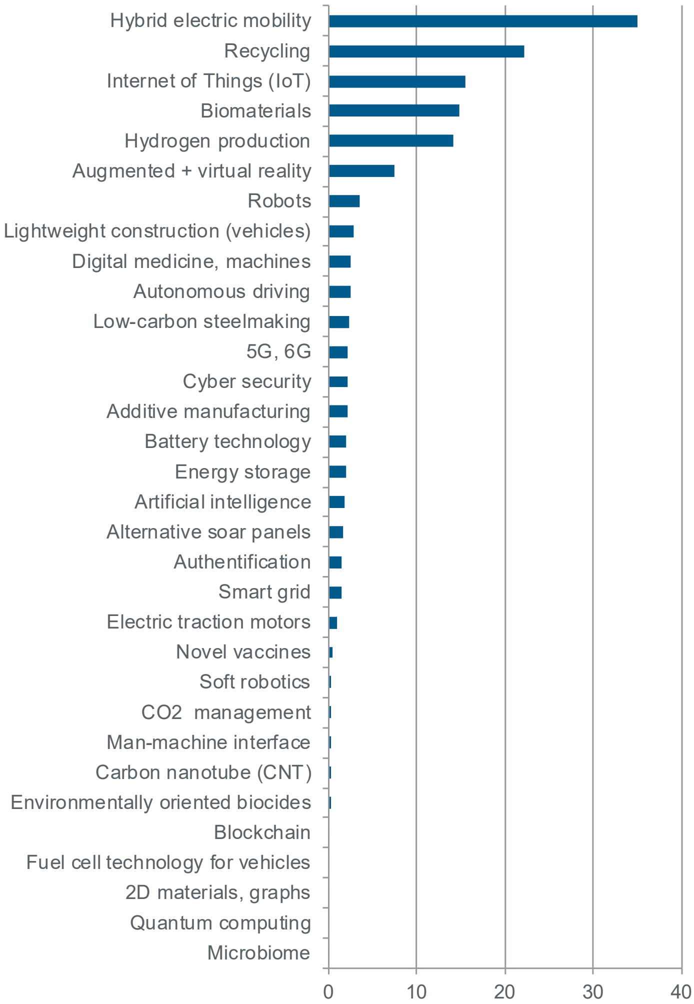
The comparison of technological and economic importance shows that market value and technological index are on a similar level in many cases. This is true of seven of the first ten technologies with the highest market value, for example. They are also among the first ten technologies of the technology index (Figure 4). The market value is particularly high in recycling, biomaterials and augmented and virtual reality but also in robotics and lightweight automotive construction.

However, this does not apply to all technologies. In the case of hybrid electric vehicles, the internet of things and hydrogen production, the rank on the technology index is well below the market value rank. For hybrid electric vehicles, this is due to the below-average patents family size, while in the internet of things it is due to the low German specialisation, the low absolute number of patents and the below-average family size. In hydrogen production, all the values of the technological indicators are near the average.

The situation is similar for low-carbon steelmaking, 5G / 6G and smart grid technology. These technologies of the future thus also require significant technological effort to harness their growth potentials for Germany.

### Figure 3: Market value of technologies from a German perspective

in EUR bn




Source: Schmoch et al. (2021)

### Good starting position in automotive-related technologies

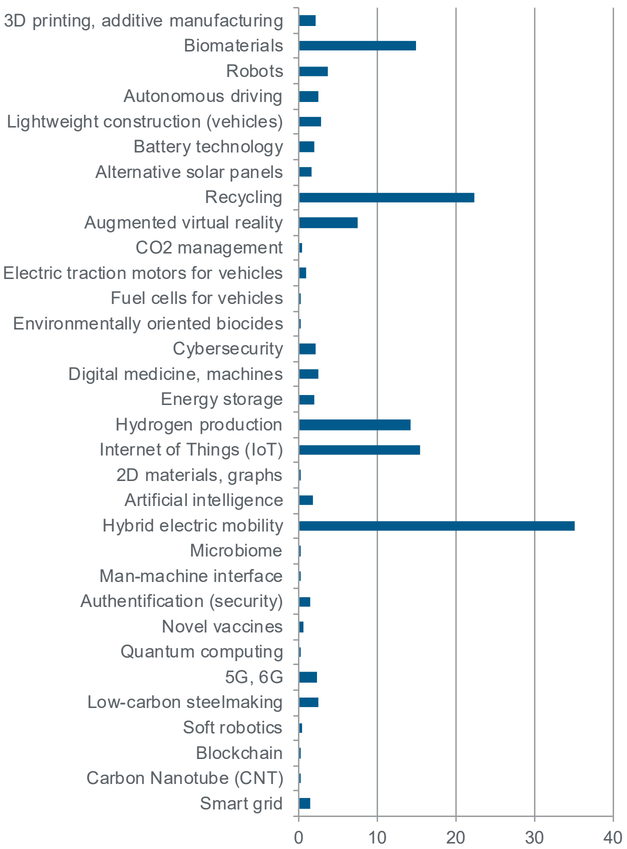
The highest-ranking technologies of the future can be subdivided into technologies that are related to motor vehicles, information technologies and environmental and climate technologies. Technologies associated with the production of medicines also come into play.

Motor vehicle technologies include hybrid-electric vehicles, battery technology, electric traction motors, lightweight automotive construction and autonomous driving. In general, German companies are technologically well-positioned here. With the exception of hybrid electric vehicles, these technologies are in the top 12 places in the ranking of Germany's technological strengths. The outlook for German car manufacturing as a key German industry is therefore positive but requires more research. With respect to hybrid electric vehicles, Germany faces stiff competition from France and especially Japan and competitors in battery technology are Japan and South Korea.

Above all, major efforts are necessary to build competencies in electric mobility. This is absolutely essential because Southeast Asian markets and large parts of the US market are focusing their efforts on this area. In the automotive market it is important to supply the various markets with the same technology in order to generate sufficient profitability. Against this background it appears to make sense not to provide public support to improve internal combustion engines as this technology will be obsolete in the medium term. A clear framework that supports electric mobility and purchase incentives for electric vehicles are especially important. Another key approach consists in improving charging infrastructure in Germany.

### Figure 4: Market value of technologies compared with technological ranking

in EUR bn




Source: Schmoch et al. (2021)

### Germany's lag in information technology

Information technologies are a challenge for Germany. The key issue here is that information technology is gaining increasing importance for sectors such as automotive engineering, mechanical engineering and chemicals and having to rely on foreign companies is problematic. The information technologies that have potential include the internet of things, augmented and virtual reality, 5G / 6G, cybersecurity, authentication, artificial intelligence, blockchain, quantum computing and, derived from these, robotics, soft robotics, digital medicine, smart grids and autonomous driving. These technologies are closely connected, so it does not appear to be useful to focus merely on specific ones.

But it must be acknowledged that Germany's specialisation in all areas of information technology is well below average in patents and publications. It is hardly realistic to attempt to catch up here with other countries within a few years through more research and development. To be sure, these fields should be supported by expanding the relevant departments in universities or the activities of non-university research institutes. The first critical step, however, is to improve the skills in the application of information technologies in manufacturing. This can involve developing relevant expertise in manufacturing technology companies, for example. Businesses that specialise in software development and implementation and possess manufacturing technology skills, for example, are important to achieve this, as they can advise companies on the introduction of digital technologies such as Industry 4.0. Finally, expanding relevant training is a key element for strengthening information technologies.

With a view to the debate on technological sovereignty it also appears to be appropriate to develop own information technology competencies and achieve sufficient relevant autonomy. While it has generally proven worthwhile to defend national strengths in technological competitiveness and maintain the acquired profile steady in the long term, making dedicated efforts to build skills in information technology is a crucial exercise.

### Making environmental and climate technologies profitable already in the short term

Environmental technologies of the future include recycling, biomaterials, hydrogen production, low-carbon steel making, energy storage, smart grids, $CO_2$ management, environmentally oriented biocides and, in a broader sense, battery and fuel cell technology. In the vast majority of cases, the technological basis in Germany is good. The critical question is usually whether these technologies pay off economically. Given the progressive depletion of natural resources and climate change, that is certainly the case over the medium term but may be problematic in the short term. It is therefore important to create a reliable framework through official regulations, which include the recently approved carbon tax, for example. Many measures also need to target enterprises. Recycling, for example, is not just the responsibility of the relevant sector. Rather, measures that encourage returning and recycling materials at production facilities of all sectors must be supported, including through tax incentives, for example. All incentives that link environmental action and businesses are generally beneficial.

### Manufacturing technology: combining information technology and additive manufacturing with German strengths

Manufacturing technologies include robotics, lightweight construction, low-carbon steel making and additive manufacturing. The technological basis for German companies is generally good. A particular challenge for German enterprises, besides further integrating information technology, is to assert themselves in the new market of additive manufacturing. This market targets products with a complex geometry and small-series production. Technical quality, bespoke solutions and price are competitive factors. German companies applying for patents are not just SMEs but include large enterprises such as Siemens, BMW, BASF and Airbus. Many new applications are still at an experimental stage and fraught with risk. A number of start-ups will likely emerge here that will develop technically complex solutions for specific applications. A sufficient supply of venture capital will be important.

### High potential in the medical field

The technologies of the future in the field of medicine include novel vaccines, digital medicine and microbiome technologies. Vaccines have long had limited economic attracttiveness and their sales and research have stagnated. With the coronavirus pandemic, vaccines have gained new importance. Experts believe novel viruses will emerge time and again in the coming years, requiring novel vaccines to be developed within short periods of time. New types of vaccines will be able to make important contributions. As the data used in the present analysis predates the coronavirus pandemic, it does not yet take into account the new findings. However, considerable growth potential can be assumed. Several German companies are already well-positioned in this field. The task here is to protect German interests through appropriate measures.

German enterprises are generally well-positioned in the field of digital medical devices. The considerations on strengthening competencies in the application of information technology apply here equally. Microbiome technology research is still in an early stage. Reliable treatment procedures for arthritis, allergies, immune diseases or cancer are yet to be established, which explains why their long-term importance based on patent analyses and market studies is significantly underestimated. The clear upward trend and Germany's specialisation in publications are positives. At present, medical research must be the primary recipient of support.

### Conclusion

Germany has a differentiated technological profile with many starting points for future value creation. These strengths should not be frivolously jeopardised but continuously developed further. This applies to the automotive industry and manufacturing technologies in particular. Germany has developed far-reaching technological strengths in both areas in recent years. Now is the time for the country to tackle the challenges of electric drivetrains and autonomous driving as well as additive manufacturing and the integration of information technology. With respect to information technologies, however, it is imperative to expand the competences in this direction. Otherwise Germany will not succeed in developing precious value creation potential for the country.

With a view to promoting future technologies, there is no promising one-size-fits-all approach. Given the vast differences, specific forms of support must be contemplated for each individual technology. As this study focused on the medium term and the examined technologies are usually already present in the market, supporting research is not the most important component of promotion. Creating a reliable market environment, tax incentives, financial assistance for the development of new activities within businesses or in the market and targeted public demand are often more important.

## Methodology

**Calculating the overall indicator for assessing a technology**
In order to assess the technologies, we examined the technological development and Germany's contribution. We availed ourselves of patents, research publications and trademark registrations. Patents reflect the short to medium-term development of a technology, while research publications tend to show the more long-term development. Trademark registrations are an indication of how easily a technology is already available in the market.

With regard to patents, we used transnational patent applications.[4] They provide the advantage that their multinational character gives them high value. They also make international comparisons easy as there are no 'home advantages' as there would in the assessment of patent applications with national patent offices. To obtain specific indicators of application activity, we identified the global trend in the development of patent applications for each technology, Germany's specialisation in the relevant technology, the absolute number of German patents and the size of the patent families (e.g. the number of countries in which a patent is applied for). In an alternative calculation we also took into account the share of SMEs in patents.

With a view to research publications, parameters that can be taken into account are the development of the global trend over time, the specialisation of German publications in the relevant technology, the absolute frequency of German publications and their rate of citations.[5] With respect to trademark registrations we also included the global trend, Germany's specialisation and the number of German trademark registrations.[6]

The relevant global trend stands for the development trend of a technology overall. For patent applications this value is based on the 2010–2017 period, for publications 2010–2019 and for trademarks 2010–2018. Germany's specialisation was measured on the basis of relative specialisation in a technology.[7] The degree of specialisation and the number of German patents, publications and trademarks represents Germany's position in a technology. The data on specialisation and the absolute number in Germany refer to the 2015–2017 period for patents, 2017–2019 for publications and 2016–2018 for trademarks. The size of the patent family and the rate of citations in publications are measures of the quality of a patent or publication. They refer to the 2014–2016 period and the year 2017. The underlying time periods are based on data availability and the requirements of the calculation.

The values of all individual indicators were stratified into a five-point scale. Sub-indicators were then calculated for patents, publications and trademarks by adding the values for the individual key figures. For the patent figures the number of German patents and the size of the patent family were multiplied by the factor 1.5. The three sub-indicators thus obtained were then aggregated into a total index. The sub-indicator for patents was weighted 1.0, publications 0.5 and trademarks 0.3.

**Calculating market value**
As official statistics on the economic value of technologies do not exist and there is no way to derive values from product statistics or data on economic sectors (classification to rough or data not sufficiently up to date), we evaluated market studies on individual technologies. These were applied to the technologies examined in this study on the basis of patent analyses and broken down to German enterprises. To validate this approach, we derived the market value directly from patent analyses. This was done by assigning patent applications to the applicant's affiliation with an economic sector and on the basis of further calculations. In this way we were able to determine the market value of a technology – measured by turnover – at the current margin from a German perspective.

[1] Cf. Federal Ministry for Education and Research (2018): Research and innovation that benefit the people. The High-Tech Strategy 2025, German Federal Government (2018): Artificial Intelligence Strategy of the Federal Government; Federal Ministry of Economics and Technology (2020): The National Hydrogen Strategy or Federal Ministry of Economics and Technology (2021): Lightweight construction strategy for Germany as an industrial location, to name just a few initiatives.

[2] Cf. Schmoch, U. et. al (2021): Identifizierung und Bewertung von Zukunftstechnologien für Deutschland (*Identifying and assessing future technologies for Germany* – our title translation, in German only). Final report to KfW.

[3] Although robotics is comprehensively defined as one technology, the study additionally examined the new sub-segment of soft robotics, which enables increased flexibility and adaptation to tasks as well as increased safety in spaces where robots and humans work in close proximity.

[4] Transnational patent applications are applications in patent families, with at least one application filed with the World Intellectual Property Organization (WIPO) via the PCT process or an application with the European Patent Office. Cf. Neuhäusler, P. and Rothengatter, O. (2020): Patent Applications – Structures, Trends and Recent Developments 2019, Studien zum deutschen Innovationssystem 4-2020.

[5] The research on publications was conducted in the multidisciplinary Web of Science (WoS) database in the Scisearch version of the provider STN.

[6] The research was based on European trademarks with the European Union Intellectual Property Office (EUIPO, Alicante).

[7] This is the RPA value that is customary in patent analyses. Cf. Soete, L. and Wyatt, S. (1983): The use of foreign patenting as an internationally comparable science and technology indicator. In: Scientometrics 5(1), p. 31–54.