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Advanced Technologies for Industry – Proof of concept

Capturing technology adoption via Twitter

This report has been prepared by Dr. Paresa Markianidou and Kincsö Izsak from Technopolis Group.

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European Innovation Council and SMEs Executive Agency (EISMEA)

Unit I-02.2 SMP / COSME Pillar

E-mail: EISMEA-SMP-COSME-ENQUIRIES@ec.europa.eu

Directorate General for Internal Market, Industry, Entrepreneurship and SMEs

Unit D.2 — Industrial forum, alliances, clusters

E-mail: GROW-ATI@ec.europa.eu

European Commission

B-1049 Brussels

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Section 1

1. Introduction and Methodology

1.1 Background

This report has been developed as a proof of concept in the framework of the Advanced Technologies for Industry (ATI) project, initiated by the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the European Innovation Council and SMEs Executive Agency (EISMEA).

The objective of this analysis is to investigate how social media analytics and in particular Twitter data can be used by policymakers to support them in terms of policy intelligence, problem identification and monitoring. To demonstrate some of the possibilities, this report provides a test case for two industries, notably automotive and chemicals and it zooms into two technological fields notably Artificial Intelligence and green technologies selected based on their suitability to gather Twitter data and provide first insights.

1.2 The use of Twitter data for science technology and innovation policy questions

Social media analytics can respond to a range of policy questions although it has to be interpreted with caution and in light of other data available in the subject. In Table 1 below we summarise the list of potential research questions and related policy framework.

Table 1: Policy framework – policy questions to test the use of Twitter as a source for policymaking intelligence

Function of the innovation system[1]	Key policy question and rationale	What Twitter can offer	How to extract information from Twitter	How it complements and what is the major drawback
Research and Innovation	**Key question:** What are technologies that dominate the transformation of the sector/domain and represent high technology readiness innovations? Are other technologies representing lower technology readiness innovations picked up by companies? **Rationale:** Identify technologies with major transformation potential in order to support EU/national policy agendas in their objectives such as decarbonisation **Key question:** How do technological trends change over time? **Rationale:** Monitor the development of an industry and a technological domain over a period of time – monitor the effects of the publication of a specific programme, communication or event	Which are the transformative technologies in the sector/thematic area in focus according to Twitter mentions? Which technologies represent strong and which weaker signals in terms of mentions and reach? Do they represent higher or lower technology readiness levels? Are there differences observed between EU27 and the US? How do Twitter mentions of technologies change over time?	Queries to extract mentions and corresponding social media metrics from major R&D investors in the industry and other innovative companies across the value chain	(+) Complements traditional insights from bibliometrics, patents, project data and expert consultations (-) Is subject to semantic analysis' limitations in big data sources in terms of 'noise' in the data and currently a lack of temporal evolution which can however be addressed via regular updates

[1] See Hekkert et al. (2007) for the seven functions of the innovation system

Function of the innovation system[1]	Key policy question and rationale	What Twitter can offer	How to extract information from Twitter	How it complements and what is the major drawback
Entrepre-neurial activity	**Key question**: Where should resources be invested to support actors within value chains to adopt transformative technologies which allow them to compete in global value chains and contribute to reaching policy objectives such as for example the 2030 and 2050 targets on decarbonisation? **Rationale:** Understand whether and which types of companies are active in transformative technologies and are likely to excel in the future and understand the degree to which traditional industry is lagging behind	Are companies adapting to technological transformation trends identified as key for the EUs competitiveness and policy objectives? (i) Are companies investing in technologies to decarbonise the sector/thematic area as proposed by e.g. the High-Level Panel of the European Decarbonisation Pathways Initiative? (ii) How do EU27 countries compare among them and internationally in terms of innovation competitiveness?	Mentions and corresponding social media metrics from the traditional industry in focus and wider value chain	(+) Complements insights from surveys (-) Faces limitations in the representativeness of companies due to the varying popularity of Twitter across EU countries and sectors
Creation of legitimacy/ counteract resistance to change	**Key question:** What is the opinion of stakeholders on transformative technologies? **Rationale:** Find out potential problems and corresponding perceptions that may inhibit market creation for technologically advanced products/services/solutions	Are major technological transformations in the sector positively received by the general public in Europe?	Sentiment of mentions from the general public plus industry on major technological transformations in the market	(+) Covers a gap in traditional evidence based on general public acceptance of emerging technologies (-) Equally representativeness limitations apply due to geographic and sectoral representation in Twitter

Source: authors

1.3 Twitter data metrics pros and cons

Twitter data includes social mentions, so called tweets (short messages) read and posted by registered users of the Twitter social networking and microblogging platform. Users can follow other users appearing in their feed with public posts remaining searchable and viewable by anyone, even without an account. Twitter captures a very large set of online conversations and expressions in a text format which can be easily analysed by machine algorithms and thus provide insights into relevant discussions around a specific topic. Social media communications can be redistributed through retweeting[2] and enable researchers to study online information flows. More precisely, they can "*identify what information or sentiment is being endorsed and propagated by users, and which users have the most or least influence in the spread of such messages*".[3] Typical metrics used in Twitter analysis include mentions, users, impressions, reach and sentiment (see definitions below). Originally, Twitter was used as a source of data for social science research to capture public expressions and reactions to events and it has slowly moved into advising also the policymaking sphere. Among the methodologies applied for this data we find speech classification - understanding the dynamics, enablers, drivers and inhibitors of certain types of conversations, applying supervised machine

[2] Boyd, D., Golder, S., Lotan, G. (2010, January). Tweet, tweet, retweet: Conversational aspects of retweeting on Twitter. In Proceedings of the Annual Hawaii International Conference on System Sciences (pp. 1–10). IEEE.
[3] Williams, M. L., Burnap, P. (2016). Cyberhate on social media in the aftermath of Woolwich: A case study in computational criminology and big data. British Journal of Criminology, 56(2), 211–238. And Ozalp (2020). Antisemitism on Twitter: Collective Efficacy and the Role of Community Organisations in Challenging Online Hate Speech

learning methodology to classify content and topic intelligence - text-mining conversations and identifying associated topics as the most relevant to extract insights for policy.

Twitter Metrics – definitions:

Mentions: measures the **volume of tweets** for a technology in the sector in focus

Users: measures the **unique Twitter users** associated to a technology in the sector in focus

Impressions: measures the **total number of followers for all tweets** associated to a technology in the sector in focus

Reach: measures the **potential total audience** for a technology in the sector in focus based on an estimate of total follower count for all unique Twitter handles

Sentiment: classification of people's opinions, attitudes and emotions as **positive, negative or neutral** using the method of Natural Language Processing

The use case for Twitter in policymaking is that social media and in particular Twitter data could provide a complementary source of data to the traditional survey-based monitoring mechanisms to enrich and/or validate existing findings but also to allow for more regular and timely collection of evidence for policymaking. With the appropriate methodology, Twitter data do allow the analysis of millions of users and companies that otherwise would be very costly to reach out to in a survey design. Advantage of social media data over surveys is that the latter might leave room for misinterpretation of questions or definitions and do not reveal the original motivations while online conversations are an indirect way of capturing true expressions around a topic.

More specifically and in particular in the field of research, technology and innovation policies, Twitter and social media can complement the findings of widely used data sources such as patent applications or bibliometrics that are traditionally used to analyse technology development but are limited since not all innovations are patented or academically written about. Also, Twitter helps address the lag in patent analysis by more actual mentioning of technological innovations of industry analysts. The latter is in fact another advantage of using Twitter as it includes mentions of the companies themselves and earned mentions. This helps capture companies without a Twitter account and in the case of companies which do not openly announce for instance the use of AI technologies it can capture market analysts who would likely refer to their use.

Analysing social media content can be a novel way to get additional complementary insights into technological trends and technology diffusion. Many of the companies and their business representatives have a Twitter account that they use for communication and thus leave a 'digital footprint' about their intentions and thinking. According to the latest publications, Twitter had 192 million active daily users in the last quarter of 2020, out of which 28% originated from the US and around 25% from the EU. Some 67% of all B2B businesses used Twitter as a digital marketing tool in 2018[4] that also proves the relevance of analysing the data from an industry or company perspective. Analysing the texts of these Tweets provides a new method to get a better understanding about certain technological transformational aspects. The advantage of using Twitter is the possibility to include earned tweets (notably third-party share from companies' blog posts or online content) as companies themselves may not always announce technological breakthroughs especially before they are brought to the market. Twitter data can be used for a vertical analysis of an industry and a technology. It is less suitable to make comparisons among EU Member States due to the different patterns of use across countries.

Finally, there is a lot of demand from policymakers for international comparison and benchmarking the EU in particular with the US, however not all traditional data collection methods allow for this and especially in real time. Twitter and some of the social media channels popular globally can provide a pathway for some international measurement. At least with the US, Japan and Canada, although not with China where Twitter has been blocked (despite this around 10 million Twitter accounts are from China).

Despite the promises of novel data sources such as social media there are drawbacks that should be taken into account when interpreting the results. Among the limitations in its use, there are uncertainties with respect to **representativeness** due to its popularity among companies across different sectors, locations and type of companies i.e., the inclusion of SMEs besides the large companies or more innovative and young companies. As a consequence, in terms of the analysis, Twitter can at best be used to perform analysis at the level of industry not at the combined level of country and industry due to representativeness limitations in the EU. Also, Twitter is one social media source but is not the only one and there will be others in the future. Many companies choose to have Twitter but equally many have Facebook or Instagram only. Thus,

[4] Statista, 2018

ideally, a combination of social media sources should be used to improve the coverage. Overall, using social media sources for the design of key performance indicators for policymaking requires an understanding of the sample biases and the consideration of eventual corrections as typically done for surveys applying e.g., post-stratification methodologies. Another disadvantage is the **reliability of the sources** which requires careful manual quality review process. Solutions to overcome this involve the inclusion of earned tweets from individuals with a minimum reach or following a predefined set of companies but quality reviewing remains a necessity as social media data is highly volatile, impacted by popular events, meaningless content and even tweets by web robots. From a technical viewpoint, sentiment analysis that can accurately classify content as positive or negative in the case of for instance tweets using sarcasm is still under development and needs improvements.

1.4 Scoping advanced technologies and industries

For this proof of concept, a pre-identified sample of companies have been included in the analysis in order to limit the uncertainties notably:

- R&D investors as identified by the European Commission Joint Research Centre in the Industrial R&D investment scoreboard which allows benchmarking between the EU and US companies.
- Companies that received private equity or venture capital investment as represented in the database called Crunchbase[5] that allows also a differentiation among traditional automotive companies and startups (including tech firms that develop a specific technological application and are specialised in the field of automotive)

The Twitter account of companies have been identified and carefully checked. By monitoring a controlled pre-identified sample, we limit false positives and improve the quality reviewing of outcomes and hence the reliability of messages of relevance to policymakers.

To scope mentions of an advanced technology in Twitter the query was based on the set of keywords of Artificial Intelligence defined within the Advanced Technologies for Industry (ATI) project (see ATI methodological report) for other data query purposes. Data were collected for the period of April 2020 to April 2021.

[5] https://www.crunchbase.com/

Section 2

2. Results of the analysis – Automotive sector

2.1 Global Twitter mentions on technology and innovation in the automotive sector

Globally, Twitter mentions on automotive technologies and innovations has had an estimated global reach of above 500 million followers during the years 2020-2021, which is an estimate based on the total follower count for all unique Twitter handles. Moreover, 53% of tweets have been retweeted. This makes the sector a good candidate for a proof of concept of Twitter-based analysis of automotive technologies and innovations given the high volume of mentions and engagement.

The volume of mentions and engagement in terms of technologies and innovation has been extracted by means of related keywords and it represents a sample of the tweets associated to the automotive industry. The setup of the query was motivated by the focus of the proof of concept on science and technology in order to reduce the noise in data (e.g. there is a large volume of meaningless information in Twitter associated to car sales and carmakers in general). This assessment is a necessary first step for each sectoral analysis as it impacts the calculation of indicators.

As the global Twitter data also suggest, the sector is undergoing a major transformation enabled by digital technologies (e.g. software on connectivity, battery management software, powertrain control software, autonomous and cooperative software), and electric motors and battery technologies associated to autonomous vehicles and electric vehicles, which dominate mentions on technologies and innovations. Mentions related to 5G technologies hint to the importance of connectivity reshaping the future of transportation. Vehicle-to-vehicle and vehicle-to-infrastructure communication is in the focus of automotive related social media discussions.

Tweets with a predominantly positive sentiment are associated to autonomous driving, electric vehicles and mobility paradigms while tweets with a predominantly negative sentiment are associated to mentions on autonomous driving related technologies. There is hence substantial controversy observed in Twitter mentions as measured by the sentiment analysis classifying tweets on autonomous vehicles as both positive and negative. Especially the negative sentiment of autonomous vehicles is associated to references on accidents, liability and performance of sensors.

A lot of the global attention in Twitter is concentrated on the American technology/car manufacturing company Tesla which was (according to Inovev)[6] the market leader of electric vehicles in 2020 in terms of global sales (model Tesla 3) and second in Europe after the Renault model called Zoe. Competitiveness in the automotive industry revolves around autonomous and electric vehicle technologies and the major role cooperation with technology firms play, ranging from multinationals to startups which have transformed the automotive value chain. The digital and environmental technological trends are as such blended producing innovative products, which represent technology readiness levels from low to high considering continuous improvements and research on batteries, sensors, charging modalities etc. Another hype is observed around the ola air pro, developed by Ola Cabs (OLΛ) an Indian multinational ridesharing company offering services for hire and food delivery.

[6] A market business company specialised in the automotive sector

Figure 1: Twitter insights on technology and innovation in the automotive industry globally

Automotive sector
insights from Twitter globally

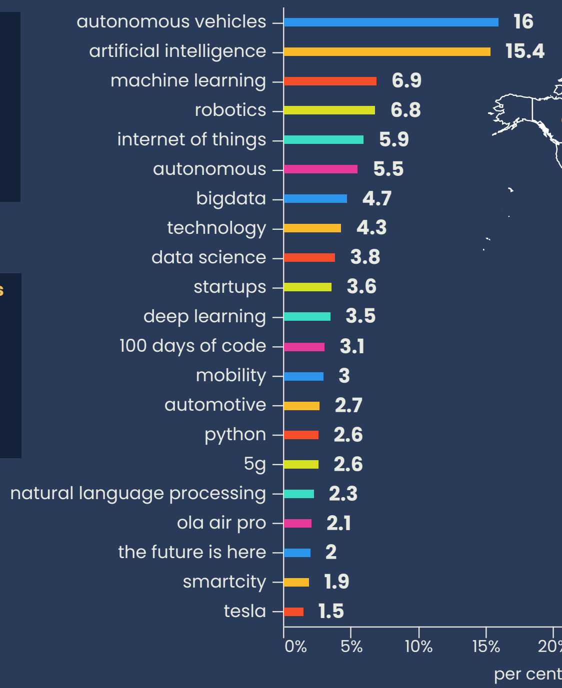
Keywords

Top 5 positive keywords

1. Autonomous driving
2. Future
3. Artificial Intelligence
4. Electric Vehicles
5. Mobility

Top 5 negative keywords

1. Autonomous driving
2. Accident
3. Fault
4. Humans
5. Wear sensors



Geographies

Top 10 countries

1. United States
2. United Kingdom
3. India
4. Germany
5. Canada
6. Italy
7. France
8. Australia
9. Netherlands
10. Nigeria

Top 5 European cities

1. London
2. Paris
3. Munich
4. Berlin
5. Frankfurt am Main

111 220 USERS	53% RE-TWEETS	516 609 319 REACH	398 46 44 949 IMPRESSIONS

MOST RETWEETED STORIES

- [...] Tesla Full Self-Driving Beta downloaded to your car Doubling beta program with 8.2 & probably 10X size with 8.3.
- [...] the world's first and only fully autonomous electric flying car. The Ola AirPro.
- [...] Japan building a futuristic smart city. AI, self-driving cars, robotics and more... all in one place
- [...] All Of Google's Self-Driving Cars Are Veering To The Left For Some Reason
- [...] Machine Learning engineers training self driving cars
- [...] SLAC, MIT, TRI researchers advance machine learning to accelerate battery development; insights on fast-charging
- [...] each year as the start date for autonomous cars gets pushed back the industry reveals that they have no real solution for their product crushing humans to death
- [...] Hyundai shares have surged on the back of reports that it is in talks with Apple over the development of self-driving cars
- [...] Imagine electric car chargers implanted in the street. A roadway that can keep self-driving cars on course. That's the goal for this Kansas City company
- [...] China is quickly catching up with the U.S. in autonomous vehicles, with 600+ robo taxis already conducting public road tests or ride-hailing pilots

Source: Technopolis Group, 2021

2.2 Twitter insights on transformative technologies in the automotive sector

The transformation of the automotive sector is observed along the value chain including carmakers, the first and second tier suppliers and technology companies either startups or large technological companies. To identify transformative technologies along the automotive value chain, this analysis relied on a sample of 1 138 companies in total including 43 top R&D investors as identified in the JRC's R&D industrial scoreboard and 1 095 companies from Crunchbase classified as companies active in the automotive sector (received private equity or venture capital investment or relevant in developing innovations for the sector).

The automotive sector is an R&D intensive industry which is undergoing transformation as a result of digital innovations, environmental objectives and pressures to decarbonise transport fully. The industry is urged to invest in technologies reducing costs for electric vehicle batteries and fuel-cell vehicles by means of EU regulation (the emission targets currently set at 95 g CO_2/km) but also competition pressures from companies such as Tesla, Amazon, Google, Microsoft etc.

Technologies that dominate current transformative trends are impacted by EU regulation in place and guidance such as through the '*High-level panel European decarbonisation pathways'* initiative suggesting concretely what are the technologies needed to decarbonise the transport sector. These include: electric vehicles, charging infrastructures, battery technology, communication between or within battery management systems, standards for integrated battery systems, ultra-fast plug-in chargers, wireless inductive charging (charging while driving), all-solid-state lithium-ion (Li-ion) batteries, hydrogen fuel cells. Also, in the Innovation Radar[7] 109 innovations have a very explicit reference to the automotive sector. A relevant question for policymakers is whether the industry is investing in technologies that facilitate and accelerate progress towards meeting the 2050 decarbonisation target, whether EU industry is competitive vis-à-vis international competition and how quickly could those technologies be brought to market.

Technologies that dominate the transformation process:

- **Social mentions** posted by the automotive sector in the EU27 countries and the US developing products/solutions for the automotive industry **are dominated – not surprisingly - by** the applications of digital technologies with a clear emphasis on technologies enabling **autonomous driving and Electric Vehicles (EVs) and in particular batteries, battery range and high-resolution point clouds.** These technologies represent a key source for transformation in the sector with environmental implications when scaled.
- What is however more interesting is the analysis of **weaker signals that include various technologies piloted by specialist companies** and startups:
  - high-resolution point clouds and technologies for autonomous vehicles,
  - optimising future connected and autonomous vehicle systems,
  - teleoperations to monitor smart cars from a distance with applications also for robotaxis or controlling freight up to 40 tons,
  - sensor simulation, advanced computer vision, neural network acceleration hardware, edge computing addressing human error and accidents,
  - sound and climate control technologies alleviating motion sickness,
  - connected vehicle data, blockchain for connected vehicle data.
- Tweets on technologies such as **(autonomous) aerial vehicles for vertical mobility** have a wide reach. References to such 'flying car technologies' represent weak signals relative to EVs and can be considered as futuristic alternatives as robotics and drone technologies further develop. Flying car technology is expected to reduce pressure on traditional motorways and ease traffic congestion especially relevant for large urban areas and for smart city concepts.
- Another group of tweets is concentrated around **automotive component solutions** that help adapt car interiors to autonomous driving. These include for instance curved and multiple displays needed for connected cockpit, the integration of light detection and ranging technology, radar technologies into vehicle, adding ambient lighting, alerts, information in the seats or headrests.
- **Automotive cybersecurity** represents a weak signal in Twitter and is typically addressed by specialist companies but corresponds to technological advancements that are necessary for safe use of big data analytics on mobility with vast applications considering smart cities and sustainable mobility planning among others.

[7] https://www.innoradar.eu/

- Environmental pressures are discussed and areas in which major EU carmakers are investing in include solutions to **bring down the cost of electric vehicles** for wider scale adoption which in turn contributes to achieving EU targets on ‘Greenhouse Gas Emission reduction’.
- Environmental technologies dominating social mentions refer to Electric Vehicles (EVs) and batteries. EVs are currently the main avenue to decarbonise the automotive industry and the most important topic when talking about green technologies in this sector. Weaker signals of relevance in environmentally friendly technologies relate to use cases of **hydrogen powered fuel cells** and **solar electric vehicles**. Hydrogen storage systems are expected to drive competitive performance in the industry.

In terms of technology readiness, the aforementioned technologies represent medium to high technology readiness levels (TRLs). Priority technologies associated to batteries and hydrogen fuel cells suggested by the high-level panel represent weak signals in Twitter in terms of volume of mentions and reach although they do represent areas of investment in the automotive value chain.

The following patterns and differences can be observed along the value chain:

- EU27 and US **top R&D performers** tend to put greater emphasis on **electric vehicles** e.g. battery range, battery cost and software for Electric Vehicles (EVs) compared to the wider automotive value chain. In the case of innovative startups the emphasis is more strongly attributed to technologies on autonomous vehicles. A major driver for this is EU regulation and in particular emission targets.
- Among automotive tech startups, different technological needs are addressed typically connected to autonomous vehicles such as **sound and climate control technologies** (technology that creates ambient comfort within the vehicle) **alleviating motion sickness or connected vehicle data** which has wide reaching use cases in terms of applications and business models.
- While top R&D performers and startups are highly focused on autonomous driving and electric vehicles related technologies, traditional car component manufacturers are following these trends more slowly as the Twitter patterns demonstrate.

Cooperation and alliances along the value chain

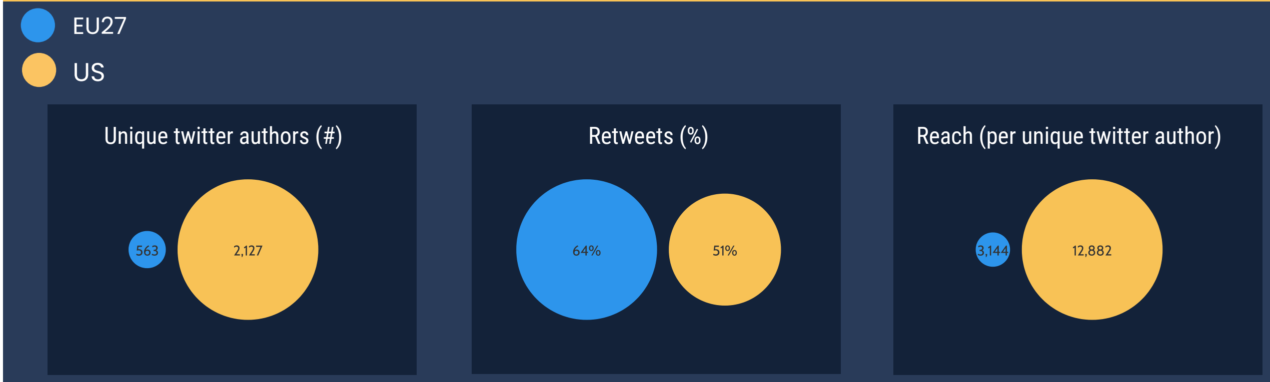
From a competitiveness perspective, despite the absence of major high-tech companies in the EU27, carmakers have been establishing collaborations with major high-tech companies overseas such as the cooperation between Volkswagen and Microsoft or between Audi and Huawei or between Volvo with NVIDIA as also revealed by the high Twitter mentions. These trends are relevant since digital transformation trends and technological breakthroughs have been leading traditional carmakers to go beyond alliances and cooperation vertically and horizontally. Today, they pursue more and more strategic collaborations with technology companies ranging from small to multinational companies to get access to state of the art digital technologies applied in the automotive sector. The competitiveness of the European automotive industry with respect to scalable new products implies overcoming barriers not just in terms of higher technology readiness but also access to material and density of urban charging stations and fast charging station networks seamlessly integrated across EU countries. As such greater intensification of cooperation will be necessary between all the EU27 carmakers but also with fuel suppliers, the semiconductor and mining industries which does not appear yet to be the case.

The question whether sufficient investments are being made to accelerate technology readiness that improve environmental performance cannot be addressed only by analysing social media. Nevertheless, the insights from Twitter data suggest that less emphasis is placed on technologies with an impact on decarbonising transport in the short term given the lower technology readiness level of these technologies. Reasons may be the involvement of a large volume of technology companies which are more likely to invest in digital technologies and software applications for autonomous driving rather than solid state battery technologies with a greater environmental impact. Stimulating further research and innovation in these areas may thus be needed. Accounting for the fact that no alternative source of data is available to monitor research and innovation activities besides patenting and surveys, regular monitoring of companies via social media might represent a good mechanism to monitor activities of companies on technologies and innovations expected to have a significant impact on decarbonising transport.

Figure 2: Twitter insights of the automotive sector in the EU27 and US

Automotive sector

insights from twitter in the EU27 and US from the automotive value chain



Popular tweets from Top R&D investors in EU27 (measured according to reach)
Volkswagen to build half a dozen battery cell factories
Volkswagen is working on technology to bring down cost of EV batteries
Daimler truck unit to focus on CO2-neutral technology
Volkswagen is conducting a feasibility study in China about flying cars, Europe's biggest automaker said on Tuesday, joining a growing number of companies looking into the potential technology
Volkswagen and Microsoft Extend Collaboration to Self Driving Car Software
Wuppertal, Germany's innovative approach to zero emission mobility? [...] a fleet of #hydrogen fuel cell electric buses

Popular tweets from automotive manufacturers (measured according to reach)
Leveraging sound design technologies from the gaming industry
Sound design to help relieve motion sickness when traveling in self-driving vehicles
Smart climate control system with an increased use of artificial intelligence
Autonomous aerial vehicles (AAV)
Service generating simulation scenarios from recorded measurement data used to validate functions for autonomous driving and driver assistance
Smart climate control system with an increased use of artificial intelligence
Connected vehicle data for smart mobilie [...] smarter, safer, and more accessible cities [...] Enhanced precision, accuracy, frequency, latency, sensor volume and intelligence

Source: Technopolis Group, 2021

Comparing the EU27 with companies in the United States, we observe a four-fold difference in absolute numbers of unique twitter authors (based on Crunchbase data) and reach in the United States. In terms of the share of retweets which is used as a proxy of endorsement of tweets by users we observe that it is higher in tweets associated to EU companies compared to tweets associated to companies in the United States. The figures for the United States are driven by one company, the technology/automotive company Tesla which has a very wide reach in terms of tweets. It is also a company with a strong presence in the EU27 in terms of sales numbers and share of total EVs in the EU27, with a very wide coverage in its supercharging network in the EU, with technologically advanced products in terms of autonomous driving and a high R&D investment including in its research and engineering portfolio raw material alternative sources and solid-state batteries. As such it represents a major competitor to EU27 carmakers but also a company that can contribute to the acceleration of decarbonisation in the transport sector globally.

2.3 Twitter insights on automotive companies’ adaptation to technological transformation

Monitoring the uptake of Artificial Intelligence (AI) and Electric Vehicle (EV) technologies in the automotive sector is relevant information for EU and national policymakers when setting the policy agenda, when evaluating or assessing policies/regulations supporting or impacting the uptake of AI and EV technologies and during the monitoring of progress towards the 2030 and 2050 targets of transport decarbonisation.

Regular monitoring of activities can be performed via patent analysis for patentable technologies and via surveys with the industry which represent commonly used sources of data providing valuable insights. In this report we investigate whether the use of Twitter data can provide an additional mechanism in the monitoring of AI and EV technologies uptake by industry and in particular the automotive sector. The main motivation is the regularity and timeliness it allows but question marks arise with respect to the depth of the insights gained and the robustness of the results. The metrics we use to proxy uptake are:

1. The ratio of AI/EV related Twitter mentions/ users/ impressions/ reach to technology and innovation tweeter mentions/ users/ impressions/ reach. This indicator proxies the AI/EV activity of automotive companies as reflected in social media by comparing it to any other activities on technology or innovation. The ratio is then converted to decimal numbers to allow comparison across geographies and benchmark AI/EV activity. The definitions of social media metrics (mentions, users, impressions and reach) have been provided above under Section 1.3.
2. The share of retweeted mentions. This indicator proxies the endorsement and propagation of AI/EV tweets by users.
3. The share of positive and negative sentiment derived from the total Twitter mentions.

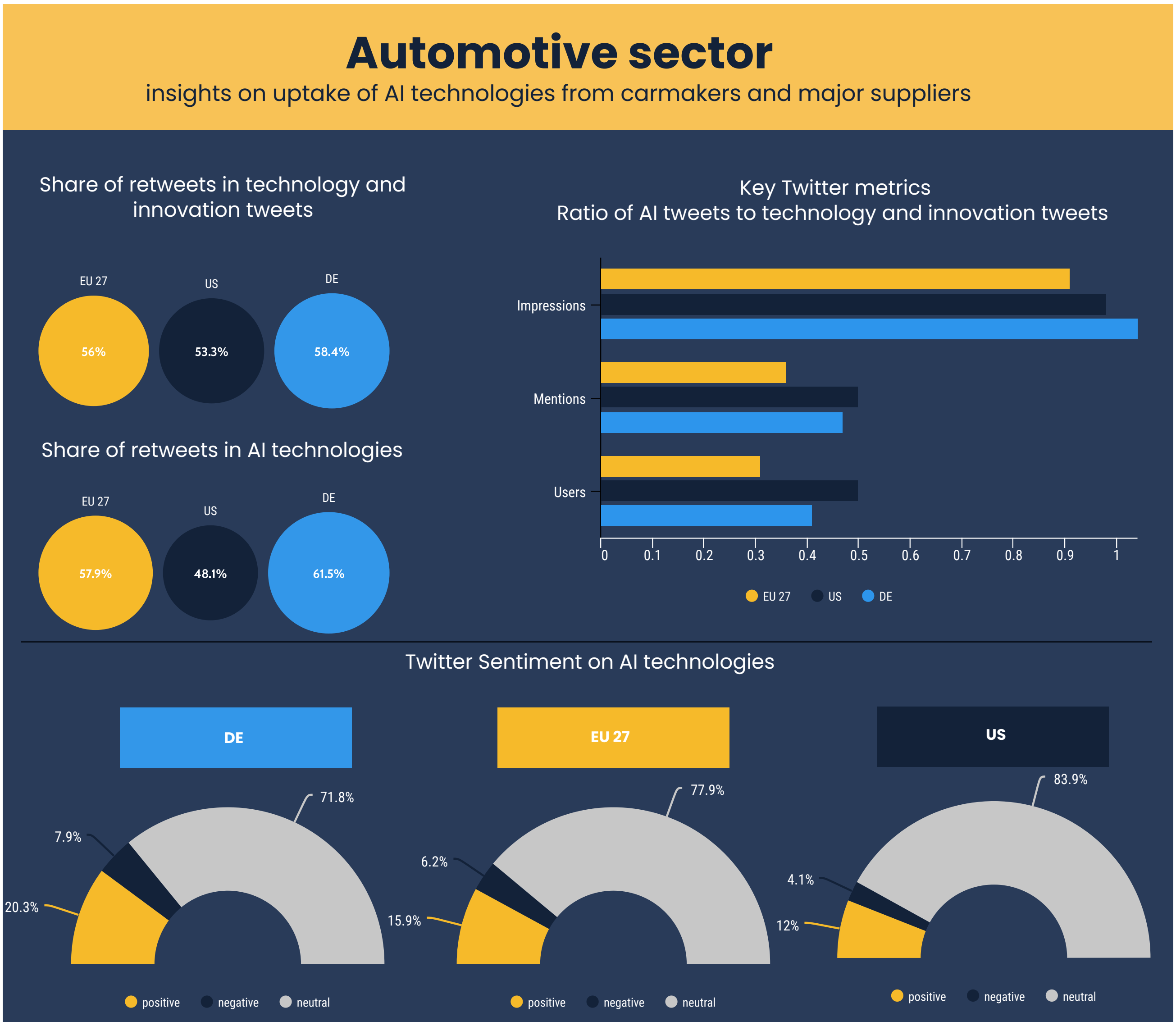
All indicators are presented as ratio of data extracted via queries on AI/EV technologies to queries on technology and innovation. The reason to use this ratio instead of a share in total tweets is that in the automotive sector, companies are referred in numerous non-technology related contexts inflating the number of mentions and distorting the interpretation of the indicator.

All indicators are compared across geographies to benchmark AI/EV social media activity within Twitter over the same period of April 2020-April 2021.

Below, main findings are summarised based on the tweets of EU27, Germany and US companies from the automotive sector and major suppliers. In total the sample includes 206 EU27 companies of which 49 are German. The US is represented by 64 companies with an equal mix of car manufacturers and major suppliers. Main observations derived include the following:

- In terms of impressions the converted ratio is ca. 1 for all geographies which means that followers of AI/EV compared to followers of technology and innovation are equivalent. The ratio is slightly higher for Germany compared to the EU27 and the US.
- Volume of mentions are equally comparable across the geographies and in all cases lower than mentions in AI/EV technologies.
- The reach of AI/EV technologies is larger than the reach in technology and innovation tweets with Germany standing out. This shows the importance of the latter technologies in the country.
- Unique Twitter users are comparable across geographies with a highest ratio of AI/EV users in the US.
- It should be mentioned that the US company Tesla in Twitter represents the main driver behind the US statistics.

Figure 3: Twitter insights on uptake of Artificial Intelligence technologies and electric vehicles



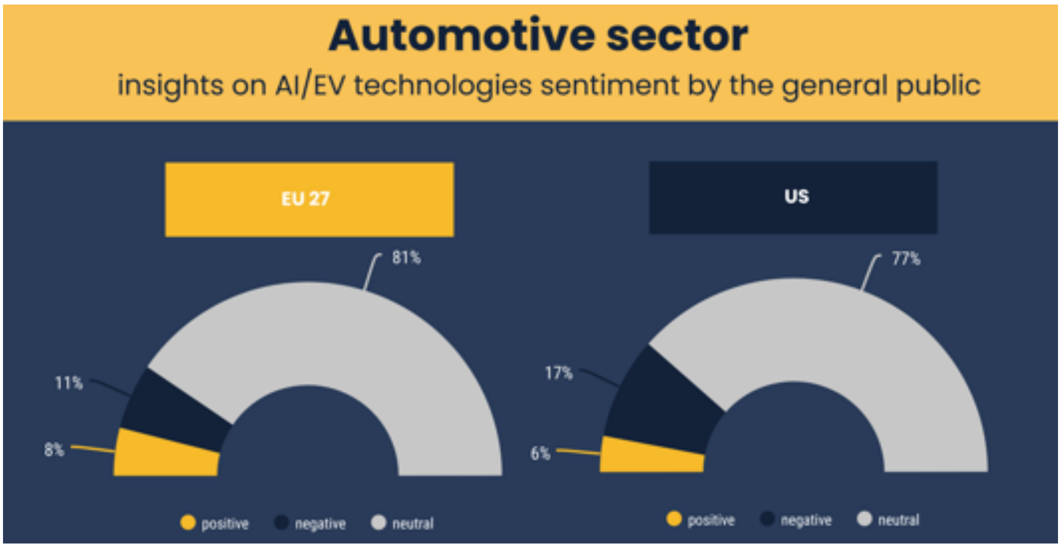
Source: Technopolis Group, 2021

2.4 General public sentiment on automotive transformative technologies

The adoption rate of technologies is expected to contribute and accelerate the reduction of greenhouse gas emissions and lead to decarbonisation of the transport sector, and it can have a substantial contribution to meeting 2030 and 2050 targets. As such acceptance or the lack of adoption is a relevant metric for policymakers to monitor and social media offers the possibility to quantitatively measure by means of sentiment analysis.

The main observations derived from Twitter is that sentiment on AI/Electric Vehicles technologies in the EU27 is 8% positive sentiment versus 11% negative when considering all authority levels, hence all unique users irrespective of the number of followers they have. Restricting the results to a so-called high authority level and hence those unique users with a high number of followers the results do not change substantially with positive sentiment at 9% and negative sentiment at 7%. There is hence no indication of a strong negative sentiment towards AI/EV technologies in the EU27. The analysis also suggests that in the US a somewhat higher percentage is associated to positive sentiment of AI than to negative sentiment when compared to the EU. To some extent this might reflect more ongoing discussion around the ethical use of AI in the EU than in the US. In the case of AI/EV combination the results differ with a more notable negative sentiment (6% positive versus 17% for all authority levels and 7% positive versus 14% negative for high authority level).

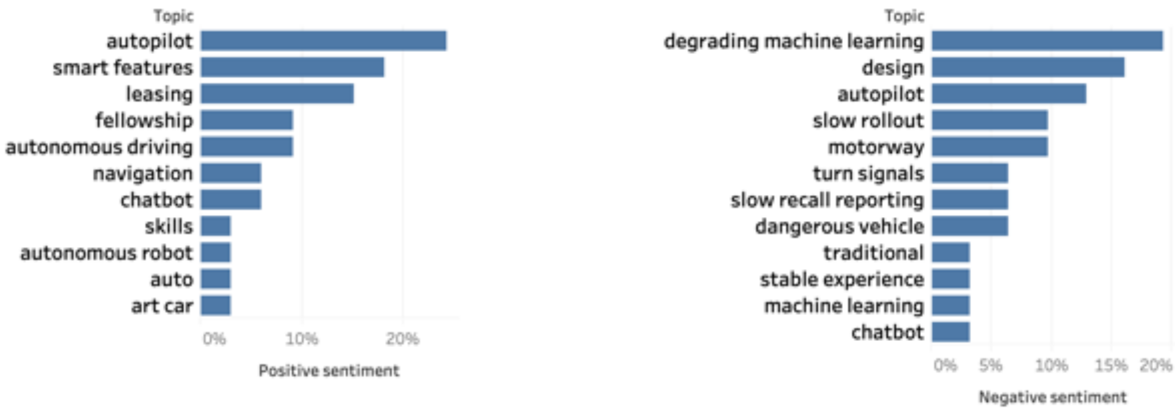
Figure 4: Twitter insights on sentiments related to AI/EV in the automotive sector



Source: Technopolis Group, 2021

Positive sentiments are linked to topics around autopilot, smart features, leasing, fellowship. Negative sentiments have been captured around topics such as degrading machine learning models, design, autopilot, slow rollout, motorway, turn signals.

Figure 5: Topics linked to tweets with a positive or a negative sentiment



Source: authors

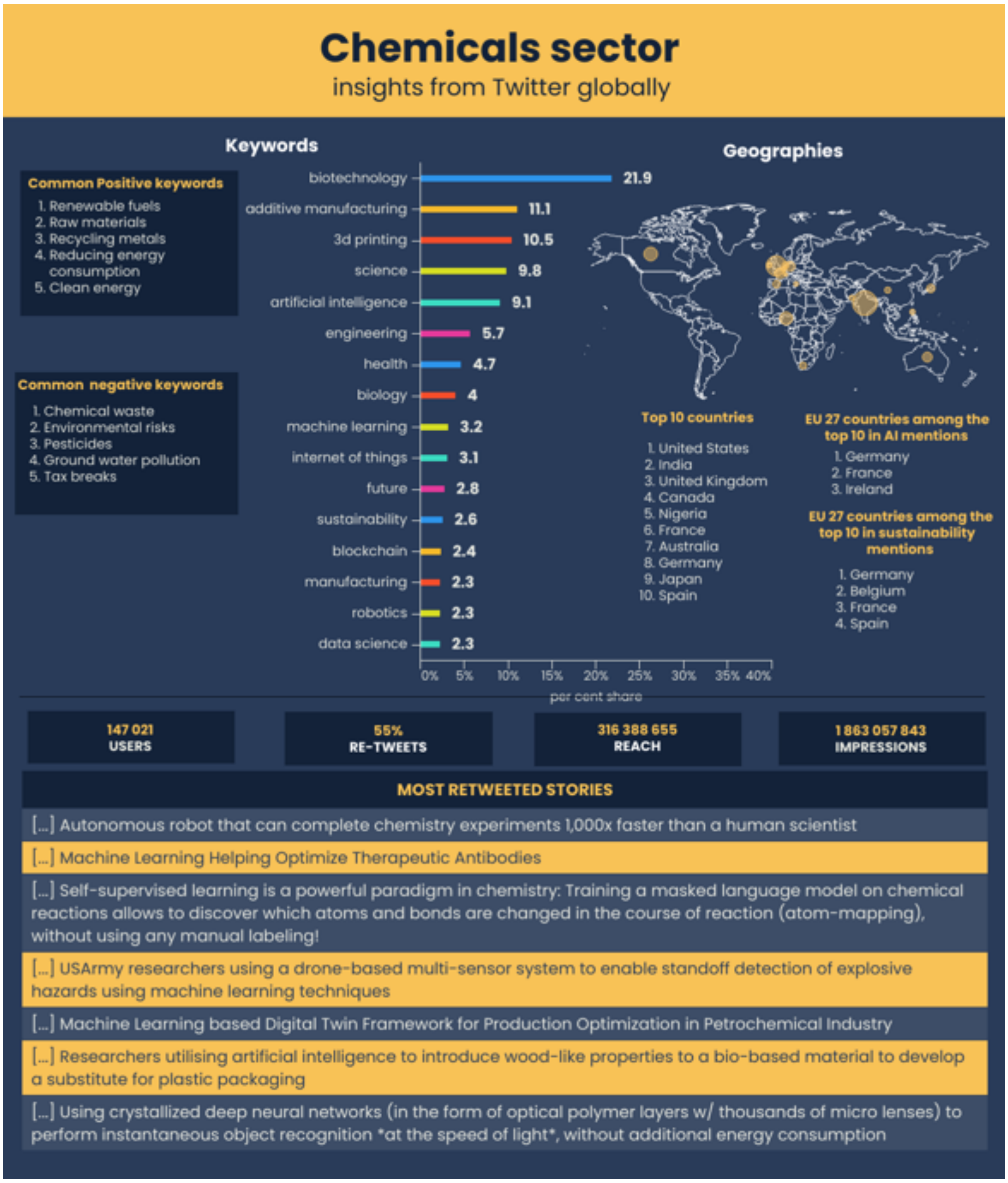
Section 3

3. Results of the analysis – Chemicals industry

3.1 Global Twitter mentions on technologies and innovations in the chemicals sector

Globally, Twitter mentions on chemical technologies and innovations has had an estimated global reach of above 300 million followers during the years 2020-2021, which is an estimate based on the total follower count for all unique Twitter handles. Moreover, 55% of tweets have been retweeted.

Figure 6: Twitter insights on technology and innovation in the chemicals industry globally



Source: Technopolis Group, 2021

According to global Twitter data, mentions are dominated by digital technologies and sustainability concerns especially in relation to pesticides and plastics generated by the industry. As chemicals cut across many other sectors and value chains undergoing transformation there is equally several mentions in the automotive and agricultural sectors. Chemical companies are undergoing a radical transformation from raw materials supply, R&D via production to customers and end users increasingly affected by disrupting trends such as sustainability and the circular economy, digitalisation and additive manufacturing[8]. Twitter mentions also confirm these well-known trends with keywords such as biotechnology, additive manufacturing, 3D printing, AI on the top. The Internet of Things and industrial automation are expected to increase the performance of chemicals manufacturing plants and have been also a topic of social mentions.

Tweets with a predominantly positive sentiment are associated to environmental related topics such as renewable fuels, raw materials, recycling, clean energy and better energy consumption. Negative sentiment can be observed in relation to topics such as chemical waste, pesticides, water pollution. Tax breaks are also seen in a negative context which might reflect that companies that produce pesticides, fossil fuels, chemicals for industrial farming are still getting subsidies and tax breaks worldwide, while their impact on the environment is devastating.

3.2 Twitter insights on transformative technologies in the chemicals sector

Overall Twitter mentions on technologies from top R&D investors, traditional chemicals manufacturers and startups emphasise sustainability, namely decarbonisation, climate change and circular economy in relation to plastics, waste and recycling.

Given the importance and impact of the EU Green Deal on the chemicals industry there is equally several mentions on sustainability statements of large corporations stepping up investments to meet 2030 targets. They also publish about the establishment of cooperation with academic/research institutions, which reflects the high expectations around the commercialisation of technological innovations. Also, Artificial Intelligence technologies stand out with numerous applications from data sharing, optimising global value chains to sustainability applications counting or detecting plastic waste in oceans. There is equally a large diversity of R&D applications across different technologies given the diversity of the chemicals industry and especially in the case of R&D sensitive technological fields such as biotechnology.

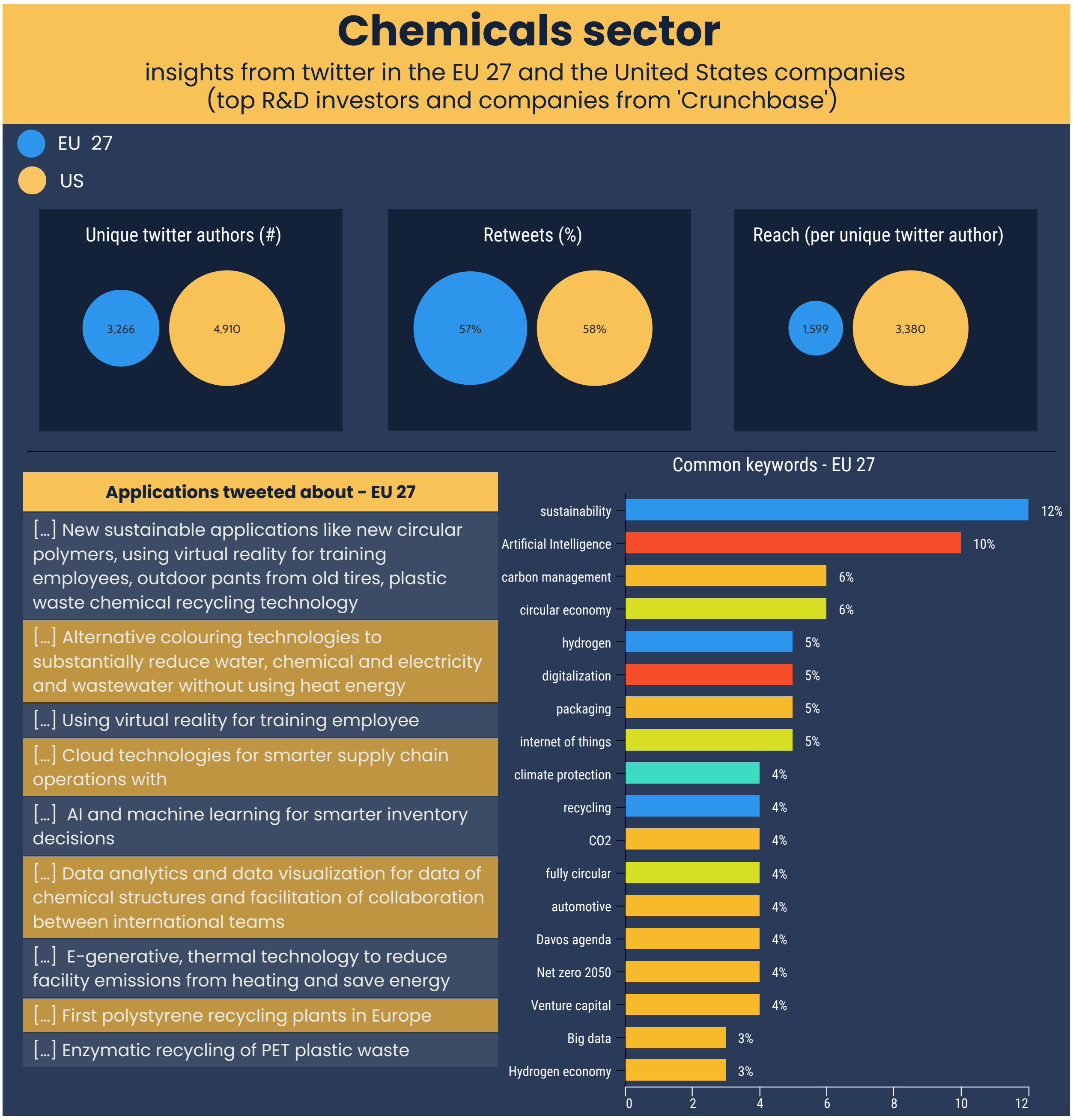
The main observations from the tweets of European chemical industry companies investigated are the following:

- As the social mentions reveal, several ongoing collaborations stand out between **chemical industry companies and major AI tech providers that aim at advancing data analytics**. This is particularly relevant for large R&D intensive chemical industries generating substantial data across different geographies.
- **Investment in climate friendly production methods** by chemicals industry companies is a hot topic on social mentions. An example is the investment in regenerative thermal technology to reduce facility emissions from heating, or electrical heating and technologies to reduce chemical waste.
- In the field of plastics, several technologies and initiatives have been pursued for instance related to **biodegradability, non-toxicity and with the objective to create microplastic free** plastics especially used in cosmetics.
- 2030 targets appear to have further incentivised commitment for new technologies to reduce CO2 emissions in the chemical industry as expressed by the social mentions of multinationals and large companies. These sectors, however, have been under regulatory pressure for many years and the technologies to reduce CO2 emissions in chemical reactions for the production of chemical products **have not reached high technology readiness levels** as **most mentions refer to pilots**.
- Technological breakthroughs achieved by the chemical industry are impacting also many other sectors. An example is the production of hydrogen without CO2 emissions with high impact on other sectors such as the automotive sector. Cooperation between major industry players includes for example the mass manufacturing of electrolysers for green hydrogen or the use of biomethane gas for cyclopentanone production.
- A major driver towards sustainable chemicals appears also the **US Sustainable Chemistry R&D Act** to which European headquartered multinationals commit to as well. It involves innovations in redesigning products and manufacturing processes starting at the molecular level for better health,

[8] https://ati.ec.europa.eu/reports/sectoral-watch/technological-trends-chemical-industry

environmental and energy use profiles and is expected to accelerate sustainable innovation across the entire value chain in the US.

Figure 7: Twitter insights from EU27 and US chemicals sector



Source: Technopolis Group, 2021

Weaker signals of technological transformation include various technologies piloted by specialist companies and startups:

- **Hydrogen** and more specifically green hydrogen processes, providing hydrogen storage is an opportunity for the chemicals industry as the tweets around this topic highlight.
- **Biostimulants** that promote plant growth mineral nutrient uptake and vegetative protection without the need for chemical pesticides.

Comparing Twitter patterns of EU27 versus US chemical industry companies (based on Crunchbase data) there is three-fold difference in reach with US companies at ca. 16 million while EU companies at ca. 5 million. The share of retweets, however, does not vary with both EU27 and US headquartered companies at ca. 50%.

3.3 Twitter insights on chemical companies' adaptation to technological transformation

Monitoring the uptake of digital technologies namely AI and technologies related to sustainability in the chemicals sector is relevant information for the EU and national policymakers when setting the policy agenda, when evaluating or assessing policies and regulations supporting or impacting the uptake of AI and sustainability supportive technologies and during the monitoring of progress towards the 2030 and 2050 targets of decarbonisation.

Regular monitoring of activities can be performed via patent analysis for patentable technologies and via surveys with the industry which represent commonly used sources of data providing valuable insights. In this report we investigate whether the use of Twitter data can provide an additional mechanism in the monitoring of AI and sustainability supportive technologies uptake by industry and in particular the chemicals sector. The main motivation is the regularity and timeliness it allows but question marks arise with respect to the depth of the insights gained and the robustness of the results. The metrics we use to proxy uptake are:

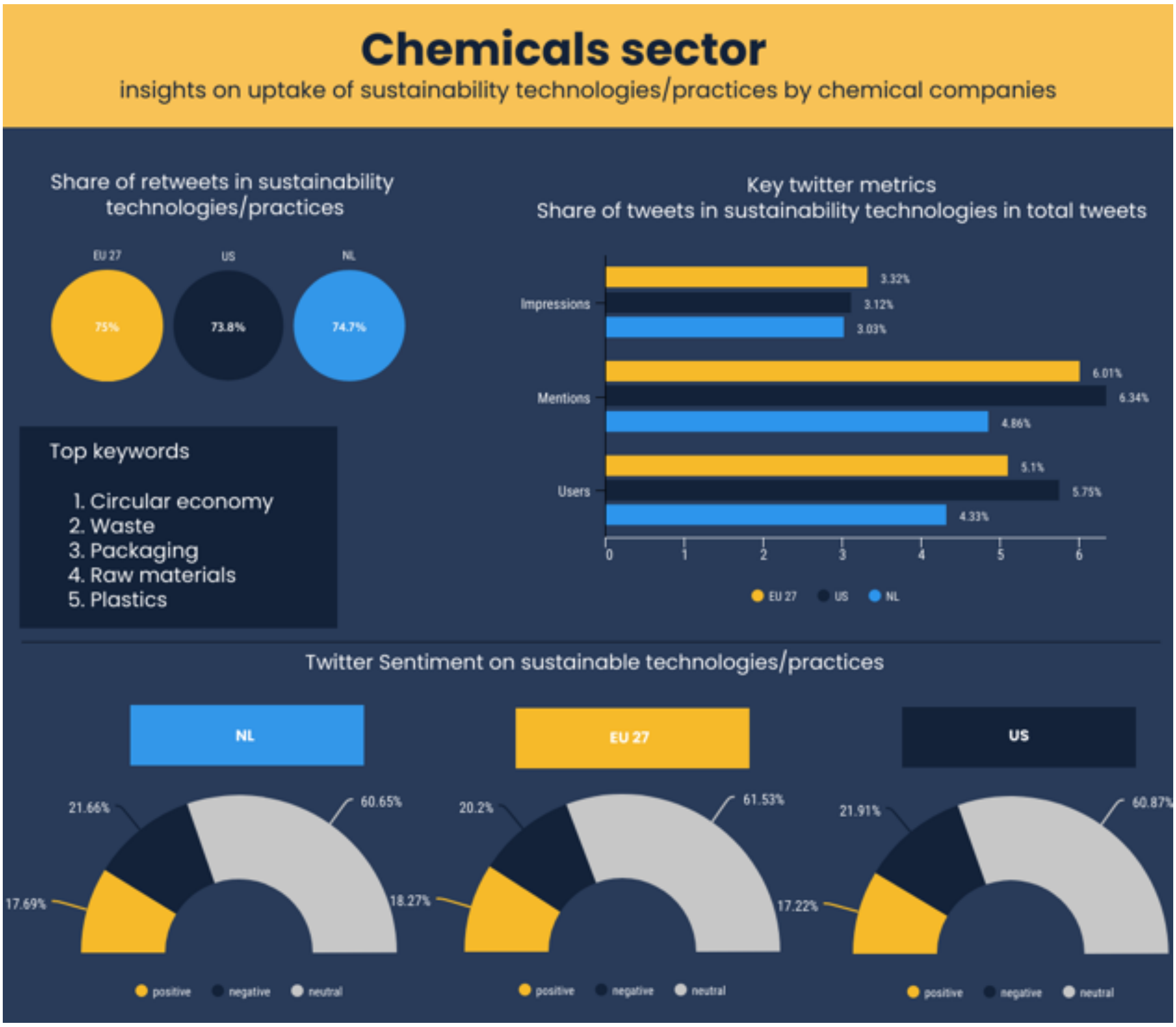
1. The share of AI/sustainability related Twitter mentions/ users/ impressions/ reach to technology and innovation tweeter mentions/ users/ impressions/ reach in total tweets in the sector. This indicator proxies the AI/sustainability activity of chemical companies as reflected in their social media activities
2. The share of retweeted mentions. This indicator proxies the endorsement and propagation of AI/EV tweets by users
3. The share of positive and negative sentiment derived from the total Twitter mentions.

Below, main findings are summarised based on the tweets of EU27, the Netherlands and US companies from the chemicals sector. In total the sample includes 1 215 EU27 companies, 100 companies from the Netherlands and 100 US companies.

The following observations can be made based on the above data:

- In sustainability technologies/practices, only minor differences are observed across the three geographies in terms of impressions, mentions and users. The share of retweets is high with above 70% of tweets being retweeted.
- The shares of all metrics in the EU27 and in the Netherlands are low, below 10%. **This shows that while sustainability is certainly present in social media mentions it still represents a niche.**
- In AI technologies, mentions from companies for all geographies are too low (representing below 0.5% of total mentions) to use meaningfully for the construction of key performance indicators. In all cases (EU27, US and Netherlands) there are below 150 mentions over the year in focus (in the period from April 2020 to April 2021) and with impressions ranging from 300 000 to 700 000.

Figure 8: Twitter insights on uptake of sustainability technologies by chemical companies



Source: Technopolis Group, 2021

3.4 How are major transformations received by the general public in Europe?

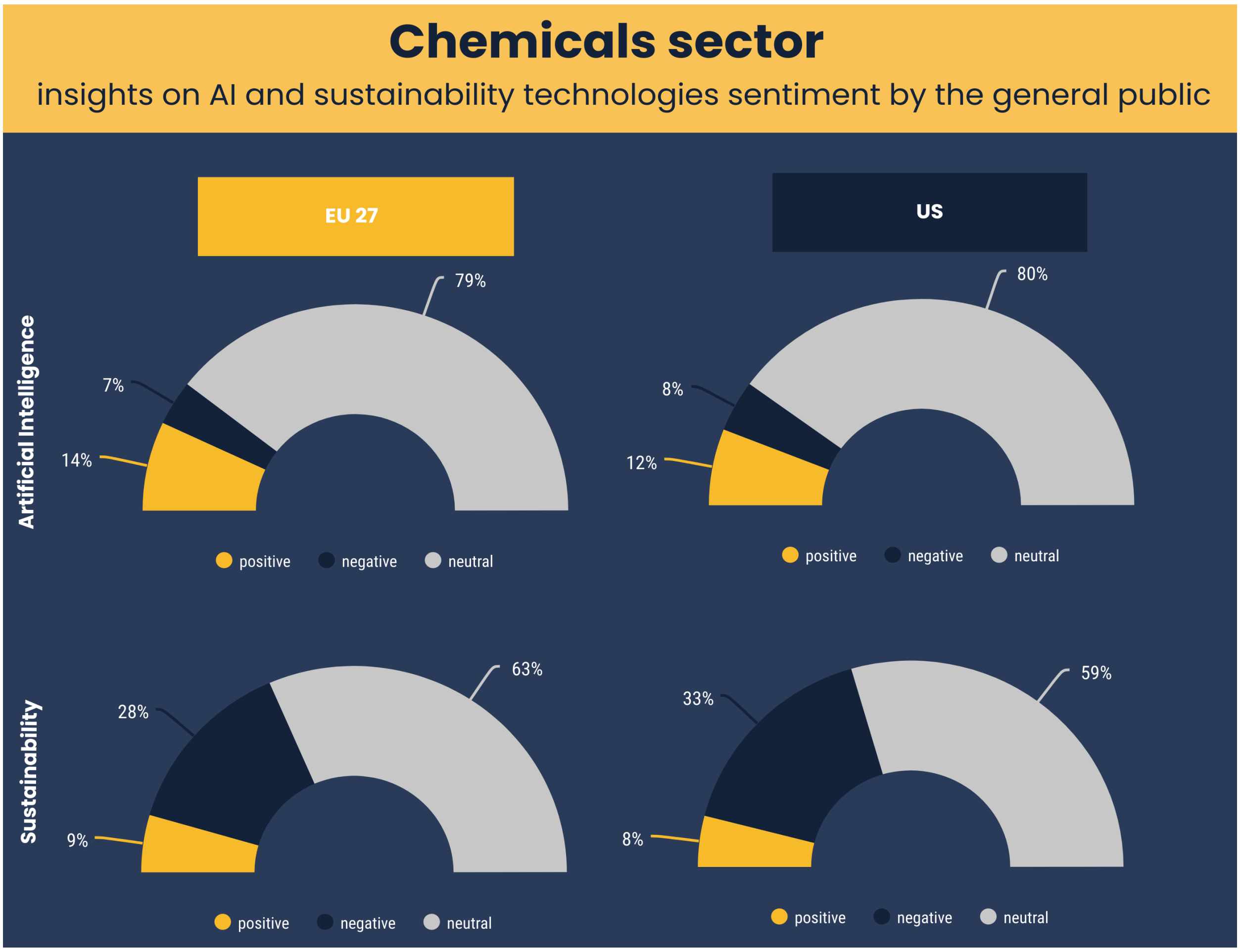
Analysing the sentiment of the general public on AI and sustainability technologies in the chemicals sector is relevant for policy makers as it allows the monitoring of behavioural change as a result of increasing awareness of citizens on their role towards a zero-carbon transition. Sentiment analysis helps understand whether momentum is being created towards decarbonisation. Results obtained for this proof of concept in the chemicals sector are summarised below.

The main observations derived from Twitter is that sentiment on AI in the EU27 and the US tends to be more positive for AI technologies and less positive on sustainability technologies.

More specifically in the case of AI we observe 14% positive sentiment versus 7% negative when considering all authority levels, hence all unique users irrespective of the number of followers they have. Restricting the results to a so-called high authority level and hence those unique users with a high number of followers the results do not change substantially with positive sentiment at 14% and negative sentiment at 6%. There is hence no indication of a strong negative sentiment towards AI technologies in the EU27. When looking at the US, results are similar (with 12% positive versus 17% and 8% negative for any authority level or high).

The conclusions change in the case of sustainability technologies with a more pronounced negative sentiment of 33% negative versus 9% positive sentiment which is similar to what is observed in the US (33% negative and 8% positive sentiment). No notable changes are observed when the authority level is high (28% negative versus 11% positive in the EU27 and 31% negative versus 12% positive in the US). The negative sentiment is driven by global sustainability discussions on social media which put substantial emphasis on: 1) the pollution from plastics and overall waste (chemical, radioactive, massive etc.) and 2) Chemical waste, environmental risks, pesticides, ground water pollution, action, money, tax breaks. On the other hand renewable fuels, **raw materials**, recycling metals, reducing energy consumption are among the top keywords used in a positive way.

Figure 9: Twitter insights on sentiments related to AI/EV in the automotive sector



Source: Technopolis Group, 2021

Section 4

4. Conclusion on the use of Twitter to analyse technological transformation

Based on the analysis of Twitter data from the automotive and chemicals sectors, the following conclusions can be drawn:

- Social media analysis and in particular topic modelling offers the possibility to monitor technological transformation of sectors and industries and allows the identification of numerous weak signals pointing at upcoming potential disruptions. In order to be able to monitor signals of technologies with scaling more regular monitoring of Twitter data would be necessary as it would allow for temporal evolution of topics in term of volume of mentions but also in terms of topic composition. To perform this analysis efficiently and effectively AI data models are needed. Quality reviewing of data is necessary and can only partially be automatised. Equally, sectoral experts are key to guide the analysis (e.g. by specifying the weak signals to monitor closely) and challenge outcomes which may be the result of noisy data.
- Performing the analysis in regular intervals would allow to reflect about trends and changes in social mentions of specific technologies. For slow moving trends and for the purpose of identifying weak signals it is necessary to work with three to six months to one year intervals.
- Technology readiness and uptake of technologies in a sector can partially be captured by looking at specific technologies and observing volume via different Twitter metrics on mentions, users, reach, impressions, sentiment. Such metrics are informative but not sufficient to assess technology readiness. Foremost, an analysis of the text is needed. Sectors that receive a lot of social media attention and include a good volume of social mentions on technologies can indeed be analysed qualitatively which can contribute to an in-depth analysis of the types of companies involved and activities undertaken to assess the technology readiness level. Given however the nature of tweets i.e., limited to short posts, further desk research is needed, by consulting those companies' websites. As such the analysis of technology readiness would be best done in the context of a case study (on a number of technologies) with Twitter providing signals and quantitative evidence. Technically, it is possible to link tweets with company websites and hence automise the labour intensiveness of this process. A simplified process could for instance entail starting from company websites, extracting references to their Twitter account and merging with the Twitter data.
- Substantial R&D, innovation and engineering activity is undertaken by companies and public organisations which is not yet patented or patentable. Twitter can provide a proxy to capture this gap if monitored on a regular basis (e.g. every three months or per semester). Such insights cannot however be used yet for statistical analysis with objective to advise policy makers as typically representativeness of the data is not addressed and outcomes cannot be validated and are hence perceived as unreliable. As such the contribution of this data is limited to the research sphere and at best complements formal statistics on business demography or economic performance. Due to the fact that the latter are not granular enough to analyse trends at the technological level, sources like Twitter offer a unique opportunity to collect evidence which otherwise would not be available. Given hence the shortcomings of traditional data and the limitations of looking exclusively at Twitter data, a way to better understand the R&D and innovation activity of companies would be to merge information from different sources including patents, bibliometrics, R&D grants, investments, social media/blogs/news, company websites, technological skills supply and demand, etc. The AI data modelling required is already advanced and is continuously improving considering many Horizon 2020 and other projects working on these technical advancements. It is the access to data considering licensing, privacy, legal considerations that requires careful consideration for each data source considered.
- Cooperation among different types of companies along the value chain (e.g. between tech firms and traditional companies) is partly possible by Twitter that can reveal new alliances and collaboration agreements. This type of data is currently monitored in other databases such as Crunchbase or Zephyr of Bureau van Dijk among others which combine different sources of data. The completeness of such analysis using Twitter only would need to be established.
- The monitoring of general public opinion is very relevant in terms of understanding the broader acceptance and scalability of specific technologies. It can be used to understand the major concerns

and then be targeted via better communication or by supporting more R&D activity in those areas. Currently and as many of the technologies discussed by industry are not yet mature it is clear that the sentiment is inconclusive. The information could serve as baseline for future monitoring to observe change in the perception of the general public. This is one of the areas were Twitter and other social media show great potential considering the role of the citizen in policymaking. Expanding the sources of social media would be necessary to address representatives of different demographic groups. A limitation is the accuracy of sentiment analysis. A careful assessment as to how well the algorithms perform in this respect is a necessary complement in studies relying on such metrics.

- Twitter data is very noisy data which means that each time an analysis is made quality reviewing of the raw data is necessary before aggregating numbers. There is no 'one algorithm/analysis fits all sectors' approach possible. Instead for each sector and its social media presence tailoring is needed to design appropriate indicators and manual exclusion of keywords/topics. In each case consultations with sectoral experts are required for both the design phase and validation phase of the analysis.
- Due to the Covid-19 pandemic that also affected tweeting behaviour, the years 2020 and 2021 are years that are expected to represent a structural break in time series analysis across domains. As such repeating the exercise in the future to re-assess its usefulness is deemed appropriate and necessary.

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Statista, 2018, 2021

Appendix A: Data calculations

Automotive

Main metrics (count and %) – Objective: help understand social media presence of a sector

Category	Count and %
Retweets	95 928 53%
Original Tweets	39 724 22%
Quoted	26 188 14%
Replies	17 354 9%

Category	Count
Users	111 220
Mentions	179 194
Impressions	3 984 644 949
Reach	516 609 319

Top hashtags

Hashtag label	Count
ai	19 066
machine learning	12 291
iot	10 634
autonomous	9 924
artificial intelligence	8 534
bigdata	8 430
autonomous vehicles	7 999
self driving cars	7 703
data science	6 722
deep learning	6 330
100 days ofcode	5 496
robots	5 468
mobility	5 287
self driving	5 030
automotive	4 803
tech	4 715
python	4 664
5g	4 616

Hashtag label	Count
driverless	4 328
nlp	4 036
robotics	4 018
olaairpro	3 700
driverless cars	3 667
The future is here	3 650
startups	3 475
smart city	3 366
startup	2 943
technology	2 902
robot	2 711
tesla	2 705

Notes: One year: April 2020-April 2021; Authority level: all; query built according to automotive keywords and AI keywords

Top global keywords

Rank	Top keywords	Count
1	**autonomous driving**	16 100
2	**ai**	7 589
3	**robotics**	5 162
4	**Machine learning**	3 987
5	**iot**	3 506
6	**startups**	3 107
7	**technology**	2 811
8	**big data**	2 786
9	**5g**	2 128
10	**mobility**	1 847
11	**smart city**	1 655
12	**data science**	1 603

AI sentiment – Objective: show positive and negative sentiment

Top 5 positive keywords	Top 5 negative keywords
1. Autonomous driving 2. Future 3. AI 4. EVs 5. Mobility Overall Positive Sentiment: 8%	1. Autonomous driving 2. Accident 3. Fault 4. Humans 5. Wear sensors Overall Negative Sentiment: 9%

Notes: only high authority level calculated according to followers.

Category	Count Authority level >=1 (scale 1-9)	Count >=7 Authority level >=7 (scale 1-9)
Neutral	140 080	27 700
Negative	25 411 (14%)	3 910 (11%)
Positive	12 487 (6%)	2 920 (8%)
Not Rated	1 216	205

Top locations - Objective: show geographic spread and concentration

Locations	Count	Top 5 European cities
United States	9 062	1. London
United Kingdom	2 165	2. Paris
India	1 507	3. Munich
Germany	1 081	4. Berlin
Canada	848	5. Frankfurt am Main
Italy	744	
France	647	
Australia	507	
Netherlands	416	
Nigeria	358	
Switzerland	334	
Japan	249	
Spain	242	

Top stories – Objective: showcase popular tweets

Most retweeted in 2020 [tweets with above 300 re-tweets]

[…] Tesla Full Self-Driving Beta downloaded to your car Doubling beta program with 8.2 & probably 10X size with 8.3.

[…] the world's first and only fully autonomous electric flying car. The Ola AirPro.

[…] Japan building a futuristic smart city. AI, self-driving cars, robotics and more... all in one place

[…] All Of Google's Self-Driving Cars Are Veering To The Left For Some Reason

[…] Machine Learning engineers training self driving cars

[…] SLAC, MIT, TRI researchers advance machine learning to accelerate battery development; insights on fast-charging

[…] each year as the start date for autonomous cars gets pushed back the industry reveals that they have no real solution for their product crushing humans to death

[…] Hyundai shares have surged on the back of reports that it is in talks with Apple over the development of self-driving cars

[…] Imagine electric car chargers implanted in the street. A roadway that can keep self-driving cars on course. That's the goal for this Kansas City company

[…] China is quickly catching up with the U.S. in autonomous vehicles, with 600+ robo taxis already conducting public road tests or ride-hailing pilots

Section I Background information and support data

Popular tweets - Objective: Highlight top technologies and popular tweets

		Top technologies	Highlights of recent popular tweets	Observations
R&D investors in EU27 (source: industrial scoreboard)	+Technology + Innovation	• Electric vehicles • Batteries • Self-driving/ autonomous. vehicles • Remote control parking • AI • IoT • Robotics • 5G • Machine learning • Data science • Cloud • Biometrics	• Volkswagen to build half a dozen battery cell factories • Volkswagen is working on technology to bring down cost of EV batteries • Daimler truck unit to focus on CO2-neutral technology • Volkswagen is conducting a feasibility study in China about flying cars, Europe's biggest automaker said on Tuesday, joining a growing number of companies looking into the potential technology • Volkswagen and Microsoft Extend Collaboration to Self Driving Car Software • Wuppertal, Germany's innovative approach to zero emission mobility? […] a fleet of #hydrogen fuel cell electric buses	• Digital technologies and battery technologies are key areas of innovation activity among companies • Benefits and potential of Hydrogen power are increasingly investigated • References to flying cars technologies represent weak signals relative to EVs but may not just be long term future breakthroughs • Automotive cybersecurity equally represents a weak signal and is typically addressed by specialist companies
Startups in EU27 (source: crunchbase)	+ Automotive + AI	• Platform as a service • Smart cities (in addition to the above)	• Leveraging sound design technologies from the gaming industry • Sound design to help relieve motion sickness when traveling in self-driving vehicles • Smart climate control system with an increased use of artificial intelligence • Autonomous aerial vehicles (AAV) • Connected vehicle data • Service generating simulation scenarios from recorded measurement data used to validate functions for autonomous driving and driver assistance	• Technologies where startups appear active relate to autonomous driving and in particular associated to sound and climate control technologies alleviating motion sickness • Several technologies associated to autonomous driving and connected vehicle data

Notes: period one year 12 April 2020 – 12 April 2021

Twitter data for Top R&D investors and companies in Crunchbase - Objective: summary of data comparing the EU with the US

ompanies	keywords	#companies	Mentions	Users -Unique Twitter authors	Retweets	Impressions	Reach	Sentiment
Top R&D investors in EU27	+Technology + Innovation	43	12 000	7 710	5 790		80.2 m	15% positive 6% negative
Companies in Crunchbase in sector in the EU27	+Automotive + AI	1 095	720	563	461 (64%)	3.9 m	1.77 m	19% positive 8% negative
Top R&D investors in the US	+Technology + Innovation	21	490	400	164			15% positive 3% negative
Companies in Crunchbase in sector in the US	+Automotive + AI	2 849	2 210 565	1 680 447	1 250 (56%) 267 (47%) Tesla effect	34.6 m 25.2 m	16.9 m 10.5 m	14 & 12% positive 7 & 8% negative

Section II

Key social media metrics - Objective: summary of data applying the ratio approach

geo	*metric*	*Ratio of AI tweets to technology and innovation tweets (converted to decimal numbers to compare on a level field between geographies)*
DE	*Impressions*	*1.04*
EU	*Impressions*	*0.91*
US	*Impressions*	*0.98*
DE	*mentions*	*0.47*
EU	*mentions*	*0.36*
US	*mentions*	*0.50*
DE	*Reach*	*1.83*
EU	*Reach*	*1.18*
US	*Reach*	*0.93*

geo	*metric*	*Ratio of AI tweets to technology and innovation tweets (converted to decimal numbers to compare on a level field between geographies)*
DE	*Users*	*0.41*
EU	*Users*	*0.31*
US	*Users*	*0.50*

Section III

Sentiment analysis data - Objective: summary of sentiment analysis data for section III

Category	EU27 no authority level	EU27 authority level high	US no authority level	US authority level high
Neutral	10 519	3 176	33 115	7 913
Negative	1 475	354	7 943	1 462
Positive	1 163	276	2 969	806
Not Rated	119	18	261	41
positive	8%	9%	6%	7%
negative	11%	7%	17%	14%

Sentiment analysis keywords - Objective: top negative keywords

Top negative	**Occurences**
self	332
neurons	32
new intelligent system	32
Millions industry	62
fully autonomous cars	28
accident	53
Technology	25
Monkey	22
Mind	22
rocket boosters land	21
reverse thrust	21
video game	21
control	21
driver	21
elon musk's teams	21
billion	20
future	20
food delivery	18
waste of money	18

Top negative	Occurences
car crashes	17
cybersecurity's visibility problem	17
responsibility	17
systems	17
humans	17

Sentiment analysis keywords - Objective: top positive keywords

Top positive	Occurences
self	173
cars	166
autonomous vehicles	82
autonomous cars	38
future	33
customers	31
safe experience	31
artificial intelligence	23
impressive autonomous electric car	22
massive battery pack	22
garage	22
mobility groups	39
autonomous mobility	21
important consultation	21
world	18
technology	16
pretty radical bet	15
suppliers	15
share	15
tesla's valuation	15
autonomous taxi pods	15
great ev	15
entire car industry	15
idle observation	15
software	14
machine	12

Chemicals

Data for all technologies for different sets of keywords – Objective: showcase differences

Metrics	Keywords		
	Technology innovation, future	AI technology	Sustainability technologies
Users	147 021	34 975	72 681
Mentions	201 184	50 858	107 182
Impressions	1 863 057 843	314 717 503	863 606 288
Reach	316 388 655	110 487 616	200 053 007
Retweets	55%	60%	56%
Sentiment	Negative 12% Positive 16%	Negative 7% Positive 14%	Negative 31% Positive 11%

Keywords returned from Technology, innovation and future query – Objective: shows the thematic scope

Keyword	Count
innovation	9 305
technology	8 860
biotechnology	6 959
chemistry	4 595
additivemanufacturing	4 509
3dprinting	4 239
science	3 951
ai	2 690
engineering	2 297
research	1 975
biotech	1 922
tech	1 730
covid19	1 665
biology	1 613
chemical	1 455
machinelearning	1 315
chemicals	1 259
iot	1 255
future	1 144
sustainability	1 057
artificialintelligence	1 015
india	986
healthcare	977
blockchain	967
manufacturing	950
art	943

Keyword	Count
health	928
robotics	919
datascience	914
automation	899

AI Top locations - Objective: shows geographic spread and concentration

Locations	Count	Country Code
United States	8 744	US
United Kingdom	4 934	GB
India	3 493	IN
Germany	1 020	DE
Canada	945	CA
Nigeria	778	NG
Japan	536	JP
France	518	FR
Australia	413	AU
Ireland	390	IE
South Africa	374	ZA
Spain	370	ES
Switzerland	347	CH
Turkey	339	TR
Mexico	316	MX
Brazil	305	BR
Pakistan	294	PL
Netherlands	276	NL
Belgium	234	BE
Mainland China	211	CN

Sustainability Top locations - Objective: shows geographic spread and concentration

Locations	Count	Country Code
United States	20 195	US
United Kingdom	9608	GB
India	7263	IN
Canada	2934	CA
Nigeria	1709	NG
Australia	1624	AU
Germany	1591	DE
Belgium	1378	BE
France	1158	FR

Locations	Count	Country Code
Spain	919	ES
Ireland	845	IE
Netherlands	803	NL
Italy	733	IT
Kenya	668	KE
Switzerland	647	CH
Turkey	498	TR
South Africa	483	ZA
Mainland China	430	CN
Mexico	419	MX
Philippines	418	PH
Finland	415	FI
Brazil	361	BR
Japan	355	JP
Sweden	337	SE

Top stories – Objective: showcase popular tweets

[…] Machine learning predicts possible antimicrobial peptides

[…] Machine Learning Helps Identify Cancerous Cells by Measuring their pH

[…] Autonomous robot that can complete chemistry experiments 1,000x faster than a human scientist. Over an 8-day period the robot chose between 98 million experiment variants and discovered a new catalyst for green technologies

[…] Machine Learning Helping Optimize Therapeutic Antibodies

[…] Self-supervised learning is a powerful paradigm in chemistry: Training a masked language model on chemical reactions allows to discover which atoms and bonds are changed in the course of reaction (atom-mapping), without using any manual labeling!

[…] Ghana installed digital petroleum monitoring system six months ago and we has had revenues GHS600 million more than same period last year. A first in Africa to install this digital metering system and second in the world only to the US

[…] USArmy researchers using a drone-based multi-sensor system to enable standoff detection of explosive hazards using machine learning techniques

*[…] using crystallized deep neural networks (in the form of optical polymer layers w/ thousands of micro lenses) to perform instantaneous object recognition *at the speed of light*, without additional energy consumption...*

[…] Machine Learning based Digital Twin Framework for Production Optimization in Petrochemical Industry

[…] Autonomous robot that can complete chemistry experiments 1,000x faster than a human scientist

[…] Machine Learning based Digital Twin Framework for Production Optimization in Petrochemical Industry

[…] Chemistry and computer science join forces to apply artificial intelligence to chemical reactions

[…] 10 radical technologies that can change the world: 1. Microneedles for painless injections and tests 2. Sun-powered chemistry 3. Virtual patients 4. Spatial computing 5. Digital medicine 6. Electric aviation 7. Quantum sensing https://t.co/uB1wfq6X5q https://t.co/tCS7JZKFuE

[…] A new autonomous robot that can detect and report dangerous chemicals on the battlefield

[…] Researchers utilising artificial intelligence to introduce wood-like properties to a bio-based material to develop a substitute for plastic packaging

Section I

Popular tweets - Objective: Highlight top technologies and popular tweets

		Top technologies	Highlights of recent popular tweets	Observations
R&D investors in EU27 (source: industrial scoreboard)	+Technology + Innovation	• circular economy • hydrogen • chemical recycling • sustainability • climate • recycling • big data analytics /cloud • virtual reality • energy transition • battery materials • thermal technology • biotechnology • machine learning • 3dprinting • Artificial intelligence • Additive manufacturing • 3D printing	• New sustainable applications like e.g. new circular polymers, Using virtual reality for training employees, outdoor pants from old tires, plastic waste chemical recycling technology • Alternative colouring technologies to substantially reduce water, chemical and electricity and wastewater without using heat energy • Using virtual reality for training employee • Cognitive cloud technologies for smarter supply chain operations with • AI and machine learning for smarter inventory decisions • Data analytics and data visualization for data of chemical structures and facilitation of collaboration between international teams • E-generative, thermal technology to reduce facility emissions from heating and save energy • First polystyrene recycling plants in Europe • Enzymatic recycling of PET plastic waste	• Intensified collaborations between the chemical industry and major AI providers to advance data analytics • AI as a driver of bioscience innovation • climate friendly production methods • 2030 targets spur commitment for new technologies to reduce greenhouse gas emissions in the chemical industry in the EU • Investments in Regenerative thermal technology to reduce facility emissions from heating • A major driver towards sustainable innovation in the chemicals value chain is the US Sustainable Chemistry R&D Act. Involves innovations in redesigning products and manufacturing processes starting at the molecular level for better health, environmental and energy use profiles. It is expected to accelerate sustainable innovation across the entire value chain in the US

[...] New sustainable applications like new circular polymers, using virtual reality for training employees, outdoor pants from old tires, plastic waste chemical recycling technology

[...] Alternative colouring technologies to substantially reduce water, chemical and electricity and wastewater without using heat energy

[...] Using virtual reality for training employee

[...] Cloud technologies for smarter supply chain operations with

[...] AI and machine learning for smarter inventory decisions

[...] Data analytics and data visualization for data of chemical structures and facilitation of collaboration between international teams

[...] E-generative, thermal technology to reduce facility emissions from heating and save energy

[...] First polystyrene recycling plants in Europe

[...] Enzymatic recycling of PET plastic waste

Twitter data for Top R&D investors and companies in Crunchbase - Objective: summary of data comparing the EU with the US

Crunchbase (sector only)

	US	EU
Users	4 910	3 266
Mentions	6 979	5 169
Impressions	46 883 967	18 824 885
Reach	16 594 870	5 222 443
Retweets	58%	57%
Sentiment	17% positive 20% negative	12% positive 6% negative

Top R&D investors (sector only)

	US	EU
Users	982	1 521
Mentions	1 254	2 061
Impressions	13 870 587	10 458 680
Reach	5 570 925	2 155 764
Retweets	56%	51%
Sentiment	26% 1%	20% positive 2% negative

Notes: sentiment driven by the fact that corporate tweets are namely included

Keywords returned from sustainability of EU top R&D investors

Keyword	Count
sustainability	104
ai	85
carbon management	55
xircular economy	53
artificial intelligence	45
hydrogen	44
digitalization	41
packaging	40
iot	40
climate protection	38
recycling	38
keep challenging	37
co2	36
fully circular	35
automotive	33
Davos agenda	31
Net zero 2050	31
Venture capital	31
Big data	28
Hydrogen economy	28

Keywords returned from sustainability of US top R&D investors

Keyword	Count
innovation	104
inventabetternow	47
technology	47
lithium	40
vechain	31
vefam	31
sustainability	24
formulae	24
ev	22
recycling	21
zerocarbon	20
agriculture	20
biocontrol	17
bioag	17
germany	17
climate	16
climatecrisis	16
dupont	16
renewables	16
cop26	16
electricvehicles	16
energy	16
research	16
batteries	16
europe	16
vulcan	16
circulareconomy	15
enzyme	15
makeanimpact	15
polystyrene	15

Section II

Key social media metrics - Objective: summary of data

Technology	Geography	Category	Count
no specification	EU	Category	Count
no specification	EU	Users	36 267
no specification	EU	Mentions	45 849
no specification	EU	Impressions	434 208 336
no specification	EU	Reach	216 117 879
no specification	EU	Retweets	24 768
no specification	EU	Original Tweets	11 996
no specification	EU	Quoted	5 621
no specification	EU	Replies	3 464
no specification	EU	Neutral	37 777
no specification	EU	Negative	4 179
no specification	EU	Positive	3 369
no specification	EU	Not Rated	524
AI	EU	Users	112
AI	EU	Mentions	143
AI	EU	Impressions	707 344
AI	EU	Reach	456 395
AI	EU	Retweets	104
AI	EU	Original Tweets	22
AI	EU	Quoted	16
AI	EU	Replies	1
AI	EU	Neutral	135
AI	EU	Positive	7
AI	EU	Negative	1
AI	EU	Not Rated	0
Sustainability	EU	Users	1 850
Sustainability	EU	Mentions	2 754
Sustainability	EU	Impressions	14 422 184
Sustainability	EU	Reach	4 816 745
Sustainability	EU	Retweets	1 301
Sustainability	EU	Original Tweets	976
Sustainability	EU	Quoted	347
Sustainability	EU	Replies	130
Sustainability	EU	Neutral	1 694
Sustainability	EU	Negative	556
Sustainability	EU	Positive	503
Sustainability	EU	Not Rated	1
AI	US	Neutral	43

Technology	Geography	Category	Count
AI	US	Positive	4
AI	US	Negative	0
AI	US	Not Rated	0
AI	US	Retweets	26
AI	US	Original Tweets	18
AI	US	Quoted	3
AI	US	Replies	0
AI	US	Users	26
AI	US	Mentions	47
AI	US	Impressions	320 895
AI	US	Reach	171 574
Sustainability	US	Users	1 190
Sustainability	US	Mentions	1 771
Sustainability	US	Impressions	10 306 176
Sustainability	US	Reach	3 846 509
Sustainability	US	Retweets	849
Sustainability	US	Original Tweets	627
Sustainability	US	Quoted	210
Sustainability	US	Replies	85
Sustainability	US	Neutral	1 078
Sustainability	US	Negative	388
Sustainability	US	Positive	305
Sustainability	US	Not Rated	0
no specification	US	Users	20 680
no specification	US	Mentions	27 954
no specification	US	Impressions	330 487 090
no specification	US	Reach	190 493 505
no specification	US	Retweets	16 339
no specification	US	Original Tweets	7 118
no specification	US	Quoted	3 129
no specification	US	Replies	1 368
no specification	US	Neutral	23 928
no specification	US	Negative	2 171
no specification	US	Positive	1 773
no specification	US	Not Rated	82

Section III

Sentiment analysis data - Objective: summary of sentiment analysis data

Authority level	AI all	Sustainability all
Global authority level any	Positive:14 Negative:7	Positive:9 Negative:33
Global authority level high	Positive:14 Negative:6	Positive:11 Negative:28
EU27 authority level any	Positive:15 Negative:5	Positive:10 Negative:30
EU27 authority level high	Positive:17 Negative:4	Positive:12 Negative:28
US Authority level any	Positive:12 Negative:8	Positive:8 Negative:33
US authority level high	Positive:12 Negative:8	Positive:12 Negative:31

About the 'Advanced Technologies for Industry' project

The EU's industrial policy strategy promotes the creation of a competitive European industry. In order to properly support the implementation of policies and initiatives, a systematic monitoring of technological trends and reliable, up-to-date data on advanced technologies is needed. To this end, the Advanced Technologies for Industry (ATI) project has been set up. The project provides policymakers, industry representatives and academia with:

- Statistical data on the production and use of advanced technologies including enabling conditions such as skills, investment or entrepreneurship
- Analytical reports such as on technological trends, sectoral insights and products
- Analyses of policy measures and policy tools related to the uptake of advanced technologies
- Analysis of technological trends in competing economies such as in the US, China or Japan
- Access to technology centres and innovation hubs across EU countries

You can find more information about the 16 technologies here: https://ati.ec.europa.eu.

The project is undertaken on behalf of the European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs and the European Innovation Council and SMEs Executive Agency (EISMEA) by IDC, Technopolis Group, Capgemini, Fraunhofer, IDEA Consult and NESTA.

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