Overall output of select geographical group comparators and related FP7- and H2020-funded publication output

FINAL REPORT
Overall output of select geographical group comparators and related FP7- and H2020-funded publication output

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EUROPEAN COMMISSION
ECDG and Elsevier study on overall output of select geographical group comparators and related FP7- and H2020-funded publication output
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Introduction
The general objective of the framework programmes are to contribute to building a society and an economy based on knowledge and innovation across the Union by leveraging additional research, development and innovation funding and by contributing to attaining research and development targets.

The outcome of this project is an analysis of the FP7 and Horizon 2020 cooperation networks, and in particular the extent to which both have, or are currently, supporting interdisciplinarity and cross-sectoral approaches for research and innovation.

This analysis is presented in two parts. The first, this executive summary, provides high-level analysis and data on the FP7 and H2020 framework programmes (and non-framework output for context), per geographical group, and per comparator country including the United States, China, South Korea and Japan. Specifically for FP7, an overview of the component programmes is provided.

The second part is in the form of excel data files which cover each sector, Academic, Medical, Corporate and Government, and each journal classification subject area (All Science Journal Classification).

Scope of analysis for executive summary
The breakdown of objects to be analysed cover each geographical grouping of countries, namely:

1. EU-28
2. EU-13
3. EU-15
4. Associated Countries (AC)
5. Third countries (TC)

Additionally, specific countries including the United States (USA), Japan (JPN), China (CHN) and South Korea (KOR) are also examined.

Each sector, namely, Academic, Government, Medical and Corporate. Analyses covered in this executive summary focus on overall output whilst the data file output examines each sector individually.

Please note, as agreed with ECDG, due to the relative paucity of data for H2020, ECDG requested a more in-depth analysis of the individual programmes within FP7.
Output, impact, growth, excellence and interdisciplinarity

The non-framework output of each of the geographical groupings are examined in detail first to provide essential context for the framework-funded publication output. Following the non-framework output section, the FP7 and H2020 output are examined in the same level of detail, and comparisons are drawn to non-framework output. It should be noted that publication counts for more recent years, namely 2015 and 2016 display a slight decline. This is due to individual journals having a slight indexing delay in the most recent years.

1 Non-framework output

Scholarly outputs, as measured by the publication of journal articles, reviews, and conference proceedings papers, are a traditional indicator of research intensity. The term ‘publication’ used in this executive summary refers to the documents that fall under the journal article, reviews and conference proceedings categories. The apparent decline in all group outputs in 2015 and 2016 is an artefact of the lengthy journal indexing process and all bibliometric databases, including Scopus, suffer from this lag in indexing.

Total output for each of the geographical groups was characterised by low growth and decline rates. The EU28 total output in 2007 was 592,339 publications, and 554,502 in 2016. In terms of Compound Annual Growth Rate (CAGR), this equates to a -0.7% year on year decline. Growth values for all groups and countries varied by fairly large margins: EU 15 (-0.8%), EU 13 (0.7%), AC (1.4%), TC (1.0%), CHN (4.8%), KOR (2.2%), USA (-2.0%) and JPN (-3.8%). Much of the growth declines were directly due to CHN’s large output volume and growth rate.

World output for the same period slowly declined at -0.4%, from 1,840,506 publications in 2007 to 1,778,309 publications in 2016.

Table 1.1 provides per year and selected period data for the publication output for each of the geographical groups, countries and world as a whole.

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Table 1.1 – Total publication output per geographical entity, per year 2007-2016. Where present, row values have been highlighted to show the maximum and minimum values. Source: Scopus.
Figures 1.1a and 1.1b provide graphical representations of the non-framework output per geographical entity.

**Figure 1.1a – Total publication output per geographical group, per year 2007-2016. Source: Scopus.**

**Figure 1.1b – Total publication output per country, per year 2007-2016. Source: Scopus.**

Figures 1.2a and 1.2b provide overviews of the share of the world total output for each of the geographical dimensions and countries. At the geographical group level Shares have remained steady, verging on a slight decline, for all of the geographical dimensions, except TC. The Third Countries have shown a large increase between 2007 and 2016, with a 8.6 percentage point (p.p.) increase, whereas the EU 28 and EU 15 groups have shown p.p. drops of just over 1.0 for the same period. At the country level, CHN has increased its world share by 7.3 p.p. from 12.55% in 2013 to 19.84% in 2016. The USA has seen a large drop, 3.6 p.p. from 26.64% in 2013 to 23.05% in 2016.
Field-weighted citation impact

In this executive summary, we use field-weighted citation impact (FWCI) as the main indicator of citation impact. This metric compares the actual number of citations received with the average number of citations for a publication of the same subject, document type, and publication year. It therefore accounts for differences in citation practices between subjects, and is benchmarked against the world average, set at 1.00. For instance, an FWCI of 1.24 means that a publication in this subject is cited 24% more often than expected compared to the world, while a value of 0.90 would mean the publication is cited 10% less than the global average.

The field-weighted citation impact (FWCI) of the total output of each of the geographical groups is presented in this section. Figures 1.3a and 1.3b provide per year overviews of the changes in FWCI for each of the geographical groups and countries. In reference to Figure 1.3a, FWCI for all but the EU13
group were above the World average of 1.0 for most of the 2007-2016 period. The EU15 output FWCI was the highest for all years of the period.

For the EU 28, FWCI for the period was 23% higher than world average, 29% higher than world average for EU15, and 18% below world average for EU13.

![Figure 1.3a –Field-weighted citation impact per geographical group, per year 2007-2016. Source: Scopus.](image)

For each of the country comparators, China showed a remarkable increase from 2007 to 2016, but its FWCI remained below world average. Japan was just below world average for the period, and South Korea was just above world average. The United States has seen a slow decline from 1.48 in 2007 to 1.41 in 2016.

![Figure 1.3a –Field-weighted citation impact per geographical group, per year 2007-2016. Source: Scopus.](image)

**Highly-cited publications**

Highly cited publications are those that fall into the top 1, 5 and 10% of all cited publications worldwide. To account for variations in citation behaviour across subject areas (Medicine-oriented publications typically cite, and are cited, more often than those from, for example, Mathematics), publications are
ranked based on their field-weighted citation impact, and the top 1, 5 and 10% of the publications in this ranking are used. Presented in this section are the counts of publications that fall into the highly-cited categories for all subject areas. Per subject area breakdowns are available in the accompanying data files.

Shown in Figure 1.2 is the 2007 to 2016 period shares of each geographical group’s total output that are in the world’s a) top 1% of cited publications, b) top 5% of cited publications, and c) top 10% of cited publications. For each top x% share value, if the percentage shown is higher than the respective category, it can be inferred that the entity’s contribution to top x% share is higher than the world average. For example, the EU28 group has 12.7% of its publications in the world top 10% of publications. This is higher than the world average which is, by definition, 10%. This reasoning can be applied to the top 1 and top 5% accordingly.

![Comparative Figure 1.2](image)

*Figure 1.4 – Share of total publication output in world top cited publications categories – a) top 1%, b) top 5%, and c) top 10%, per geographical group and country, 2007-2016. Source: Scopus.*

Both the EU28 and EU15 groups are over-represented in all the top cited categories. The EU13 group’s representation is below world average expectations, with 0.8% of its publication in the world top 1%, 3.8% in the top 5%, and 8.0% in the top 10%. The USA is the highest performing country – and of all comparator types – with 1.7% of its publications in the top 1%, 8.0% in the top 5%, and 15.5% in the top 10% cited categories.

**Interdisciplinary research**

Interdisciplinary research (IDR) is often believed to have great potential to contribute to research breakthroughs, address societal problems, and foster innovation. Conceptually we use IDR as a broad term that is inclusive of multidisciplinary, interdisciplinary and transdisciplinary research. In this executive summary and associated analyses, a citation-based approach is employed to identify and measure IDR. The basic principle behind this approach is that an article is likely to be interdisciplinary if it cites papers that are “far away” from each other in terms of the similarity of the journals they appear in (based on how often those journals are cited together in a certain period). On the other hand, if it cites papers in journals that are cited together very frequently, it is likely to be a monodisciplinary article. By thus focusing on the outcomes of research (i.e. journal publications and citations), this approach does not take into consideration the underlying processes of knowledge integration in cross-
disciplinary research (e.g., research teams whose members have a variety of disciplinary backgrounds). The advantage of measuring IDR by looking at citation patterns is the lack of reliance on any pre-defined subject classification, making it flexible enough to capture the dynamics of a research landscape in which subjects are constantly emerging and changing. We do however recognise the limitations of this approach (e.g., dealing with non-article document types or subject areas with references that are not covered in the Scopus database).

Figures 1.5a and 1.5 b provide overviews of the per year non-framework interdisciplinary output per geographical group and country. IDR output across all geographic groups has risen. The TC group has consistently produced the highest volume output per year, and the highest growth at 2.6% CAGR. Both AC and EU 13 showed positive growth, 1.5 and 2.5% respectively, but more modest volumes than any other groups.

At the country level China has shown significant year on year growth, 6.7%, with 19,236 IDR publications in 2007 and 34,486 IDR publications in 2016. The United States output grew steadily between 2007 and 2015, but it’s overall period CAGR was slightly negative at -1.5%.
Figure 1.5b – Interdisciplinary publication output per country, per year 2007-2016. Source: Scopus.

The FWCI of IDR non-framework output for each of the geographical groups is shown in Figures 1.6a and 1.6b. For all groups except AC and TC, FWCI is increasing. EU 15 IDR FWCI, rises at a modest 1.4% CAGR between 2007 and 2016, compared to the EU 13 CAGR growth of 4.9%. TC IDR FWCI slipped below world average in 2011 and continues to decline at an overall CAGR of -0.5%.

Figure 1.6a – Interdisciplinary publication FWCI per geographical group, per year 2007-2016. Source: Scopus.

The United States has the highest IDR FWCI of all comparator countries. Apart from the US, only South Korea has a higher than world average FWCI, but this is only for a short period between 2011 and 2012. IDR research is generally thought to produce higher FWCI output, but only the US appears to have achieved this across the whole period. For comparison, the EU 28, EU 15 and EU 13 groups only achieve this from 2012 onwards. China has the lowest ratio of IDR FWCI to overall FWCI, with its IDR research having an FWCI 15% less that its overall output FWCI.

Figure 1.6b – Interdisciplinary publication FWCI per geographical group, per year 2007-2016. Source: Scopus.
Collaboration

Research is becoming more and more international. Researchers collaborate every day with others at universities around the world – discussing joint research, organizing conferences, sharing seminar papers. International collaboration provides researchers with the opportunity to work with the best collaborator in a specialized field and gain access to expanded resources, data, and facilities. Single-authored articles are becoming less and less common.

This report measures research collaboration through analysing patterns in co-authored publications. In general, collaboration is defined as the set of publications with at least two co-authors (as opposed to single-authored publications). The collaboration types include international, national, institutional and single-author.

International collaboration occurs if an article has at least two different countries listed in the authorship byline. If an article has only one author affiliated with institutions in two different countries though, this article is not counted as an internationally-collaborated article but as a single-authored article. Due to the nature of the comparator geographic groups, international collaboration is defined as those publications in which at least one co-author comes from outside the geographical group. Using the EU28 group as an example, if a publication has one author from the Netherlands and another from Germany, it would be classed as a national publication. If the publication had a third author from China, it would be classed as an international collaboration. Thus because of the nature of the geographical groups, international collaboration counts may appear to be under-represented.

Presented in the following figures are a) the collaboration type share of total publication numbers, and b) the FWCI for the same collaboration type per geographical group and comparator countries.

Overall patterns describe a declining share of single-authored publications across all geographical groups and comparator countries, although there is a large spread of shares between the comparator entities. FWCI for this collaboration type have remained steady, below the world average, with slight fluctuations for each comparator entity across the 2007 to 2016 period.

Institutional collaborations have likewise declined, but shares remain similar for all comparator entities. FWCI for institutional collaborations have remained steady, with increases see for the EU 13 geographical group and China.

National collaboration shares are steady with only the TC group showing an marked increase between 2007 and 2016. At the comparator country level, shares have remained steady for the period. FWCI values have fluctuated for all comparator entities, with EU 13 and China FWCI values increasing but Japan, South Korea and the US all showing declines.

International collaboration shares have markedly increased for all entities. Similarly, FWCI has moved upwards, albeit not as markedly as share. International collaboration is the only collaboration type wherein all FWCI values for all entities is above the world average.
Figure 1.7a – Single-author publication share of all publications, per geographical dimension and country, per year 2007-2016. Source: Scopus.
Figure 1.7b – Single-author publication FWCI, per geographical dimension and country, per year 2007-2016. Source: Scopus.

Figure 1.8a – Institutional publication share of all publications, per geographical dimension and country, per year 2007-2016. Source: Scopus.
Figure 1.8b – Institutional publication FWCI, per geographical dimension and country, per year 2007-2016. Source: Scopus.
Figure 1.9a – National publication share of all publications, per geographical dimension and country, per year 2007-2016. Source: Scopus.

Figure 1.9b – National publication FWCI, per geographical dimension and country, per year 2007-2016. Source: Scopus.
Figure 1.10a – International publication share of all publications, per geographical dimension and country, per year 2007-2016. Source: Scopus.
FP7-funded publication output increased dramatically as the program progressed, as shown in Table 2.1 and Figure 2.1. The EU 28 group produced 576 publications in 2007 and peak output was in 2013 with 28,438 publications. Overall growth between 2013 and 2016 was 26.4% CAGR. Growth between 2007 and 2013 was extremely high at 138.3% CAGR.

Of the EU 28 publications, the overwhelming majority came from the EU15, with EU13 countries accounting for approximately 10% of the publications in 2013. There was a large initial count of TC countries producing FP7-funded publications, with 205 publications in 2007 and 15,576 publications in 2013, just over half of the EU 28 publication output in the same period. Of the four comparator countries, the US has published the most FP7-funded publications by a factor of six.

Table 2.1 – Total publication output of FP7-funded research per geographical group, per year 2007-2016. Source: Scopus.
Figure 2.1a – Total publication output of FP7-funded research per geographical group, per year 2007-2016. Source: Scopus.

Figure 2.1b – Total publication output of FP7-funded research per comparator country, per year 2007-2016. Source: Scopus.

Figure 2.2a and 2.2b provide overviews of FP7-funded research shares of each comparator group and country’s total output. The peak shares for all groups occurred in 2013, with EU 15 and AC groups having just over 4% of the total publication output founded by the FP7 programme. The TC group had the lowest shares per year, and whilst China and the US are members of the TC group, from the per country data, the shares of FP7-funded research in those countries is very small compared to their respective total outputs.
Field-weighted citation impact

Output from FP7-funded research had particularly high FWCI values. Figure 2.3 provides an overview of the FWCI values per comparator group. For all groups, FWCI was at least twice as high as the world average, with the AC group output for the period 2007 to 2013 being the highest at 3.03. EU 28 and EU 15 FWCI for the same period was 2.54 and 2.57 respectively and TC FWCI was higher at 2.96. The EU 13 group had the lowest period FWCI at 2.27, but even this value was just over two and quarter times higher than the world average.
At the comparator country level, FWCI values are similarly high. All countries have FWCI values higher than 3.70 for the 2007-2016 period, with South Korea having the highest period FWCI at 5.45.

To provide more context for the FWCI of FP7-funded research versus overall FWCI, Figure 2.4a and 2.4b provide ratios of FP7-funded output FWCI to the overall FWCI of each comparator entity. For all groups, the ratio is well above 1.8 signifying that FP7-funded output was at least 80% higher than the overall FWCI. The EU 13 and TC groups enjoyed the highest relative increases over their own overall FWCI, with 2.78 and 3.08 ratio increases, respectively, over the 2007 to 2016 period.

The other comparators also enjoyed large ratio values in the 2007 to 2016 period, with the EU 28 and EU 15 groups having 2.11 and 2.03 ratios, and the AC group having a 2.58 ratio increase.

At the comparator country level, this effect is more pronounced. Over the 2007 to 2016 period, Chinese FP7-funded FWCI was 4.87 times as high as their overall output FWCI. The highest increase belonged to South Korea wherein a 5.25 fold increase was observed. There was a positive fold increase for the US but was more in line with the geographical groups at 2.52 for the period.
FP7 top cited publications

FP7-funded research provided high shares of publications in the world’s top 1, 5 and 10% of most cited publications. This is true for all comparator groups, across the 2007 to 2016 period. Figure 2.5 provides an overview of the share of FP7-funded publications that are found in the world’s top cited publication categories. In Figure 2.6, for each top cited category, additional data are provided in ratio form demonstrating how much higher or lower FP7-funded research occurs in the top cited category compared to overall output.

As an example, in 2007, 1.12% of all EU 28 output was in the world’s top 1% of cited research. For the same year, 3.79% of FP7-funded research from the EU 28 group was in the world’s top 1% of cited research. Using the all output share as denominator, the ratio equates to 2.8, or in simpler terms, FP7-funded research was almost three times more likely to belong to the world’s top 1% cited research.
Of the world’s top 1% of cited research, FP7-funded output for all comparator groups are proportionally much higher than the groups’ overall output in the world’s top 1% of cited research. For the 2007 to 2013 period, the EU 28 group FP7-funded output was 3.31 times more represented in the top 1% category than the group’s overall output. For EU 15 and EU 13, FP7-funded output was proportionally higher in the top 1% category by factors of 3.17 and 4.39 respectively.

At the country level, China enjoyed the highest ratio of shares, with FP7-funded publications found in the top 1% category 12.5 times more than its own overall output, 6.12 times more for the top 5% category and 4.56 times more in the top 10% category. Japan and South Korea had similar high values, and the US was on par with the geographical groups’ values.

This pattern was observable across all top cited categories indicating that, overall, FP7-funded research was much more likely to be in the world’s top cited research no matter the geographical group from where the research came from.

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**Figure 2.5 – Shares of FP7-funded research in world top cited research categories, per geographical group and country, 2007-2016. Source: Scopus.**

**Figure 2.6 – Ratio of FP7-funded research versus overall output in world top cited research categories, per geographical group and country, 2007-2016. Source: Scopus.**
FP7 interdisciplinary output

Proportionally, FP7-funded interdisciplinary research does not occupy as large a share as it does in the world top cited research categories. This is initially counter-intuitive as interdisciplinary research typically has higher FWCI values than monodisciplinary research. However, when considering the programme level details of FP7, each programme – for example BIOTECH, ENV, Energy, Health, ICT – is highly focussed to the point where interdisciplinary research is rare. That being said, presented below in Table 2.2 are the number of interdisciplinary publications per entity. Figures 2.7a and b, and Figures 2.8a and b provide the relative shares of FP7-funded research that are interdisciplinary and the relative ratios to each comparator group’s overall output.

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<td>-</td>
<td>2</td>
<td>7</td>
<td>15</td>
<td>19</td>
<td>22</td>
<td>23</td>
<td>18</td>
<td>15</td>
<td>4</td>
<td>125</td>
<td>.</td>
</tr>
<tr>
<td>USA</td>
<td>4</td>
<td>24</td>
<td>66</td>
<td>142</td>
<td>244</td>
<td>310</td>
<td>313</td>
<td>338</td>
<td>226</td>
<td>60</td>
<td>1,727</td>
<td>35.1%</td>
</tr>
</tbody>
</table>

Table 2.2 – Total interdisciplinary publication output of FP7-funded research per geographical group and comparator country, per year 2007-2016. Row maximums have been highlighted. Source: Scopus.

Figure 2.7a – Interdisciplinary share of FP7-funded output per geographical group, per year 2007-2016. Source: Scopus.
For the period 2007 to 2016, EU 28 FP7-funded interdisciplinary output accounted for 7.2% of the group’s total FP7-funded output. For the same period, EU 15 and EU 13 shares were 7.14% and 7.33% respectively. The TC group share was the lowest at 6.03%. As output counts increased, interdisciplinary shares stabilised at, or near, 7% of overall FP7-funded output for all comparator groups.

At the country level, China, South Korea and Japan published no IDR publications in 2007, and South Korea only published IDR articles from 2010 onwards. Overall shares varied greatly between the countries, with 2007 to 2016 period shares between ranging from 3% (Japan) to just over 6% (China).

Ratios to non-framework output interdisciplinary shares were below one for all comparator groups and countries from 2009 onwards. The EU 13 group was the only comparator to show an increase in its relative ratio, from 0.14 in 2007 to 0.54 in 2016.

A similar pattern is found at the country level. South Korea is the only country to increase its relative ratio of shares, from 0.22 in 2010 to 0.87 in 2016. All other countries showed noticeable declines or remained steady.
Figure 2.8a – Ratio of interdisciplinary FP7-funded output share to overall interdisciplinary output shares, per geographical group, per year 2007-2016. Source: Scopus.

Interdisciplinary research typically attains a higher FWCI than other research. Figures 2.9a and 2.9b provide overviews of the FWCI of FP7-funded interdisciplinary output for each of the comparator groups and countries.

Figure 2.8b – Ratio of interdisciplinary FP7-funded output share to overall interdisciplinary output shares, per comparator country, per year 2007-2016. Source: Scopus.

Figure 2.9a – Interdisciplinary FWCI of FP7-funded output per geographical group, per year 2007-2016. Source: Scopus.
Figure 2.9b – Interdisciplinary FWCI of FP7-funded output per comparator country, per year 2007-2016. Source: Scopus.

All comparator groups attain higher than world average FWCI for all years. FWCI remained steady during the 2010 to 2014 period, but peaks were seen in 2009 for all groups. To compare the FWCI of interdisciplinary output to that of the overall FP-funded output, Figures 2.10a and 2.10b provide ratio depictions for each comparator group and country.

For all geographical groups, the ratio of interdisciplinary FP7-funded output FWCI to overall IDR FWCI is higher than 1.0, levelling off between 1.8 and 3.5 between 2010 and 2014. Whilst FP7-funded interdisciplinary research shares are low (See Table 2.3), the associated FWCI is higher than the overall IDR output FWCI.

Figure 2.10a – Ratio of FP7-funded interdisciplinary FWCI to overall interdisciplinary output FWCI per geographical group, per year 2007-2016. Source: Scopus.
Figure 2.10b – Ratio of FP7-funded interdisciplinary FWCI to overall interdisciplinary output FWCI per comparator country, per year 2007-2016. Source: Scopus.

FP7 collaboration
Presented in Figures 2.11 to 2.14 are the publication count shares for each of the collaboration types of FP7-funded research for each of the geographical groups. Please note, axis values have been modified to increase readability.

It is immediately noticeable that FP7-funded output has very low counts and associated shares of single-authored publications. The primary aim of the programme is to stimulate collaboration, thus by its very nature, single-author publication output are rare. Of more interest is the national collaboration type shares as this encompasses the within geographical group collaborations. National collaboration shares for the EU 28 and EU 15 groups are high, with national collaboration publications making up 36.8% and 33.8% of total output, respectively, for the 2007 to 2016 period. For the AC and TC groups, national collaboration shares, wherein none of the authors are from EU countries, the shares were expectedly low, 7.6% and 3.5% respectively.

International collaboration, that between geographical groups, was very high for all FP7-funded output. It is worth reiterating at this point that international collaboration in this context is defined as collaboration between a geographical group member and a country outside that geographical group. For the EU 28 and EU 15 groups it reaches 37.9% and 41.4%, respectively, for the 2007 to 2016 period, and for AC and TC groups was more than double, at 77.4% and 73.3% respectively. From these data, and the context of how international collaboration is defined, it becomes more apparent that collaboration in FP7-funded research is primarily between EU members but a large share of the output is with multinational, non-EU coauthors.
Figure 2.11a – Single-authored FP7-funded shares of all FP7-funded output per geographical group, per year 2007-2016. Source: Scopus.

Figure 2.11b – Single-authored FP7-funded shares of all FP7-funded output per comparator country, per year 2007-2016. Source: Scopus.

Figure 2.12a – Institutional FP7-funded shares of all FP7-funded output per geographical group, per year 2007-2016. Source: Scopus.
Figure 2.12b – Institutional FP7-funded shares of all FP7-funded output per comparator country, per year 2007-2016. Source: Scopus.

Figure 2.13a – National FP7-funded shares of all FP7-funded output per geographical group, per year 2007-2016. Source: Scopus.

Figure 2.13b – National FP7-funded shares of all FP7-funded output per comparator country, per year 2007-2016. Source: Scopus.
Figures 12.5 to 12.8 provide overviews of the publication FWCI per collaboration type for FP7-funded output. Interestingly, and in opposition to the FWCI values for non-framework output, even though there were few single-authored publications, the associated FWCI is generally above the world average. National collaboration output FWCI was, for most of comparator entities, higher than the world average. The international collaboration output FWCI, which is typically considered to have the highest impact, is very high. Compared to the overall FWCI for FP7-funded research, the internationally collaborated FWCI output was in many cases 0.5 points higher. This pattern extended to all comparator entities.
Figure 2.15a – Single-author FP7-funded FWCI of all FP7-funded output per geographical group, per year 2007-2016. Source: Scopus.

Figure 2.15b – Single-author FP7-funded FWCI of all FP7-funded output per comparator country, per year 2007-2016. Source: Scopus.

Figure 2.16a – Institutional FP7-funded FWCI of all FP7-funded output per geographical group, per year 2007-2016. Source: Scopus.
Figure 2.16b – Institutional FP7-funded FWCI of all FP7-funded output per comparator country, per year 2007-2016. Source: Scopus.

Figure 2.17a – National FP7-funded FWCI of all FP7-funded output per geographical group, per year 2007-2016. Source: Scopus.

Figure 2.17b – National FP7-funded FWCI of all FP7-funded output per comparator country, per year 2007-2016. Source: Scopus.
3. FP7 output per programme

In this section, output statistics for each of the nineteen programmes are broken down by year. The data is presented for all sectors, with individual sector data available in the accompanying data files. In this summary, only data for the EU 28 geographical group is presented. Other geographical groups can be found in the accompanying data files.

Figures 3.1a and 3.1b present EU28 geographical group publication output counts for each of programmes. Figure 3.1b is a modified version of 3.1a, without the four largest programmes.
 ERC is the largest, by output, programme by a factor of just over three. Interestingly, ERC’s peak output occurs in 2014, as opposed to almost all the other programmes. ICT showed a large drop in output between 2011 and 2012, which is not seen in any other programmes. The JRC programme output dropped to zero in 2014, and was the only programme to do so.

**Figure 3.1a** – Per programme output of FP7-funded research for the EU28 geographical group, per year 2007-2016. Only largest programmes have been labelled. Please see Figure 3.1b for other programmes. **Source: Scopus.**
Programme FWCI

Generally speaking FWCI values for each of the were well above the world average. For the 2007-2016 period, Energy had the highest FWCI, at 3.26, and the programme with the lowest FWCI for the same period was SEWP at 1.86, or 86% better than the world average.

Figure 3.2 provides FWCI values per year for each of the programmes. Figure 3.3 provides a comparison between two periods, 2007-2013, and 2007-2016 for each of the programmes.

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1 With smaller numbers of publications, FWCI values can be dramatically affected by outlier values. Counts of less than 100 publications per year indicate care should be taken when interpreting FWCI values.
Figure 3.3 – Per programme FWCI of FP7-funded research for the EU28 geographical group, per periods 2007-2013 and 2007-2016. Source: Scopus.

Top cited publications per programme

The share of publications found in the world top cited percentiles are shown in Figure 3.4. Output from all programmes over-perform, relative to their expected shares, to a very large degree. ENV is one of the highest performing programmes in that over 35% of its total output is in the world’s top 10% of cited publications. It is over three and a half times the world average, the world average being 10%. ENV has the highest share of publications in the world top 1% of cited publications – 5.4%. Similar comparisons can be made across all other programmes and top percentile groups. For comparison, all output shares in the world top cited categories are shown in Figure 3.4 as hollow dots on the far right of the figure.

Figure 3.4 – Per programme share of world top cited categories for the EU28 geographical group, 2007-2016. Source: Scopus.

4. H2020 output

The research and publishing phases of science are affected by time lags, and as such the earliest year in which there are output data from H2020-funded research is 2015. Presented in this chapter are data from the years 2015 and 2016. These years overlap with those that have output from FP7-funded
research which serves to further highlight the, sometimes significant, delay between receiving funding and observing the output of research resulting from that funding.

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2016</th>
<th>2015-2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>E28</td>
<td>1,165</td>
<td>1,827</td>
<td>2,992</td>
</tr>
<tr>
<td>E15</td>
<td>1,123</td>
<td>1,757</td>
<td>2,880</td>
</tr>
<tr>
<td>E13</td>
<td>153</td>
<td>210</td>
<td>363</td>
</tr>
<tr>
<td>AC</td>
<td>148</td>
<td>257</td>
<td>405</td>
</tr>
<tr>
<td>TC</td>
<td>333</td>
<td>596</td>
<td>929</td>
</tr>
<tr>
<td>CHN</td>
<td>69</td>
<td>104</td>
<td>173</td>
</tr>
<tr>
<td>KOR</td>
<td>16</td>
<td>20</td>
<td>36</td>
</tr>
<tr>
<td>JPN</td>
<td>46</td>
<td>62</td>
<td>108</td>
</tr>
<tr>
<td>USA</td>
<td>164</td>
<td>292</td>
<td>456</td>
</tr>
</tbody>
</table>

Table 4.1 – Total publication output of H2020-funded research per geographical group, per year 2015-2016. Source: Scopus.

It is immediately apparent that the volume of publications from the first year of output for H2020 research was lower than for FP7. However, as more data becomes available, we expect the numbers to increase. Presented in Figure 4.1 is a graphical representation of the output from H2020-funded research. For all groups and comparator countries, a noticeable increase between years is seen. Output from the EU 15 geographical group comprise the bulk of the EU 28 group. The US has the highest number of publications for the comparator countries, as also seen in FP7-funded output.

Figure 4.1 – Total publication output of H2020-funded research per geographical group and comparator country, per year 2015-2016. Source: Scopus.
Figure 4.2 – H2020-funded research share of overall output per geographical group and comparator country, per year 2015-2016. Source: Scopus.

Figure 4.2 highlights the H2020-funded share of overall output for each entity. Shares for all geographical groups have more than doubled, and similar rises are seen for each of the comparator countries. The initial shares and share increases are slightly higher than those seen for FP7-funded output.

Field-weighted citation impact

The FWCI of H2020-funded research is above the world average for all groups and countries. For each of the geographical groups, FWCI has increased between years, but the same pattern is not observed for the comparator countries. Only the US and China appear to have at least similar FWCI values between 2015 and 2016, whereas Japan and South Korea display a declining FWCI between years. However, the FWCI values at the country level may be affected by outliers and low publication counts. As these publications attract citations over time, we do expect the FWCI values to change for all groups and countries. Figure 4.3 provides a graphical representation of the FWCI values for each entity.

Figure 4.3 – H2020-funded publication FWCI per geographical group and comparator country, per year 2015-2016. Source: Scopus.
Keeping in line with data from analysis of FP7-funded output, provided in Figure 4.4 is the ratio of the FWCI of H2020-funded research versus overall FWCI. For all groups in 2015, the ratio is above 1.7 signifying that H2020-funded output was at least 70% higher than the overall FWCI. The EU 13 group enjoyed the highest relative increase, between 2015 and 2016, over their own overall FWCI, with 1.84 and 2.29 ratio increases, respectively.

Figure 4.4 – Ratio of H2020-funded publication FWCI to overall FWCI per geographical group and comparator country, per year 2007-2016. Source: Scopus.

H2020 top cited publications
H2020-funded research provided high shares of publications in the world's top 1, 5 and 10% of most cited publications. This is true for all comparator groups, across both 2015 and 2016. Figure 4.5 provides an overview of the share of H2020-funded publications that are found in the world’s top cited publication categories. In Figure 4.6, for each top cited category, additional data are provided in ratio form demonstrating how much higher or lower H2020-funded research occurs in the top cited category compared to overall output.

Figure 4.5 – Shares of H2020-funded research in world top cited research categories, per geographical group and country, 2015-2016. Source: Scopus.
Of the world’s top 1% of cited research, H2020-funded output for all comparator groups are proportionally much higher than the comparators’ overall output in the world’s top 1% of cited research. For 2015 and 2016, the EU 28 group H2020-funded output was 3.74 times more represented in the top 1% category than the group’s overall output. For EU 15 and EU 13, H2020-funded output was proportionally higher in the top 1% category by factors of 3.65 and 5.57 respectively.

At the country level, Japan enjoyed the highest ratio of shares, with H2020-funded publications found in the top 1% category 11.45 times more than its own overall output, 3.94 times more for the top 5% category and 3.43 times more in the top 10% category.

**H2020 interdisciplinary output**

The proportion of interdisciplinary H2020-funded research is initially high, as also seen with FP7-funded interdisciplinary research. However, compared to FP7 data in subsequent years, the interdisciplinary H2020 research share is increasing. Table 4.2 provides the number of interdisciplinary publications for each comparator entity, and Figure 4.7 demonstrates the share growth from 2015 to 2016.

<table>
<thead>
<tr>
<th>Comparator</th>
<th>2015</th>
<th>2016</th>
<th>2015-2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>E28</td>
<td>74</td>
<td>152</td>
<td>226</td>
</tr>
<tr>
<td>E15</td>
<td>67</td>
<td>143</td>
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<td>E13</td>
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<td>23</td>
<td>37</td>
</tr>
<tr>
<td>AC</td>
<td>9</td>
<td>31</td>
<td>40</td>
</tr>
<tr>
<td>TC</td>
<td>21</td>
<td>34</td>
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</tr>
<tr>
<td>CHN</td>
<td>7</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>KOR</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>JPN</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>USA</td>
<td>11</td>
<td>17</td>
<td>28</td>
</tr>
</tbody>
</table>

*Table 4.2 – Total interdisciplinary publication output of H2020-funded research per geographical group and comparator country, per year 2015-2016. Source: Scopus.*
For each of the geographical groups a marked increase can be seen in the shares between 2015 and 2016. For the comparator countries, South Korea and Japan have no interdisciplinary output, and the shares for China and the US are declining. It should be noted that, as with FP7 interdisciplinary data, it is likely that as H2020 publication volumes increase, interdisciplinary shares will stabilise over time.

FWCI values for H2020 interdisciplinary output are presented in Figure 4.8. A degree of caution is required when interpreting these data: low publication counts and associated outliers will likely affect FWCI values. Thus, with this in mind, FWCI increases for the EU 28 and EU 15 groups, but declines drastically for the EU 13, AC and TC groups. Similarly sharp declines can be seen at the country level, and data for South Korea and Japan are not available as they have no H2020 interdisciplinary publications.
The ratio of H2020 interdisciplinary FWCI compared to overall interdisciplinary FWCI is positive in that H2020-funded interdisciplinary output achieves higher impact than their respective overall IDR output, as seen in Figure 4.9.

Figure 4.9 – Ratio of H2020-funded interdisciplinary FWCI to overall interdisciplinary output FWCI per geographical group and comparator country, per year 2015-2016. *Source: Scopus.*

**H2020 collaboration**

Collaborative publications in H2020-funded output are overwhelmingly dominated by international collaborations. International collaborations also display consistently high FWCI values, as compared to other collaboration types and publications overall. Presented in the following figures, 4.10 to 4.13, are the shares and FWCI values of single-authored, institutional, national and international collaborative H2020 publications.
Figure 4.10 – Single-authored shares of all H2020-funded output, and respective FWCI values per geographical group and comparator country, per year 2015-2016. Source: Scopus.

Shares of single-authored publications have declined from already low levels of just under 3% in 2015 to almost 2% in 2016 for each comparator entity. Only China had shares higher than 4% in 2015, but had no single-authored H2020 publications in 2016. FWCI for single-authored publications was just over the world average, 1.0, in 2015 but dropped to below 1.0 in 2016.
Institutional collaborations are at approximately the same levels as FP7-funded research, with no clear pattern of decline or rise in shares between geographic groups or countries. FWCI values for 2016 show increases over 2015 values for all entities except EU 13 and AC groups.

Figure 4.11 – Institutional collaboration shares of all H2020-funded output, and respective FWCI values per geographical group and comparator country, per year 2015-2016. Source: Scopus.
National collaboration shares are declining for the EU 28 and EU 15 groups. Shares remain steady for the EU 13, TC and AC groups. South Korea has no national collaboration H2020 publications for both 2015 and 2016, and the US has no H2020-funded national collaboration publications in 2016. FWCI remains steady for most of the comparator entities with the exception of the TC group which saw a large increase in FWCI in 2016.
Figure 4.13 – International collaboration shares of all H2020-funded output, and respective FWCI values per geographical group and comparator country, per year 2015–2016. Source: Scopus.

International shares for the EU groups were relatively low, due to the definition of international collaboration. For the non-EU groups, TC and AC, international collaboration share was very high with over 80% of all output. The comparator countries also displayed very high international collaboration shares, and South Korea’s H2020 publication output was exclusively of the international collaboration type. FWCI for international collaboration was the highest of all the collaboration types, with all entities’ FWCI higher than the world average.

5. FP7- and H2020-funded collaboration maps

Network maps provide graphical representations of the collaboration patterns between entities. Each node represents a publishing entity with each link, or edge, indicating that authors from the two entities have collaborated on one or more publications\(^2\). To draw attention to entities that collaborate frequently and repeatedly with the same partners, nodes are coloured to represent these clusters. Clusters are designated algorithmically wherein the degree of the nodes, that is to say the number of

\(^2\) Publications are defined as articles, reviews and conference proceedings.
links from or to a node, and the volume of these links, generally indicated by the thickness of the links, are used to calculate which nodes show historically strong grouping characteristics.\(^3\)

Collaborations between the EU 28 geographical group and countries around the world are shown in the network map in Figure 5.1. Of the collaborations, the EU 28 group is very central with its core collaborators in close proximity. Many countries appear to collaborate in publications with only themselves and an EU28 group member. These countries are shown as the single-linked nodes in the top left of the figure. This is not the norm as seen by the extensive links between other country nodes and the EU 28 node. The most frequent collaborations occur between the EU 28 group, the US, Japan, Canada, China, Russia and Switzerland.

![Network map of EU 28 collaborations](image)

**Figure 5.1** – *FP7-funded inter collaboration between EU28 geographical group and non-EU28 countries, 2007-2016*. Node colour is determined algorithmically to designate clusters. Nodes that have similar collaboration patterns and volume of collaborations have the same colour. Node size is number of FP7 publications. Edge thickness is number of collaboration publications between entities. Collaborations with less than 100 publications have been removed to improve readability. *Source: Scopus.*

The intra-EU 28 collaborations are shown in Figure 5.2. The most frequent collaborations occur between the larger and more R&D intensive countries. Collaboration frequencies are highest between these

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\(^3\) The mechanics and process of the clustering algorithm can be found in ‘Fast unfolding of communities in large networks’, Vincent D Blondel, Jean-Loup Guillaume, Renaud Lambiotte, Etienne Lefebvre, Journal of Statistical Mechanics: Theory and Experiment 2008 (10), P10008 (12pp)
countries, but the smaller research nations do collaborate often with each other and with at least one of the R&D intensive nations. The UK, Netherlands and Germany form one cluster, and Spain, Italy and France form another. There are two smaller clusters with the Nordic countries, Belgium and Ireland in one, and eastern European countries in the other.

Figure 5.2 – FP7-funded intra-EU28 collaboration, 2007-2016. Node colour is determined algorithmically to designate clusters. Nodes that have similar collaborations and volume of collaborations have the same colour. Node size is number of FP7 publications. Edge thickness is number of collaboration publications between entities. Collaborations with less than 100 publications have been removed to improve readability. LV, MT and LU have less than 100 collaboration publications with any one partner. Source: Scopus.

Collaboration patterns for H2020-funded research occurs in a different pattern to FP7-funded research. This, however, is likely due to the lower number of publications in general so far from H2020. The network map of H2020-funded collaboration between the EU 28 group and non-EU 28 countries is presented in Figure 5.3. As with FP7-funded collaborations, the most frequent collaborations occur between the EU 28 group, the US, Japan, Canada, China, Russia and Switzerland. More noticeable in this network map is the prominent role that the US has in collaborations between the EU 28 and other countries.
Figure 5.3 – **H2020-funded inter collaboration between EU28 geographical group and non-EU28 countries, 2015-2016.** Node colour is determined algorithmically to designate clusters. Nodes that have similar collaborations and volume of collaborations have the same colour. Node size is number of H2020 publications. Edge thickness is number of collaboration publications between entities. Edge labels are number of collaborations. Source: Scopus.

Figure 5.4 presents the H2020-funded intra-collaboration map of EU 28 countries. The orientation of the nodes has been kept constant in relation to the FP7 intra EU 28 map to aid the comparison between the two frameworks. However, the clusters shown are different. While Germany, The Netherlands and the UK remain in the same cluster, Belgium and France are now part of the same cluster. Spain and Italy remain part of their original cluster but now have more, smaller countries as part of their cluster. While the Nordics and Ireland formed their own distinct cluster, they are now joined by more of the eastern European countries. It should be noted that in the H2020 map, all collaborations are shown but the FP7 map has been edited to show only collaborations with more than 100 publications.
Figure 5.4 – **H2020 intra-EU28 collaboration, 2015-2016.** Node colour is determined algorithmically to designate clusters. Nodes that have similar collaborations and volume of collaborations have the same colour. Node size is number of H2020 publications. Edge thickness is number of collaboration publications between entities. Node position has been preserved between this figure and Figure 4.2 to compare FP7 and H2020 collaborations. MT has no H2020 collaborations with any other EU28 member. Source: Scopus.
Appendix A
Methodology and Data Sources

Methodology and Rationale

Our methodology is based on the theoretical principles and best practices developed in the field of quantitative science and technology studies, particularly in science and technology indicators research. The *Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems* (Moed, Glänzel and Schmoch, 2004)\(^4\) gives a good overview of this field and is based on the pioneering work of Derek de Solla Price (1978),\(^5\) Eugene Garfield (1979)\(^6\) and Francis Narin (1976)\(^7\) in the US, and Christopher Freeman, Ben Martin and John Irvine in the UK (1981, 1987)\(^8\), and in several European institutions including the Centre for Science and Technology Studies at Leiden University, the Netherlands, and the Library of the Academy of Sciences in Budapest, Hungary.

The analyses of bibliometric data in this report are based upon recognized advanced indicators (e.g., the concept of relative citation impact rates). Our base assumption is that such indicators are useful and valid, though imperfect and partial measures, in the sense that their numerical values are determined by research performance and related concepts, but also by other, influencing factors that may cause systematic biases. In the past decade, the field of indicators research has developed a best practices which state how indicator results should be interpreted and which influencing factors should be taken into account. Our methodology builds on these practices.

Counting

All analyses make use of whole counting rather than fractional counting. For example, if a paper has been co-authored by one author from the EU 28 group and one author from the TC group, then that paper counts towards both the publication count of EU 28, as well as the publication count of the TC group. Total counts for each entity are the unique count of publications.

Collaboration

Research collaboration is indicated by articles with at least two different entities listed in the authorship by-line.

Collaborations in this report can be classified as:

- Institutional: all authors are from the same institution.
- National: authors are affiliated with at least two countries within a geographic group.
- International: at least one author is from a country outside of the geographic group.
- Single-authored publications are used as a benchmark in this report.

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Scopus is Elsevier’s abstract and citation database of peer-reviewed literature, covering 62 million documents published in over 22,500 journals, book series and conference proceedings by some 6,000 publishers.

Scopus coverage is multi-lingual and global: approximately 21% of titles in Scopus are published in languages other than English (or published in both English and another language). In addition, more than half of Scopus content originates from outside North America, representing many countries in Europe, Latin America, Africa and the Asia Pacific region. Scopus covers approximately 6,400 titles from North America, 11,800 from Europe and 2,500 from Asia-Pacific and 1,500 from Latin-America and Africa. The geographical breadth of Scopus ensures comprehensive coverage of research outputs and impact of regionally-collaborated research.

Scopus coverage is also inclusive across all major research fields, with 7,500 titles in the Physical Sciences, 6,800 in the Health Sciences, 4,500 in the Life Sciences, and 8,100 in the Social Sciences (the latter including some 2,800 Arts & Humanities related titles). Titles which are covered are predominantly serial publications (journals, trade journals, book series and conference material), but considerable numbers of conference papers are also covered from stand-alone proceedings volumes (a major dissemination mechanism, particularly in the computer sciences). Acknowledging that a great deal of important literature in all fields (but especially in the Social Sciences and Arts & Humanities) is published in books, Scopus has begun to increase book coverage in 2013, and currently covers more than 121,000 books.

For this report, a static version of the Scopus database covering the period 2007-2016 inclusive was aggregated by geographical group, and subject. Subjects were defined for all subject areas, and by ASJC subject areas. When aggregating article and citation counts, an integer counting method was employed where, for example, a paper with two authors from a TC group country and one a EU 28 group country would be counted as one article for each group (i.e. 1 TC and 1 EU 28). This method was favoured over fractional counting, in which the above paper would count as 0.67 for TC and 0.33 for the EU 28, to maintain consistency with other reports (both public and private) we have conducted on the topic.

A body of literature is available on the limitations and caveats in the use of such ‘bibliometric’ data, such as the accumulation of citations over time, the skewed distribution of citations across articles, and differences in publication and citation practices between fields of research, different languages, and applicability to social sciences and humanities research. In social sciences and humanities, the bibliometric indicators presented in this report for these fields must be interpreted with caution because a reasonable proportion of research outputs in such fields take the form of books, monographs and non-textual media. As such, analyses of journal articles, their usage and citation, provides a less comprehensive view than in other fields, where journal articles comprise the vast majority of research outputs.
Appendix B
Glossary of terms

Article/Publication types (unless otherwise indicated) denotes the main types of peer reviewed documents published in journals: articles, reviews, and conference papers.

Article/Publication output for an entity is the count of articles with at least one author from that geographical group respectively (according to the affiliation listed in the authorship byline). All analyses make use of ‘whole’ rather than ‘fractional’ counting: an article representing international collaboration (with at least two different geographical groups listed in the authorship byline) is counted once each for every entity listed.

Compound Annual Growth Rate (CAGR) is defined as the year-over-year constant growth rate over a specified period of time. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series.

\[
\text{CAGR}(t_0, t_n) = \left( \frac{V(t_n)}{V(t_0)} \right)^{\frac{1}{t_n-t_0}} - 1
\]

- \(V(t_0)\): start value
- \(V(t_n)\): finish value
- \(t_n - t_0\) number of years.

Citation is a formal reference to earlier work made in an article or patent, frequently to other journal articles. A citation is used to credit the originator of an idea or finding and is usually used to indicate that the earlier work supports the claims of the work citing it. The number of citations received by an article from subsequently-published articles is a proxy of the importance of the reported research.

Field-weighted citation impact (FWCI) is an indicator of mean citation impact, and compares the actual number of citations received by an article with the expected number of citations for articles of the same document type (article, review or conference proceeding paper), publication year and subject field. When an article is classified in two or more subject fields, the harmonic mean of the actual and expected citation rates is used. The indicator is therefore always defined with reference to a global baseline of 1.0 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different document types (reviews typically attract more citations than research articles, for example) as well as subject-specific differences in citation frequencies overall and over time and document types. It is one of the most sophisticated indicators in the modern bibliometric toolkit.

When field-weighted citation impact is used as a snapshot, an un-weighted variable window is applied. The field-weighted citation impact value for ‘2008’, for example, is comprised of articles published in 2008 and their field-weighted citation impact in the period 2008-12, while for ‘2012’ it is comprised of articles published in 2012 and their field-weighted citation impact in 2012 alone. When field-weighted citation impact is used in trend analysis, a weighted moving window is applied. The field-weighted citation impact value for ‘2010’, for example, is comprised of the weighted average of the unweighted variable field-weighted citation impact values for 2008 and 2012 (weighted 13.3% each), 2009 and 2011 (weighted 20% each) and for 2010 (weighted 33.3%). The weighting applies in the same ratios for
previous years also. However, for 2011 and 2012 it is not possible to extend the weighted average by 2 years on either side, so weightings are readjusted across the remaining available values.

**Highly-cited articles** are those in the top cited X% of all articles published and cited in a given period. An entity’s number or share of highly-cited articles is treated as indicative of the excellence of their research. In this report, we present data on top 1, 5 and 10% cited articles.

**International collaboration** (i.e., research collaboration) in this report is indicated by articles with at least two different geographical groups listed in the authorship byline.

**Institutional collaboration** (i.e., research collaboration) in this report is indicated by articles with a single institute listed in the authorship byline.

**National collaboration** (i.e., research collaboration) in this report is indicated by articles with at least two different institutes from the same geographical group listed in the authorship byline.

Collaboration type labels are mutually exclusive. An international collaboration cannot be counted as a national or institutional publications.

**Journal** is a peer-reviewed periodical in which scholarship relating to a particular research field is published, and is the primary mode of dissemination of knowledge in many fields. Research findings may also be published in conference proceedings, reports, monographs and books and the significance of these as an output channel varies between fields.