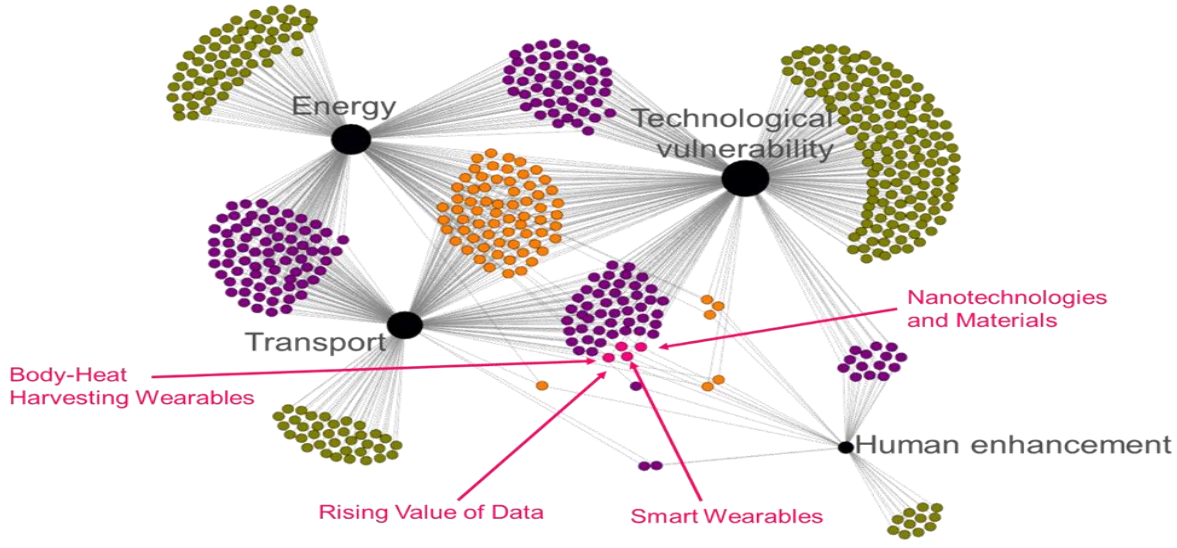
European Commission

JRC TECHNICAL REPORT

Interlinkages for a Megatrend on Accelerating Technological Change and Hyperconnectivity

A text-mining assisted approach

2022



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Contents

Acknowledgements

The figures of this report were prepared by the authors. Should figures be based on contents from third parties (e.g., Futures Platform or JRC Megatrends Hub), the original source is indicated. For example: 'Authors, based on Futures Platform material' or 'Authors, with materials from JRC Megatrends Hub'.

Network-graph visualisations use the open-source Gephi tool on contents retrieved from Futures Platform. Below the first network graph in each chapter or section in this report, the authors mention: 'Source of network graphs in this chapter/section: Authors, based on data text-mined from Futures Platform and visualised in Gephi'.

Text-mining relies on the open-source KNIME tool, as acknowledged under Figure 9, with standard spreadsheet software.

Annex 2 provides a tabular overview of the Futures Platform phenomena used in this report, and of their Interlinkages as identified and/or retrieved by the authors.

Authorship

The authors are JRC analysts who contributed to various parts of the report as indicated in the respective chapters. Each drew upon and extended his/her experience in thematic horizon scanning for identifying and analysing megatrend-interlinkages, focusing on but not limited to the four technology themes covered by the report.

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Abstract

The work described in this report aims at contributing to interdisciplinarity and policy-anticipation capacity in the Joint Research Centre (JRC) of the European Commission. The authors propose, pilot and document a novel approach to explore and visualise interlinkages within (and potentially among) megatrends.

Megatrends are long-term forces that are observable now and will most likely have a global impact. They can help us to identify probable and preferable futures, and to reflect on the future in a systemic way. The JRC Competence Centre on Foresight developed, curates and updates via expert workshops the Megatrends Hub, a publicly available website monitoring fourteen selected megatrends ([1]). In order to identify the interlinkages among the trends constituting the megatrend 'Accelerating Technological Change and Hyperconnectivity', the authors developed an approach to text-mine ([2]) and analyse a catalogue of 712 phenomena ([3]) and their descriptions from Futures Platform, a commercially available tool used to support strategic foresight ([4]). The present report describes this approach and applies it to four out of eight themes ([5]) identified during an expert workshop on the 'Accelerating Technological Change and Hyperconnectivity' megatrend, held in early 2021. In the context of this report, phenomena refer to all signals including emerging or weak signals but also more established trends (micro- and macro-trends). The authors also use the term topic when referring to a group of phenomena within a theme.

The approach developed by the authors can potentially be expanded to a broader range of interlinkages (e.g. between megatrends), or targeted more in-depth at other specific themes. It is also potentially adaptable to data sources other than Futures Platform. As of writing, collaboration is on-going with the JRC Competence Centre on Text Mining and Analysis towards integrating the authors' approach with their Tools for Innovation Monitoring (TIM) for text mining and network visualisation.

The focus of this report is on describing and illustrating the approach developed by the authors for detecting, describing and visualising interlinkages. This, in turn, can provide a basis for policy analysts to systematically examine, substantiate and integrate interlinkages into their analyses.

([1]) Chapter 1 and section 2.1 of this report further discuss megatrends.

([2]) Text-mining can be defined as the automatic finding and extraction of information from given text (https://doi.org/10.1186/gb-2005-6-7-224 ; https://doi.org/10.1007/978-981-15-0184-5_35). The most efficient way to convey human knowledge is through natural language text. To manage the exponential growth of digital data, text information systems can organize huge amounts of unstructured text data into well-defined forms (https://doi.org/10.1007/978-981-16-0507-9_21).

([3]) https://info.futuresplatform.com/en/hub/how-content-is-produced

([4]) Section 2.2 of this report outlines key features of Futures Platform and provides links to its website.

([5]) Terms such as interlinkages, themes, phenomena are defined for the purposes of this document in the list of abbreviations and definitions at the end of the report.

Highlights

This report provides an overview of the role, application and outcomes of an approach co-developed and piloted by the authors to support interdisciplinarity and anticipation in a European Union (EU) policy context. It sheds light onto various emerging technologies and highlights their interlinkages, based on curated data from Futures Platform ([6]).

The authors developed and piloted an approach to identify and make sense of interlinkages for 'Accelerating technological change and hyperconnectivity', which is one of the 14 megatrends in the Joint Research Centre (JRC) Megatrends Hub. This approach relies on text-mining 712 phenomena descriptions from Futures Platform and using analyst intelligence to select and allocate 450 of these phenomena to 18 topics, spanning four themes. Network graphs then visualise interlinkages. The selected themes are:

— 'Technology vulnerability', with 340 phenomena

— 'Human enhancement', with 38 phenomena

— 'Energy', with 262 phenomena

— 'Mobility and transport', with 228 phenomena

Most phenomena are deemed relevant to one or two themes. They are interlinked to other phenomena, but within the relatively well-defined scope of their theme(s). Only four phenomena are allocated as relevant to all four themes. The first two are highly cross-cutting and already pervasive, while the third and fourth on wearables are related to the more emergent 'Human enhancement' theme:

— Nanotechnologies and materials

— Rising value of data

— Smart wearables

— Body-heat harvesting wearables

This approach aims at providing a basis for policy analysts to systematically examine interlinkages. It can potentially be expanded to broader interlinkages (e.g., between megatrends), or targeted more in-depth at other specific themes. It is also potentially adaptable to data sources other than Futures Platform.

As of writing, work is on-going towards integration with the JRC Tools for Innovation Monitoring (TIM) for network visualisation and analysis. TIM is provided by the JRC Competence Centre on Text Mining and Analysis ([7]).

This report targets a readership of analysts with expertise in specific European Union (EU) policy domains (e.g., transport, environment and health), some familiarity with foresight in EU institutions, and possibly, albeit not necessarily, an awareness of basic text-mining and network visualisation principles.

([6]) The Futures Platform company (https://info.futuresplatform.com/en/hub/introduction-to-the-content) provides a commercially available tool with the same name

([7]) https://knowledge4policy.ec.europa.eu/text-mining/TIM_tools_en

Extended abstract

Context

We live in a complex and fast-paced world, increasingly shaped by technological change. Policy makers face multifaceted challenges posed by phenomena that seem disconnected at first glance but can turn out to be closely linked upon further analysis. Providing policy makers with insights about such connections can help to more holistically address the many political, social, economic, technological and environmental implications of interacting phenomena.

To give a few examples:

- Deploying self-driving-cars not only entails advances in engineering but also requires addressing issues such as trust, liability, ownership, cyber-security, job-market implications ([8]). See also section 3.4.4 of this report;
- Rapidly evolving technology advances and miniaturisation of digital components have led to cheaper satellites, resulting in more actors having access to space;
- Electricity grids face increasing amounts of intermittent power generation. Balancing supply and demand often requires a mixture of approaches, involving digital solutions and cyber-security, energy storage, demand-side management (e.g. reducing and/or shifting demand). See also section 3.3.3 of this report.

A recent study on foresight-based policy analysis from the European Parliament Panel for the Future of Science and Technology ([8]) underscores the importance of ensuring that wide-ranging evidence is available for assessing the impacts on society. Analysts can make sure that the collected evidence is as comprehensive as possible by including evidence from a wide range of disciplines and by analysing these findings in an interdisciplinary way.

In the European Commission a significant effort to build an anticipatory culture has also been launched. In-house initiatives systematically detect and analyse signals of change as a service to support policy makers. An example is the Competence Centre on Foresight of the Joint Research Centre (JRC), which developed and curates the Megatrends Hub ([9]). As a Commission website open to the public, the Megatrends Hub presents and monitors 14 selected megatrends relevant to the future of the world, with some focus on Europe. JRC experts from across its research teams regularly contribute to keeping the information broadly up to date.

Megatrends are long-term forces that are observable now and will most likely have a global impact. They can help us to identify probable and preferable futures, and to reflect on the future in a systemic way ([10]). Megatrends are often interconnected. Systematically analysing such interlinkages increases the probability of detecting a phenomenon related to a megatrend that could have an impact on another megatrend. This, in turn, can help early detection and integrated assessment of issues that would require (changes in) legislation.

The importance of interlinkages has been mentioned in Commission strategic foresight reports, for example with regard to considering multiple dimensions of resilience and their interlinkages ([11]), and to the fact that crises can reveal interlinkages ([12]) which can be very complex to define and untangle.

([8]) see , item 6.3.2 of https://www.europarl.europa.eu/RegData/etudes/STUD/2021/690031/EPRS_STU(2021)690031_EN.pdf#:~:text=Guidelines%20for%20foresight-based%20policy%20analysis%20Policy%20analysis%20examines,policy%20options%20might%20not%20always%20be%20socially%20acceptable

([9]) https://knowledge4policy.ec.europa.eu/sites/default/files/what_is_the_megatrends_hub_and_how_to_use_it.pdf

([10]) https://knowledge4policy.ec.europa.eu/foresight/tool/megatrends-hub_en

([11]) https://ec.europa.eu/info/sites/default/files/strategic_foresight_report_2020_1_0.pdf (p. 35)

([12]) https://publications.jrc.ec.europa.eu/repository/bitstream/JRC125994/open_strategic_autonomy_2040_online_1.pdf (p. 51)

Contents of this report

The authors of this report recognise the importance, wide scope and challenges associated with interlinkages. Starting with four themes in one megatrend ([13]), we undertook to develop and pilot an approach to identify and make sense of interlinkages. As detailed in Chapter 2 of this report, this approach relies on text-mining 712 phenomenon descriptions from Futures Platform ([14]) and using analyst intelligence to select and allocate 450 of these phenomena to 18 topics, spanning four themes.

As detailed in Chapter 3 and Annex 2 of this report, the themes and topics broadly correspond to trends and micro-trends identified during a workshop run by the JRC Competence Centre on Foresight in early 2021. Within the 'Accelerating technological change and hyperconnectivity' megatrend, the four selected trends, which we have renamed and classified as themes in this report, are:

— Great power, great risk ([15]) ('Technology vulnerability' in this report).

— Cyborg me! ([16]) ('Human enhancement' in this report).

— Energy ([17]).

— Mobility revolutions ([18]) ('Mobility and transport' in this report).

For each of these four themes, the authors selected four or five topics broadly corresponding to micro-trends identified during the early 2021 workshop. To name a few examples:

— 'AdTech', 'Cybersecurity' and 'Big data' are three topics analysed within the technology vulnerability theme.

— 'Autonomous vehicles', 'Flying cars' and 'Mobility as a service' are among the topics in the transport theme.

— 'Human robotics' and 'Brain-computer interface' are two topics within the human enhancement theme.

— 'Resilient energy systems' and 'New sources of energy' are among the topics in the energy theme.

The authors use network graphs to visualise interlinkages between a wide range of phenomena from Futures Platform and a number of themes and topics identified during the JRC megatrends workshop. Through experimentation with these two sources of contents the authors identified a novel approach to using the Futures Platform tool, based essentially on text-mining and network visualisation as detailed in Chapter 2 of this report. We believe this approach could help to further understand, substantiate, describe and visualise how megatrends, themes and/or topics are interlinked at various levels of detail.

As detailed in the report, out of 450 selected phenomena, ca. 170 are allocated to a single topic; ca. 120 to two topics; and 80 to three topics. The ten most interlinked phenomena, listed below, are allocated to six or seven topics each. Within the scope of the themes selected for this report, these ten phenomena are relevant mainly to 'Technological vulnerability' (the largest theme), 'Energy' and 'Transport' (also sizeable themes), and to a lesser extent to human enhancement (a much smaller and emerging theme).

— 'storage' (strengthening).

— 'cloud computing' (strengthening).

— 'energy' (summary).

— 'rising value of data' (strengthening).

— 'small nuclear power plants' (strengthening).

— 'dependency on electric grids and data networks' (wild card).

— 'data security of human body under threat' (wild card).

— 'microgrids' (strengthening).

— 'solar panel roads' (strengthening).

([13]) 'Accelerating technological change and hyperconnectivity', one of the 14 megatrends in the JRC Megatrends Hub
([14]) Futures Platform is a company providing a commercially available tool of the same name https://info.futuresplatform.com/hub/about-futures-platform
([15]) https://knowledge4policy.ec.europa.eu/foresight/great-power-great-risk_en
([16]) https://knowledge4policy.ec.europa.eu/foresight/cyborg-me_en
([17]) https://knowledge4policy.ec.europa.eu/foresight/computer-processing-energy-saving_en
([18]) https://knowledge4policy.ec.europa.eu/foresight/mobility-revolution_en

— ‘community microgrids’ (strengthening).

Allocating the highest share of phenomena to ‘Technical vulnerability’ likely reflects how deeply and widely digital technologies already underpin most human activities. This also applies to Energy and Transport, to a considerable extent. The count of phenomena allocated to ‘Human enhancement’ is much smaller, likely pointing to a much more specific and emerging topic – albeit with potentially huge future impact if emerging phenomena such as ‘controlling machines with thoughts’ do become widespread.

Afterthoughts

The analysis relies on quantifiable and reproducible elements but is not devoid of subjectivity. For example, the Futures Platform catalogue is the only source of phenomenon descriptions. Also, the authors of this report rely on their own knowledge and insights to make choices on what to search and consider for analysis.

The approach developed by the authors can potentially be expanded to broader interlinkages (e.g., between megatrends), or targeted more in-depth at other specific themes. It is also potentially adaptable to data sources other than Futures Platform.

As described and illustrated in the present report, this approach requires substantial data manipulation effort. The authors are therefore streamlining the text-mining approach to allow data to be imported by the JRC TIM ([19]) tool for visualisation and analysis. As of writing, this streamlining and import appear feasible. Practical implementation aspects are undergoing verification and testing, in collaboration with the JRC Competence Centre on Text Mining and Analysis. Further deployment of this more automated approach may require clearing other practical aspects including access rights to commercially available data.

This report targets a readership of analysts with expertise in specific EU policy domains (e.g., transport, environment and health), some familiarity with foresight in EU institutions, and possibly, albeit not necessarily, an awareness of basic text-mining and network visualisation principles.

([19]) www.timanalytics.eu

1 Introduction

By Elisa Boelman (JRC.C.7), Amalia Muñoz Piñeiro (JRC.F.7), Alain Marmier (JRC.C.7)

As a contribution to strengthen the European Commission's anticipatory capacity in support to policy making, this report proposes an approach to identify, describe and map interlinkages within the megatrend 'Accelerating Technological Change and Hyperconnectivity', one of fourteen megatrends identified by the Joint Research Centre (JRC) of the European Commission ([20]).

Previous work on megatrend interlinkages in the JRC include a Policy Brief on 'Security and geopolitics in a changing climate' ([21]). Interlinkages are also addressed, for example, by the European Environment Agency ([22]) and by the World Economic Forum ([23]), as well as in the Sustainable Development Goals.

The approach developed by the authors of this report relies on the analysis of 712 phenomenon descriptions from Futures Platform that were available in June/July 2021. Some of these phenomena are still weak signals with small impacts at present, but their future impact could grow in strength and extent if or when they interlink.

The Interlinkages work developed for the present report builds on thematic horizon scanning capacity developed in the JRC in the past few years. It combines text-mining and network visualisation with human analyst intelligence, for interlinking wide ranges of issues while also focusing on specific technology related themes.

The authors bear in mind that horizon scanning is concerned with emerging issues and weak signals of change, while megatrends are about much stronger and already observable long-term driving forces ([24]). The approach developed for this report recognises this important difference when applying and extending capacity built for horizon scanning to the broader and more visible megatrends. Both approaches are complementary as megatrends enable making some sense of weak signals detected via horizon scanning, which in turn may influence the evolution of megatrends. Bridging horizon scanning and megatrends can be done through, for example: disaggregation of megatrends into relevant macro- and micro- trends (called 'themes' and 'topics' in this report); identification of (possible new/future) trends and analysis of impacts between and across these.

Acknowledging the challenges inherent in bringing together breadth and depth, there are different 'levels' of horizon scanning, from broad to deep ([25]). One can:

- Observe from a higher level, for instance to identify general (mega) trends.
- Focus on a specific domain for a more focused horizon scan with agreed purpose and theme.
- Dive deeply into a sub-domain for an in depth scan into a more specific topic, such as in technology analysis.

Such analyses may appeal to experts open to looking at wider developments, as well as to policy makers amenable to accept the challenges involved in untangling complexity. While there is wide-ranging domain expertise in the JRC for in-depth exploration well beyond the scope of the present report, the authors opted to start from a small-scale exercise.

As a departure point, the authors explore interlinkages within and between technology-related topics associated to their own broad thematic domains of expertise. The approach developed and piloted for this exercise can be adapted to other thematic domains, with the analyst-intelligence part provided by in-house and/or external experts.

In this context, the present report explores interlinkages within and between four of the eight themes put forward by participants of a workshop on the megatrend 'Accelerating Technological Change and Hyperconnectivity' held by the JRC Competence Centre on Foresight.

Figure 3 in Chapter 2 gives an overview of the themes and topics put forward by participants of this workshop. Chapter 2 then delves into the text-mining and analysis procedures developed by the authors for identifying and describing interlinkages between and within the selected themes:

1. Technological-vulnerability (Tech-vulnerability).
2. Human enhancement.

([20]) https://knowledge4policy.ec.europa.eu/foresight/tool/megatrends-hub_en
([21]) https://knowledge4policy.ec.europa.eu/publication/security-geopolitics-changing-climate_en
([22]) https://www.eea.europa.eu/publications/drivers-of-change/at_download/file
([23]) https://www.weforum.org/platforms
([24]) https://knowledge4policy.ec.europa.eu/foresight_en
([25]) with thanks to foresight expert Lieve van Woensel

3. Energy.
4. Transport.

Chapter 3 dwells into results, first within and then between the four selected themes by different analysts. Section 3.5 presents interlinkages between themes, which can be potentially up scaled towards an analysis at megatrend level.

Chapter 4 outlines the main findings of this study, including options for expanding in scope and re-using the approach developed by the authors of this report.

The Annexes present lists of phenomena and further details on their interlinkages.

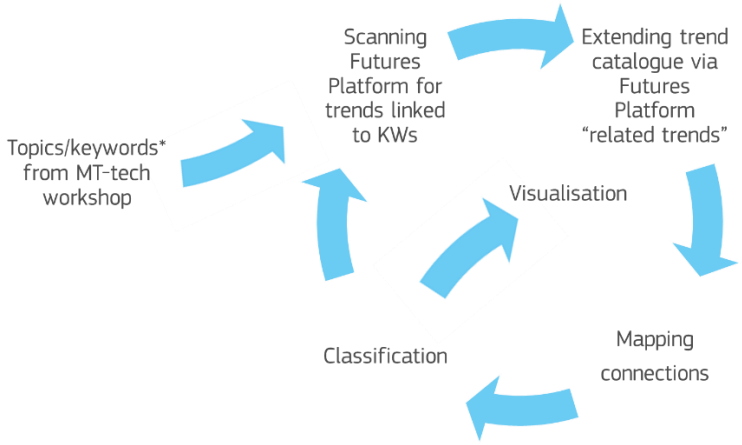
2 Approach developed by the authors to identify interlinkages

By Alain Marmier (JRC.C.7), Amalia Muñoz Piñeiro (JRC.F.7), Mayya Hristova (JRC.E.7), Elisa Boelman (JRC.C.7) and Ana Lisa Vetere Arellano (JRC.E.7).

The authors of this report are a small cross-disciplinary and collegial working group of five analysts in three JRC Knowledge Management units. As analysts experienced in thematic horizon scanning in the fields of energy, transport health and defence, the authors held weekly discussions on possible approaches to and sources for exploring interlinkages. Given the novelty of this exercise, the authors opted for curated contents, combining a broader range of 712 phenomena from Futures Platform (text-mined in June 2021), with specific contents from the workshop in January 2021 on the megatrend 'Accelerating Technological Change and Hyperconnectivity' shown in **Figure 3**.

In order to make sense of megatrends, the idea is to look into trends of lower importance/scope/impact (micro- and macro-trends that in this report will be addressed as topics and themes, respectively) and to map how they do relate to each other. The more trends are considered, and the finer their connections are mapped, the more precisely once can investigate the related megatrends. Key steps in this approach are thus the identification of relevant (micro- and macro-) trends and how they do interlink at the different levels.

Figure 1. Process proposed in this report



Source: Authors.

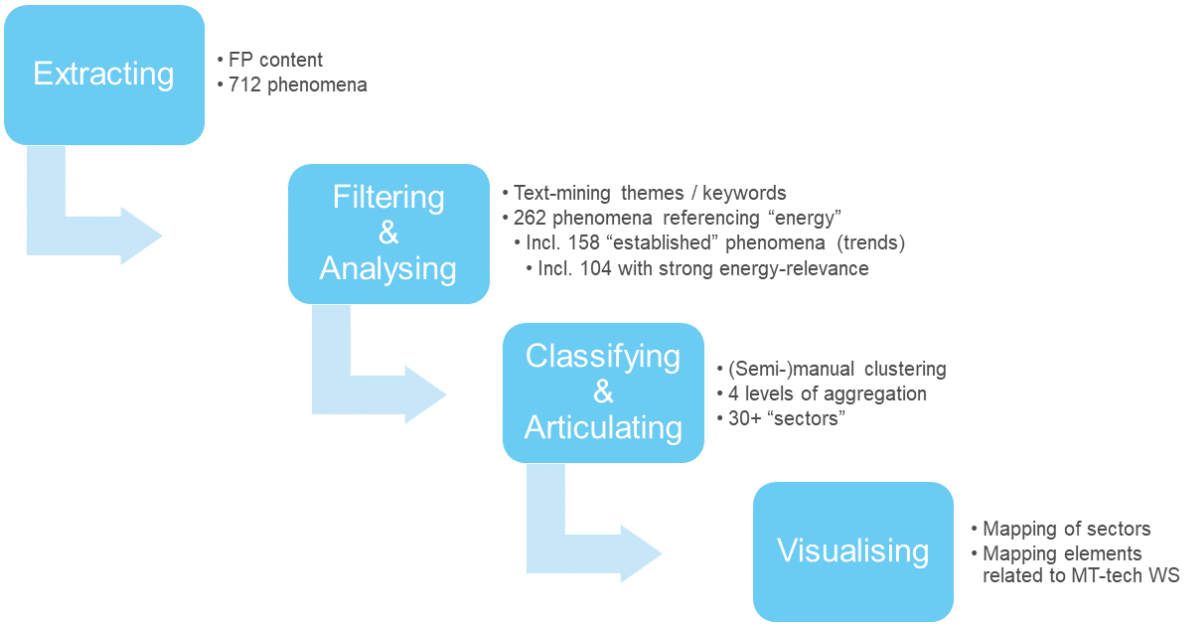
Through the JRC workshops in January 2021, the 14 JRC megatrends were investigated, highlighting themes and topics of relevance. These workshops served as a starting point for this work, allowing the definition of our scope.

For the identification of trends and their interlinkages, the authors rely on the content of Futures Platform. Futures Platform provides us with the material needed to kick start the analysis: Curated trends and (some) relations among them. In addition, the content of Futures Platform is structured and of textual nature, which allow for its (text-mining assisted) analysis:

- Individual authors identify and retrieve phenomena of relevance for their themes.
- Via the connections between phenomena identified by Futures Platform, additional phenomena (related to the initial ones) are discovered and retrieved, enhancing the catalogue of trends.
- Checks are made to ensure that all 'related phenomena' of the captured phenomena are retrieved.
- Connections among phenomena are mapped, highlighting phenomena of relevance to specific topics and themes within the analysed megatrend and eventually with the other 13 megatrends.

Dwelling more in details, **Figure 2** below summarises the above approach applied to the energy theme. By replicating this approach across our themes of interest, the scope of the analysis can be extended to the megatrend of interest.

Figure 2. Visualisation of the approach, applied to the energy theme



Source: Authors.

The classification and articulation step aims at structuring the information along established (theme-related) classifications. The objective here is to make sense of the obvious connections and relations to present the wealth of information in a digestible way for persons knowledgeable of the theme. This step repeats the 'filtering and analysis' approach, though with different keywords.

The authors of this report define and use keywords to retrieve phenomena from Futures Platform associated to the different themes put forward in the megatrends workshop (**Figure 3**). Those keywords were used to text-mine the information provided by Futures Platform for each of their 712 phenomena, targeting fields such as title, description, background, impact or additional information. Following this text-mining based retrieval, validated by analysts, relevant phenomena are allocated to broader themes and more specific topics within each theme. This generates data which are then used to build network graphs to illustrate interlinkages.

These interlinkages, and the resulting network graphs that illustrate them, are defined by iterative combinations of complementary steps:

— Direct text-mining based retrieval of links between phenomena from their descriptions, where these associations have already been defined by Futures Platform in the phenomena description section 'Related phenomena'.

— Text-mining and analysis to indirectly identify relevant phenomena. For the sake of focus keywords are defined as search terms, so as to correspond to the broader themes and/or more specific topic put forward in the JRC megatrends workshop on 'Accelerating Technological Change and Hyperconnectivity'.

— Network visualisation and clustering.

This highly iterative process requires a combination of domain knowledge of the various themes (e.g., energy, health, transport), some functional literacy in text-mining and network visualisation, an open inquisitive mind-set and affinity with inductive creative thinking.

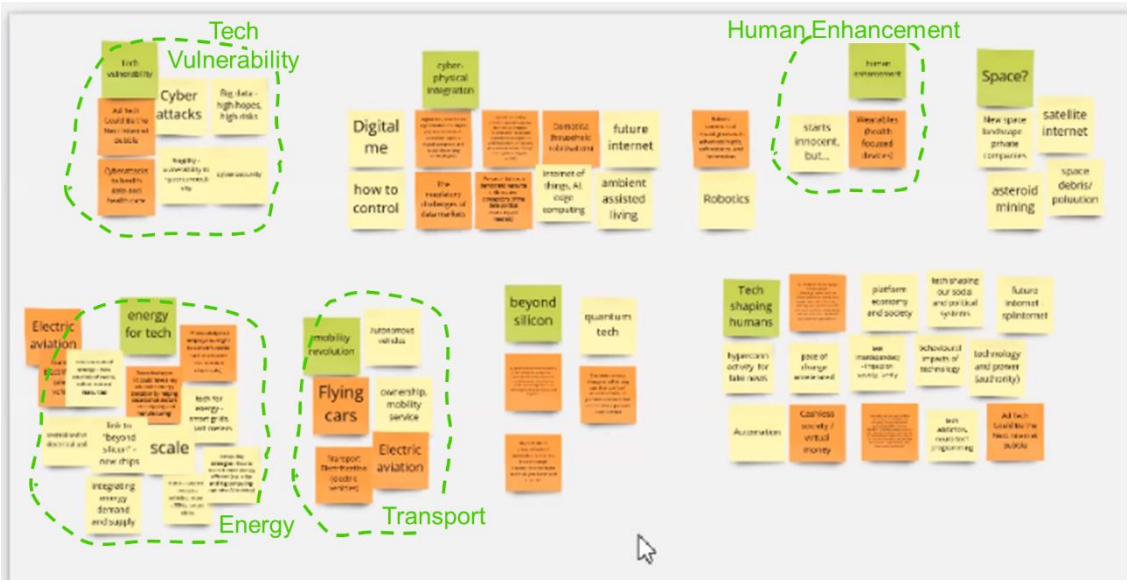
2.1 Selection of themes from a JRC megatrends workshop

The JRC Megatrends Hub ([26]) held a series of workshops in early 2021 to prepare updates for each of its fourteen megatrends. **Figure 3** shows the eight themes (green post-its) selected by participants of the workshop on the megatrend 'Accelerating Technological Change and Hyperconnectivity' ([27]) (*abbreviated as MT-tech*). Within each of these themes, participants also selected relevant news items (orange port-its) and identified relevant topics (yellow post-its).

([26]) https://knowledge4policy.ec.europa.eu/foresight/tool/megatrends-hub_en
([27]) https://knowledge4policy.ec.europa.eu/accelerating-technological-change-hyperconnectivity_en

A group of five workshop participants from three JRC Knowledge Management (KM) units undertook to develop an approach to explore interlinkages within the 'MT-tech' and to prepare this report. As an outcome of frequent and extensive brain-storming sessions, the authors decided to integrate four themes from the JRC 'MT-tech' workshop (circled in blue dotted lines in **Figure 3**) with a broader range of 712 phenomena from the Futures Platform tool.

Figure 3. Contents from the workshop on the megatrend 'Accelerating Technological Change and Hyperconnectivity'

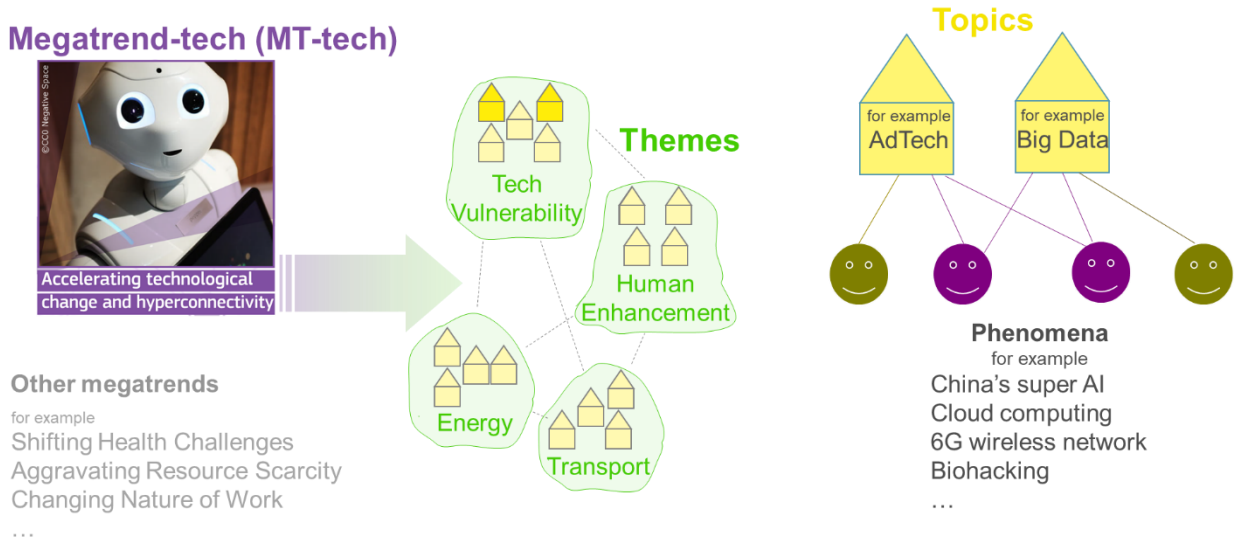


Source: 2021 JRC megatrends workshop.

As shown in **Figure 3**, the themes selected for this work are: Tech-vulnerability, Human Enhancement, Energy and Transport. For each of these themes, the authors extracted a number of topics from the ideas associated to each of the themes during the workshop. These topics are indicated with their respective themes in Chapter 3 of this report.

In the context of this report, phenomena refer to all signals including emerging or weak signals but also more established trends (micro- and macro-trends). The authors also use the term topics when referring to groups of phenomena allocated to each of the themes within the megatrend 'Accelerating Technological Change and Hyperconnectivity'.

Figure 4 Themes, topics and phenomena – terms used in this report



Source: Authors, with materials from JRC Megatrends Hub.

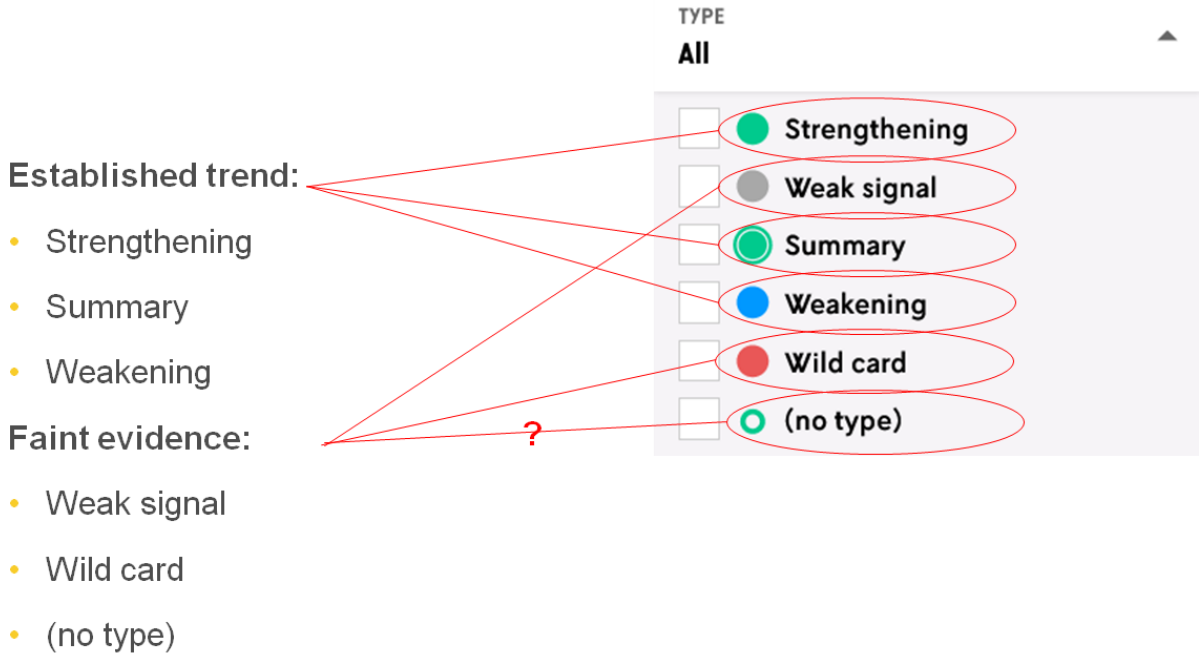
2.2 Futures Platform tool – some key features outlined

JRC.F.7 has been using Futures Platform as a source of health-related news items and trends.

Futures Platform ([28]) is a Finnish company, offering commercial support in strategic foresight and a catalogue of phenomena ([29]): After the selection of a topic, the content of a phenomenon is created by members of a team of futurists through a peer-reviewed process. The content is then made public and may be enriched by the feedback of users. Large part of the description is man-made and curated. In addition established phenomena have a newsfeed, displaying daily news items. These news items are retrieved based on experts' defined keywords and are updated automatically.

This catalogue of phenomena is then mapped for 30 themes ([30]), each of which has a ready-to-use radar ([31]). These thematic radars display changes that are affecting or related to the developments of the given themes. The radar functionality is also open to users for grouping, categorising and visualising phenomena in a customable manner. Users can create customised radars, for example by finding relevant phenomena through keyword-based searches in Futures Platform catalogue of phenomena, which are curated by their futurists. The timeline dimension of the radars can also be customised depending on the phenomena they contain. Futures Platform allows in-house curation of customer-defined phenomena and customer-defined radars by the experts of the customer organisation. This can be done via collaboration tools that allow voting and commenting on the phenomena and customer-defined radars. Phenomena are further described in Section 2.3.3 of this report, while **Figure 7** and **Figure 20** provide examples of (resp.) a thematic radar and a custom-made radar.

Figure 5. Types of phenomena provided by Futures Platform

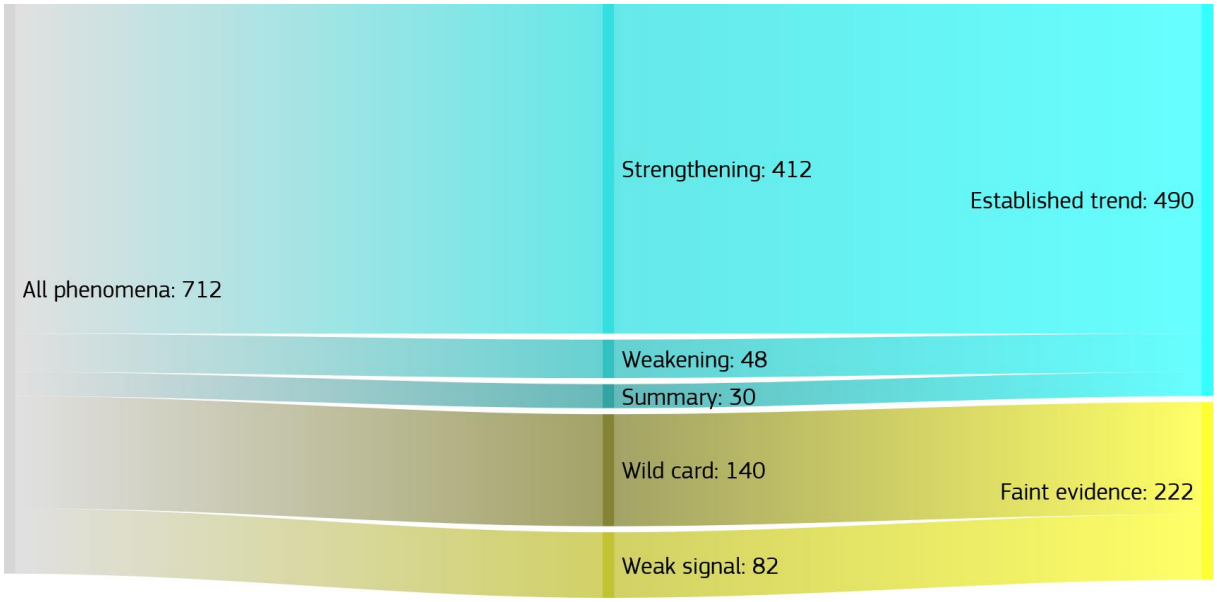


Source: Authors, based on Futures Platform material.

Futures Platform provides metadata ([32]) for each of their phenomena, such as a title, a type and a timeline. As summarised in **Figure 5** and detailed in the list of abbreviations and definitions at the end of this report, Futures Platform categorises phenomena into five types: Strengthening; Weakening; Weak signal; Wild card; Summary. These metadata are of importance for our analysis, particularly the types of phenomena and their timeline: One could deem 'strengthening'; 'summary'; 'weakening' to relate to 'established' phenomena, while 'weak signal' and 'wild card' can be seen as relating more to Horizon Scanning or emerging issues than to 'trending'.

([28]) http://info.futuresplatform.com/hub/about-futures-platform
([29]) http://info.futuresplatform.com/hub/how-content-is-produced
([30]) http://info.futuresplatform.com/en/hub/introduction-to-the-content
([31]) http://info.futuresplatform.com/en/hub/foresight-radars
([32]) http://info.futuresplatform.com/hub/how-content-is-produced

Figure 6. Quantification of types of phenomena retrieved from Futures Platform

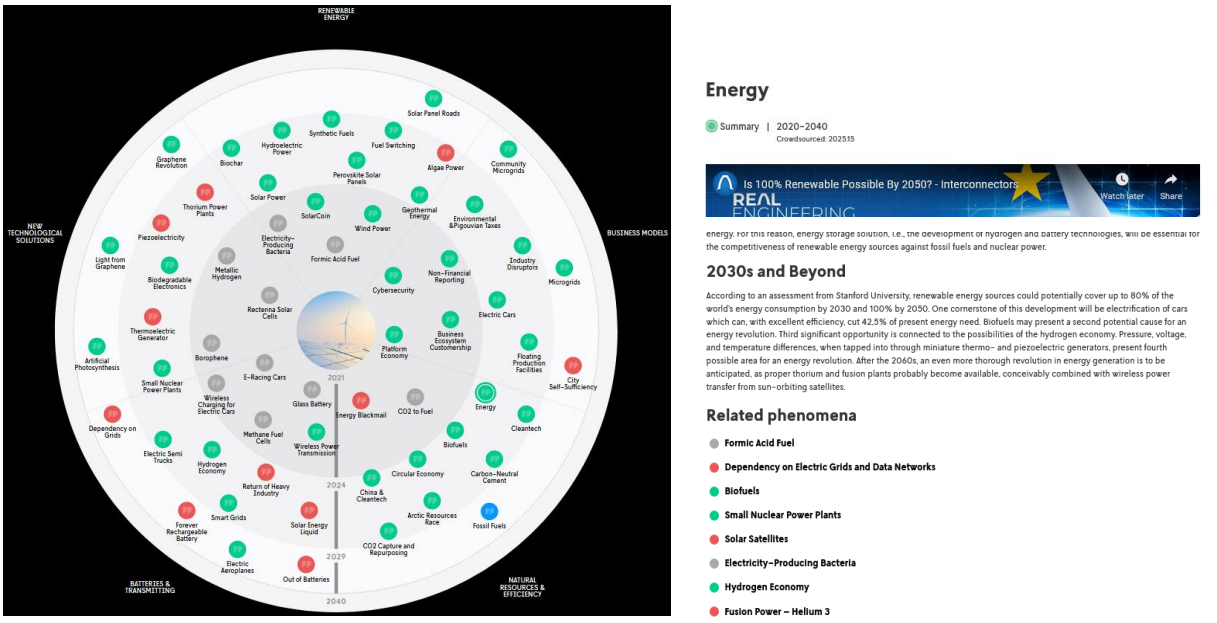


Source: Authors, based on Futures Platform material.

The contents of phenomena are created, placed on a timeline, and chosen from a greater database by the Futures Platform expert team following their view on what might significantly shape societies in a given timeline. For example, if a green dot is placed on years 2022-2027, the Futures Platform foresight team expects the phenomenon to rise in significance and cause the most essential change in that time period. This does not mean that the issue or trend in question could not be clearly visible already prior to that time or that it could not continue to grow later.

Figure 7 shows an example of various types of phenomena plotted by Futures Platform on a 'radar' for various timelines ([33]). In addition to type of phenomena and timelines, Futures Platform also provides names of related phenomena, as illustrated in the right part of **Figure 7**.

Figure 7. Example of phenomena with timelines (left) and related phenomena (right) from Futures Platform

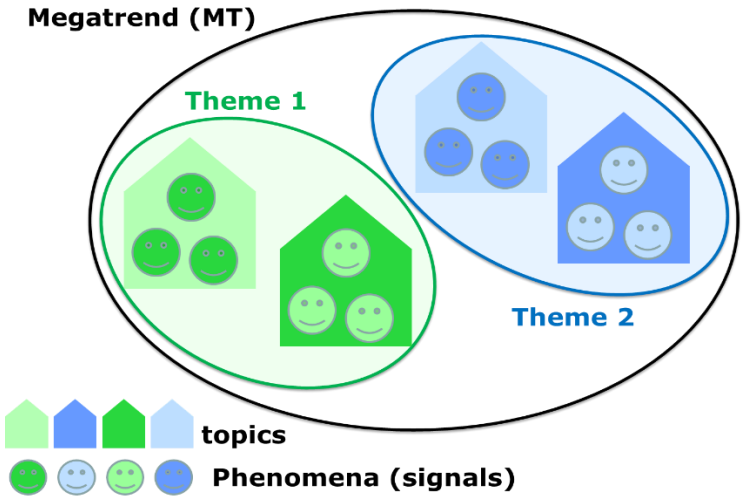


Source: Authors, based on Futures Platform material.

([33]) https://go2.futuresplatform.com/radar?node=521450&ret_id=a0669ed7-bb83-407b-92d6-7dbf362eaa19

In this report the information is structured in different levels of complexity, as illustrated in **Figure 8**. Phenomena are allocated to (sometimes multiple) topics, topics relate to themes and finally themes form the megatrend. This report flags the complexity of this scheme linked to the allocation of phenomena within the topics or themes, as some phenomena fall at their intersections.

Figure 8. Schematic representation of how information is structured in this report



Source: Authors.

2.3 Key steps of the approach developed by the authors

2.3.1 Phenomena extraction

Futures Platform displays a catalogue of phenomena. Those can be identified in different ways:

— By searching Futures Platform for a keyword or looking into the 'new phenomena' section of the platform.

— By looking into Futures Platform standard radars.

— By using text-mining to look into 'related phenomena' referred to in the description of (other) phenomena. The authors developed and applied such a text-mining approach for the purposes of this report.

All of the above approaches have been applied to recover as many trends as possible, leading to a collection of 712 phenomena.

2.3.2 (Text-mining assisted) phenomena allocation and classification

Text-mining is instrumental to conduct the phenomena allocations and classifications: It allows for a quicker processing of Futures Platform content, extracting relevant part of the 712 phenomena description for analysist's review. The authors rely on KNIME ([34]) for this task, which allows for the design of custom-made workflows. The workflows shown in the figure below are used for text-mining Futures Platform phenomena description:

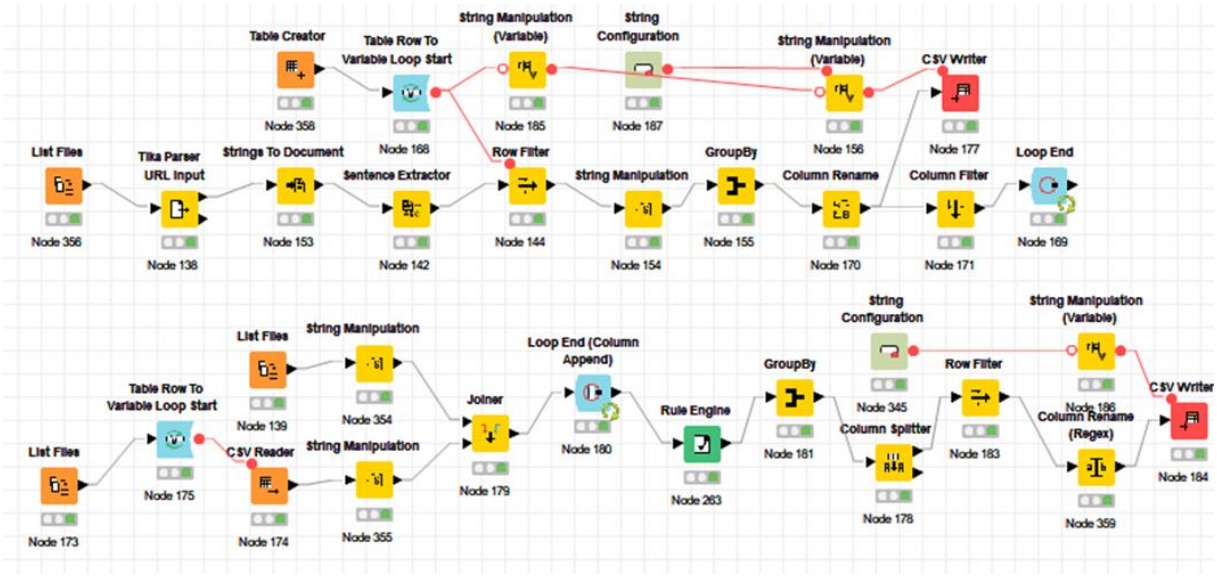
— For each of the themes, an analyst provides a list of keywords. The workflow on the top of the figure then reads all phenomena descriptions, extracts relevant sentences containing the keywords, bundles them together (per phenomena and keyword) and saves this information in a csv file per searched keyword.

— The workflow at the bottom of the figure reads all csv files and maps the content on the overall list of phenomena.

The output of this second workflow contains a matrix. This matrix has the 712 phenomena as rows and a column for each keyword.

In addition to the extraction of keywords for allocating the phenomena to the various themes and topics, a similar approach has been applied to extract 'metadata' from the phenomena description (e.g., title, type of phenomenon, timeline), for the analyses described below.

Figure 9. KNIME workflows for the processing of Futures Platform content



Source: Authors, with Knime.

([34]) KNIME, or Konstanz Information Miner, is a software that enables the automation of information processing: https://www.knime.com/knime-analytics-platform

2.3.3 Analysts' allocation approach

Previous sections describe how the full descriptions are retrieved for all 712 Futures Platform phenomena (as of July 2021) and text-mined for specific keywords defined for each theme. Here, the authors provide more details on some of the (subsequent) human analyses, leading to the phenomena allocations and classifications.

Analyst content review

Keywords may not be properly defined or may have several meanings. For the energy theme, the keyword *energ* is queried to cover both energy and energies. This however also includes energetic, which could detect phenomena as false positives. For instance, phenomena 'ways to use free time' refers to "The opportunity to choose and tailor energetic or useful free time activities is available to an ever-growing number of people." This reference is of no use for the scope of this report and has to be dismissed.

Further, the keyword mining approach has limitations. By reading the phenomena description, analysts may identify additional connections which would not be evidenced by keyword-based searches.

Defining a JRC typology of 'core' and 'related' phenomena

In this section the authors present a JRC typology classifying phenomena as 'core', 'related' or 'not relevant' to a given theme or topic.

When analysts deem a phenomenon of relevance to a given theme (e.g., energy, transport, human enhancement, technological vulnerability) or to a more detailed topic within a theme (e.g., resilient energy system or electric aviation, or human robotics), this phenomenon is allocated to this theme or topic as 'core'.

In its phenomena description, Futures Platform establishes links between phenomena through a 'related phenomena' section (see **Figure 10** below). Using this information one can retrieve 'related' phenomena for a given theme or topic from the 'related phenomena' sections of the phenomena descriptions relevant to that theme or topic (i.e., of the 'core' phenomena). Should a 'core' phenomenon be also referenced as a 'related' phenomenon by another 'core' phenomenon, this former phenomenon would then be deemed both 'core' and 'related'. In the frame of this report, then only the 'core' typology remains The links defined by Futures Platform as 'related phenomena' are also used to draw network graphs in this report. Further interlinkages are defined by JRC analysts' allocations of phenomena to themes and topics.

Any of Futures Platform 712 phenomena which are not considered 'core' or 'related' for a given theme or topic are then deemed 'not relevant'.

Relevance of keywords in phenomena descriptions

Here the authors look into the location of the keywords within the phenomena description, making a distinction between keywords appearing in 'title', 'background' and 'impacts' sections on one hand and 'additional information' and 'latest news' on the other hand. The title, background and impacts sections of phenomena descriptions are written and reviewed by Futures Platform futurists. As such they are curated and fairly stable. These sections of the phenomena descriptions are then used by Futures Platform to generate keywords for automatically retrieving news items that fit into the phenomena contexts. This automated collection of news items changes with time, populating the 'additional information' and 'latest news' sections of the phenomena descriptions. Due to the different dynamics between these two types of information, the authors make a distinction on the location of keywords, deeming keywords retrieved in futurists-written sections of higher relevance.

When keywords are retrieved in the text of title, background or impact of a phenomenon description, that reference is deemed located in 'core content' to that phenomenon. When the keywords are retrieved only in the text of additional information or latest news, then the reference is deemed to be located in 'related aspects' to that phenomenon.

Figure 10. Example of phenomenon description

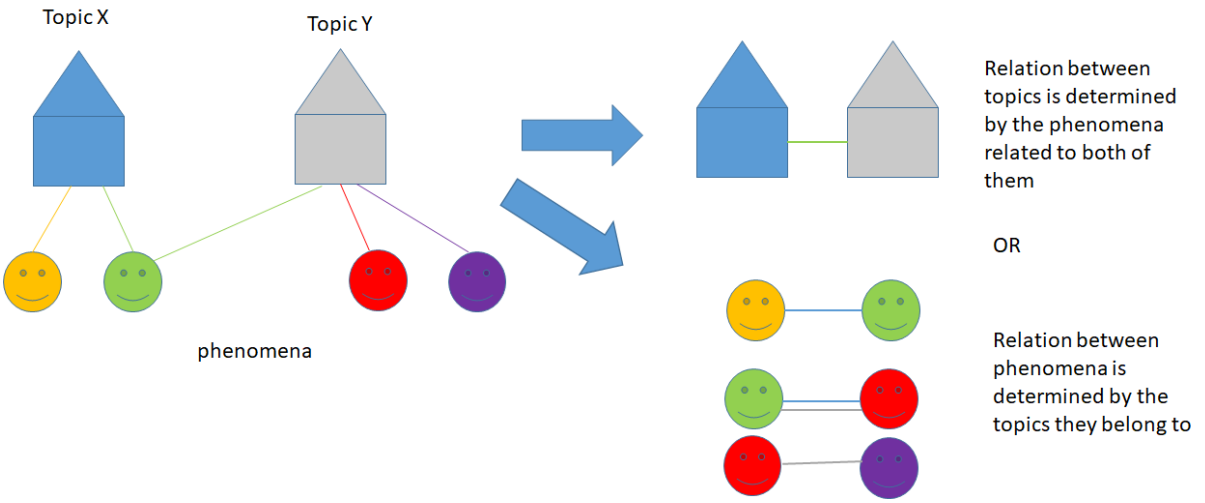
Source: Authors, based on Futures Platform material.

2.3.4 Identifying other interlinkages than those defined by Futures Platform

The allocation of Futures Platform phenomena to topics defined by the authors also allows drawing an indirect link among the topics analysed in this report.

Figure 11 provides a schematic representation of the logic followed to identify interlinkages among topics. The fact that one or more phenomena are independently from each other allocated to the same topics X and Y allows to infer that these two topics are interlinked. Similarly, the fact that two or more phenomena are allocated to one and the same topic, allows inferring a link among these phenomena. In the present analysis, the authors are interested in the former relationship, i.e., a relation among topics determined by phenomena allocated simultaneously to multiple topics. The higher the number of shared phenomena, the stronger the link is assumed to be.

Figure 11. Identification of interlinkages from phenomena allocation to topics



Source: Authors, based on Futures Platform material.

Figure 12 shows an example for the tech vulnerability theme, with phenomena allocated to both single ('Big Data' in this case) and to multiple topics (yellow-highlighted). The multiple-topic phenomena are then allocated to 'interlinks', as shown in the figure below.

Figure 12. Allocation of phenomena to interlinks

Phenomen_Title	AdTech	Cyber Att	Cyber Sec	Big Data5	Fragility6	TechVuln_C	TechVuln_In
Harmful Functionality in F		3	1	1		CyberAttacks	Interlink
Health & Wellness Coachi				1		BigData	BigData
Health Monitoring Spaces				2		BigData	BigData
High-Tech Ecovillages			1	2	1	BigData	Interlink
Hijacking a Hospital		4	1	1		CyberAttacks	Interlink
Home Robots	1			1		Mix	Interlink
Hybrid Warfare		2				CyberAttacks	CyberAttacks

Source: Authors, based on Futures Platform material.

Figure 12 shows both Interlinkages and individual topic allocations in tabular form. The numbers indicate the counts of keywords retrieved by text mining from the phenomena texts: title, description, background, impact or additional information. The 'Interlink' allocations are defined by the authors for those phenomena where keywords are retrieved for more than one topic.

A phenomenon is allocated to a topic when containing keywords defined for a single topic, as in the case of ´Health Monitoring Spaces´ that contains two keywords from 'Big Data'. Other phenomena contain keywords from two or more topics, for example, 'hijacking a hospital' belongs to three of the topics of the theme 'Tech-vulnerability' (i.e., 'Cyberattacks', 'Big data' and 'Cybersecurity') and therefore this phenomenon should appear as connected to all three; Phenomena allocated to more than one topic are allocated as 'interlink'.

2.3.5 Visualising interlinkages among topics

In addition to developing the text-mining approach to identify interlinkages, the authors also apply network visualisation to support analysis and presentation of the results. In the frame of this report, network visualisation is done with Gephi.

Gephi ([35]) is an open-source network analysis and visualization software package written in Java on the NetBeans platform. The user interacts with the representation to reveal hidden patterns. Gephi complements statistics facilitating the identification of certain patterns within the network. The data defining the network can be imported as either database or spreadsheets containing information on the nodes and information on the edges or connections.

Gephi contains different layout algorithms shaping the network graphs. The layout palette allows user to change layout settings while running, and therefore allowing to visualise different aspects of the network including the readability. These visualisations do not alter the structure of the network but facilitate its readability.

It also allows the use of different statistics and metrics for social network analysis (SNA) and scale-free network, such as

- Betweenness Centrality, Closeness, Diameter, Clustering Coefficient, PageRank.
- Community detection (Modularity).
- Random network generators.
- Shortest path.

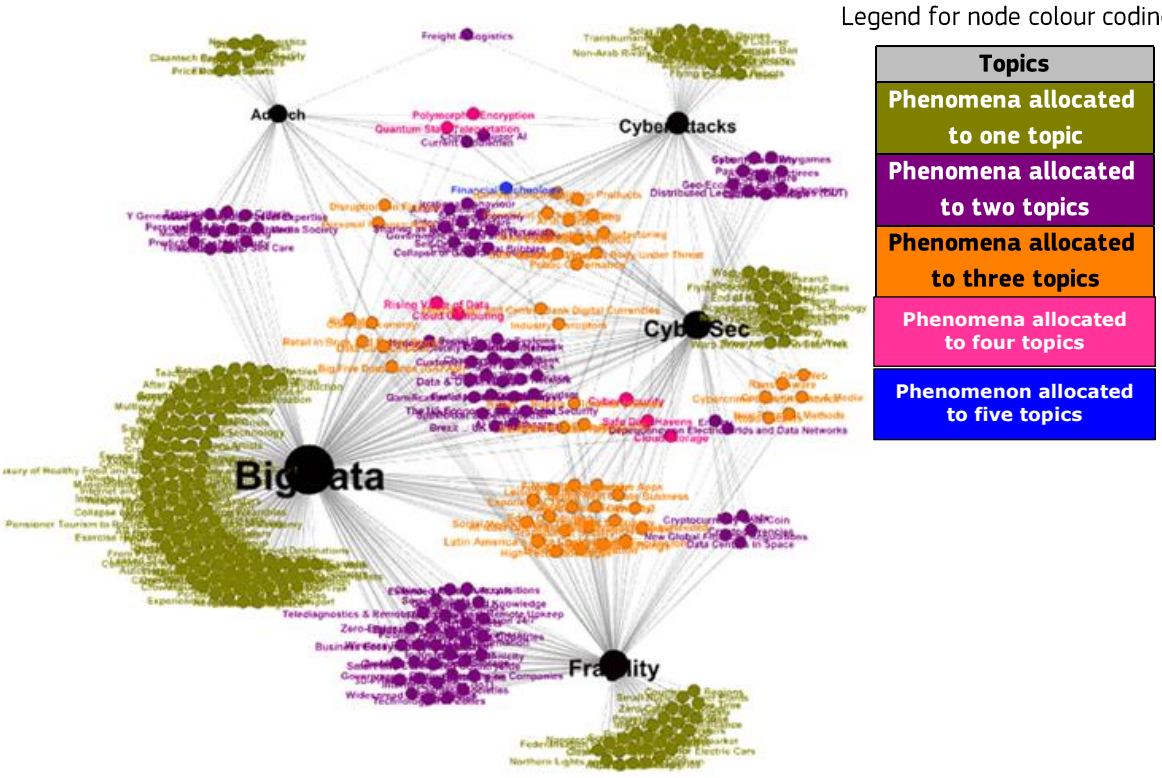
Gephi also allows dynamic and in real-time filtering of nodes and edges based on the network structure or data. This allows to create or visualise sub-networks of interest within the network by the application of a variety of filters.

Figure 13 below shows a network graph of the 'Technological vulnerability' theme, compiled with Gephi. Topics appear as larger black nodes, while phenomena are smaller coloured nodes. The black 'topic' nodes are sized proportionally to the numbers of phenomena connected to them. The 'Big data' node is the largest, since it has the highest number of connected phenomena, while 'Ad tech' is the smallest topic. Topics are shown in black, while phenomena appear as small nodes in the graph, coloured according to the number of topics they are connected to. Phenomena interlinked to five topics appear as small blue nodes; those interlinked four topics appear in pink; three topics in orange; phenomena interlinked to two topics appear in purple. Phenomena allocated to a single topic appear in olive green.

Phenomena allocated to single topics (olive green nodes) tend to be more specific and mono-disciplinary. They tend to appear in the periphery of the graph, close to their respective topics. Conversely, phenomena allocated to four (pink) or five (blue) topics tend to be more cross-cutting with potentially wider-reaching impact. This is further discussed in Chapter 3.

([35]) https://gephi.org/

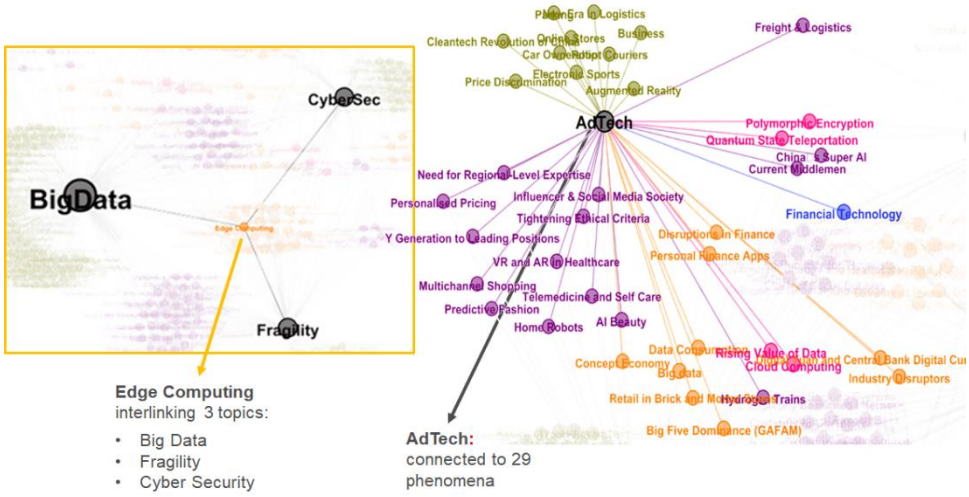
Figure 13. Network graph of topics and phenomena for the 'Technological vulnerability' theme



Source of network graphs in this chapter: Authors, based on data text-mined from Futures Platform and visualised in Gephi. Annex 2 provides a tabular overview of the Futures Platform phenomena and their Interlinkages.

The sub-network graph of **Figure 14** shows on the right the 29 phenomena allocated to the topic 'Ad-Tech'; on the left it shows the phenomenon 'edge computing' as a small orange node interlinking three topics: Big Data, Cyber Security and Fragility. The colour code is the same as in **Figure 13**. Zooming into a single topic (right part of **Figure 14**) allows seeing in more detail the phenomena, including those that are linked to multiple topics. Zooming into a single phenomenon (left part of the figure) can help provide insights on more interconnected phenomena and the topics they may impact.

Figure 14. Detailed sub-network graph



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

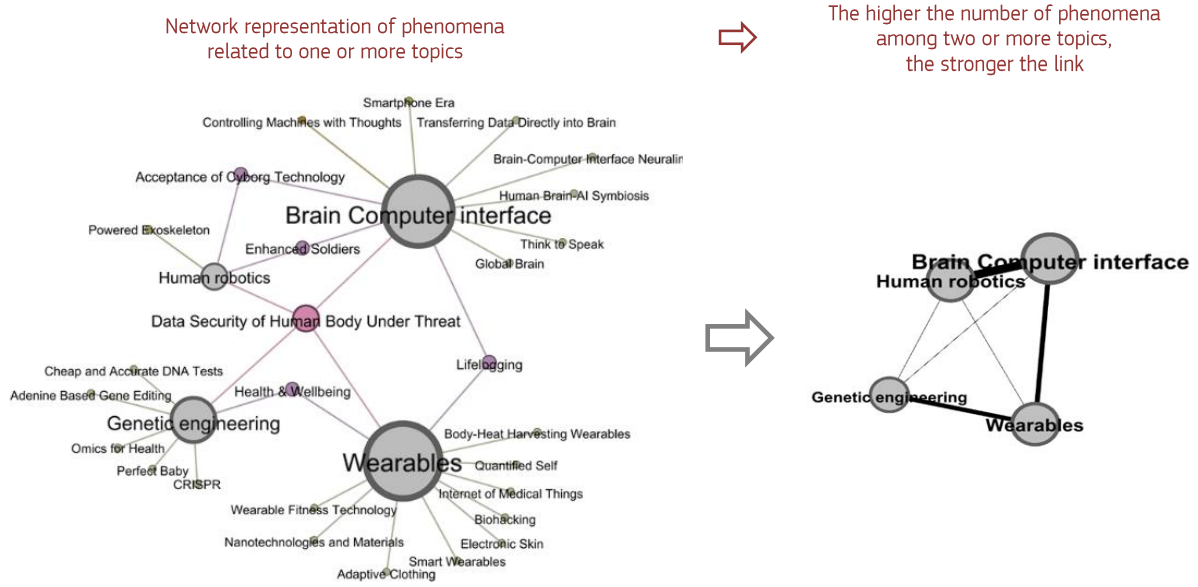
The network graph of **Figure 13** and its sub-network of **Figure 14** are two-mode graph visualisations which allow to visually distinguish as two categories the phenomena and the topics to which they are allocated. The number of connections determines the size of the nodes, therefore the number of phenomena allocated to a

topic influences its node size. Transforming the two-mode network to one-mode, i.e., projecting the phenomena on the topics, allows deriving a link among the topics based on the phenomena they have in common. The connection will be stronger if these topics share many phenomena.

In addition to zooming in, as in **Figure 14**, it is also possible to zoom out, as in the right part of **Figure 15**, to see how interconnected the topics within a theme are. Zooming out is obtained by embedding the phenomena within the nodes representing their respective topics. The size of the nodes (topics) represents the number of phenomena allocated to the topics. The thickness of the edges represent the number of phenomena interlinking each pair of topics.

Figure 15 shows an example for the 'Human Enhancement' theme. 'Human Robotics' and 'Brain Computer Interface' are the two topics sharing the highest number of phenomena, with the thickest edge between them. The edges are much thinner between each of these two topics and 'Genetic Engineering', which have lower numbers of shared phenomena.

Figure 15. Network graph of phenomena and topics to which they are allocated



Source: Authors, based on Futures Platform data.

2.3.6 Various levels of interlinkages for finer-grained analysis

The previous analyses are based on:

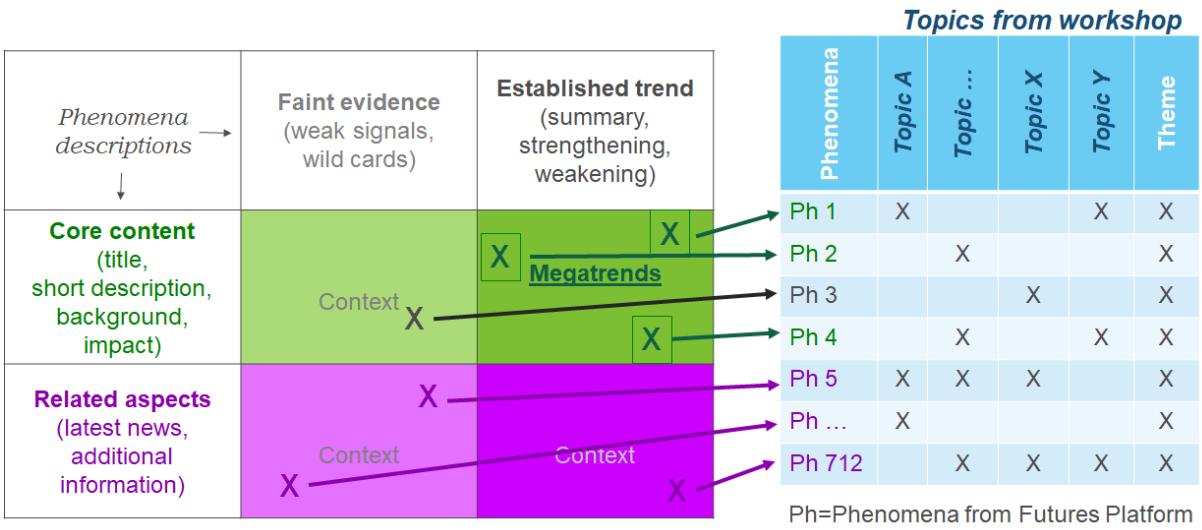
- Whether Futures' Platform classified a given phenomenon as 'faint evidence' or 'established trends'.
- Whether a keyword is retrieved in the 'core content' or 'related aspects' of a Futures Platform phenomenon description.

These analyses entail two-dimensions and two-choices. One of these two dimensions is types of phenomenon: 'faint evidence' vs. 'established trends'. The other dimension is related to whether a keyword is retrieved in the 'core content' or 'related aspects' part of a phenomenon description.

By intersecting these two analyses, one defines four quadrants as illustrated in **Figure 16**, looking into the relevance of each phenomenon for a given theme. Phenomena in the darker-green upper-right quadrant are deemed to be of key relevance, being not only established trends but also displaying theme-references in the 'core content' of their description: These phenomena are deemed part of the megatrend 'domain'. Other phenomena, still relevant to the theme yet not meeting the requirement for being part of the megatrend domain, are part of the other three quadrants. These phenomena in other quadrants define context 'domains'.

Subsequently, as illustrated in the right part of the figure, this additional information can be added to the phenomena allocations at theme and topic levels.

Figure 16. Intersecting phenomena depending on the location of the reference and the type of phenomena



Source: Authors, based on Futures Platform material.

In the case of the energy theme, described in Section 2.4, all of the phenomena referencing energy in all quadrants above are mapped in **Figure 19**. Then only the 'megatrends' quadrant is compared to the Futures Platform standard energy radar and displayed in **Figure 20**.

Another analysis looks into the JRC phenomena typology and how one phenomenon may be differently allocated to various topics or themes: Following the relevance-mapping of phenomena to topics and themes, one can work with various levels of interlinkages as schematised in **Figure 17**. Phenomena allocated as:

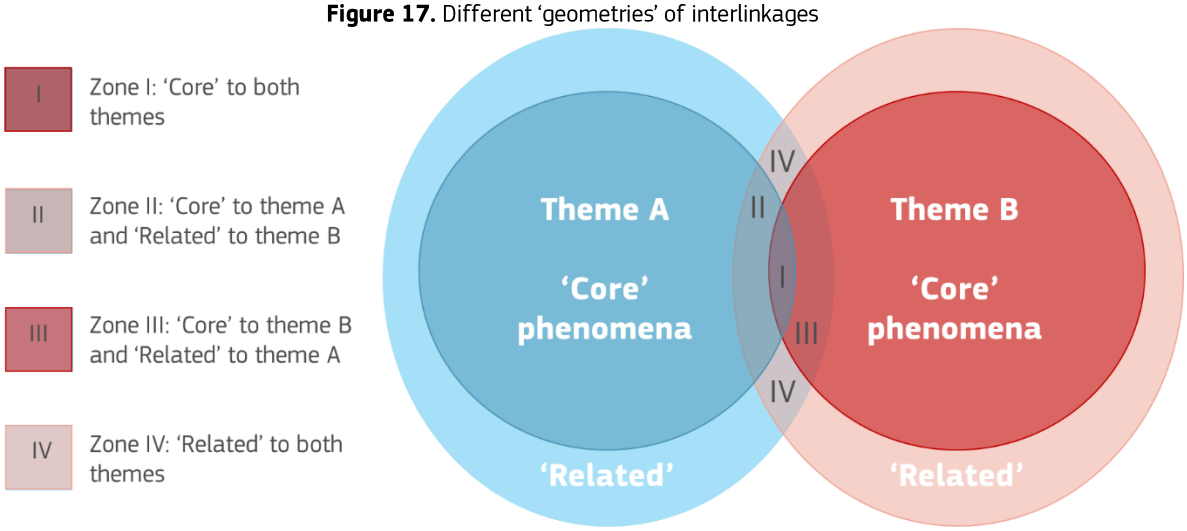
— 'Core' to two topics (or themes) would be situated at the intersection of the two topics or themes (zone 1 in **Figure 17**), thereby making a connection or an interlinkage between these topics (or themes).

— 'Core' to one topic (or theme) and 'related' to another topic (or theme) would be situated in zones II and III of **Figure 17**.

— 'Related' to two topics (or themes) would be situated in zones IV of **Figure 17**.

Connections involving not only core but also related phenomena are discussed in Section 3.2 (for human enhancement 'related' phenomena which are 'core' to other MT-tech themes) and Annex 3.4 (for the energy theme). Connections involving related phenomena allow for the identification of possible fainter / less obvious connections between topics, and potentially also between themes.

Figure 17. Different 'geometries' of interlinkages



Source: Authors, based on Futures Platform material.

2.4 Making sense of Futures Platform content beyond MT-tech topics, example of the energy theme

Text-mining provides means to process a large amount of information on short notice. This approach is used to filter Futures Platform content with respect to energy relevance, by searching over 80 (energy relevant) keywords in the phenomena descriptions. Should no keywords appear anywhere in the entire description, the phenomenon is deemed 'not energy relevant'. Should one or more keywords appear, the sentences bearing the keyword(s) are extracted for manual review. The manual review consists of looking at the extracted sentences from a phenomenon to decide:

(a) If the phenomenon is indeed energy-relevant or a false positive.

(b) What is the impact of this phenomenon on or from the energy system; this in turn allows deciding where the phenomenon should appear on a mapping of phenomena from an energy-system perspective (**Figure 19**).

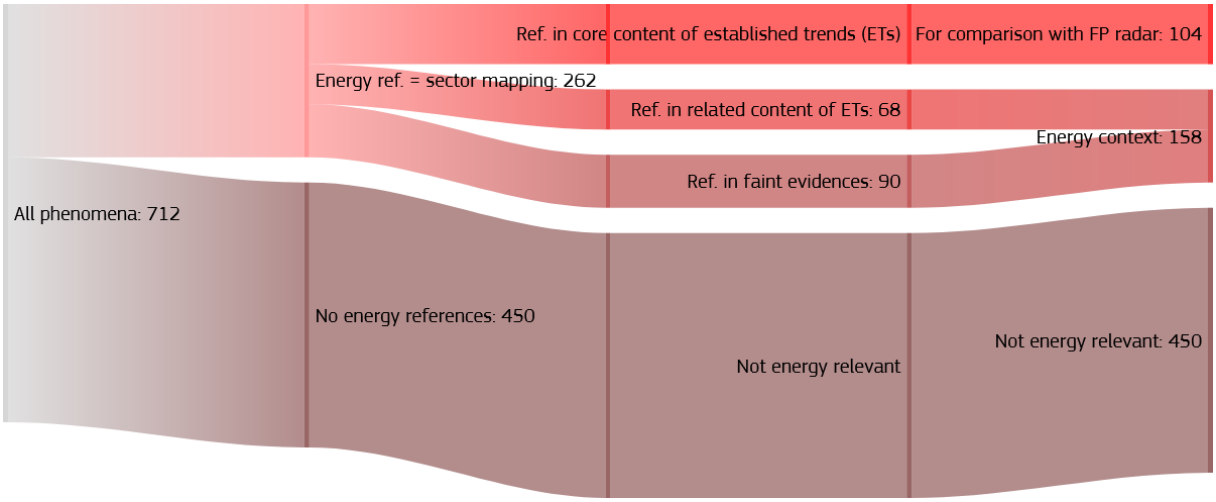
Through this process, 262 out of 712 Futures Platform phenomena are flagged as 'energy relevant', as shown in the first coloured column of the Sankey diagram of **Figure 18** and mapped according to various aspects of the energy system that they refer to or impact (**Figure 19**).

The authors then examined each of these 262 phenomena to verify whether the energy-relevant keywords are retrieved in core content of established trends (104 phenomena); in related content of established trends (68 phenomena); or in faint evidences (90 phenomena), as shown in the second coloured column of the Sankey diagram of **Figure 18**.

— Should the reference appear in the core content (title, short description, background or impact) of an established trend: The phenomenon is deemed 'high energy relevant trend' and earmarked for adding to a customised radar using functionality provided by Futures Platform (**Figure 20**).

— Should the reference appear in the related content (additional information, latest news) of an established trend OR should the reference appear in faint evidences: The phenomenon is deemed 'context' relevant.

Figure 18. Futures Platform phenomena relevance to the energy theme



Source: Authors, based on Futures Platform material.

The Sankey diagram of **Figure 53** in Annex 3.2 shows an example of this allocation process at topic level.

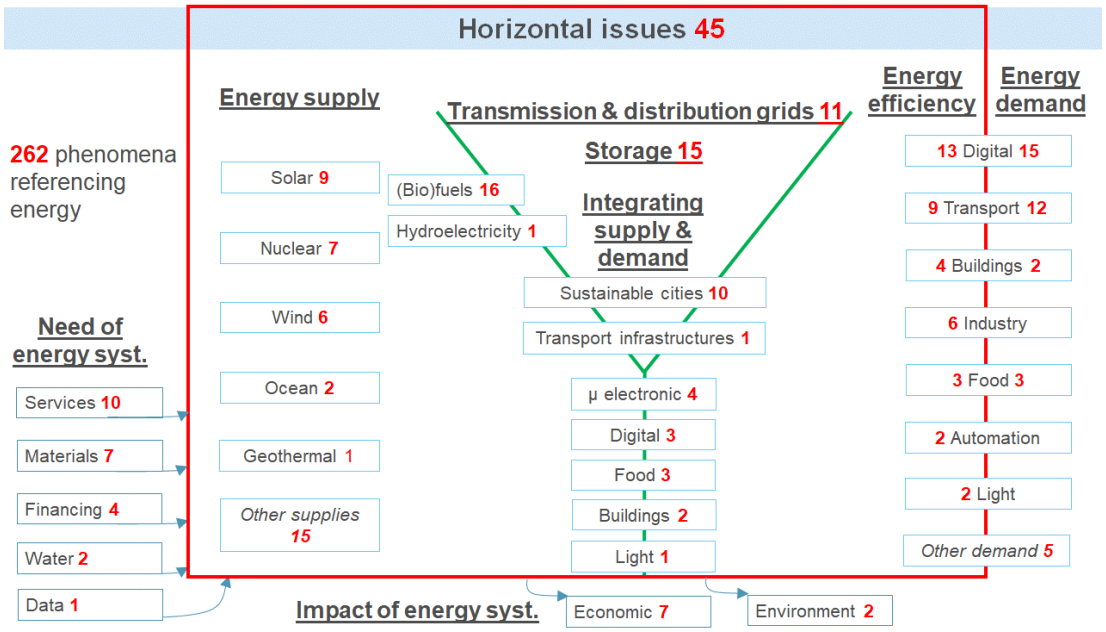
Mapping Futures Platform phenomena from an energy-system perspective

In an attempt to make sense of these data, the author undertook to map these 262 phenomena according to various headings referring to aspects of the energy system that they refer to or impact. **Figure 19** shows 30 headings, such as 'services', 'solar' 'sustainable cities' and 'digital'. This mapping endeavours to make sense of whether an energy-relevant phenomenon suggests an impact on the energy system from within (by supplying, transmitting or saving energy), from outside (by feeding the energy system with resources, by demanding energy, or hinting at impacts of the energy system) or both (via horizontal issues or the integration of energy supply and demand).

Such allocation entails a level of subjectivity. For the sake of simplification of the visual of **Figure 19**, each phenomenon was allocated to only one heading: each phenomenon is therefore linked to only one aspect of the energy system, even if it may impact or be impacted by other aspects. Furthermore, not all allocations are unequivocal. For example, the security aspect entails both an 'impact on the energy system' (e.g., security of energy grid and systems) as well as broader societal issues (e.g., a collapsing energy system is a threat to established order). Phenomena allocated to a security heading may impact the energy system from within (e.g., resilience of the energy infrastructure) or from outside (e.g., needs for uninterrupted power supplies).

The figure below shows this mapping of Futures Platform phenomena from an energy-system perspective.

Figure 19. Futures Platform phenomena from an energy-system perspective



Source: Authors

The upper-right of **Figure 19** shows 28 Futures Platform phenomena referring to 'digital', positioned between 'energy efficiency' (13 phenomena) and 'energy demand' (15 phenomena). These are worth further analysis in the frame of the green and digital twin transition. In the centre of the figure there are 24 phenomena referring to 'integrating supply and demand', grouped under headings ranging from 'sustainable cities' (ten phenomena) to 'buildings' (two phenomena) and 'light' (one phenomenon). These phenomena are of relevance to the topic 'scales of energy' put forward in the MT-tech workshop of January 2021. The headings in the figure group a wide variety of phenomena that affect or relate to the energy system from within (e.g., energy supply technologies, grids) or from outside (e.g., natural resources, financing). By organising a wide range of phenomena from the perspective of a specific system (in this case energy), this exercise can help open up the analysis beyond conventional system boundaries, while also providing some depth recognisable to domain experts.

Customising a Futures Platform radar

Futures Platform provides standard radars and offers users the possibility to create custom-made ones. Radars are a visualisation of phenomena along two user-defined dimensions, such as selected topics and timelines. In its standard energy radar ([36]), Futures Platform displays 60 phenomena mapped along five topics (i.e., Natural resources & efficiency; Business models; Renewable energy; New technological solutions; Batteries and transmitting) and three timelines (i.e., 2021-2024; 2024-2029; 2029-2040).

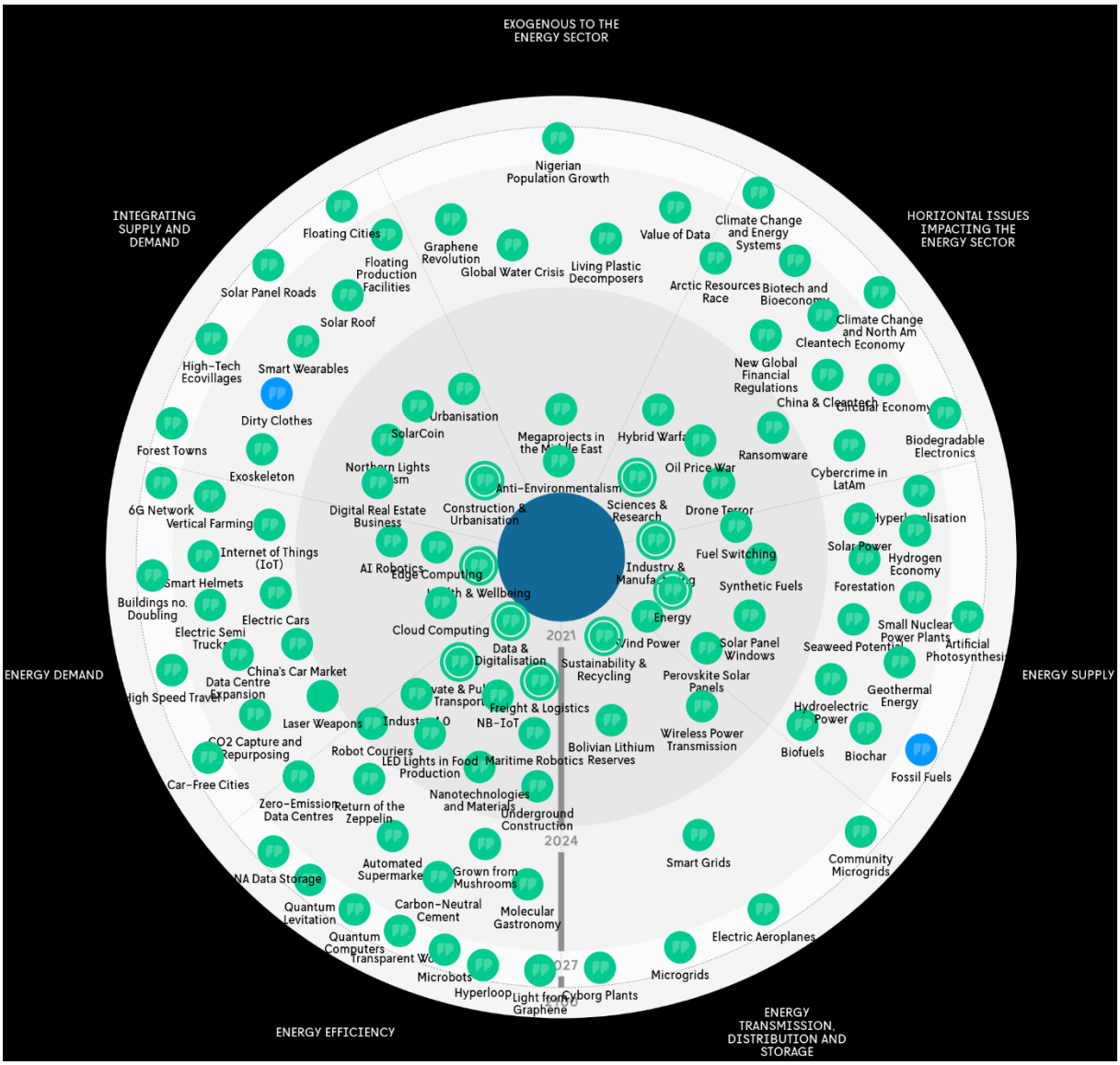
Using this functionality, the authors compiled a customised radar dedicated to energy, displaying the previously identified 'high energy relevant trends' ([37]).

([36]) https://go2.futuresplatform.com/radar?node=521450&ret_id=a0669ed7-bb83-407b-92d6-7dbf362eaa19

([37]) Of the 712 Futures Platform phenomena, 262 are identified as energy-relevant. Out of these, 104 are (a) considered 'established trends' (phenomena designated by Futures Platform as either 'strengthening', 'weakening', or else presented as a broader 'summary' of various more specific phenomena) and (b) bearing the energy-relevant keywords in the core content of their description.

The customised energy radar in the figure below shows a buzzing energy system, mostly affected by strengthening trends (in green below) with only two weakening trends (in blue) displayed. Furthermore, this radar displays nine of the 30 summaries proposed by Futures Platform. This underscores how energy underpins various themes, such as 'health and wellbeing', 'private and public transport' and 'data and digitalisation'.

Figure 20. Customised radar for energy, based on Futures Platform phenomena and functionality



Source: Authors, with Futures Platform tool.

3 Interlinkages within and between four technological themes

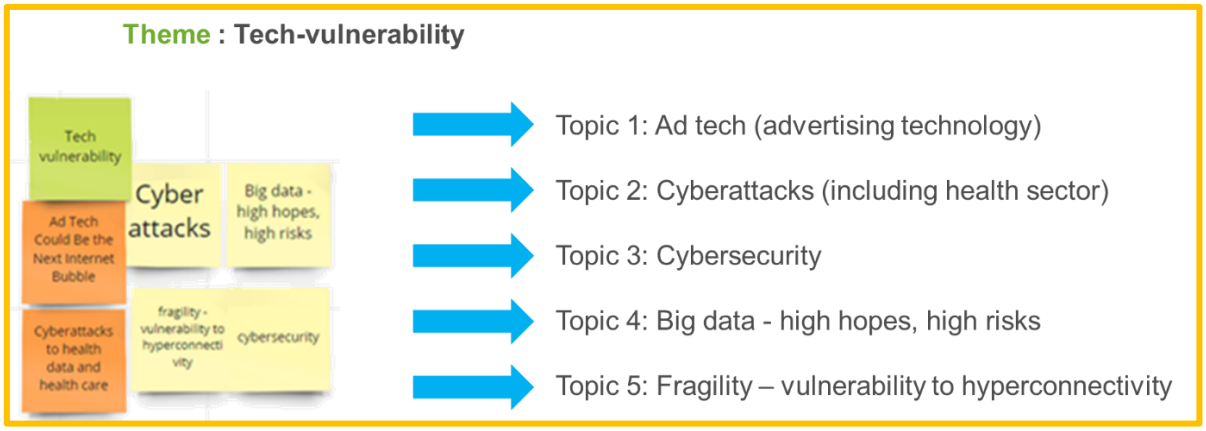
3.1 Interlinkages relevant to Tech-vulnerability

By Amalia Muñoz Piñeiro (JRC.F.7).

3.1.1 Approach

One of the themes identified during the megatrend 'Accelerating Technological Change and Hyperconnectivity' MT-tech workshop was 'Technological vulnerability' (Tech-vulnerability). Four topics (see **Figure 21** yellow stickers) and two news items (see **Figure 21** orange stickers) were associated as high-relevant for the Theme. The right part of the figure lists topics as identified during the workshop and used for this analysis. For this report, 'cyberattacks to health data and health care' was included in the more general 'cyberattacks' topic.

Figure 21. Theme and topics for 'Tech vulnerability' from the JRC megatrend workshop



Source: Authors, based on 2021 JRC megatrend workshop.

A list of keywords was created to search the Futures Platform repository and identify phenomena relevant to the Tech-vulnerability theme and its five topics:

- Ad tech (advertising technology). Software and tools used to set up and manage digital advertising activities, in the context of e-commerce and personalised offers.
- Cyberattacks (including health sector). A cyberattack is an attempt to disable computers, steal data, or use a breached computer system to launch additional attacks. There are different types of cyberattacks: malware, phishing, ransomware, etc. ([38]).
- Cybersecurity. Cybersecurity is the practice of protecting critical systems and sensitive information from digital attacks ([39]).
- Big data – high hopes, high risks. Big data is a combination of structured, semi-structured and unstructured data that can be mined for information and used in machine learning projects, predictive modelling, and other advanced analytics applications ([40]).
- Fragility – vulnerability to hyperconnectivity. The downside to hyper-connectivity is unquestionably hyper-vulnerability.

3.1.2 Overview of the Results

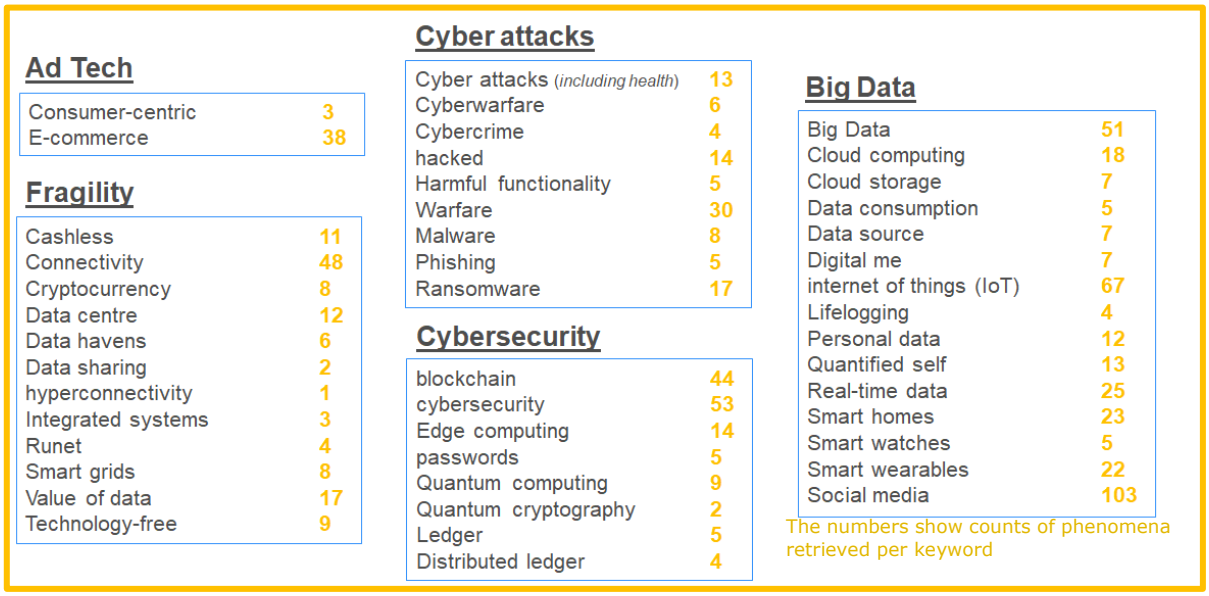
Based on the above topic descriptions, the author prepared a list of keywords (**Figure 22**) relevant to Tech vulnerability; these keywords were used as search terms to text mine 712 phenomena and identify those containing at least one of these keywords. **Figure 22** shows the keywords and the counts of phenomena where each keyword was retrieved. Keywords not retrieved in at least one phenomenon were removed from the list. Keywords having a high coverage of phenomena, such as 'digital', were also removed. The phenomena identified through this keyword-retrieval process were then manually checked to filter out false positives. Another manual

([38]) https://parachutetechs.com/2021-cyber-attack-statistics-data-and-trends/
([39]) https://www.globaltechcouncil.org/cyber-security/12-emerging-cyber-security-trends-in-2021/
([40]) https://searchdatamanagement.techtarget.com/definition/big-data

check was done to identify additional phenomena clearly belonging to at least one topic of the theme 'Tech-vulnerability', though escaping text-mining. These additional phenomena were then included in the analysis. This procedure identified 340 phenomena as core to Tech-vulnerability.

It is important to recall that such an allocation of phenomena to a theme entails some subjectivity, for example in the selection of keywords and more upstream in the curation of these phenomena by futurists.

Figure 22. Keywords used to identify topic-relevant phenomena

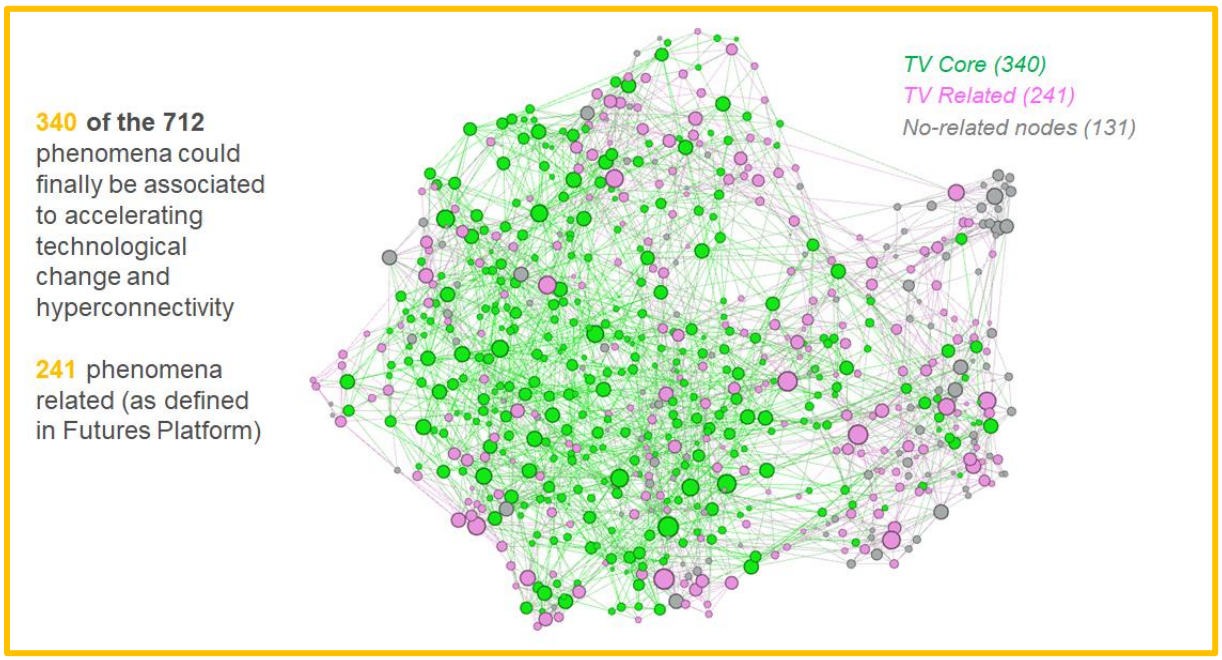


Source: Authors, based on data text-mined from Futures Platform.

As described in Chapter 2, most Futures Platform phenomena descriptions contain references to related phenomena as defined by their futurists. These relations allow visualising phenomena interlinkages in network graphs.

Figure 23 shows a network graph for all 712 Futures Platform phenomena, highlighting in green and pink those deemed relevant to 'Tech-vulnerability'.

Figure 23. Network graph of core and related phenomena allocated to the 'technological vulnerability' theme

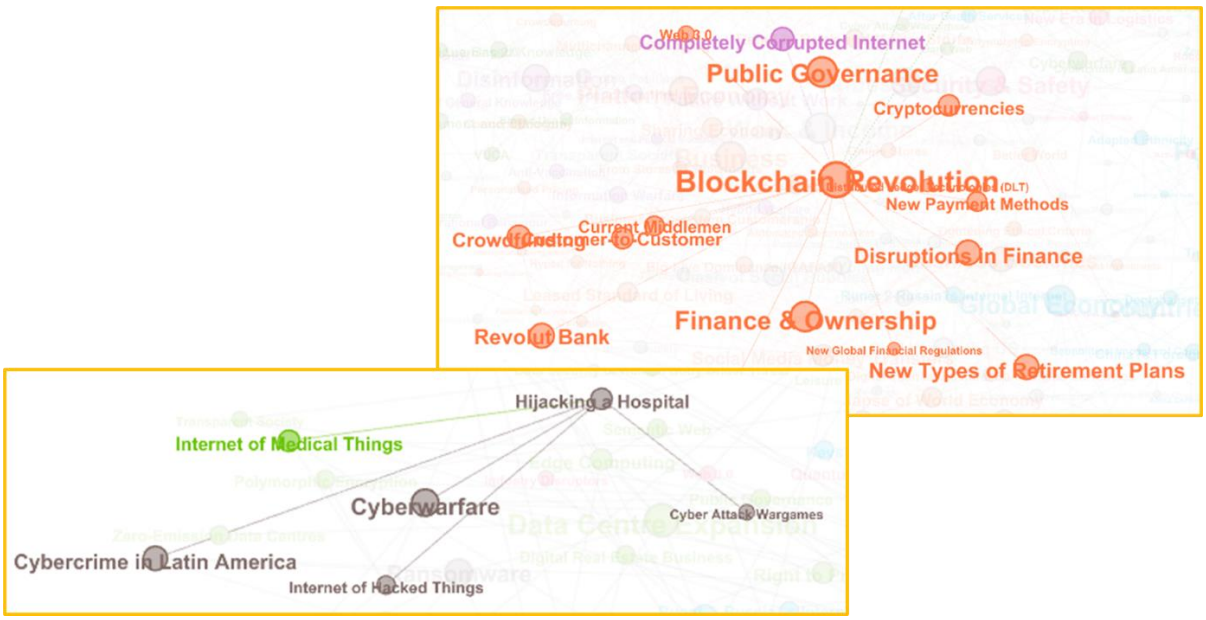


Source of network graphs in section 3.1: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

About 50% of the phenomena are deemed directly relevant to the theme 'TV Core' (green nodes in the graph), since their descriptions contain at least one keyword from the list in **Figure 22**. Pink nodes show those phenomena where Futures Platform descriptions mention relatedness to the 340 core phenomena. However, for these related phenomena none of the keywords listed in **Figure 22** was retrieved in the phenomena descriptions. Their link to the Tech-vulnerability theme can therefore be deemed indirect. The network graph also shows phenomena where no relevant information, keywords or mentions of relatedness, was found in Futures Platform descriptions (grey nodes).

The subsequent analysis focuses on 'TV Core' phenomena, due to their relatively large number. Gephi allows to focus on specific phenomena to see how these are interconnected in futures platform (**Figure 24**).

Figure 24. Sub-networks with phenomena related to 'blockchain revolution' and 'hijacking a hospital'



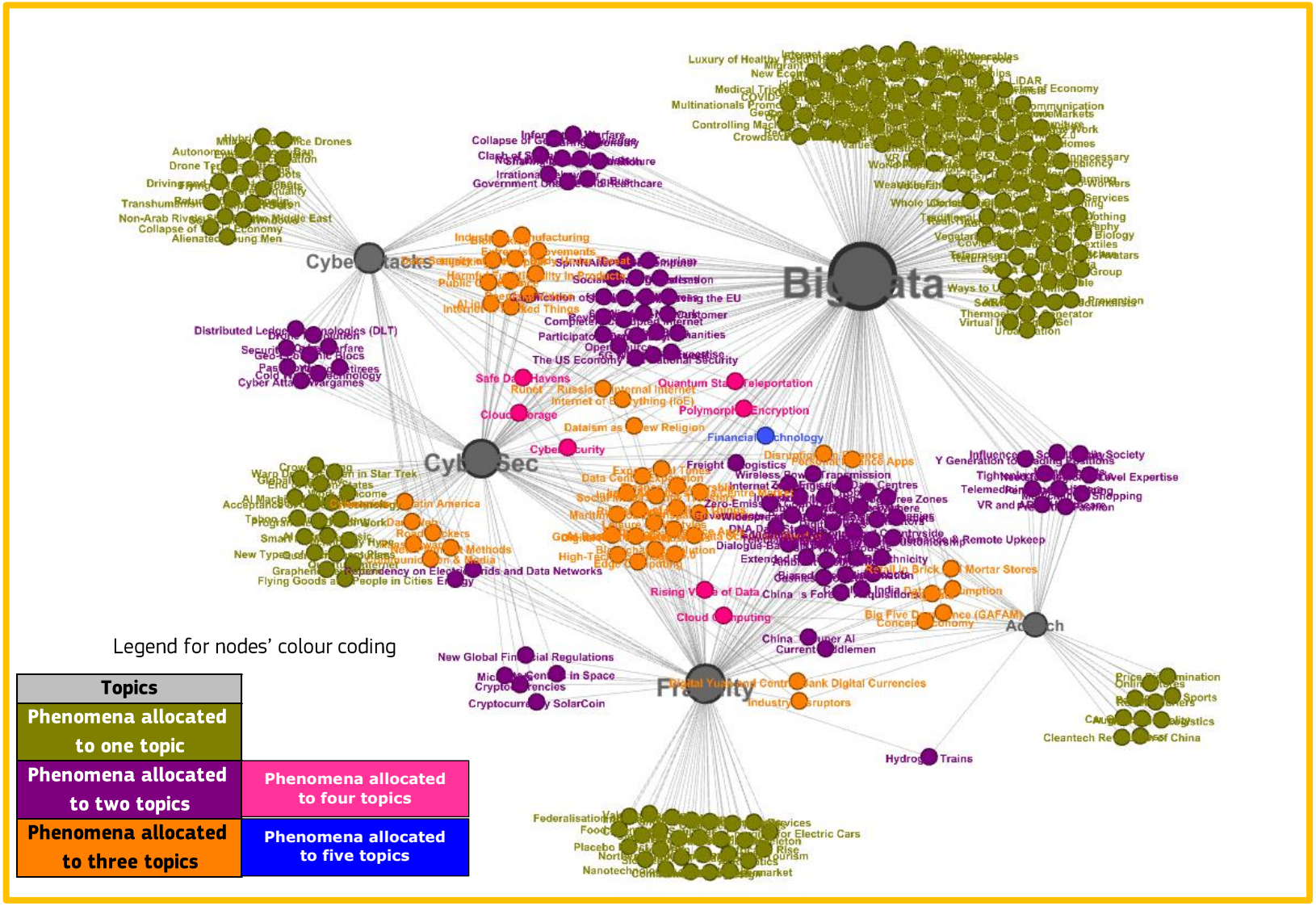
Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

'Block chain revolution' is a well-established trend. As shown in the graph with associated phenomena, it started in the finance area and is slowly expanding to other areas where traceability is crucial, such as the food chain. 'Hijacking Hospital' is an emerging issue, highly inter-related to the increased value of data, more concretely health data. To give an example of the strategic value of data in a political context: hospitals, medical regulatory agencies, supply chains and medical research organisations were cyberattacked during the COVID-19 pandemic.

Figure 25 shows a two-mode network visualisation with phenomena imbedded in topics. The size of each topic node is proportional to the count of phenomena allocated to the topic, while the thickness of the edges linking these nodes are proportional to the counts of phenomena found to interlink each pair of topics. In large complex network graphs, such two-mode representation greatly facilitates the identification of the most connected topics. In this case 'Big Data' and 'Fragility' are the most interconnected pair of phenomena; they are linked to other phenomena such as 'publish anything everywhere', 'real time data', 'right to privacy', 'rising value of data', 'safe data havens', 'social media money transfers', 'technology-free zones' or 'transparent society' among others. The second most interconnected pair are 'Big Data' and 'Cybersecurity', that share phenomena as: '5G wireless networks', 'biohacking', 'cloud computing', 'cloud storage', 'edge computing', 'internet of hacked things' or 'internet of medical things' among others.

Topics are shown as dark grey nodes, sized according to counts of retrieved keywords. Phenomena are shown as small nodes, coloured according to the number of topics they are linked to: phenomena interlinking five topics appear in blue, four topics in pink, three topics in orange, and two topics in purple. Phenomena allocated to a single topic are shown in olive green.

Figure 25. Network graph of phenomena allocated to the 'Technological vulnerability' theme



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

One potential application of this approach is the identification of phenomena to follow up over time. For example, **Figure 26** shows a list of phenomena interlinking three or more topics of the 'Technological vulnerability' theme. Changes to these phenomena will have bigger impact than changes on phenomena allocated just to a single topic.

The list also shows some phenomena classified as either weakening, wild cards or weak signals by Futures Platform futurists. In fact, 'right to privacy' and 'keys' (passwords) is losing impact due to the growing of cloud data storage and data processing, where data belong to the service provider and no longer to the private citizen. The 'data security of human body under threat' phenomenon is classified as a wild card. Due to its strong and relatively recent eruption in the arena, it is difficult to foresee how it could impact the future. Finally, 'polymorphic encryption' and 'quantum state teleportation' are emerging signals for which it is difficult to foresee if they will become trends and have an impact in the future.

Figure 26. Phenomena interlinking three or more topics of the 'Technological vulnerability' theme

Linking the 5 topics

Financial Technology

Linking 4 topics

Cloud Computing
Cloud Storage
Cybersecurity
Polymorphic Encryption (w.signal)
Quantum State Teleportation (w.signal)
Rising Value of Data
Safe Data Havens

Linking 3 topics

AI in Warfare
At least One Million New Data Scientists Needed
Big data
Big Five Dominance (GAFAM)
Biohacking
Blockchain Revolution
Communication & Media
Concept Economy
Cybercrime in Latin America
Dark Web
Data Centre Expansion
Data Centre Expansion
Data Consumption
Data Security of Human Body Under Threat (w.card)
Dataism as a New Religion
Deepfake Videos
Digital Real Estate Business
Digital Yuan and Central Bank Digital Currencies
Disruptions in Finance
Edge Computing
Exponential Times
Extremist Movements
Finance & Ownership
Gold-Backed Currency
Harmful Functionality
High-Tech Ecovillages
Hijacking a Hospital (w.card)
Industry & Manufacturing
Industry 4.0
Industry Disruptors
Internet of Everything (IoE)
Internet of Hacked Things
Internet of Medical Things
Keys (weakening)
Latin America´s Data Centre Market
Leisure & Lifestyles
Maritime Robotics
Mobility-as-a-Service Apps
New Payment Methods
Personal Finance Apps
Public Governance
Ransomware
Retail in Brick and Mortar Stores
Right to Privacy (Weakening)
Road Hackers
Runet – Russia's Internal Internet
Social Media Money Transfers
Transparent Society
Web 3.0

Source: Authors, based on Futures Platform material.

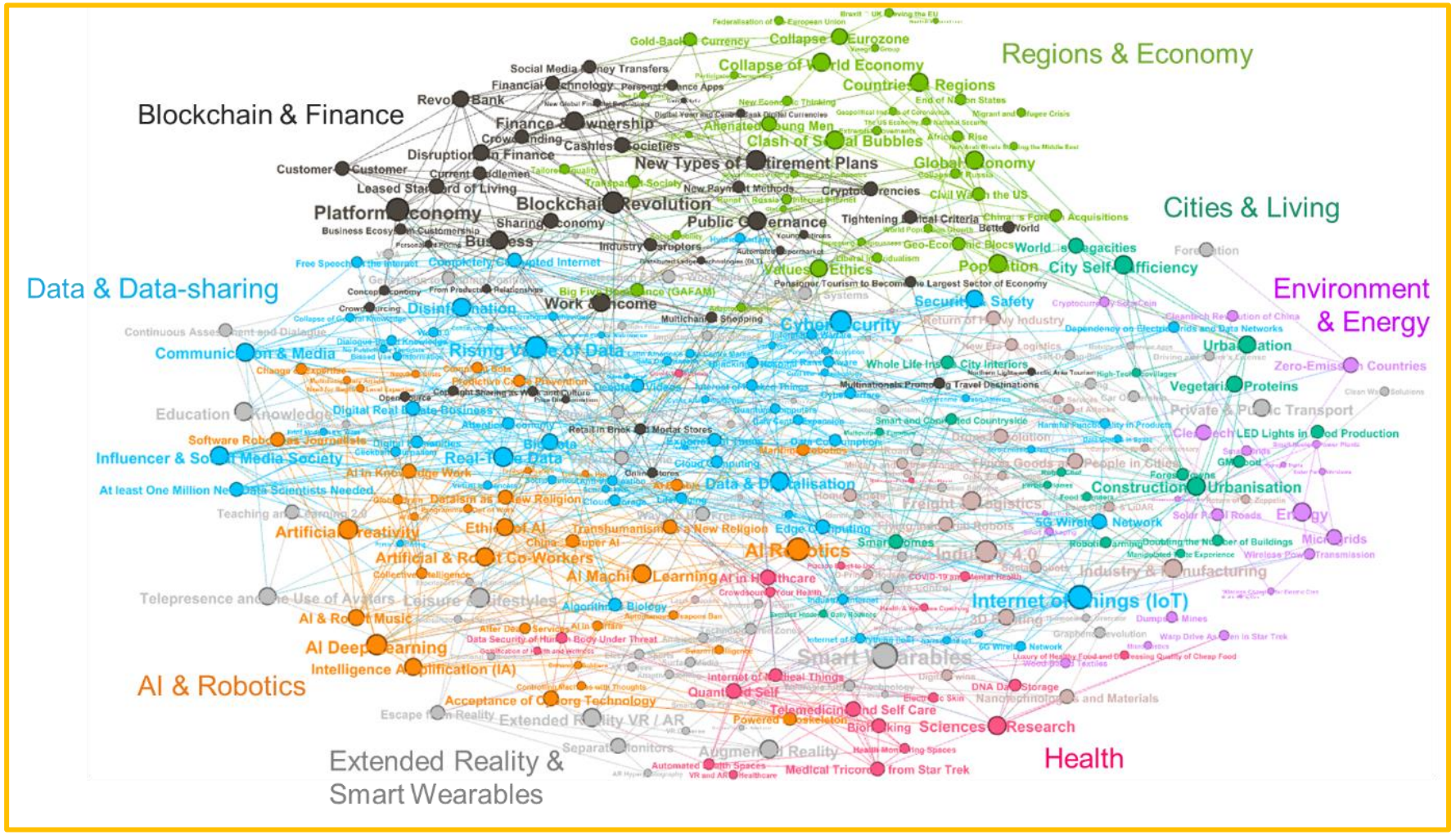
The list of phenomena highlights in blue weak signals, in red wild cards and in green weakening phenomena.

3.1.3 Additional analysis – clustering algorithms

The Girvan–Newman algorithm available in Gephi detects communities by focusing on edges that are most likely 'between' communities. In the network graph of **Figure 27**, the community-detection algorithm formed eight clusters, which the author names: 'regions & economy', 'cities & living', 'environment & energy', 'health', 'extended reality & wearables', 'AI & robotics', 'data & data-sharing' and 'blockchain & finance'. These clusters are broader in scope than the five topics defined during the megatrends workshop for the theme 'Tech-vulnerability'.

Finally, by zooming out of the theme 'Tech-vulnerability' and extending the analysis to other themes of the megatrend, one can identify interlinkages across themes, as discussed in Section 3.5 of this report.

Figure 27. Clustering of Futures Platform phenomena relevant to Technological vulnerability



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.
Note: This clustering uses the Girvan-Newman algorithm in Gephi, with default settings.

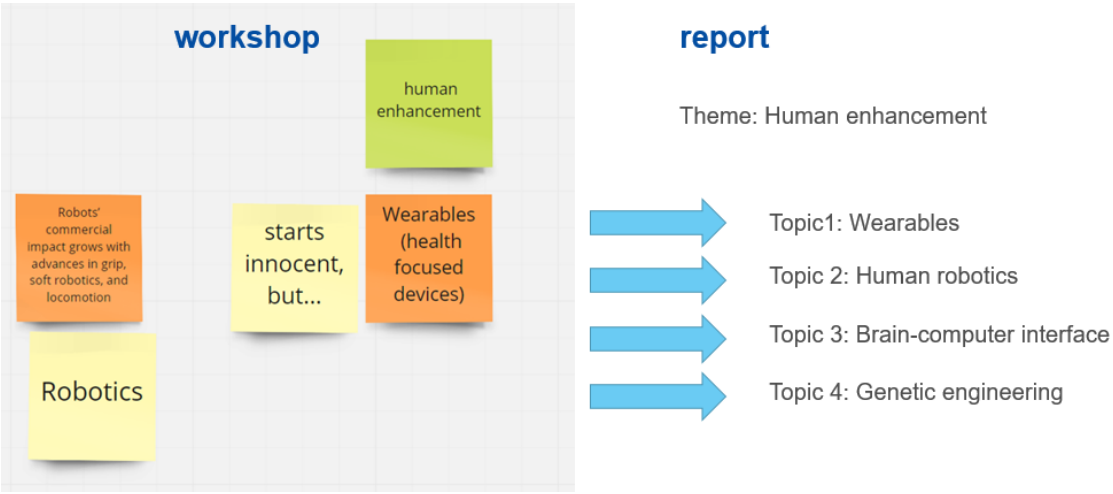
3.2 Interlinkages relevant to human enhancement

By Mayya Hristova (JRC.E.7)

3.2.1 Approach

The approach for analysing the theme 'human enhancement' is based on the topics identified during the January 2021 workshop on the megatrend 'Accelerating Technological Change and Hyperconnectivity' and the phenomena available in the Futures Platform relevant to them. **Figure 28** shows the topics put forward during the workshop (left side) and the corresponding topics selected for the analysis in this report (right side).

Figure 28. Human enhancement topics put forward during the JRC megatrends workshop and discussed in the report



Source: Author, based on 2021 JRC megatrend workshop.

The information from Futures Platform is retrieved via text-mining using the following keywords: human enhancement; human augmentation; augment*human ; augment*human; mental enhance; mechanic*enhance; cognitive enhance; super soldier; enhanced soldier; cyborg; augmented troop; dominant soldier; modular human; transhumanism; humanoid; wearables; wearable technolog; smart textile; enhanc*sensing; sensor; wearable robot; exoskeleton; neuromechanics; human?robot; robot?human; bio-printed; bionic; brain human interface; brain?machine; brain?computer; BCI; genetic engineering; recombinant DNA.

The author reviewed the extracted set of phenomena and selected 38 of them. It should be noted that this last step is highly subjective and depends on personal appreciation whether a phenomena is relevant to the theme human enhancement or not. Those 38 phenomena were allocated to one or several of the four topics listed in the figure above. For the sake of completeness one additional category 'other' was introduced. It comprises phenomena that are considered relevant for the theme but falling outside of the scope of the other four topics.

The theme as well as the four topics are very broad and sometimes it could be difficult to decide whether a phenomenon falls within their scope or not. A brief description of the scope of each of them is provided below.

- **Human enhancement**: natural or artificial modification of the human body in order to enhance physical or mental capabilities. Technology based interventions restoring lost or damaged abilities as well as creating new ones ('augmented human').
- **Wearables**: Machine-based augmentation. Computational technologies used by the user to communicate with other devices, services or technologies. Can be worn on any part of the body. Example of products: smartwatches, head-mounted displays, smart clothing, fitness trackers, body-worn camera, medical devices.
- **Human robotics**: Machine-based augmentation. Semi-autonomous robot attached to and directly operated by the human body. Wearable robots. Products: robotic hand, exoskeletons or exosuits to help reduce worker strain and improve grip, strength, endurance, adapt to the patients desired movements, help them regain some mobility and autonomy.
- **Brain-computer interfaces** (BCIs): Machine-based augmentation. Systems that translate 'brain signals into new kinds of outputs' and thus bridge communication between the brain and an external device (e.g., 'mind-controlled prosthetic robotic arm'). Conducted with therapeutic goals, especially for physical

rehabilitation. But also, to improve memory encoding, operate tools and vehicles with the brain, downloading information directly out of the brain, etc.

— **Genetic engineering**: genetic intervention; enable advanced preventative medicines and anti-aging interventions. It encompasses a large scope of techniques, which are still mostly experimental. They aim to use genetic material or genetic tools to treat or cure diseases. Genome editing (or gene editing) is a term used only in recent years, which refers to genetic engineering using a particular group of tools or group of molecular technologies that enable an intervention directly on the genome in order to change, add or remove specific locations on the DNA sequence.

3.2.2 Overview of results

From the full set of 712 phenomena extracted from Futures Platform, the text-mining and review process lead to a set of 38 core phenomena considered in the current analysis as relevant to theme and topics. Those flagged by Futures Platform as related to the 'core' ones are 137. The remaining 537 were considered as not relevant.

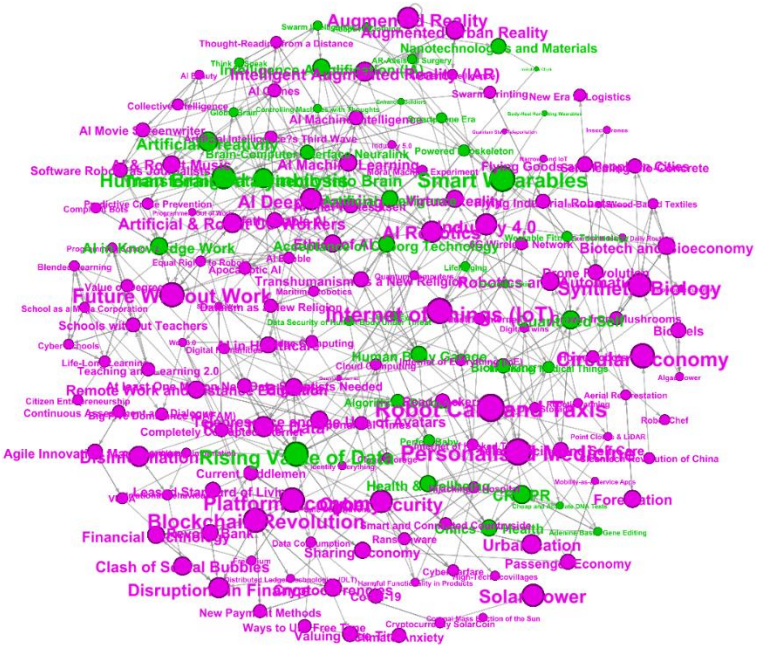
The core phenomena are allocated to one or several of the topics as follows:

— 'wearables': 12.
— 'human robotics': 4.
— 'brain-computer interface': 11.
— 'genetic engineering': 7.
— 'other': 11.

The high number of related phenomena indicates already the fact that the theme is not isolated from other domains in life and points to interlinkages with other themes. The topic 'wearables' has the highest number of related phenomena, which is not a surprise, as it includes, among other devices, smartwatches and fitness trackers that are already well accepted and largely used in the society and strongly related to big data, Internet of Things and health in general. The fifth topic 'other' includes several phenomena related to Artificial Intelligence and Data, which as well are strongly related to machine intelligence, machine learning, big data and robotics in general. Undoubtedly, the human enhancement theme has an impact and is simultaneously affected by developments in other fields largely present in the society today.

A network graph of those core and related phenomena can provide a visual of the complexity of links without drawing a causal relationship (see **Figure 29**). The core phenomena are highlighted in green and the related ones in purple. The size of the node is determined by the number of connections each phenomenon has with others. That is, the bigger the node, the higher the number of connections with other phenomena.

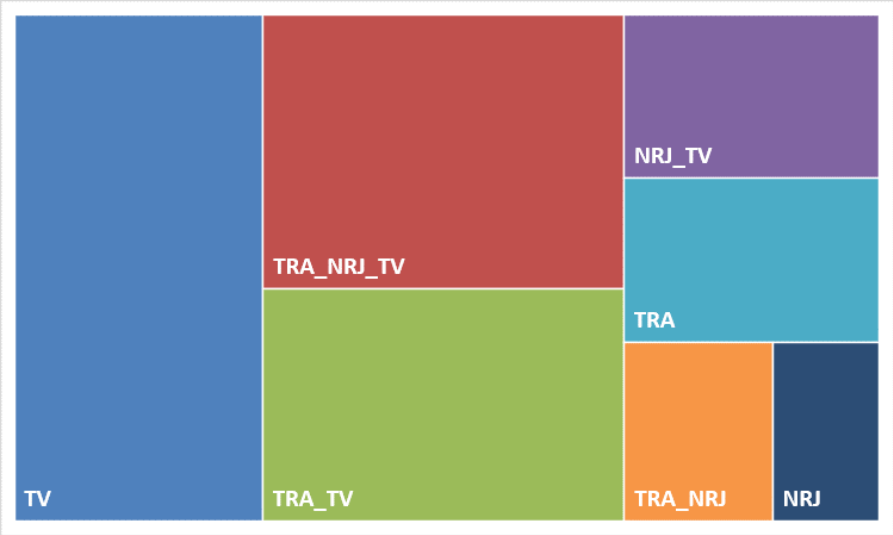
Figure 29. Network graph of 'core' and 'related' phenomena in the 'Human enhancement' theme



Source of network graphs in section 3.2: Authors, based on data text-mined from Futures Platform and visualised in Gephi. Annex 2 provides a tabular overview of the Futures Platform phenomena and their Interlinkages.

In order to explore the interlinkages between MT-tech themes, one can analyse the related phenomena and map them to the other MT-tech themes presented in this report. **Figure 30** presents the MT-tech themes to which the human enhancement related phenomena correspond. Those that did not match any of the themes were excluded. The latter represent only 16% of the related phenomena and the remaining 84% were mapped to at least one of the three other themes. The link with the theme 'Tech-vulnerability', and more particularly with the topic 'Big data' stands out.

Figure 30. Distribution of human enhancement related phenomena to other MT-tech themes

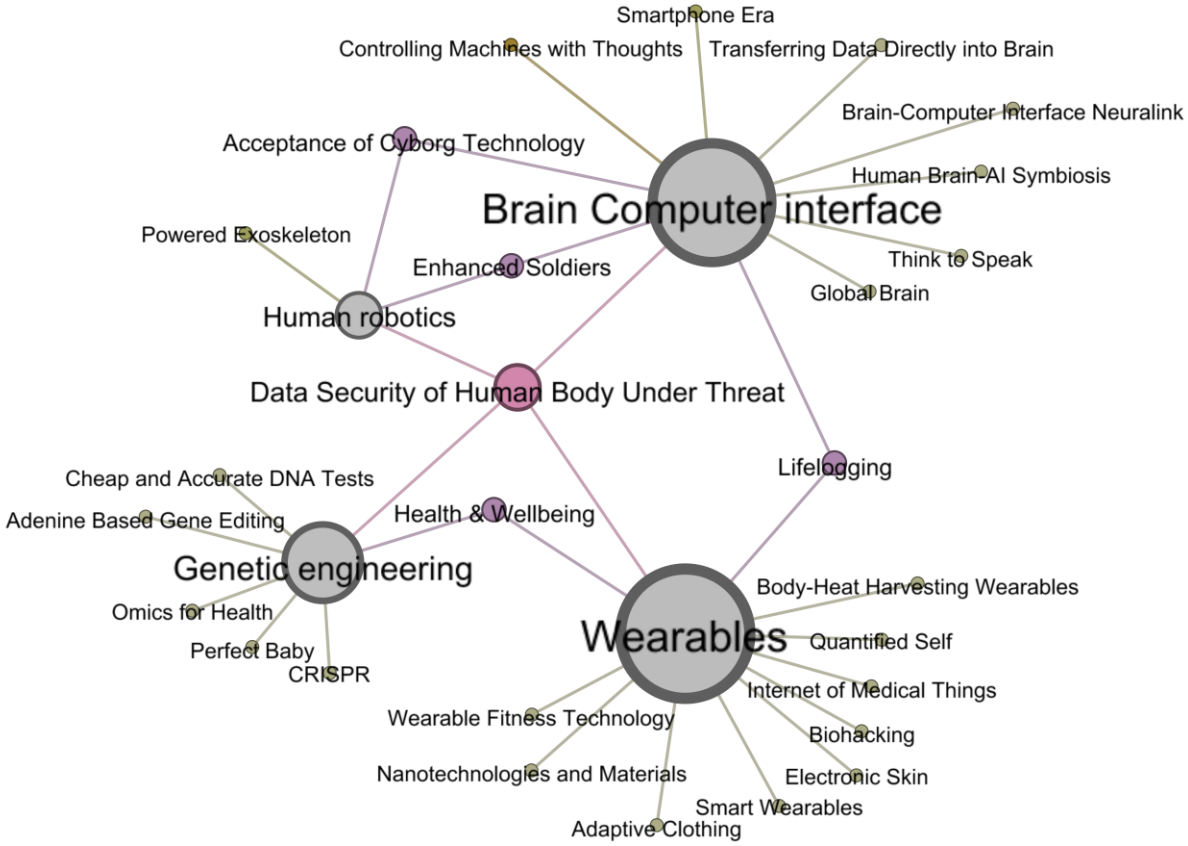


Source: Authors based on Futures Platform materials.

Another approach is to concentrate on the core phenomena only and analyse their link not only to the 'human enhancement' theme and topics but also to the other MT-tech themes and topics.

With the aim of visualising the interlinkages among the core phenomena and the human enhancement topics a 2-mode network graph is drawn (see **Figure 31**). The term '2-mode' stands for the fact that two types of nodes are represented in the network: phenomena (smaller nodes) and four topics to which they are linked (larger grey nodes). This allows to visually distinguish the two type of nodes and visually inspect the relations among them. For example, the 'Data security of human body under threat' phenomenon (larger pink node in the centre of the graph) is connected to all four topics. Other phenomena are connected to two topics (e.g., the 'Health and well-being' purple node between the 'Genetic engineering' and 'Wearables' topics in the lower left part of the graph).

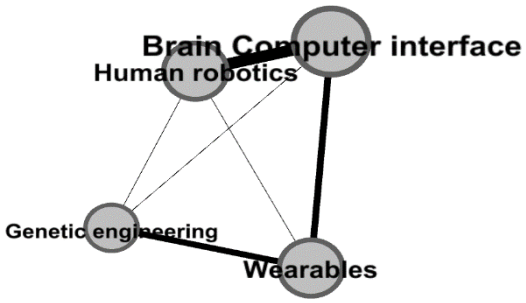
Figure 31. Two-mode network graph of human enhancement core phenomena, and topics to which they are allocated



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

The 2-mode network can also be transformed to a one-mode network, i.e., representing only the topics and the links among them (see **Figure 32**). The phenomena are projected on the topics: if two topics have one or more phenomena in common, then a link is drawn between those topics. The higher the number of shared phenomena between the two topics, the stronger the link between them (thicker line on the graph).

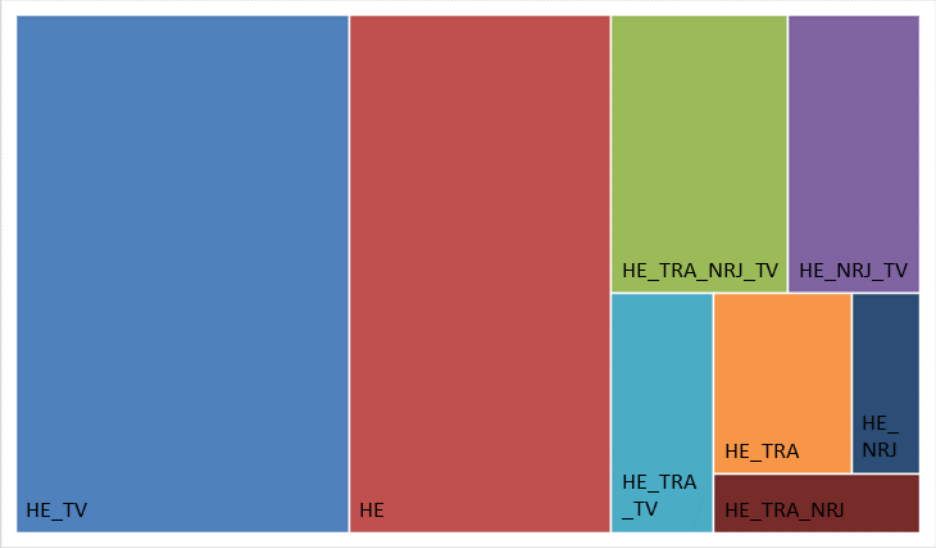
Figure 32. Network graph of human enhancement topics obtained by projection of core phenomena



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

The human enhancement topics are mostly linked with the MT-tech theme 'Tech-vulnerability' followed by the themes 'Transport' and 'Energy' (see **Figure 33**).

Figure 33. Distribution of human enhancement core phenomena allocated to MT-tech themes



Source: Authors based on Futures Platform material.

Wearables is the most interlinked with the other themes topic. There are four phenomena that are common for all four themes: 'body-heat harvesting wearables', 'nanotechnologies and materials', 'smart wearables' and 'rising value of data'.

The first one, 'body-heat harvesting wearables', is a weak signal worth following as its time frame is in the next two years (2023) and it could impact cross-cutting domains. According to Futures Platform this phenomenon is about the thermal energy of the human body, which could be used to power different devices.

The other three phenomena are all strengthening with a very short-term time frame (2024-2028). They could have an impact on energy (fuel, rare-earth), health (treatment but also potential risks), politics and economics (private entities controlling data).

3.3 Interlinkages relevant to energy

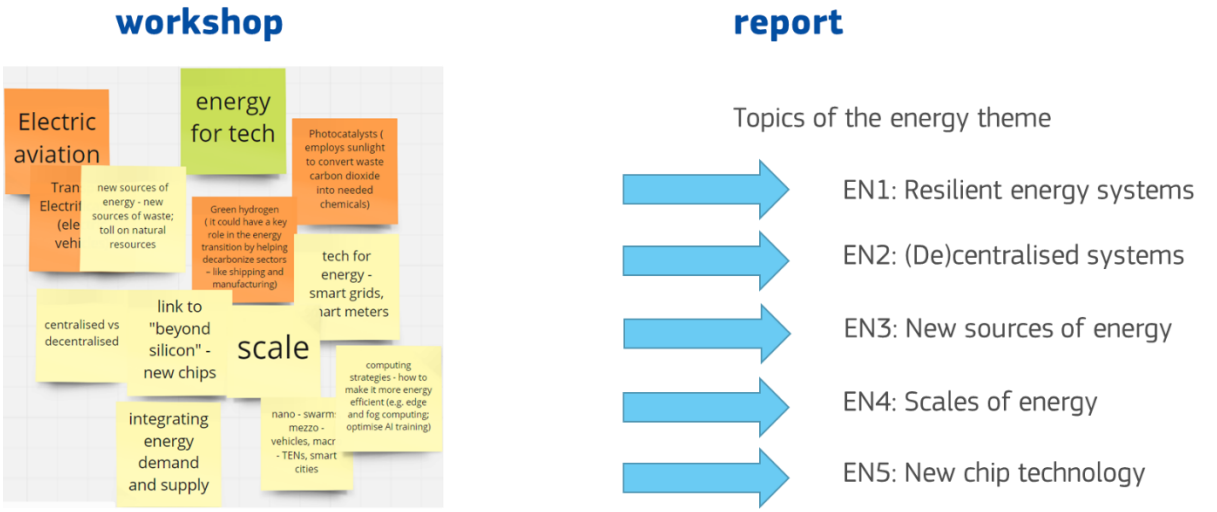
By Alain Marmier (JRC.C.7) and Elisa Boelman (JRC.C.7).

3.3.1 Approach

As detailed in Chapter 2, the approach developed by the authors relies on iterations of text-mining and analysis to retrieve Futures Platform phenomena relevant to topics identified during the January 2021 workshop on the megatrend 'Accelerating Technological Change and Hyperconnectivity'.

Figure 34 below shows these topics as put forward during the workshop, under an 'energy' heading (left side), and indicates the corresponding topics selected for analysis in this report (right side of the figure).

Figure 34. Energy topics investigated in this report, stemming from January JRC megatrend workshop



Source: Authors, based on 2021 JRC megatrend workshop.

3.3.2 Overview of results

Out of 712 phenomena extracted from Futures Platform, 262 are allocated to the energy theme in general. Out of these, 71 core phenomena are allocated to one or more specific energy topics. The following list displays phenomena counts per topic, accounting for phenomena allocated to several topics as detailed in Annex 2:

- 'resilient energy systems' topic: 6 phenomena.
- '(de)centralised energy systems': 12.
- 'new sources of energy': 32.
- 'scales of energy': 42.
- 'new chip technologies': 15.

Of these unique phenomena, 19 are allocated to two topics and seven to three topics, for example:

- 'community microgrids' phenomenon, allocated to the topics: 'resilient energy systems'; '(de)centralised energy systems'; 'scales of energy'.
- 'doubling the number of buildings': 'resilient energy systems'; 'scales of energy'.
- 'fuel switching': 'resilient energy systems'; 'new sources of energy'; 'scales of energy'.
- 'seaweed potential': 'new sources of energy'; 'scales of energy'.
- 'use of wind power': '(de)centralised energy systems'; 'new sources of energy'; 'scales of energy'.

Allocating Futures Platform phenomena to multiple topics already allows inferring some interlinkages. Furthermore, one can also establish broader conceptual interlinkages between these five topics. For example:

— Energy efficiency enabled by new chip technologies (topic EN5 in this analysis) mitigates demand, thereby reducing supply and demand bottlenecks, leading to a more resilient system (topic EN1).

— Diversification of energy supplies (topic EN3) contributes to resilience (topic EN1).

— Low density sources (topic EN4) are likely to be decentralised (topic EN2).

— Decentralised energy systems (topic EN2) are deemed more resilient (topic EN1).

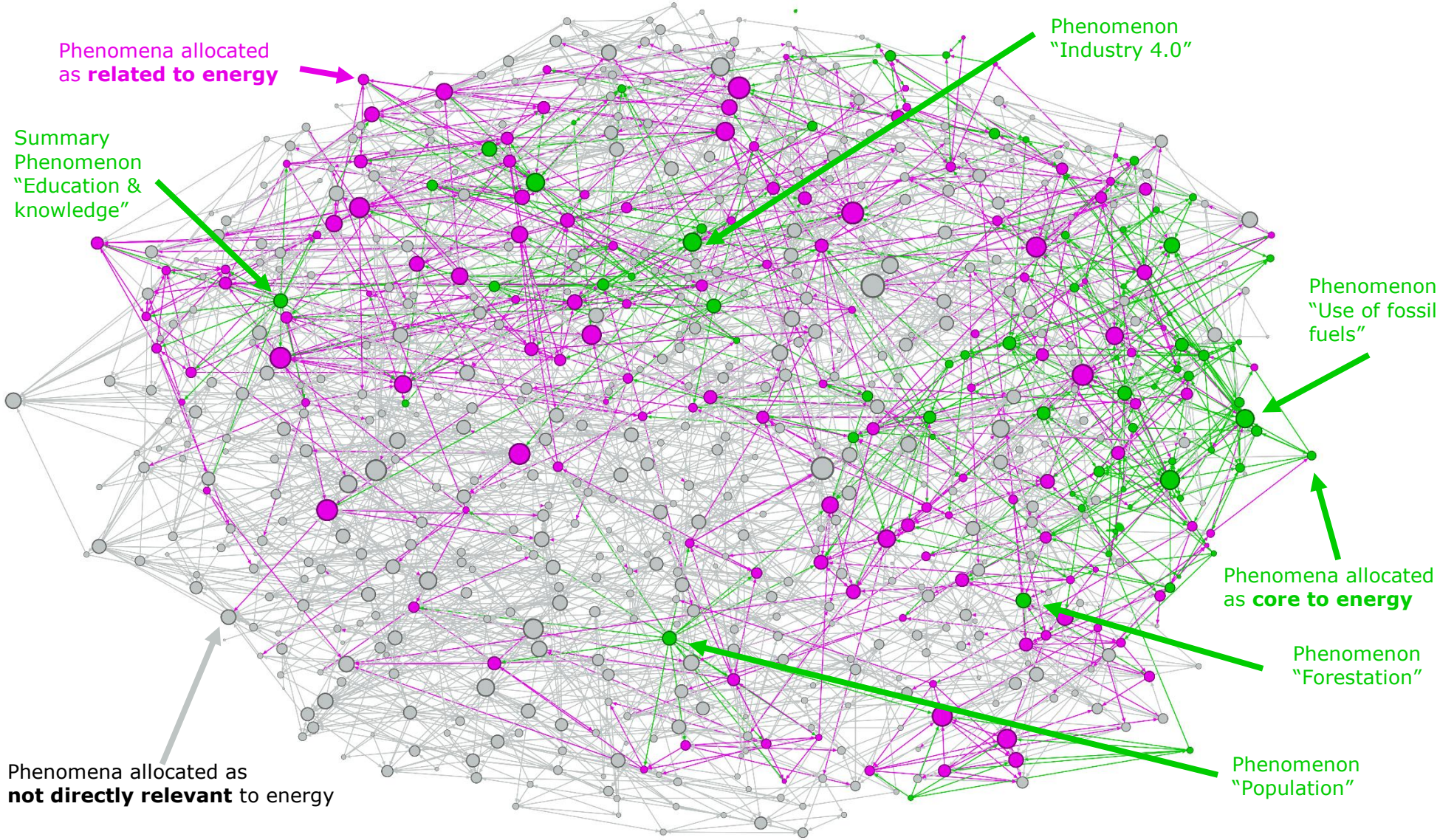
The network graph below (**Figure 35**) shows the phenomena deemed relevant by the author to at least one of the five energy topics listed above and detailed in Annex 2. The Fruchterman Reingold algorithm was used in the Gephi tool to visualise the full network of 712 Futures Platform phenomena. This network graph is structured through the connections defined as 'related phenomena' by Futures Platform, linking two phenomena together. The number of connections define node sizes.

The phenomena which the author deemed 'core' to the energy theme are shown as green nodes, while their related phenomena (as retrieved from Futures Platform descriptions) are displayed as purple nodes. The remaining phenomena (neither core nor related to energy, thus considered 'not relevant') are displayed as light grey nodes. The number of core phenomena is relatively small compared to the number of related and not directly relevant phenomena, reflecting the authors' choice to focus on phenomena directly and clearly pertinent to the energy system.

Most of the core phenomena (green nodes) appear on the right side of the graph, as evidenced by phenomena such as 'use of fossil fuels'. A few other core phenomena also appear as green nodes around the bottom and left side of the network graph. Among them, phenomena 'population' and 'education & knowledge' stand out for their node size – and thus for the number of connections they have with other phenomena as defined by Futures Platform. These are summary phenomena, according to Futures Platform, i.e., well connected phenomena, displaying a broad content affecting various themes. The connection to the energy theme is relatively weak compared to the connections to the other themes. The top side of the graph displays a pocket of core phenomena, including 'industry 4.0'. These phenomena partly relate to 'new chip technologies', a topic further discussed below.

Examples of phenomena where no energy-related keywords were retrieved from Futures Platform descriptions include 'personalised medicine', 'robot cars and taxis', 'leisure and lifestyles', 'future without work' etc. While it is conceivable that lifestyle changes may influence energy demand, the present analysis focuses on more direct relevance and therefore excludes phenomena without explicit reference to energy by Futures Platform.

Figure 35. Network graph of Futures Platform content, highlighting content of relevance to the energy topics of this report



Source of network graphs in section 3.3: Authors, based on data text-mined from Futures Platform and visualised in Gephi.
Annex 2 provides a tabular overview of the Futures Platform phenomena and their Interlinkages.

3.3.3 Interlinkages within the energy theme

Visualising connections between phenomena retrieved from Futures Platform

Figure 36 shows a subset of the full network graph of **Figure 35**, namely the 74 phenomena allocated as 'core' to energy. **Figure 36** shows these core phenomena coloured according to the topic(s) they are allocated to. Some phenomena were allocated to two or three topics (shown in turquoise).

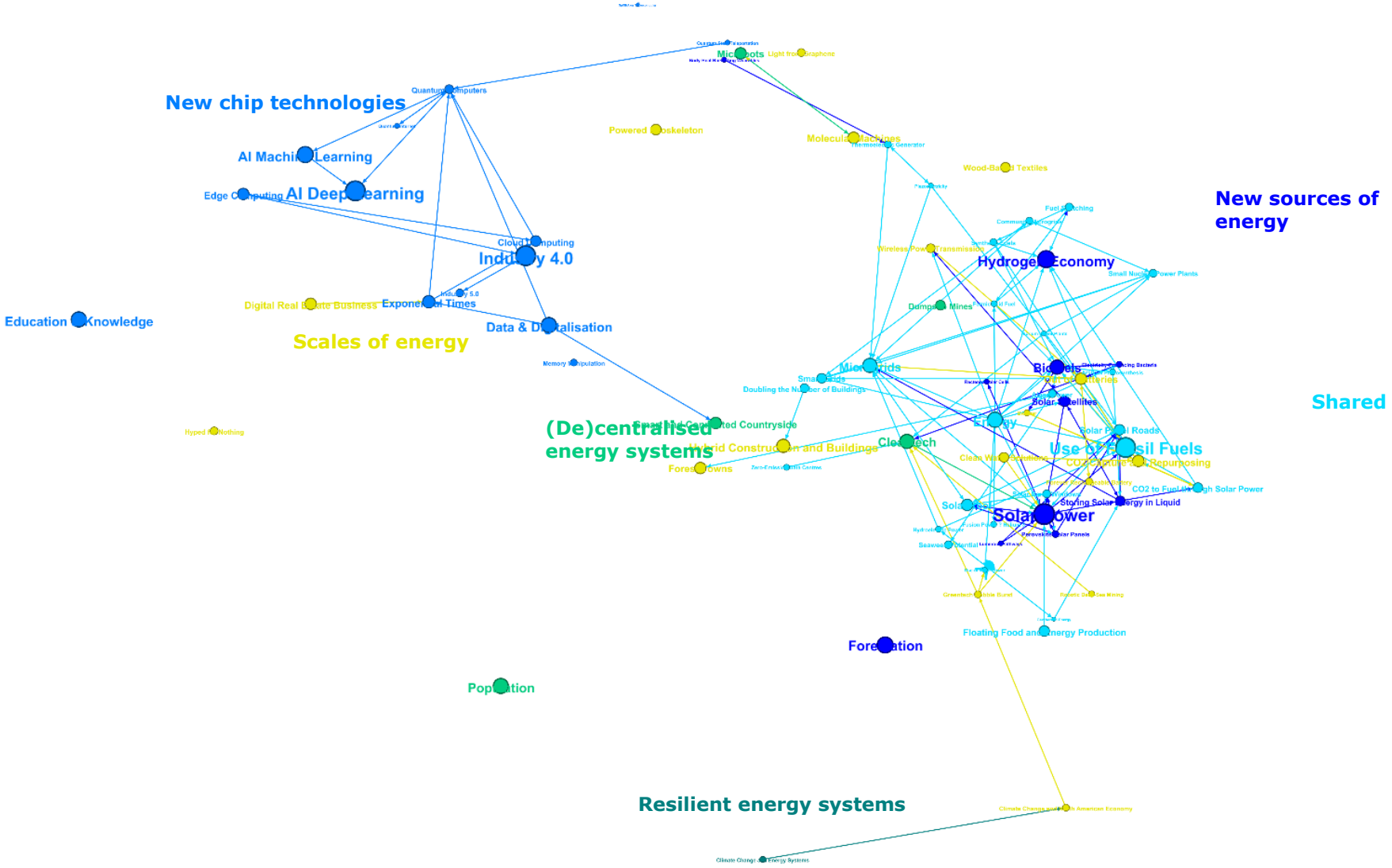
Regarding the 'new sources of energy' topic (coloured in dark cobalt blue on the right side of the graph), relatively well-deployed sources such as solar power, biofuels and hydrogen appear as relatively large nodes (or large circles, in the form of phenomena 'solar power, 'biofuels', 'hydrogen economy'), with connections to many other phenomena. More emerging sources of energy, such as electricity producing bacteria, luminous pathways or rectenna solar cells (possibly related to space applications), appear as small nodes (or small circles, in the form of phenomena 'electricity-producing bacteria', 'luminous pathways', 'rectenna solar cells') with few connections. One large node (implying connections to many phenomena), however, appears as an isolate in this graph: 'forestation' at the right bottom. It has been allocated as core to energy, as belonging to 'new sources of energy' topic though it has no links to any of the other energy core phenomena according to Futures Platform descriptions. 'forestation' is, however, linked by Futures Platform to phenomena allocated as related to energy (e.g., 'vegetarian proteins', 'untouched nature'), as well as phenomena allocated as not directly relevant to energy (e.g., 'nature', 'climate change').

Phenomena allocated as relevant to the 'scales of energy' topic (yellow coloured) tend to appear though the entire network graph and to be more varied, such as 'molecular machines', 'powered exoskeleton', 'hybrid construction and buildings', 'forest towns', etc. There are relatively few phenomena allocated (only) to 'de-centralised energy systems' (light green coloured) and to 'resilient energy systems' (darker green coloured, bottom-right of the graph).

'New chip technologies' is one of the topics that emerged from the MT-tech workshop in January 2021. The phenomena allocated to it in an energy context (blue coloured nodes in the upper left) have more interlinkages among themselves than with the other phenomena in the lower-right part of the graph. This is a likely indication that Futures Platform has described and framed these phenomena in an artificial intelligence (AI) context, without explicitly linking energy to 'industry 4.0', 'AI deep learning' or 'data and digitalisation' for example. Although weakly connected in the energy-context represented in this network graph, these nodes are large in size, indicating that they have many connections to other phenomena. For example, 'industry 4.0' is connected by Futures Platform to a wide range of phenomena allocated as not directly relevant to energy, (e.g., 'China's super AI', 'robotics and automation', 'freight & logistics').

Text-mining of Futures Platform contents retrieved 15 phenomena for the 'new chip technologies' topic in the energy context of this report. Out of these, twelve can be directly related to the energy system while three do not explicitly refer to the energy system in the descriptions provided by Futures Platform. These 15 phenomena can be found in Annex 2, when the 'energy' column refers to 'EN5'.

Figure 36. Network graph of Futures Platform content, filtered to display only content of relevance to the energy topics investigated in this report



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

The emphasis put to 'new chip technologies' by Futures Platform concerns mainly the (additional) energy needs for powering these technologies. The phenomena descriptions in Futures Platform do not specifically refer to potential opportunities provided by such novel chip technologies – for example facilitation of better integration of variable supply from renewables with energy storage and demand; smaller and more energy-efficient chips; etc. This example shows that an energy-related service, computing in this case, may or not be explicitly linked to the energy system in a given context.

Therefore, one could argue in favour of examining all phenomena, as far as feasible, irrespective of them having or not explicit connections in Futures Platform to the energy system.

In-depth analysis, beyond the scope of this work, might well provide further evidence that most Futures Platform phenomena are dependent on energy, and also that the evident connections are already known (i.e., phenomena related to systems demanding a significant share of energy). It may nonetheless bring precious insights for the energy system, should a sector or a service that currently demands little energy be poised to drastically increase demand in order to meet new needs. This happened for example with the digital world over the last 2-3 decades.

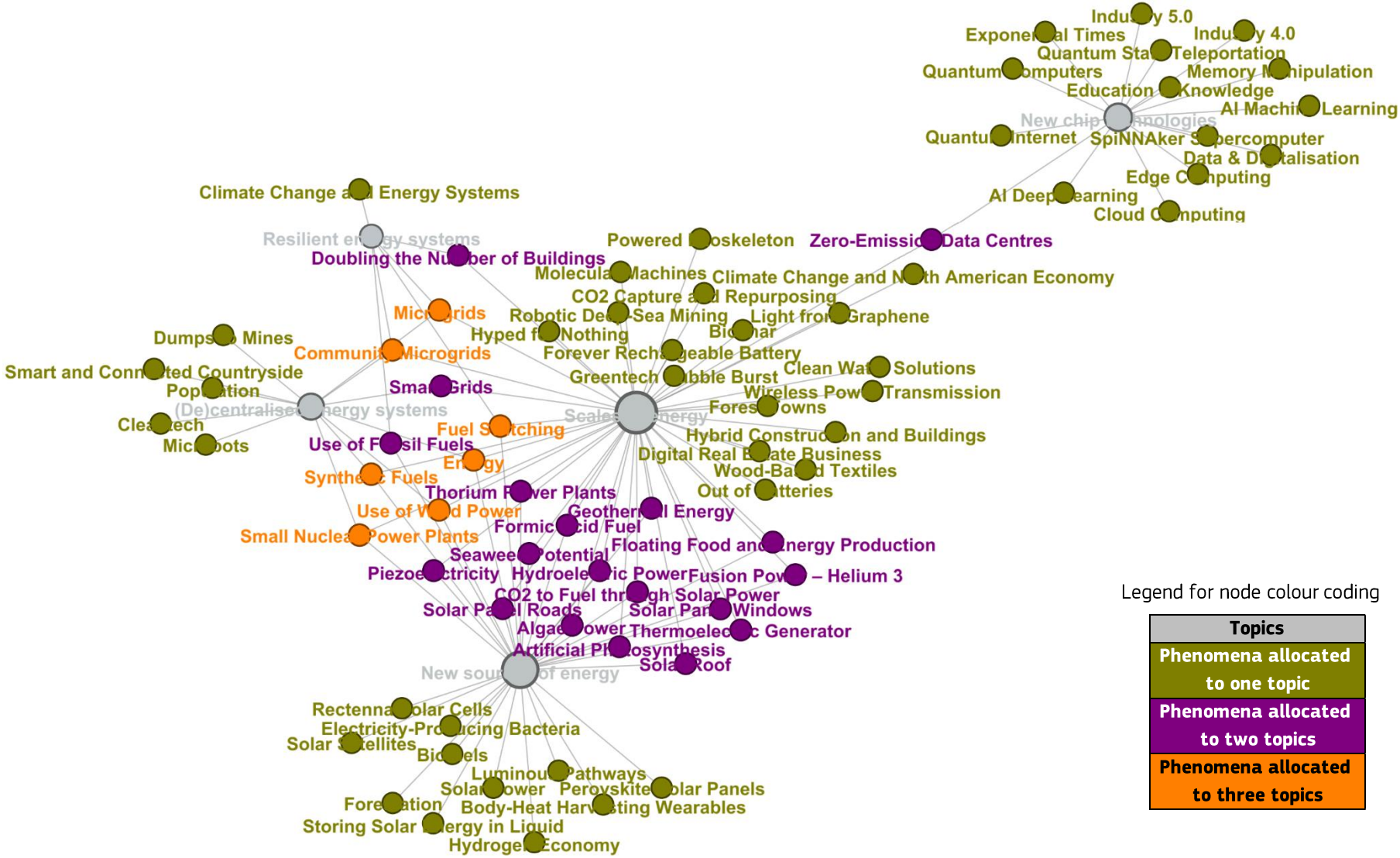
Visualising connections between phenomena and energy topics

The network graph of **Figure 37** below displays the 74 phenomena allocated to the five energy topics (the same content as **Figure 36**) in a 2-mode graph emphasising the numbers of connections between phenomena and the energy topics. It focuses on the energy theme, highlighting the interlinkages.

In this graph, topics are displayed in grey. Phenomena allocated to only one topic are displayed in light brown/olive. Purple indicates phenomena allocated to two topics. One stands out: Zero-emission data centres, as the only energy-relevant phenomenon making the connection between the topics of 'new chip technologies' and 'scales of energy'. In its description, Futures Platform indicates "more and more businesses are migrating to green data centres to maximise energy efficiency and minimise carbon footprint." In this sentence, the words "more and more businesses" are interpreted as expressing an upscaling of deployment while "green data centres" can be interpreted as one factor enabling 'new chip technologies' to achieve enhanced computing power. "To maximise energy efficiency" highlights the relevance of this phenomenon to the broad theme of energy.

Orange-coloured nodes indicate phenomena allocated to three topics. For example, for Synthetic fuels (strengthening, timeframe 2023-2028) the Futures Platform description mentions that "Synthetic fuels can be produced from various carbon sources and are similar to fossil fuels in terms of volume and energy density." Out of the sentence, three references led to the allocation of this phenomena to the different topics. Allocation to 'new sources of energy' is due to reference to "the synthetic nature of these fuels"; allocation to 'scales of energy' has to do with the reference to volumes; their impact on a (de)centralised energy system can be inferred from their "energy density". In addition, the notion of resilience was also inferred from the phenomenon description: "they can easily replace existing fuels in engines without major infrastructural changes".

Figure 37. 2-mode network graph, displaying energy topics investigated in this report and allocated phenomena



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

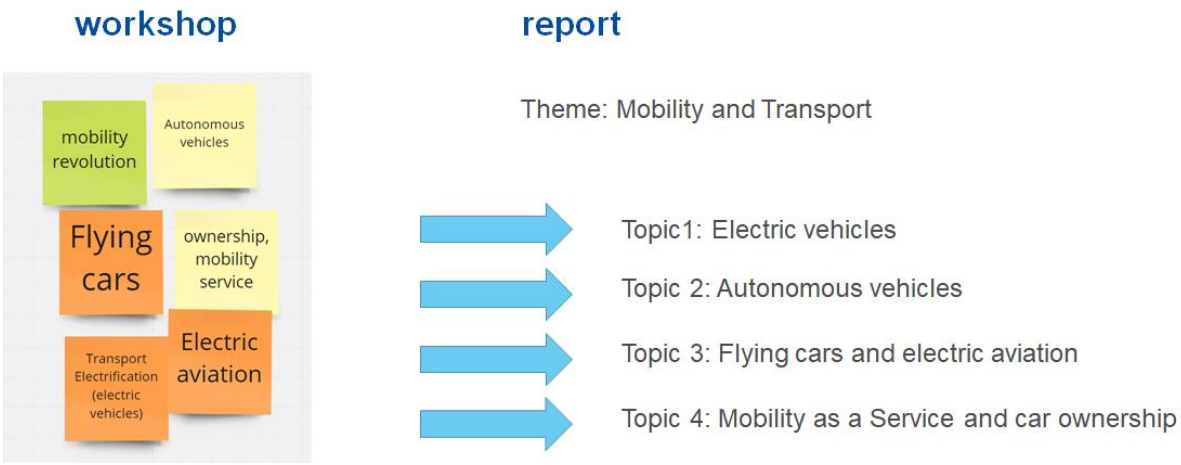
3.4 Interlinkages relevant to mobility and transport

By Anastasios Tsakalidis (JRC.C.4), Elisa Boelman (JRC.C.7) and Alain Marmier (JRC.C.7)

3.4.1 Approach

The approach to the 'mobility and transport' theme relies on iterations of text-mining and analysis to retrieve Futures Platform phenomena relevant to topics identified during the January 2021 workshop on the megatrend 'Accelerating Technological Change and Hyperconnectivity'. **Figure 38** below shows these topics as put forward during the workshop, under a 'mobility revolution' heading (left side), and indicates the corresponding topics selected for analysis in this report.

Figure 38. Transport topics put forward during the JRC megatrends workshop and discussed in the report



Source: Authors, based on 2021 JRC megatrend workshop.

A JRC transport analyst manually reviewed a table listing titles and short descriptions of all the 712 phenomena available in Futures Platform as of July 2021, and flagged 228 of these phenomena as broadly relevant to mobility and transport.

A text-mining step followed to retrieve information from the full contents of Futures Platform phenomena, including fields such as 'abstract', 'background', and 'impacts'. In view of topical relevance to the January 2021 workshop, the keywords below were selected for text-mining Futures Platform content with KNIME workflows developed by the authors:

- *transport*
- *mobility*
- *electric*
- *vehicle*
- *flying car*
- *electric aviation*
- *electric plane*
- *autonom*
- *mobility as a service*

Sentences extracted from Futures Platform were text-mined for these specific keywords, manually cleaned from false-positives, highlighted in tabular format and resubmitted to the transport analyst for refinement. This second iteration step narrowed down the transport-relevant phenomena to 212. Each of these 212 transport-relevant phenomena was allocated one or more of the topics from the January 2021 workshop - with text-mining workflows developed by the authors followed by manual validation by two analysts. In the interest of conciseness, these topics were consolidated into four broad topics by merging 'mobility as a service' with 'ownership', and 'flying cars' with 'e-aviation'.

Again using workflows developed by the authors (in KNIME and Excel), lists of nodes and edges were then generated for the 'mobility and transport' theme as a whole (Section 3.4.2 below) and for each of the four topics broadly derived from outcomes of the January 2021 workshop (Section 3.4.3 below).

3.4.1.1 Network visualisation

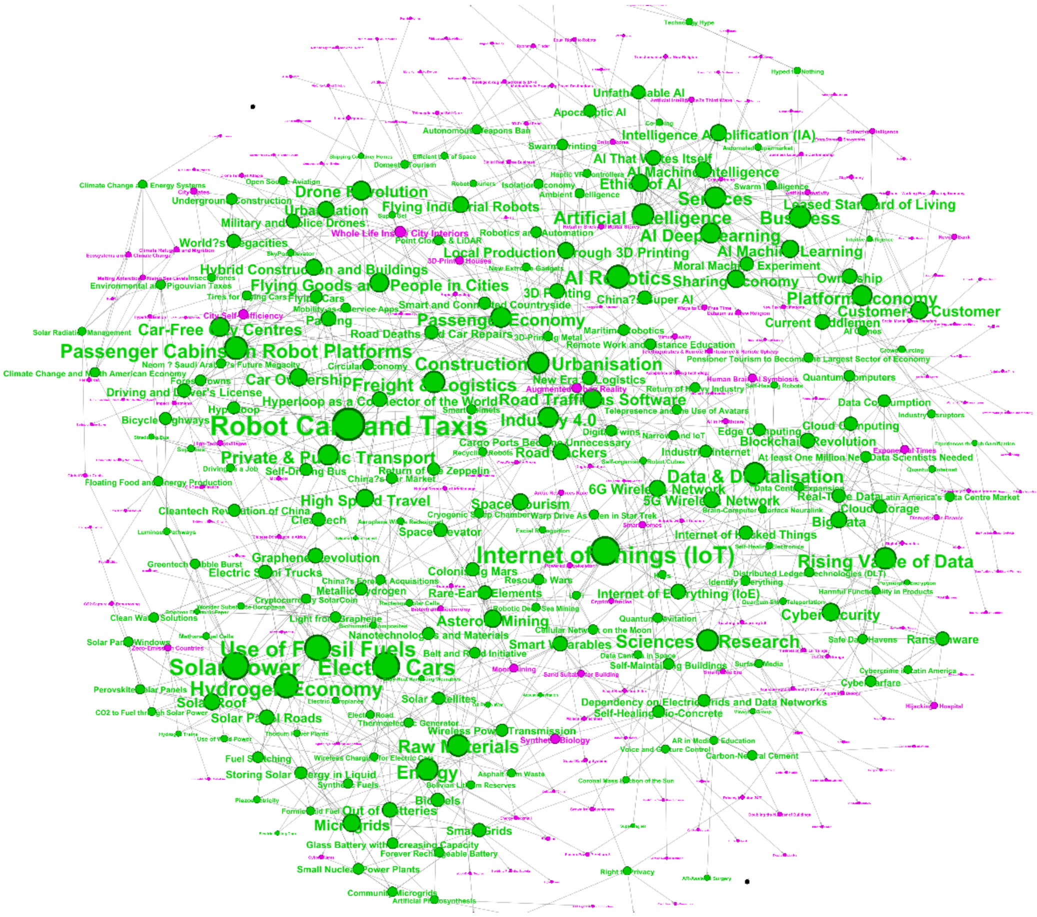
These lists of nodes and edges were imported into the Gephi network visualisation tool for generating network graphs. Node sizes are proportional to the number of connections each phenomenon has with others, as

retrieved from the Futures Platform repository of phenomena. The Girvan-Newman ([41]) clustering algorithm available in Gephi was then run with standard settings for each dataset. This clustering relies on the network properties of 'community structure': some network nodes (Futures Platform phenomena in this case) are joined together in more tightly knit groups, between which there are lesser connections. As further discussed by Girvan and Newman, their clustering method can detect significant and informative community structures. The communities detecting by this clustering algorithm are the main cornerstone of this section on transport and mobility.

3.4.2 Overview of results

The first network graph shows in green phenomena that are considered as 'core', and in purple phenomena that are deemed 'related' to transport and mobility. Core phenomena are not only larger in number but also tend to appear as larger nodes, i.e., as more connected to other phenomena. This reflects the broad and established character of transport and mobility as a theme, as contrasted to more specific and emerging themes such as human enhancement. It is also worth noting that the lists of phenomena are reviewed by human analysts, who may or not be inclined to be broad and inclusive in their selection.

Figure 39. Network graph of 'core' and 'related' phenomena in the theme 'mobility and transport'



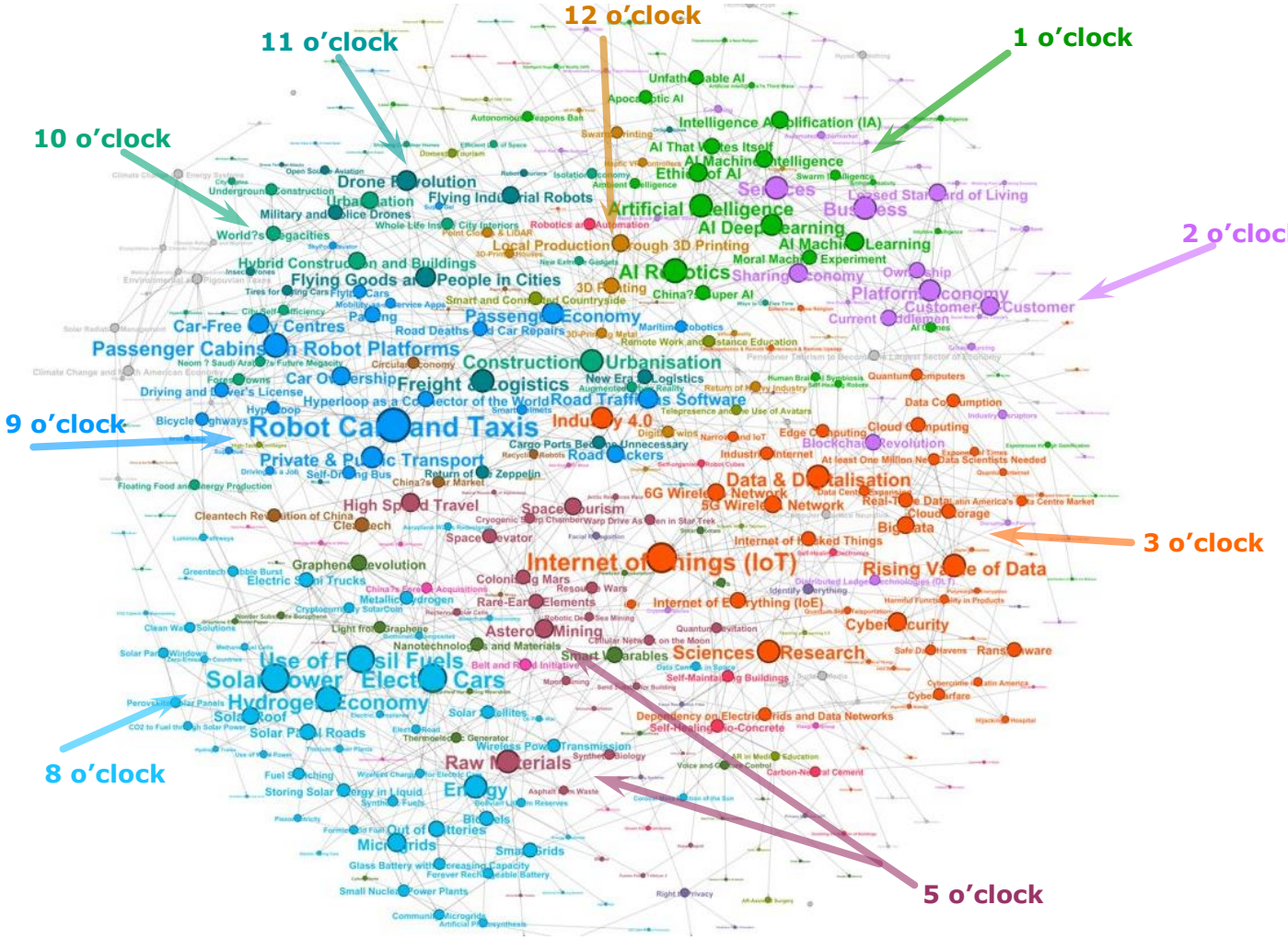
Source of network graphs in section 3.4: Authors, based on data text-mined from Futures Platform and visualised in Gephi. Annex 2 provides a tabular overview of the Futures Platform phenomena and their Interlinkages.

In this network graph one can see some clusters of phenomena, for example, on the lower left for energy, solar power, hydrogen, microgrids and fossil fuels.

Running the Girvan-Newman clustering algorithm available in Gephi allows detecting and highlighting such topical clusters, as shown in the network graph below. This second network graph has the same layout as the first, but uses colours to highlight the different clusters detected.

([41]) Network analysis experts Girvan and Newman have proposed a method for using centrality indices to find community boundaries, see 'Community structure in social and biological networks' https://www.pnas.org/content/99/12/7821

Figure 40. Areas of interest detected by a clustering algorithm for the transport and mobility theme



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

The numbers on the figure, broadly corresponding to time on a clock, are used to designate the clusters:

- 1 o'clock: The rise of **Artificial Intelligence.**
- 2 o'clock: New **business models** to redefine transport and **mobility** (**as a service**).
- 3 o'clock: **Digitalisation**, data and connectivity.
- 5 o'clock: The rising needs for new (raw) **materials** / rare earths and new resources.
- 8 o'clock: Transport **Electrification** / Electric Vehicle Technologies.
- 9 o'clock: Mobility as a Service (**MaaS**), enabled by **automation** and digitalisation.
- 10 o'clock: The role of transport/**urban infrastructure** and urbanisation as a trend.
- 11 o'clock: Emergence of **urban aerial**/vertical mobility.
- 12 o'clock: New **production methods** / 3D printing manufacturing.

The graph shows an overview of text-mined phenomena relevant to the transport theme as a whole, underscoring a paradigm shift in transportation. Two new trends, namely transport electrification and connected and automated mobility, gradually appear as an emerging reality. Transport electrification is linked to various new technologies touching upon vehicle design, manufacturing and the energy system. Transport electrification is clearly visible in the graph (8 o'clock). It is linked to new materials (5 o'clock) that will be required for the further advancement of battery technologies, which are in turn linked to countries rich in raw materials, rare earths, etc. In the future, lack of raw materials and need of rare earth elements will call for development of new technologies, as well as for new sources of materials as can be seen from the 'asteroid mining' or 'colonization of Mars' nodes.

Cooperative, connected and automated mobility is linked to technologies relevant to communications and data processing: such as 5G, data management solutions, internet of things, and artificial intelligence (3 o'clock). The introduction of electrification and cooperative connected and automated mobility will also have to be

accompanied by new business models (2 o'clock) to accommodate transportation and mobility needs using innovative technologies. Mobility as a service (MaaS), sharing economy, platform economy are just some of the terms that will be more and more linked to the transport theme (9 o'clock).

Within this context, and especially at urban level (10 o'clock), aerial mobility, and most probably electrified aerial mobility (11 o'clock), will compliment or even in some cases substitute land mobility. Meanwhile, for medium and long-range air transport, new fuel types will be further adopted in order to substitute the current paradigm.

The main link between electrification and automation includes also extensions to new business models (MaaS, sharing economy, etc.) and (electrified-) aerial mobility/aviation. The electrification of transport comes hand in hand with the need for adequate provision/management of energy, storage technologies and advanced distribution grid solutions that will support a sustainable and resilient transition in the transport sector. Meanwhile, the ever-increasing introduction of connected, automated and eventually autonomous driving systems will require the development of adequate technologies through research and innovation in a number of fields covering, inter alia, internet of things, artificial intelligence, chips and sensors and an advanced human-machine interface and interaction (HMI).

3.4.3 Topical clusters

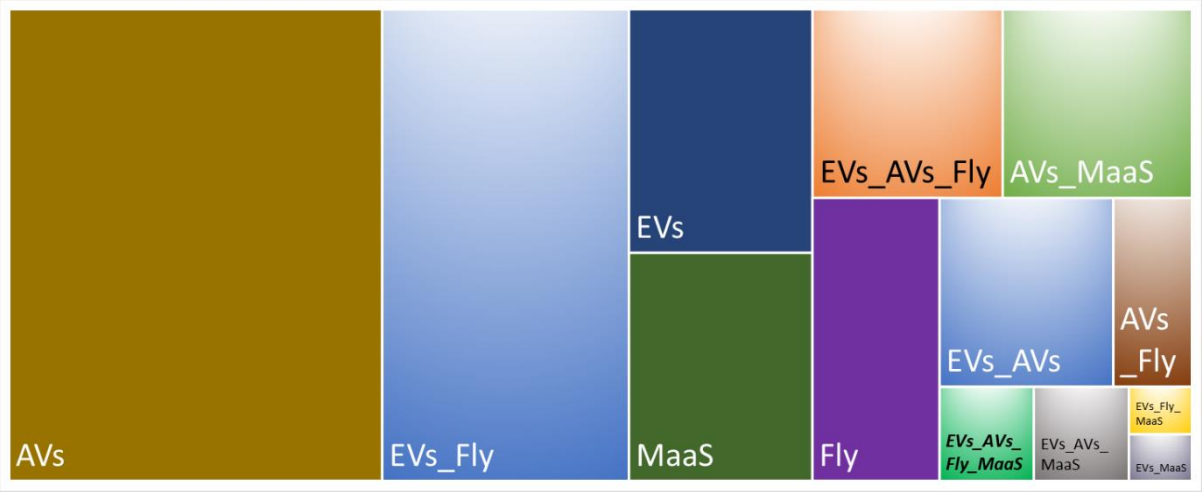
This network graphing and clustering was also done for each of the four topics from the megatrends workshop: Electric vehicles, Autonomous vehicles, Flying cars and electric aviation, Mobility as a Service and car ownership.

The approach is the same as for the entire transport theme, albeit with smaller specific datasets containing only phenomena allocated to each topic. Different datasets result in different network graphs with varying numbers of phenomena and node sizes per graph.

3.4.3.1 Allocation of phenomena to the various topics

The 212 phenomena selected as core and related to transport are allocated to one or more topics as follows:
- Electric vehicles (EVs): 85.
- Autonomous vehicles (AVs): 105.
- Flying cars and electric aviation (Fly): 72.
- Mobility as a Service and car ownership (MaaS): 34.

Figure 41. Distribution of transport phenomena allocated to transport topics



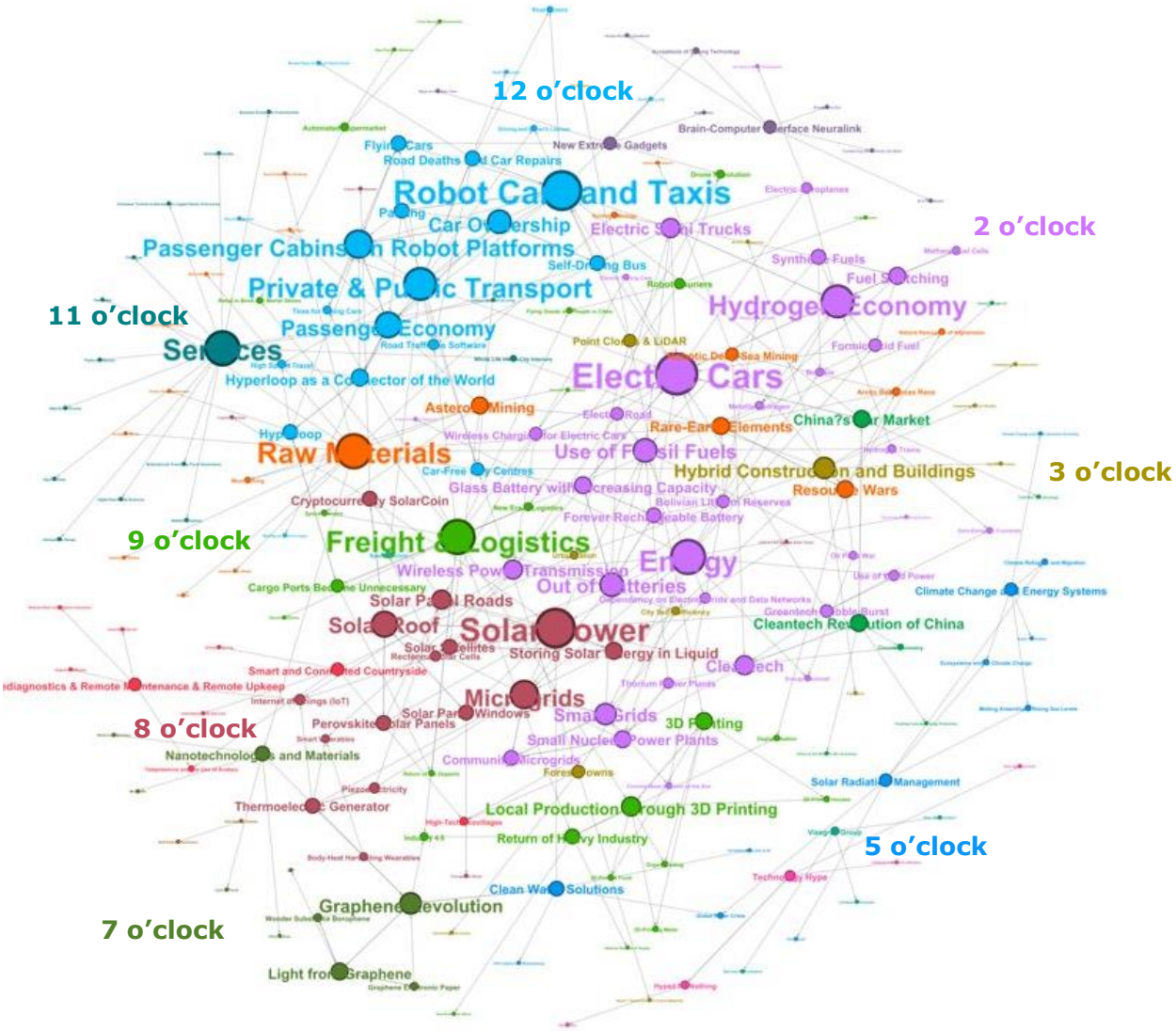
Source: Authors based on Futures Platform material.
Note: some of the boxes are shaded to highlight interlinkages between topics within the transport theme.

About 25% of transport-relevant phenomena are allocated to autonomous vehicles only. Circa 17% are allocated to both electric vehicles and flying cars/electric aviation. Trailing these two major allocations the graph shows six similarly sized boxes, each with about 6% of the allocated phenomena: electric vehicles, flying cars/electric aviation and mobility as a service/ownership. Two further portions of 6% each account for phenomena allocated to two topics: autonomous vehicles jointly with electric vehicles and mobility as a service. Another portion of 6% goes to autonomous vehicles, jointly with flying and electric vehicles. Towards the bottom-right of the graph, a small green box represents three phenomena allocated to all four topics:

Dependency on Electric Grids and Data Networks; New Extreme Gadgets; Private & Public Transport. These phenomena span across transport topics but also across themes, being also linked to energy and technical vulnerability.

3.4.3.2 Electric Vehicles

Figure 42. Areas of interest detected by a clustering algorithm for the electric vehicles topic



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

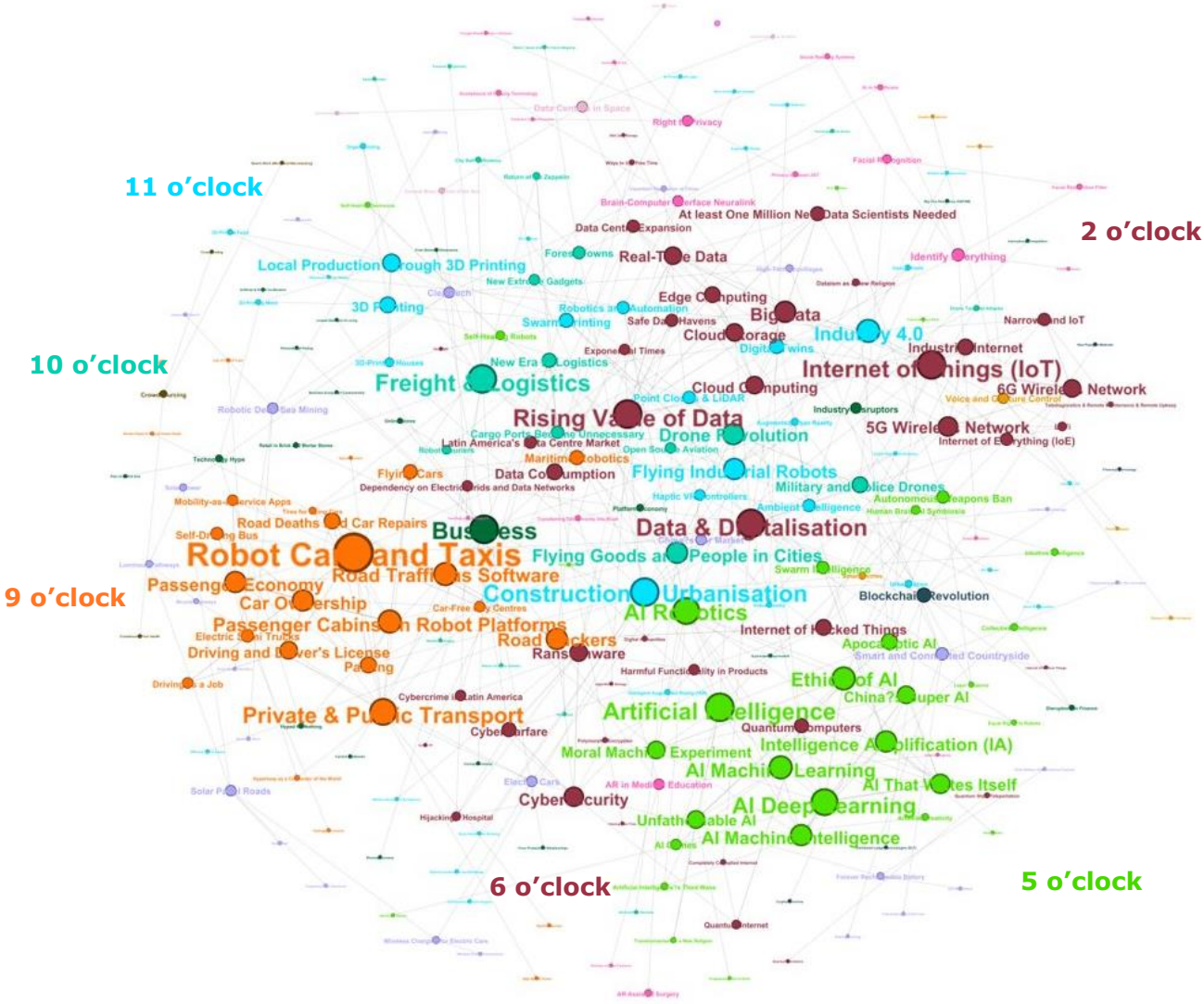
- 2 o'clock: Electric and alternative fuelled **vehicles.**
- 3 o'clock: New **construction/manufacturing** technologies and elements.
- 5 o'clock: **Climate** and resource management.
- 7 o'clock: New and innovative **materials** to further advance **EV** development.
- 8 o'clock: **Solar power** technologies for electrification (for recharging infrastructure and for solar powered transport means).
- 9 o'clock: **Electrification** of **freight** transport and first/last-mile **deliveries.**
- 11 o'clock: **Electrification** and transport **services.**
- 12 o'clock: **Electrification** of transport (public and private); future of **automated/autonomous** vehicles.

Transport decarbonisation is key to future sustainability. Transport electrification and specifically road transport electrification through development of electric, hydrogen and other alternative-fuelled vehicles promises to contribute towards this aim. Electric vehicle development requires relevant technology developments (e.g., in batteries and recharging infrastructure). The need for raw materials in rare earths becomes prominent.

Renewables (e.g., solar power) become more and more relevant to power charging stations, also paving the way for more energy independent vehicles through the development of solar electric cars.

3.4.4 Autonomous Vehicles

Figure 43. Areas of interest detected by a clustering algorithm for the autonomous vehicles topic



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

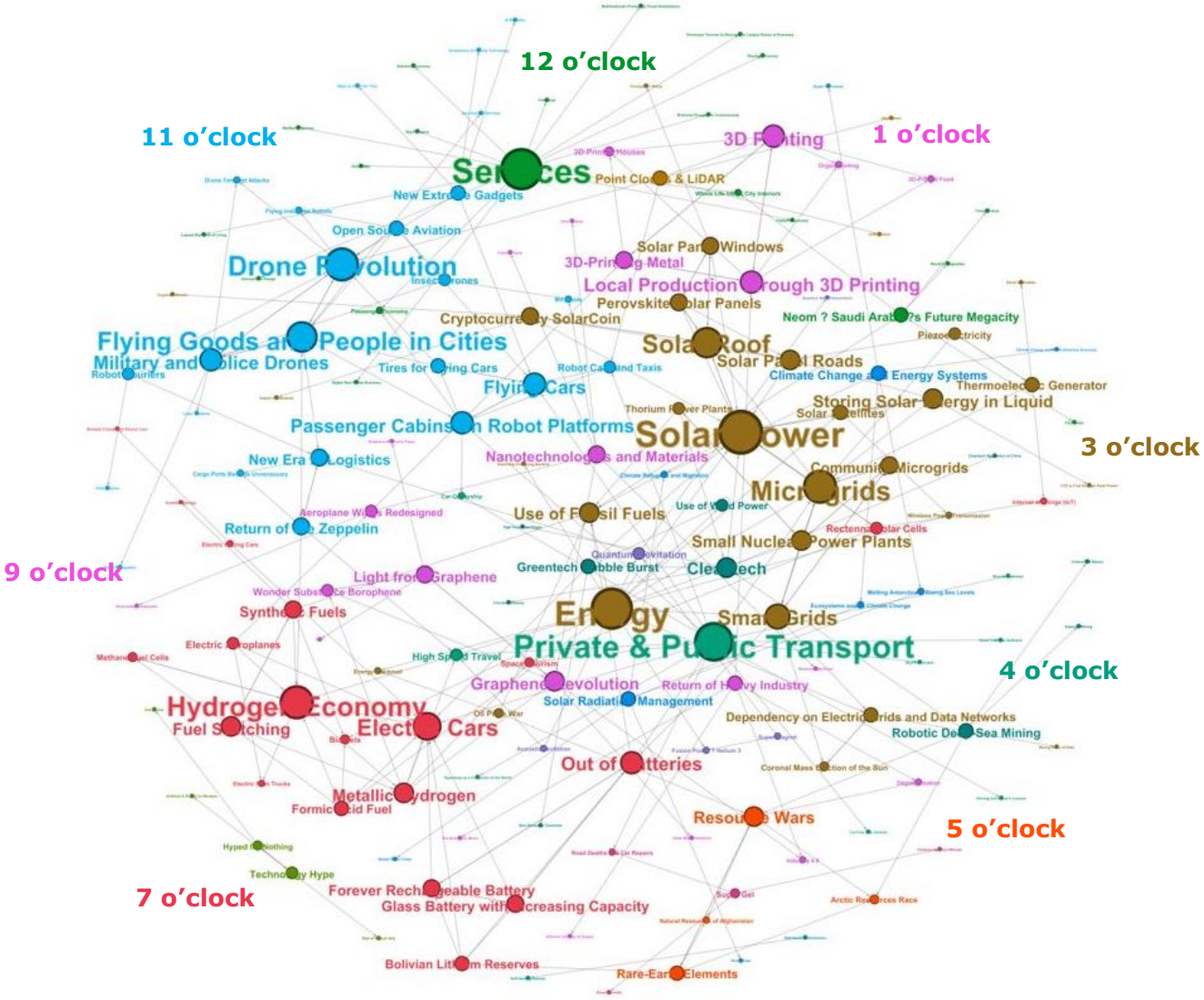
- 2 o'clock: The rising **value** of **data** and **connectivity.**
- 5 o'clock: Driving **automation** and the emerging role of **artificial intelligence** (e.g., for **vehicle decision making**).
- 6 o'clock: Threats of increased automation and connectivity within the transport sector (e.g., **Cybersecurity**).
- 9 o'clock: **Connectivity**, driving automation and future full **autonomy** of road transport.
- 10 o'clock: **Automation** of **freight** transport and first/last-mile deliveries, and **aerial mobility** (e.g., drone mobility, delivery drones).
- 11 o'clock: New **production** methods / 3D printing manufacturing.

Connected and automated mobility is another emerging trend, which requires development of technologies related to communications, data management, artificial intelligence etc. Connected and automated vehicles will allow new services for passenger and freight transport. Passenger transport and logistics can be transformed by autonomous vehicles that will substitute transportation as currently known. Automation can in turn be combined with transport electrification, new business and production models etc. These can contribute in their

own way towards a sustainable future. Clearly there will be rising value when it comes to data, need for more computing power and provisions for security against digital and cyber threats.

3.4.4.1 Flying cars and electric aviation

Figure 44. Areas of interest detected by a clustering algorithm for the flying cars and electric aviation topic



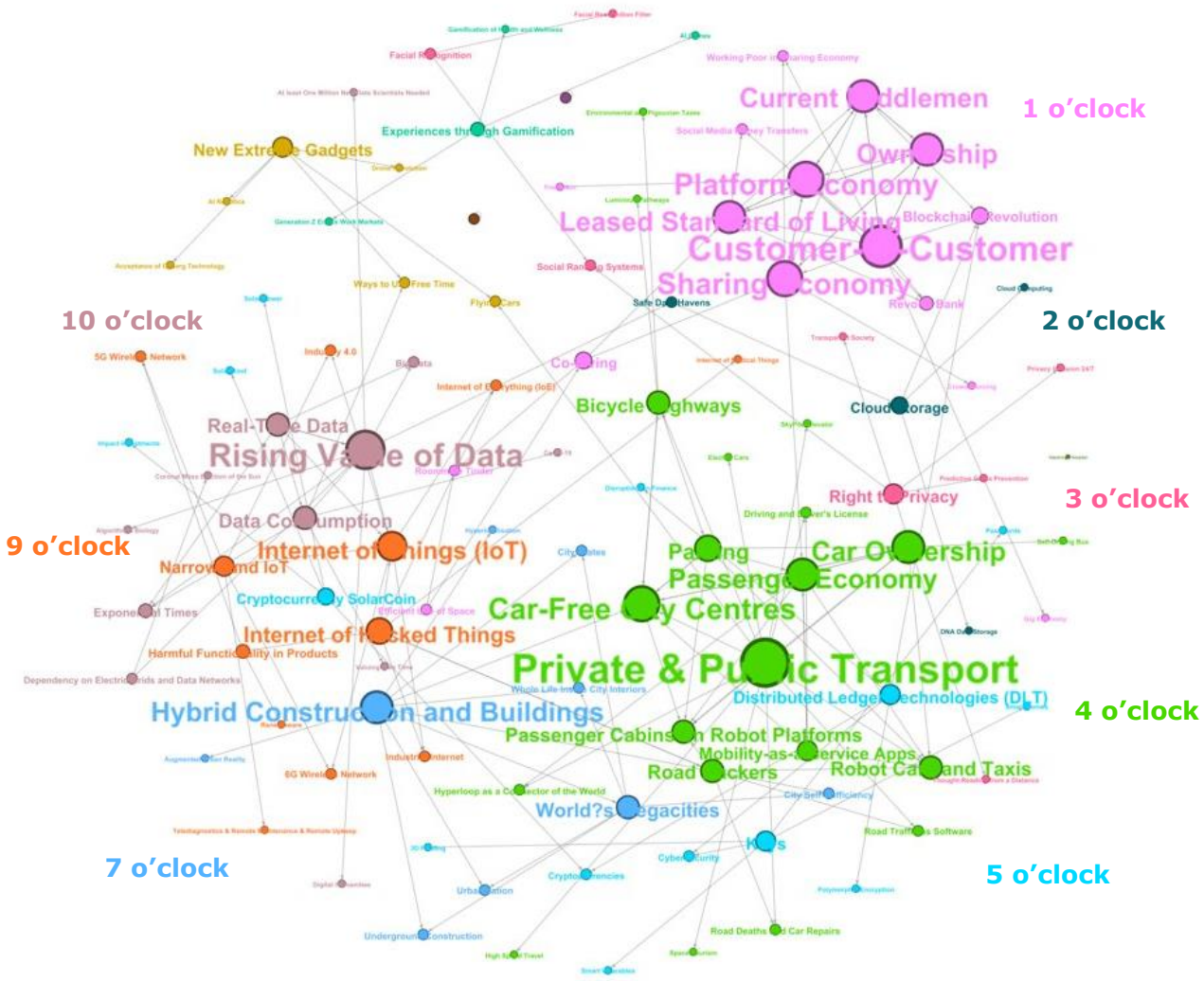
Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

- 1 o'clock: New **production methods**/3D printing manufacturing.
- 3 o'clock: The role of **energy technologies** and the uptake of alternative fuels to support e-aviation and electrified aerial mobility and logistics.
- 4 o'clock: **Flying cars** and **e-aviation** integration to existing transport systems and future use as an alternative to the existing paradigm.
- 5 o'clock: The upgraded role of **raw materials** within the transport **electrification** context, current and future implications (incl. commercial and **geostrategic** aspects).
- 7 o'clock: Alternative fuels and **power** technologies as an enabler to power electrified aerial mobility.
- 9 o'clock: New materials and relevant technologies towards new aerial mobility solutions.
- 11 o'clock: Emergence of **urban** aerial/**vertical mobility** as an alternative to the current passenger and freight transport paradigm.
- 12 o'clock: Novel **services** based on **aerial** (urban) mobility.

The development of vehicle design and manufacturing technologies will allow the development of flying cars combined with medium and long range electrified or alternatively fuelled aviation as part of the transport electrification process.

3.4.4.2 Mobility as a Service and car ownership

Figure 45. Areas of interest detected by a clustering algorithm for the Mobility as a Service topic



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

- 1 o'clock: New **business models** to complement and potentially substitute the current transport/mobility paradigm.
- 2 o'clock: **Connectivity** and information and communication technology (ICT) as enablers towards a digitalised and data-driven transport system.
- 3 o'clock: Rising concerns about **privacy** and data-related threats as the digitalisation and connectivity within the transport systems increases.
- 4 o'clock: Transport/Mobility as a Service and new business models as an alternative to the current mobility paradigm. Less car ownership and emergence of a **sharing economy**.
- 5 o'clock: Digitalisation/connectivity and **Cybersecurity.**
- 7 o'clock: The role of **urban (transport) infrastructure** and urbanisation as a trend, and the need for transport to adapt to this shift.
- 9 o'clock: **Digitalisation**, Connectivity and Internet of things - ICT in the service of a smart and **shared mobility** future.
- 10 o'clock: The rising **value of data** and connectivity.

In line with the new transport technologies discussed above, new business models will be emerging or even be required to better manage the new transport reality. Mobility as a service, sharing economy and other business models will be used as a means to substitute the current private car ownership paradigm.

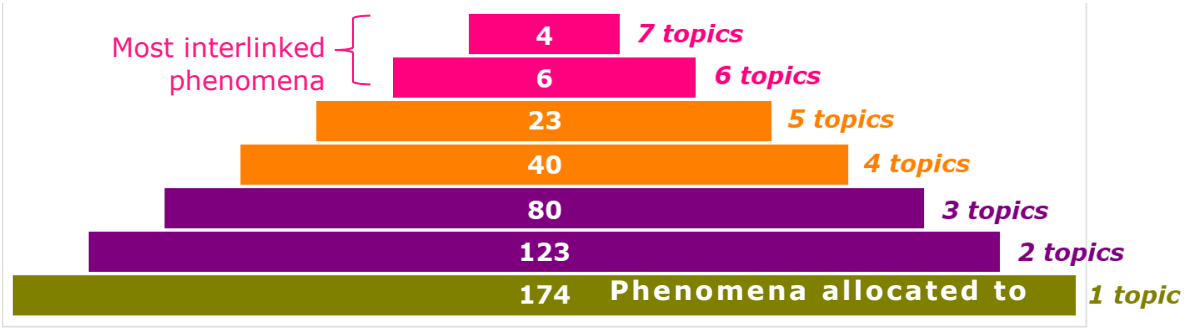
3.5 Interlinkages between themes in the megatrend 'Accelerating Technological Change and Hyperconnectivity'

This section moves out to the megatrend level, focusing on connections between phenomena and topics across the four themes discussed in the previous sections of this chapter.

3.5.1 Interlinkages at phenomenon level

Out of 712 phenomena from Futures Platform, a total of 450 phenomena are allocated to at least one of the topics of the megatrend 'Accelerating technological change and hyperconnectivity' (MT-tech). The remaining 263 phenomena are not allocated to any topic of this megatrend (as considered in this report) and therefore do not appear in the graphs below. **Figure 46** shows that, out of 450 phenomena allocated to the MT-tech, 174 are allocated to a single topic and 123 to two topics. Therefore, two-thirds of these 450 phenomena may be seen as relatively specific, as they span only one or two topics. Within the context of this report, only ten (less than 2% of the 450) phenomena are allocated to six to seven topics. These phenomena can be seen as highly interconnected. This observation opens the door to look further into how phenomena are connected to topics in the frame of this report.

Figure 46. Allocation counts of Futures Platform phenomena to topics of the megatrend 'Accelerating technological change and hyperconnectivity'



Source: Authors, based on Futures Platform material.

The most interlinked phenomena appear in pink in the **Figure 46** and in the network graph of **Figure 47**:

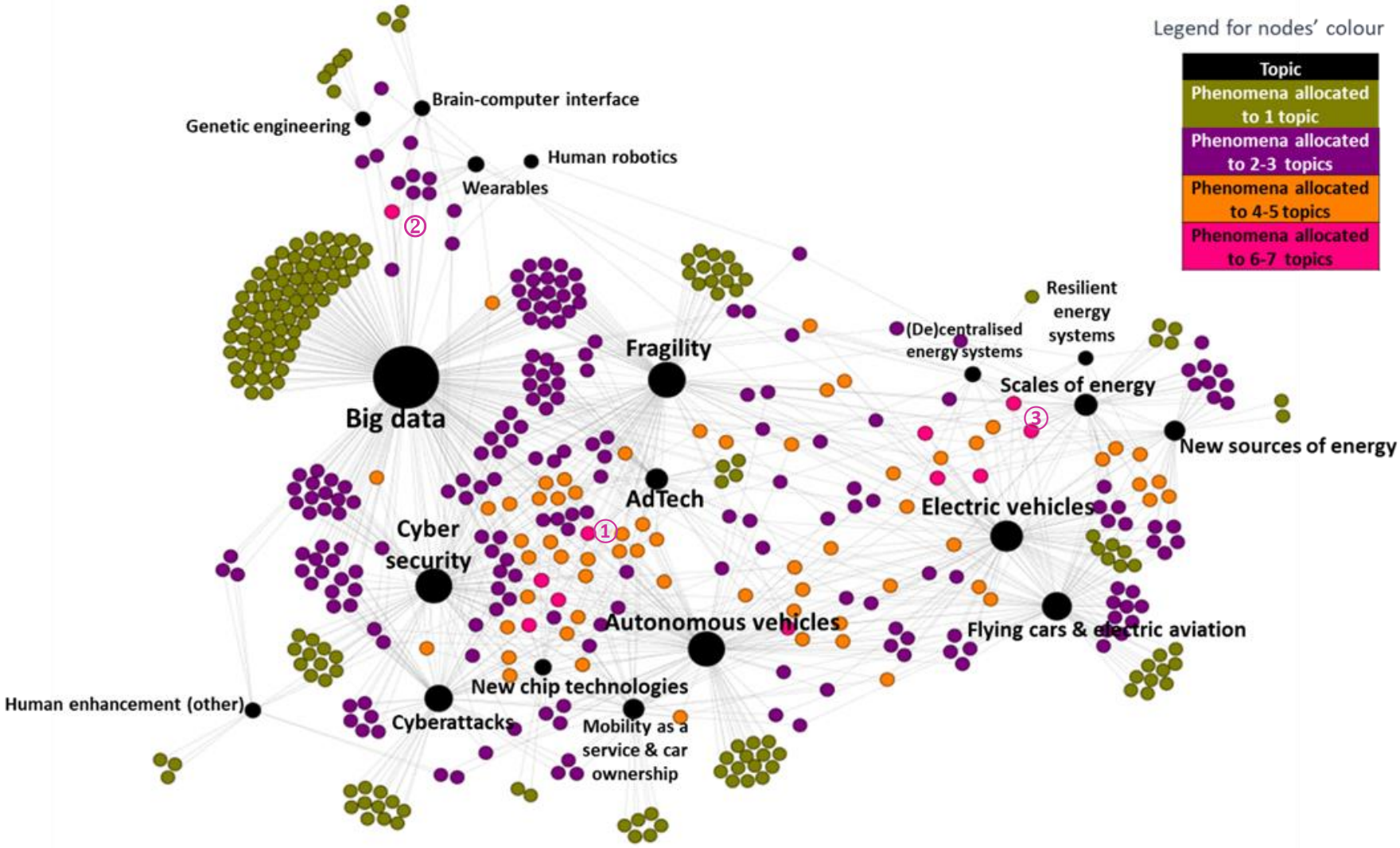
- 'cloud storage' (strengthening).
- 'cloud computing' (strengthening), marked as ① in **Figure 47** and shown on **Figure 48**.
- 'energy' (summary).
- 'rising value of data' (strengthening).
- 'small nuclear power plants' (strengthening).
- 'dependency on electric grids and data networks' (wild card).
- 'data security of human body under threat' (wild card), marked as ② in **Figure 47**
- 'microgrids' (strengthening).
- 'solar panel roads' (strengthening).
- 'community microgrids' (strengthening), marked as ③ in **Figure 47** and shown on **Figure 49**.

Among them, three were already identified in the Tech-vulnerability and Transport themes: 'Cloud storage', 'Cloud computing' (also allocated to Energy) and 'Rising value of data' (also allocated to Human enhancement). Two phenomena are wild cards as defined by Futures Platform, phenomena that emerged rapidly and for which is difficult to predict the impact: 'Dependency on electric grids and data networks' (allocated to Tech-vulnerability and to Transport) and 'Data security of human body under threat' (allocated to Tech-vulnerability and to Human enhancement).

3.5.2 Interlinkages at topic level

The two-mode network graph of **Figure 47** illustrates how these interlinkages unfold for each topic.

Figure 47. Network of phenomena allocated to MT-tech themes' topics coloured according to the number of topics to which they are allocated

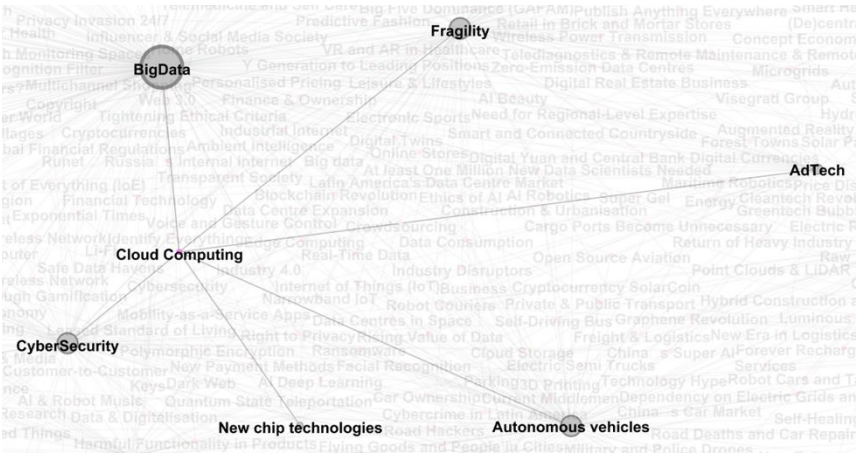


Source of network graphs in section 3.5: Authors, based on data text-mined from Futures Platform and visualised in Gephi.
Annex 2 provides a tabular overview of the Futures Platform phenomena and their Interlinkages.

The graph is obtained by projecting phenomena deemed relevant to all the four themes analysed in this report (Technical vulnerability, Human enhancement, Energy, Transport) on their respective 18 topics, for the entire megatrend ([42]).

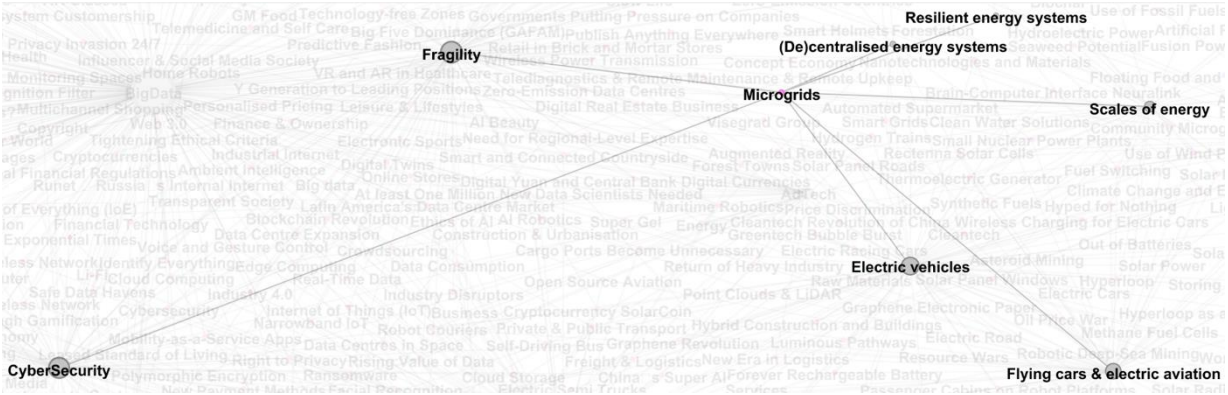
The sub-network graph of **Figure 48** shows how the 'Cloud computing' phenomenon is connected to six topics in three themes: 'Big data', 'Ad tech', 'Fragiliy' and 'Cyber-security' topics in the Tech Vulnerability theme; 'Autonomous vehicles' in the Transport theme and; 'New chip technologies' allocated to the Energy theme. Similarly, **Figure 49** shows 'Community microgrids' connected to one Tech vulnerabilty topic ('Fraglity'), two Transport topics ('Electric vehicles', 'Flying cars & Electric aviation') and three Energy topics ('Scales of energy', 'Resilient energy systems' and 'Decentralised energy systems').

Figure 48. Cloud computing phenomenon connected to six topics



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

Figure 49. Community microgrids phenomenon connected to six topics



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

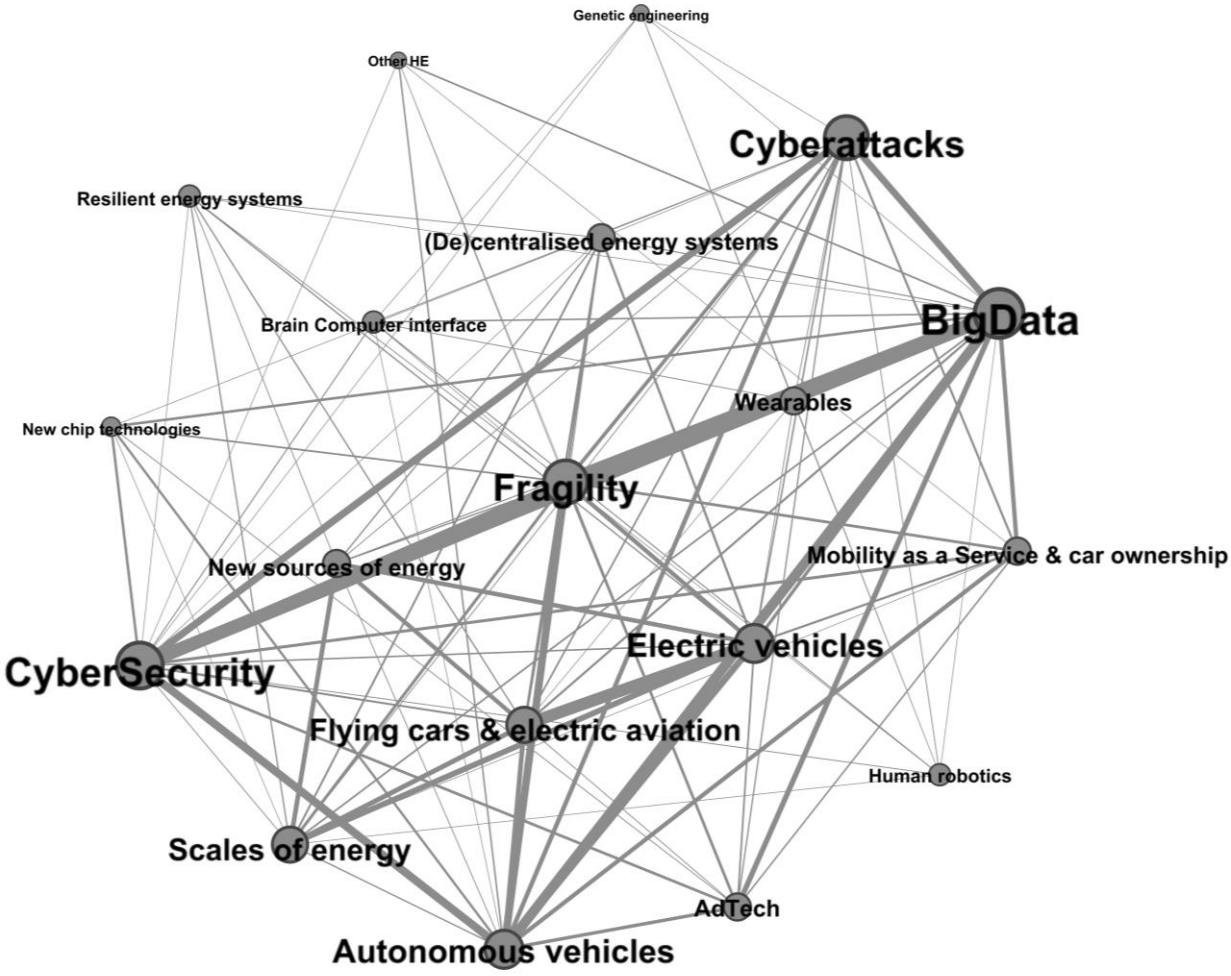
([42]) See Chapter 2 for details on making such two-mode graphs.

Annex 2 provides a full list of all phenomena and their allocations to themes and topics in this report. To further highlight interconnections among topics, the authors imbed phenomena into topics in **Figure 50**. The nodes (circles) correspond to topics and are sized proportionally to the number of phenomena allocated to the topic. The edges (lines connecting the nodes) are thickened according to the number of phenomena allocated to each pair of topics.

In the network graph of **Figure 50**, 'BigData', 'Fragility', 'Cybersecurity', 'Electric Vehicles', 'Cyberattacks', 'Autonomous Vehicles' and 'Flying cars & electric aviation' are the most interconnected topics in the network.

The topics with less phenomena allocated to them are plotted in the periphery of the network graph. Even though these smaller peripheral nodes have less phenomena allocated to them, these topics are connected to several other topics.

Figure 50. Network graph derived by projecting phenomena on topics



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

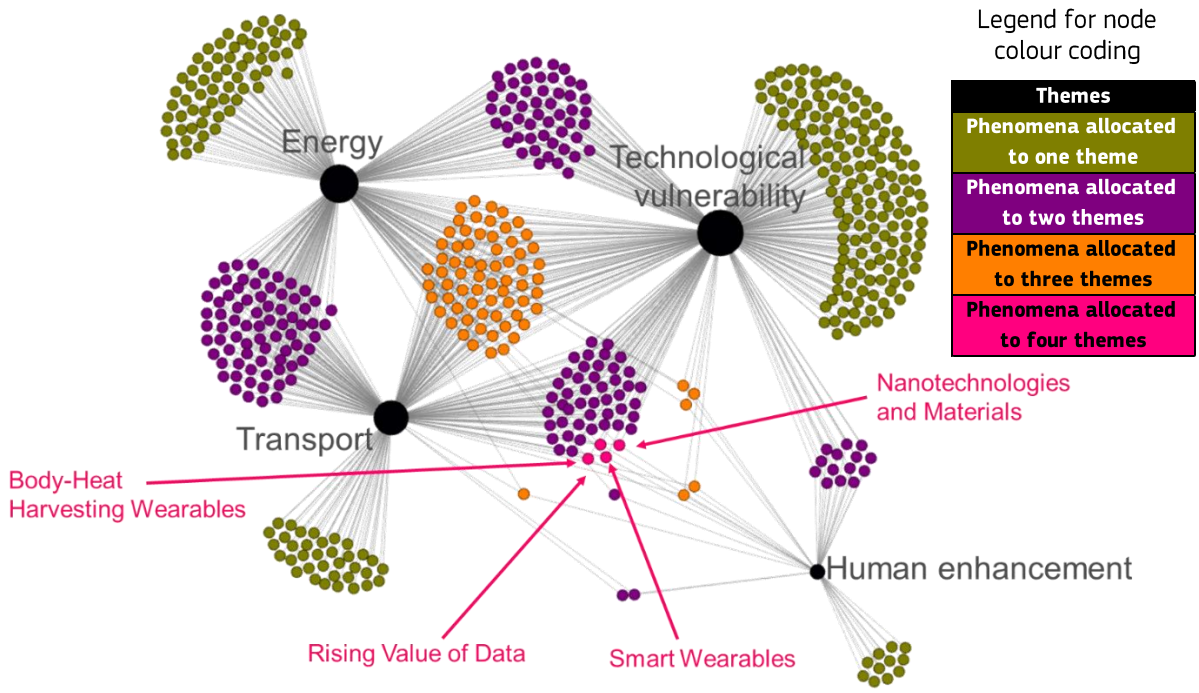
3.5.3 Interlinkages at theme level

In addition to the topic level, it is also possible to identify interlinkages between themes and phenomena, as visualised in **Figure 51**. This network graph is analogous to the one in **Figure 50**, but links themes (instead of topics) to phenomena. Phenomena allocated to one theme are coloured in olive green, two themes in purple, three themes in orange and four themes in pink. Insert: schematic representation of the interconnections among the four themes of the megatrend.

It is interesting but not surprising to see the most interconnected theme is 'Tech-vulnerability', which is the other side of the coin of hyperconnectivity. The most interconnected themes are 'Tech-vulnerability', 'Energy' and 'Transport', with 89% of the phenomena (coloured in orange) located the intersection of these three themes. Regarding interlinkages between two themes, 'Energy' is mostly connected with 'Transport', though both themes are also highly connected with 'Tech-vulnerability'.

The 'Human enhancement' theme is the least connected with other themes. Of the 16 phenomena interlinking 'Human enhancement' with other themes, one is a summary ('health & wellbeing'), nine are well established trends, (strengthening or weakening) and seven are emerging (weak signals and wild cards). Out of this relatively small number of connected phenomena, only about half (56%) are established trends. This appears to indicate a lower degree of maturity of 'Human enhancement', as compared to the other more established themes. Among the emerging phenomena allocated to 'Human enhancement' are Brain-computer interface neuralink, Data security of human body under threat, Acceptance of cyborg technology, Enhanced soldiers, Lifelogging, and Controlling machines with thoughts Global brain.

Figure 51. Phenomena allocated to each theme, coloured by the number of theme allocations



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.

There are only four phenomena interlinking the four themes analysed in this report. These phenomena are coloured in pink in **Figure 51** Three of these are strengthening phenomena: Rising value of data, Smart wearables, Nanotechnologies and materials. The fourth phenomenon (Body-heat harvesting wearables) is a weak signal for an emerging technology.

Below are two examples of how the authors examined and interpreted text-mined content to establish interlinkages between phenomena and topics.

For the Rising value of data phenomenon, the description mentions that "The key driver of this development is the rapid increase in the number of devices connected to the Internet and especially the emerging Internet of Things, including sensor technology for built environments, automatic monitoring of user data, communication between devices and the proliferation of things like smart clothes." This sentence is regarded by the authors as making a link to technologies and thus to the 'Technology Vulnerability' theme. Specifically in the case of the 'Human Enhancement' theme, mention of "smart clothes" is taken as a clue for linking this phenomenon to the theme. The authors also extend this reasoning for linking this phenomenon to the 'Energy' and 'Transport' themes, although these themes are not explicitly stated in the phenomenon description.

The Body-heat harvesting wearables phenomenon description refers to "generators [...] integrated inside the human body to harvest power for implants." This sentence is deemed important to the 'Human enhancement' and 'Energy' themes, as it refers to converting energy for supporting life. A link with the smart wearable topic is also inferred from the text "Wearable technology [...] offer[s] [...] solutions for utilising this technology". For this phenomenon too, the references to the 'human enhancement' and 'energy' themes are explicit: "Sensors can be printed or attached directly on the skin also, which will deliver more precise and detailed data" and "Widespread use of integrated devices necessitates wireless and as-independent-as-possible power sources". Though not explicit from its description, this phenomenon also opens to the 'transport' theme: "With [...] artificial intelligence and augmented reality, wearable technology has [...] potential to be useful [...] for people's everyday life", which includes mobility. For both phenomena, the 'technology vulnerability' relevance are not hinted at. However "solutions that are integrated directly into clothes and gear" or even "integrated inside the human body" and that "will deliver more precise and detailed data" surely deserve reliability and are prone to attract (possibly unwanted) attentions.

'Nanotechnologies and Materials' have applications in all themes of this report. The energy and transport themes are directly referred to in the phenomenon description. Connections to the human enhancement and transport themes (resp. 'Wearables' and 'Flying cars & electric aviation' topics) can be established through the reference to "lighter materials". In addition, this phenomenon impacts the transport and technology vulnerability themes through "smaller electronic components and equipment": Electronic components are indeed of importance for the 'electric vehicles' topics and technology 'fragility' stemming from hyperconnectivity.

4 Conclusions

The work described in this report aims at supporting anticipation and interdisciplinarity in a European Union (EU) policy context. By providing an approach to identify and visualise interlinkages, it intends to support policy analysts in detecting and better understanding interactions between relatively wide ranges of phenomena. This, in turn, can help policymakers address various political, social, economic technological and environmental implications of interacting phenomena.

The authors developed and piloted a text-mining and analysis approach for detecting and visualising interlinkages relevant to the JRC Megatrends Hub, based on 712 phenomena described by Futures Platform ([43]). Chapter 2, Annexes 1 and 4 of this report describe this approach, which combines text-mining and network visualisation with analyst intelligence to retrieve, sort and organise relevant information. Chapter 3, Annexes 2 and 3 present and discuss results for interlinkages between four trends (named 'themes' in this report) identified during a JRC workshop as relevant to the megatrend 'Accelerating technological change and hyperconnectivity'. The focus is on identifying and presenting interlinkages, as a basis for further analysis by domain-experts and/or policymakers. Such further analysis can help shed light onto, for example, potentially disruptive developments that could emerge at intersections (e.g. between phenomena) or onto emerging technologies that could need or merit policy intervention (e.g. funding, regulation).

The approach developed and piloted by the authors can be expanded to broader interlinkages (e.g., between megatrends), or targeted more in-depth at other specific themes. It is also potentially adaptable to data sources other than Futures Platform. Data manipulation was effort-intensive and the authors are exploring possibilities of further automating the approach by integration with the JRC Tools for Innovation Monitoring (TIM). As of writing, this appears feasible (see section 4.2 'Further work recommendations').

Section 4.1 below provides an illustrative overview of the kind of information obtained so far, which can be provided to (interdisciplinary groups of) experts for further analysis.

4.1 Key interlinkages identified

Out of 712 phenomena available in Futures Platform in June-July 2021, the authors deemed 450 to be relevant as core or related, and allocated them to at least one of the four themes in this report:

- Great power, great risk ([44]), called 'Technology vulnerability' in this report: 340 phenomena.
- Cyborg me! ([45]), 'Human enhancement' in this report: 38 phenomena.
- Energy ([46]): 262 phenomena, out of which 74 are core phenomena.
- Mobility revolutions ([47]), 'Mobility and transport' in this report: 228 phenomena.

The relatively high counts of phenomena deemed relevant to 'Technical vulnerability' can be seen as a reflection of how deeply and widely digital technologies underpin most human activities. This also applies to energy and transport. The count of phenomena allocated to 'Human enhancement' is much smaller, likely pointing to a much more specific and emergent topic.

The majority of these Futures Platform phenomena were allocated to one or two of the themes in this report: 265 phenomena were allocated to one theme and 187 phenomena to two themes. Below are a few illustrative examples, further detailed in Annex 2 and schematised in **Figure 51**:

- Glass Battery with Increasing Capacity: this phenomenon was allocated to both energy and transport.
- Biohacking: allocated to technology vulnerability and human enhancement.
- Co-living: allocated to transport.
- Protein out of air and electricity: allocated to energy.
- No publicity for terrorists: allocated to technology vulnerability.
- Quantified self: allocated to human enhancement.

([43]) https://info.futuresplatform.com/en/hub/introduction-to-the-content
([44]) https://knowledge4policy.ec.europa.eu/foresight/great-power-great-risk_en
([45]) https://knowledge4policy.ec.europa.eu/foresight/cyborg-me_en
([46]) https://knowledge4policy.ec.europa.eu/foresight/computer-processing-energy-saving_en
([47]) https://knowledge4policy.ec.europa.eu/foresight/mobility-revolution_en

A smaller share (71) of Futures Platform phenomena was allocated to three themes, mainly 'Technology vulnerability', 'Energy' and 'Mobility and transport'. As illustrative examples:

- Narrowband IoT: allocated to technology vulnerability, transport, energy.
- Cryptocurrency SolarCoin: allocated to technology vulnerability, transport, energy.
- Quantum Internet: allocated to technology vulnerability, transport, energy.
- Maritime robotics: allocated to technology vulnerability, transport, energy.
- Swarm Intelligence: allocated to technology vulnerability, transport, human enhancement.

Only four of the Futures Platform phenomena were allocated to all four themes. The first two are highly cross-cutting and already pervasive, while the third and fourth on wearables are more clearly related to the more emergent Human enhancement theme:

- Nanotechnologies and materials.
- Rising value of data.
- Smart wearables.
- Body-heat harvesting wearables.

This analysis combines quantifiable and reproducible elements with a certain extent of subjectivity. For example, the Futures Platform catalogue is the only source of phenomena descriptions. While these are wide ranging and well curated, they inevitably reflect the choices of the people and methods involved. The authors of this report also rely on their own knowledge and insights, for example when selecting keywords as search terms and reviewing phenomenon descriptions.

Recommendations for improvement, detailed below, include:

- Widening the range of external data sources, considering, e.g., World Economic Forum and Sustainable Development Goals.
- Digging deeper into details of external data sources, including which perspectives are addressed or not.
- Developing in-house resources further, e.g. targeted text-mining with the Europe Media Monitor (EMM ([48])), keyword detection and network visualisation with the Tools for Innovation Monitoring (TIM ([49])).

4.2 Further work recommendations

The proposed approach of text-mining, analysing and visualising Futures Platform lends itself to further automation, for example through integration with TIM. As of writing, this integration is being piloted and tested.

Data sources can also be enhanced in several ways, for example:

- Diversification of the trends catalogue, e.g., integrating World Economic Forum 'topics' and 'key issues' ([50]) for a broader picture of ongoing developments.
- Strengthening of JRC in-house tools, e.g., EMM and TIM for wider detection, monitoring and sense-making of new developments.
- Elicitation of expert feedback on specific themes, e.g., advice on putting (external) inputs in perspective and fine-tuning analyses towards expected objectives. Critical eyes may see more than what is written.

Wider applications of this approach may proceed in parallel to the above, for example:

- Retrieval of tailored material for feeding into workshops on megatrends and (thematic) horizon scanning.
- Twinning of the green and digital transitions: twinning relates to interlinkage and transition to trends.
- Twinning of health and environment to identify potential causalities.
- Identification of emerging, potentially critical technologies and their links with other developments.
- Application to wider levels such as Sustainable Development Goals and Commission policy areas.
- Identification of emerging issues at the interface between drivers of change and megatrends.

([48]) https://knowledge4policy.ec.europa.eu/online-resource/europe-media-monitor-emm_en
([49]) https://ec.europa.eu/jrc/en/scientific-tool/tools-innovation-monitoring
([50]) https://intelligence.weforum.org/topics

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World Economic Forum – Platforms https://www.weforum.org/platforms

World Economic Forum – Strategic Intelligence https://intelligence.weforum.org/

List of abbreviations and definitions

AI	Artificial Intelligence
AVs	Autonomous vehicles
BCI	Brain-computer interfaces
EMM	Europe Media Monitor
EN1	Resilient systems
EN2	(De)centralised systems
EN3	New sources of energy
EN5	Scales of energy
EN5	New chip tech
EU	European Union
EVs	Electric vehicles
Fly	Flying cars and electric aviation
FP	Futures Platform
HE	Human Enhancement
HE1	Wearables
HE2	Human robotics
HE3	Brain-computer interface
HE4	Genetic engineering
HMI	Human-Machine Interface and Interaction
ICT	Information and communication technology
JRC	Joint Research Centre
JRC.C.4	JRC unit 'Sustainable transport'
JRC.C.7	JRC unit 'Knowledge for Energy Union'
JRC.E.7	JRC unit 'Knowledge for Security and Migration'
JRC.F.7	JRC unit 'Knowledge for Health and Consumer Safety'
KM	Knowledge Management
KW	Keyword
MaaS	Mobility as a Service
MT	Megatrend
MT-tech	Megatrend 'Accelerating Technological Change and Hyperconnectivity'
NRJ	Energy
SNA	Social Network Analysis
TIM	Tools for Innovation Monitoring
TR1	Electric vehicles
TR2	Autonomous vehicles
TR3	Flying cars & electric aviation
TR4	MaaS & car ownership
TRA	Transport
TV	Technology vulnerability
TV1	AdTech
TV2	Cyberattacks
TV3	Cybersecurity
TV4	Big data
TV5	Fragility
WS	Workshop

2-mode network graphs feature two types of nodes: phenomena (small nodes), around and between the topics to which they are linked (large nodes).

Context relevant phenomenon: either 'faint evidence' or 'established trend' with reference(s) to a specific theme or topic in its 'related content'.

Core content: 'title', 'background' or 'impact' sections of a phenomenon description.

Core phenomenon: Phenomenon deemed of relevance to a given theme or topic.

Established trends: Phenomena designated by Futures Platform as either 'strengthening', 'weakening', or 'summary'.

Faint evidence: Phenomena designated by Futures Platform as either 'weak signals or 'wild cards'.

Futures Platform: Finnish company, offering commercial support in strategic foresight ([51]).

High energy relevant trend: 'Established trend' with energy reference in its 'core content'.

KNIME: Konstanz Information Miner: software that enables the automation of information processing ([52]).

Interlinkages in the context of this report, interlinkages are connections defined or identified among two (or more) topics or phenomena. Such connections may occur, e.g., if: the authors allocate

([51]) https://www.futuresplatform.com/

([52]) https://www.knime.com/knime-analytics-platform.

a phenomenon to various topics or themes or; if related phenomena are retrieved directly from the 'related phenomena' section of Futures Platform descriptions.

Mix: When equal counts of keywords are retrieved for different topics in a phenomenon description, the phenomenon is allocated to 'Mix'.

Megatrends: Long-term forces that are observable now and will most likely have a significant influence in the future.

Megatrends relevant phenomenon: 'Established trend' with reference(s) to a specific theme or topic in its 'core content'.

Not energy relevant phenomenon: Bears no energy-relevant keywords in their description.

Not relevant phenomenon: Neither a core nor a related phenomenon to a given theme or topic.

Phenomenon: All signals including emerging or weak signals but also more established trends (micro-, macro-trends). According to Futures Platform, a phenomenon needs to have a significant impact on several industries in the future, a robust core and a direction ([53]).

Radar: Futures Platform functionality for grouping, categorising and visualising phenomena in a customable manner.

Related aspects: 'Additional information' or 'latest news' sections of a phenomenon description.

Related phenomenon: Phenomenon flagged under the 'related phenomena' section in Futures Platform description of a core phenomenon of a given theme or topic.

Strengthening phenomenon: The presented issue is becoming more common or acute during the given timeframe. Most of its change potential is still ahead.

Summary phenomenon: Type of phenomenon defined by Futures Platform and considered in this report as one 'established trend'.

Text Mining: Process of extracting information from text and formatting it into structured data suitable for analysis.

Theme: Each of the broad themes (main headings) from the January 2021 workshop (e.g., space, energy, transport). In this report, themes constitute groups of topics, which in turn group relevant phenomena from Futures Platform ([54]).

Topic: Each of the 'sub-themes' identified during the January 2021 workshop, e.g., 'electric aviation' or 'autonomous vehicles' within the 'mobility and transport' theme. In this report, each topic is a group of relevant phenomena from Futures Platform.

Weakening phenomenon: Description of the overall change in a larger theme. There are 30 theme summaries in total, spanning a timeframe from the present time to 2040.

Weak signal phenomenon: A small emerging issue in the present. At the given timeframe, it is still hard to say whether it will become a trend.

Wild card phenomenon: A possible but not probable event or change. Early information about a potential emerging risk or opportunity. The probability within the given timeframe is between 5% and 30%.

([53]) https://info.futuresplatform.com/en/hub/how-content-is-produced

([54]) https://info.futuresplatform.com/en/hub/introduction-to-the-content

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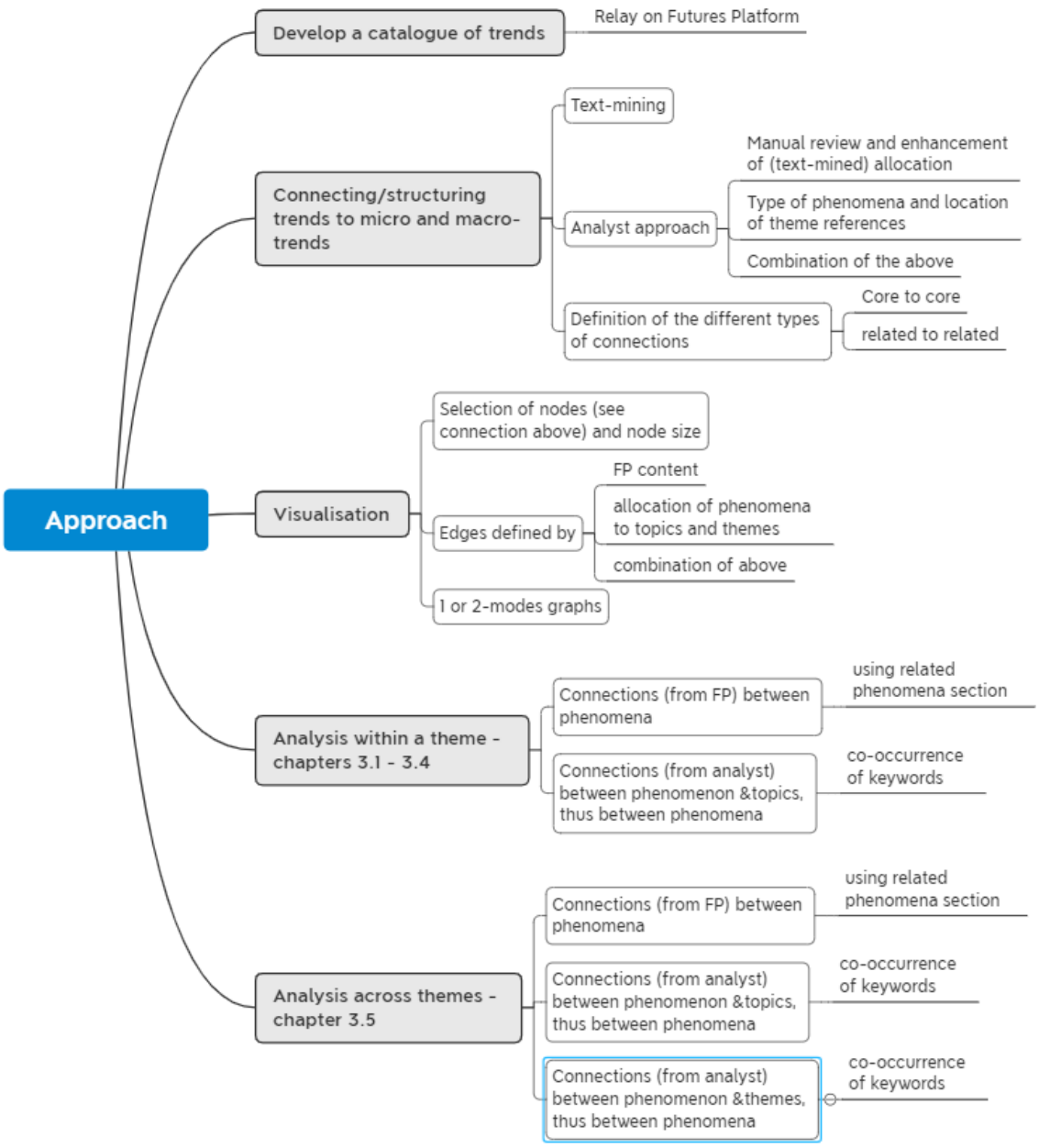
Annexes

Annex 1. Phenomena allocation based on text-mining and analysis – key steps

The approach developed by the authors, detailed in Chapter 2, relies on Futures Platform content. Descriptions of 712 phenomena are retrieved from the Futures Platform website and processed through text-mining and analysts' review for evidencing or establishing interlinkages which may connect, e.g., two phenomena; a phenomenon and a topic; several phenomena, allocated to one or more common topics; a phenomenon and a theme, serval topics or several themes together. These interlinkages are then visualised, possibly clustering phenomena together, via a network analysis tool (Gephi) for gaining further insights.

Figure 52. Schematic of the approach developed by the authors of this report



Source: Authors

Key steps of the approach:

- Develop a catalogue of trends / Rely on Futures Platform phenomena
    - Extract Futures Platform phenomena
    - Text-mine metadata
- Connect/structure trends to micro and macro-trends/Allocations of phenomena to topics and themes:
    - Text-mining of keywords for assisting phenomena allocation to themes and topics
    - Analysist approach:
        - Manual review and enhancement of (text-mined) allocation
        - Type of phenomena and location of theme references
        - Visualisation
            - Selection of nodes (see connections above) and node size
            - Edges defined by Futures Platform content or phenomena allocations
            - 1 or 2-modes graphs
        - Combination of the above
        - Definition of the different types of connections (from 'core' to 'core' to 'related' to 'related')
- Analyses within a theme (Sections 3.1 – 3.4):
    - Connections (from Futures Platform) between phenomena (using 'related phenomena' section);
    - Connections (from analysts) between phenomenon & topic; thus between phenomena (using co-occurrence of keywords).
- Analysis across themes (Section 3.5):
    - (In addition to the above) Connections (from analysts) between phenomenon & theme, thus between phenomena.

Connecting breadth and depth

This report explores ways of making sense of JRC megatrends, by connecting breadth and depth: depth by diving into specific themes and topics; breadth by considering interconnections between phenomena, topics and/or to themes through analysts' review. Analyses can be textual (stories), visual (network graphs) or tabular (counts of phenomena and/or interlinkages). By combining different angles (four themes, 18 topics, and 712 phenomena) this report highlights the complexity of the interplays.

Annex 2. Overview of Futures Platform phenomena and their allocation to themes and topics

JRC_ID	Phenomenon title	Type Trend	Timeframe	**Technology vulnerability** *TV1 - AdTech* *TV2 - Cyberattacks* *TV3 - Cybersecurity* *TV4 - Big data* *TV5 - Fragility*	**Transport** *TR1 - Electric vehicles* *TR2 - Autonomous vehicles* *TR3 - Flying cars & electric aviation* *TR4 – MaaS & car ownership*	**Human Enhancement** *HE1 - Wearables* *HE2 - Human robotics* *HE3 - Brain-computer interface* *HE4 - Genetic engineering*	**Energy** *EN1 - Resilient systems* *EN2 - (De)centralised systems* *EN3 - New sources* *EN4 - Scales* *EN5 - New chip tech*
2019.42	Narrowband IoT	Strengthening	2020-2023	TV4; TV5	TR2; TR4		NRJ
2019.51	Warren Buffett Phenomenon	Strengthening	2020-2023				
2019.94	Professional Journalism	Weakening	2020-2023				
2020.08	Programming School 42	Weak signal	2020-2023				
2020.47	Brexit - UK Leaving the EU	Strengthening	2020-2023	TV3; TV4			NRJ
2020.49	Glass Battery with Increasing Capacity	Weak signal	2020-2023		TR1; TR3		NRJ
2020.61	Donald Trump's Term	Weakening	2020-2020				
2020.63	3D Printing	Strengthening	2024-2028	TV3	TR1; TR2; TR3		
2020.67	Data Consumption	Strengthening	2020-2023	TV1; TV4; TV5	TR2; TR4		
2020.82	Self-Determination Replacing Control	Weak signal	2020-2023				
2020.86	Clickbait Journalism	Strengthening	2021-2024	TV4			
2020.88	Covid-19	Strengthening	2020-2023				
2021.04	Luminous Pathways	Weak signal	2020-2023		TR2		EN3
2021.11	Super Gel	Weak signal	2020-2023	TV4	TR3		
2021.14	New Extreme Gadgets	Strengthening	2020-2023		TR1; TR2; TR3; TR4		NRJ
2021.15	Co-Living	Strengthening	2020-2023		TR4		
2021.16	Information Warfare	Strengthening	2020-2023	TV2; TV4			
2021.17	Moral Machine Experiment	Weak signal	2020-2023		TR2		
2021.19	Protein Out of Air & Electricity	Weak signal	2020-2023				NRJ
2021.22	Breakup of UK	Wild card	2020-2023				
2021.24	Big data	Strengthening	2020-2023	TV1; TV4; TV5	TR2		

JRC_ID	Phenomenon title	Type Trend	Timeframe	**Technology vulnerability** *TV1 - AdTech* *TV2 - Cyberattacks* *TV3 - Cybersecurity* *TV4 - Big data* *TV5 - Fragility*	**Transport** *TR1 - Electric vehicles* *TR2 - Autonomous vehicles* *TR3 - Flying cars & electric aviation* *TR4 – MaaS & car ownership*	**Human Enhancement** *HE1 - Wearables* *HE2 - Human robotics* *HE3 - Brain-computer interface* *HE4 - Genetic engineering*	**Energy** *EN1 - Resilient systems* *EN2 - (De)centralised systems* *EN3 - New sources* *EN4 - Scales* *EN5 - New chip tech*
2021.25	Dumps to Mines	Weak signal	2020-2023	TV4			EN2
2021.26	Current Middlemen	Weakening	2020-2023	TV1; TV3	TR4		
2021.28	No Publicity for Terrorists	Strengthening	2020-2023	TV2; TV4			
2021.3	Cryptocurrency SolarCoin	Strengthening	2020-2023	TV3; TV5	TR1; TR3; TR4		NRJ
2021.32	Topless Feminism	Weak signal	2020-2023	TV4			
2021.33	DIY Culture	Strengthening	2020-2023	TV4			NRJ
2021.35	Seed Ball	Weak signal	2020-2023				
2021.36	Customer-to-Customer	Strengthening	2020-2023	TV3; TV4	TR4		
2021.37	Crowdfunding	Strengthening	2020-2023	TV3			
2021.39	Bio-Inspired Robotic Hand	Weak signal	2021-2024				
2021.41	Self-Compassion	Weak signal	2020-2023				
2021.42	Internationalization of Italian Organized Crime	Strengthening	2020-2023				
2021.43	Employment Discrimination	Weakening	2020-2023				
2021.45	Glocalisation	Strengthening	2020-2023	TV2			
2021.47	Agile Innovation Management	Strengthening	2021-2024				
2021.48	Multichannel Shopping	Strengthening	2020-2023	TV1; TV4			
2021.49	Participatory Budgeting	Weak signal	2020-2023				
2021.5	Slow Life	Strengthening	2020-2023	TV5			
2021.53	At least One Million New Data Scientists Needed	Strengthening	2020-2023	TV3; TV4; TV5	TR2		
2021.54	Brain-Computer Interface Neuralink	Weak signal	2020-2023		TR1; TR2	HE2	
2021.55	Irrational Behaviour	Strengthening	2020-2023	TV2; TV4			
2021.56	5G Wireless Network	Strengthening	2020-2023	TV3; TV4	TR2		

JRC_ID	Phenomenon title	Type Trend	Timeframe	**Technology vulnerability** *TV1 - AdTech* *TV2 - Cyberattacks* *TV3 - Cybersecurity* *TV4 - Big data* *TV5 - Fragility*	**Transport** *TR1 - Electric vehicles* *TR2 - Autonomous vehicles* *TR3 - Flying cars & electric aviation* *TR4 – MaaS & car ownership*	**Human Enhancement** *HE1 - Wearables* *HE2 - Human robotics* *HE3 - Brain-computer interface* *HE4 - Genetic engineering*	**Energy** *EN1 - Resilient systems* *EN2 - (De)centralised systems* *EN3 - New sources* *EN4 - Scales* *EN5 - New chip tech*
2021.57	Multipurpose Furniture	Strengthening	2020-2023	TV4			
2021.58	Super Magnet	Weak signal	2020-2023		TR3		NRJ
2021.59	Military and Police Drones	Strengthening	2021-2024	TV2	TR2; TR3		
2021.6	GM Food	Strengthening	2023-2028	TV4			
2021.61	Cybersecurity	Strengthening	2020-2023	TV2; TV3; TV4; TV5	TR2		
2021.62	Self-Healing Electronics	Weak signal	2020-2023		TR1; TR2; TR3		NRJ
2021.63	Facial Recognition	Strengthening	2020-2023	TV4	TR2; TR4		
2021.64	Metallic Hydrogen	Weak signal	2020-2023		TR3		NRJ
2021.65	Climate Anxiety	Weak signal	2020-2023				
2021.66	Oil Price War	Strengthening	2020-2023		TR1; TR3		NRJ
2021.67	Soros vs. Authoritarianism	Weak signal	2020-2023				
2021.69	VUCA	Strengthening	2020-2023	TV4			
2021.7	Cloud Storage	Strengthening	2020-2023	TV2; TV3; TV4; TV5	TR2; TR4		
2021.72	Drinkable Water Out of Air	Weak signal	2020-2023				NRJ
2021.73	Electric Road	Weak signal	2020-2023		TR1		NRJ
2021.74	Exercise Hidden in Daily Routines	Weak signal	2020-2023	TV4			NRJ
2021.75	The Collapse of the Healthcare System	Wild card	2020-2023				
2021.78	Prioritising Care and Increasing Deductibles	Strengthening	2020-2023				
2021.81	Concept Economy	Strengthening	2020-2023	TV1; TV4; TV5			
2021.83	Untouched Nature	Weakening	2020-2023				
2021.84	Aeroplane Wings Redesigned	Weak signal	2020-2023		TR3		NRJ
2021.86	Moringa Tree as a Food Source	Weak signal	2020-2023				NRJ

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2021.87	Methane Fuel Cells	Weak signal	2020-2023		TR1; TR3		NRJ
2021.89	New Pensioners	Strengthening	2020-2023				
2021.9	Publish Anything Everywhere	Strengthening	2020-2023	TV4; TV5			
2021.91	COVID-19 and Mental Health	Strengthening	2020-2023	TV4			
2021.93	Insect Drones	Weak signal	2020-2023		TR3		NRJ
2021.94	Quantified Self	Strengthening	2020-2023	TV4		HE	
2021.95	Growing Rice in Salt Water	Weak signal	2020-2023				
2021.97	Laughter and Learning	Weak signal	2020-2023				
2021.99	Freemium	Strengthening	2020-2023				
2022	Formic Acid Fuel	Weak signal	2020-2023		TR1; TR3		EN3; EN4
2022.01	Rectenna Solar Cells	Weak signal	2020-2023	TV4	TR1; TR3		EN3
2022.02	Biased Use of Information	Strengthening	2020-2023	TV4; TV5			
2022.04	Global Greening	Strengthening	2020-2023				NRJ
2022.05	European Separatists	Strengthening	2020-2023				
2022.07	Violence Against Officials	Strengthening	2020-2023				
2022.08	Mobility-as-a-Service Apps	Strengthening	2020-2023	TV3; TV4; TV5	TR2; TR4		
2022.09	Pen and Paper as Brain Activators	Weak signal	2020-2023				
2022.1	Electronic Sports	Strengthening	2020-2023	TV1			
2022.11	Non-Financial Reporting	Strengthening	2020-2023				
2022.12	Online Stores	Strengthening	2020-2023	TV1			
2022.13	Quantum Internet	Weak signal	2020-2023	TV3	TR2		EN5
2022.15	Deadly Pandemics	Wild card	2024-2029				
2022.16	Continuous Assessment and Dialogue	Strengthening	2024-2028	TV4			

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2022.17	Weakening Dedication and Engagement	Weak signal	2020-2023				
2022.26	Ways to Use Free Time	Strengthening	2020-2023	TV4			
2022.27	Shipping Container Homes	Weak signal	2020-2023		TRA		NRJ
2022.28	Microplastics	Strengthening	2020-2023	TV4			
2022.29	Cryptocurrencies	Strengthening	2021-2024	TV3; TV5			NRJ
2022.3	From Products to Relationships	Strengthening	2020-2023	TV4			
2022.31	Price Discrimination	Strengthening	2020-2023	TV1			
2022.33	AR Glasses	Strengthening	2020-2023	TV4			
2022.34	Disinformation	Strengthening	2020-2023	TV4			
2022.36	Solar Panel Windows	Strengthening	2023-2028	TV2	TR1; TR3		EN3; EN4
2022.39	Electric Racing Cars	Weak signal	2020-2023	TV4	TR1; TR3		NRJ
2022.4	AR Hyperphotography	Weak signal	2020-2023	TV4			NRJ
2022.44	Multinationals Promoting Travel Destinations	Strengthening	2020-2023	TV4			
2022.45	Wireless Charging for Electric Cars	Weak signal	2020-2023	TV5	TR1; TR2		NRJ
2022.46	Murder Rates & Risk of Violent Death	Weakening	2021-2024				
2022.47	Remote Work and Distance Education	Strengthening	2020-2023		TRA		
2022.48	Business Ecosystem Customership	Strengthening	2020-2023	TV4; TV5			
2022.49	Electricity-Producing Bacteria	Weak signal	2020-2023				EN3
2022.51	Vegetarian Proteins	Strengthening	2020-2023	TV4			
2022.52	China's Foreign Acquisitions	Wild card	2021-2024	TV4; TV5	TRA		NRJ
2022.54	Biomimetic Composites	Weak signal	2020-2023		TRA		
2022.55	Hyperloop	Strengthening	2028-2040		TR1		NRJ

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2022.56	Populistic Conservatism	Strengthening	2020-2023				
2022.57	Energy Blackmail	Wild card	2020-2023				NRJ
2022.59	Wearable Fitness Technology	Weak signal	2020-2023	TV4		HE	NRJ
2022.61	Li-Fi	Strengthening	2023-2028	TV3; TV4	TR2		
2022.62	Wireless Power Transmission	Strengthening	2023-2028	TV4; TV5	TR1		EN4
2022.66	Telemedicine and Self Care	Strengthening	2020-2023	TV1; TV4			
2022.67	Graphene Electronic Paper	Weak signal	2020-2023		TR1		
2022.7	Hybrid Warfare	Strengthening	2020-2023	TV2			NRJ
2022.71	Influencer & Social Media Society	Strengthening	2020-2023	TV1; TV4			
2022.73	Universal Cancer Treatment	Wild card	2028-2040				
2022.74	Social Impact Bonds	Strengthening	2020-2023				
2022.75	Cyber Attack Wargames	Strengthening	2024-2029	TV2; TV3			
2022.77	Inequality in Latin America	Strengthening	2021-2024				
2022.81	Harmful Functionality in Products	Strengthening	2020-2023	TV2; TV3; TV4	TR2; TR4		
2022.83	Asphalt from Waste	Wild card	2020-2023		TRA		NRJ
2022.85	Programming in VR	Weak signal	2020-2023				
2022.86	Hijacking a Hospital	Wild card	2020-2023	TV2; TV3; TV4			
2022.88	Africa Continental Free Trade Area	Strengthening	2020-2023				
2022.89	Hydrogen Trains	Weak signal	2020-2023	TV1; TV5	TR1		NRJ
2022.92	Cricket Bread	Weak signal	2020-2023				
2022.93	Use of Wind Power	Strengthening	2020-2023		TR1; TR3		EN2; EN3; EN4
2022.94	Efficient Use of Space	Strengthening	2020-2023		TR4		
2022.95	Bionic Eye	Strengthening	2023-2028			HE4	

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2023.01	Sand Suitable for Building	Weakening	2020-2023				
2023.02	Molecular Machines	Weak signal	2020-2023				EN4
2023.07	Concrete Out of Waste	Weak signal	2020-2023				
2023.1	Urbanisation	Strengthening	2020-2023	TV4	TRA		NRJ
2023.2	Deglobalisation	Wild card	2020-2023				
2023.3	China's Secret Uighur Camps	Weak signal	2020-2023				NRJ
2023.33	Cheap and Accurate DNA Tests	Strengthening	2024-2028			HE3	
2023.34	Body-Heat Harvesting Wearables	Weak signal	2020-2023	TV4	TR1	HE	EN3
2023.35	Internet and Political Mobilisation	Strengthening	2020-2023	TV4			
2023.41	Cellular Network on the Moon	Wild card	2021-2024		TRA		NRJ
2023.44	Anti-Environmentalists and Climate Change Deniers	Strengthening	2020-2023				NRJ
2023.45	Digital Yuan and Central Bank Digital Currencies	Strengthening	2021-2024	TV1; TV3; TV5			
2023.52	Smartwatches	Strengthening	2020-2023	TV4			
2023.56	Cold War of Technology	Strengthening	2020-2023	TV2; TV3			
2023.61	Runet - Russia's Internal Internet	Wild card	2020-2023	TV2; TV4; TV5			
2023.66	National Security of Supply	Strengthening	2020-2023				NRJ
2023.68	Civil War in the US	Wild card	2020-2023	TV5			NRJ
2023.69	European Recovery Fund	Strengthening	2021-2024				NRJ
2023.71	Workplace Wellness Services	Strengthening	2020-2023				
2023.72	China as the World's No1 Economy	Strengthening	2020-2023				
2023.74	Electric Cars	Strengthening	2024-2028		TR1		NRJ
2023.78	Self-organising Robot Cubes	Weak signal	2020-2023		TRA		

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2023.81	Monumental Organizations	Weak signal	2020-2023				
2023.86	Cloud Computing	Strengthening	2020-2023	TV1; TV3; TV4; TV5	TR2		EN5
2023.91	Zero-Contact Services	Strengthening	2021-2024	TV5			
2023.95	Rise of Third Sector Services	Strengthening	2024-2028				
2023.97	Chatbots	Strengthening	2024-2028				
2023.98	Y Generation to Leading Positions	Strengthening	2023-2028	TV1; TV4			
2024.01	AI Machine Learning	Strengthening	2024-2028	TV3	TR2		EN5
2024.02	Recycling Robots	Strengthening	2023-2028		TRA		NRJ
2024.05	Isolation Economy	Strengthening	2020-2023		TRA		
2024.06	Residential Blocks Made of Wood	Strengthening	2024-2028				
2024.07	Beef Tax	Wild card	2024-2028				
2024.08	AR Historic Geoinformation	Strengthening	2024-2028				
2024.09	More Human-Like Devices	Strengthening	2024-2028				
2024.11	Bicycle Highways	Strengthening	2024-2028		TR4		
2024.13	Right to Privacy	Weakening	2024-2028	TV3; TV4; TV5	TR2; TR4		
2024.14	Cyberwarfare	Strengthening	2024-2028	TV2; TV3	TR2		
2024.15	Leisure & Lifestyles	Summary	2020-2040	TV3; TV4; TV5			
2024.2	Keys	Weakening	2024-2028	TV2; TV3; TV4	TR4		
2024.25	Valuing Free Time	Strengthening	2024-2028	TV5			
2024.26	Services	Summary	2020-2040		TR1; TR3		
2024.29	Internet of Things (IoT)	Strengthening	2024-2028	TV4; TV5	TR2; TR4		NRJ
2024.39	Smart Wallet	Weak signal	2020-2023	TV3; TV4			

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2024.4	Software Robots as Journalists	Strengthening	2021-2024	TV4			
2024.41	Passenger Economy	Wild card	2040-2050		TR1; TR2; TR4		
2024.42	Robotic Farming	Strengthening	2024-2028	TV4			NRJ
2024.46	Public Governance	Summary	2020-2040	TV2; TV3; TV4			NRJ
2024.49	Home Robots	Strengthening	2024-2028	TV1; TV4			
2024.5	Security & Safety	Summary	2020-2040	TV2; TV3			NRJ
2024.51	Raw Materials	Summary	2020-2040		TR1		NRJ
2024.52	Vertical Farming	Strengthening	2024-2028				NRJ
2024.53	Adaptive Clothing	Strengthening	2024-2028	TV4		HE	
2024.55	Molecular Gastronomy	Strengthening	2024-2028				NRJ
2024.56	Biohacking	Strengthening	2024-2028	TV2; TV3; TV4		HE	
2024.57	Cleantech	Strengthening	2024-2028	TV5	TR1; TR2; TR3		EN2
2024.6	Biofuels	Strengthening	2024-2028		TRA		EN3
2024.61	Electric Semi Trucks	Strengthening	2024-2028		TR1; TR2		NRJ
2024.63	Belt and Road Initiative	Strengthening	2023-2028		TRA		NRJ
2024.66	Solar Roof	Strengthening	2024-2028		TR1; TR3		EN3; EN4
2024.67	Countries & Regions	Summary	2020-2040	TV5			
2024.68	Atmosphere Design	Strengthening	2024-2028	TV5			
2024.7	Anti-Vaccination	Strengthening	2020-2023	TV2; TV4			
2024.74	Cashless India	Weak signal	2020-2023	TV4; TV5			
2024.75	Biotech and Bioeconomy	Strengthening	2024-2028				NRJ
2024.76	Maritime Robotics	Strengthening	2023-2028	TV3; TV4; TV5	TR2		NRJ
2024.77	AI Machine Intelligence	Strengthening	2023-2028		TR2		

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2024.8	Value of Degrees	Weakening	2024-2028				
2024.81	Circular Economy	Strengthening	2024-2028		TRA		NRJ
2024.82	Blended Learning	Strengthening	2023-2028				
2024.83	Personal Branding	Strengthening	2024-2028	TV4			
2024.86	Geo-Economic Blocs	Wild card	2020-2023	TV2; TV3			NRJ
2024.87	Tailored Equality	Strengthening	2024-2028	TV2			
2024.89	Geothermal Energy	Strengthening	2024-2028				EN3; EN4
2024.91	Autonomous Teamwork (Holacracy)	Strengthening	2024-2028				
2024.93	Hyperlocalisation	Strengthening	2024-2028				NRJ
2024.94	Wild Animal Species	Weakening	2024-2028				
2024.95	Free Speech on the Internet	Wild card	2024-2028	TV4			
2024.96	Politics & Policies	Summary	2020-2040				
2024.97	Biomimicry	Strengthening	2024-2028				NRJ
2025	New Global Financial Regulations	Strengthening	2024-2029	TV3; TV5			NRJ
2025.02	Swarm Intelligence	Strengthening	2024-2028	TV4	TR2	HE4	
2025.04	Ownership	Weakening	2024-2028		TR4		
2025.06	Data & Digitalisation	Summary	2020-2040	TV3; TV4	TR2		EN5
2025.07	Covid-19 Vaccines	Strengthening	2021-2024	TV4			
2025.13	Climate Change	Summary	2020-2040				
2025.15	Energy	Summary	2020-2040	TV2; TV5	TR1; TR3		EN2; EN3; EN4
2025.16	Biodiversity	Weakening	2024-2028				NRJ
2025.17	Leadership Crisis	Strengthening	2023-2028				
2025.18	AI Games	Strengthening	2024-2028		TR2		

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2025.19	Private & Public Transport	Summary	2020-2040	TV4	TR1; TR2; TR3; TR4		NRJ
2025.2	AI in Knowledge Work	Strengthening	2024-2028	TV4		HE4	
2025.24	Biochar	Strengthening	2024-2028				EN4
2025.26	Real-Time Data	Strengthening	2024-2029	TV4; TV5	TR2; TR4		
2025.3	Voice and Gesture Control	Strengthening	2023-2028	TV4	TR2		
2025.31	Grown from Mushrooms	Strengthening	2024-2028				NRJ
2025.32	Significance of Amateurs	Strengthening	2024-2028				
2025.34	Nanotechnologies and Materials	Strengthening	2023-2028	TV5	TR1; TR3	HE	NRJ
2025.36	Self-Healing Bio-Concrete	Strengthening	2024-2028		TRA		NRJ
2025.37	Smart Homes	Strengthening	2024-2028	TV4			NRJ
2025.39	Domestic Tourism	Wild card	2020-2023	TV3; TV4	TRA		
2025.4	Placebo Effect to Use	Strengthening	2023-2028	TV5			
2025.42	Local Production through 3D Printing	Strengthening	2024-2028		TR1; TR2; TR3		
2025.43	Tightening Ethical Criteria	Strengthening	2024-2028	TV1; TV4			
2025.45	Solar Power	Strengthening	2024-2028		TR1; TR3		EN3
2025.48	The US Economy and National Security	Weakening	2029-2041	TV3; TV4			
2025.5	Activism Terrorism	Wild card	2024-2028				NRJ
2025.51	Food Scanners	Strengthening	2024-2028	TV5			
2025.52	Leased Standard of Living	Wild card	2024-2028	TV4	TR4		
2025.53	Citizen Entrepreneurship	Strengthening	2024-2028				
2025.54	Synthetic Fuels	Strengthening	2023-2028		TR1; TR3		EN2; EN3; EN4
2025.56	Rising Value of Data	Strengthening	2024-2028	TV1; TV3; TV4; TV5	TR2; TR4	HE4	NRJ

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2025.57	Traditional TV Broadcasts	Weakening	2024-2028	TV4			
2025.58	Adenine Based Gene Editing	Strengthening	2024-2028			HE3	
2025.6	Frexit - France Leaving the EU	Wild card	2024-2028				
2025.62	Hybrid Construction and Buildings	Strengthening	2024-2028		TR1; TR4		EN4
2025.63	Automated Supermarket	Strengthening	2024-2028	TV5	TR1		NRJ
2025.64	Scalable Learning	Strengthening	2024-2028				
2025.65	Telepresence and the Use of Avatars	Strengthening	2024-2028	TV4	TRA		
2025.67	Revolut Bank	Wild card	2024-2028	TV3; TV4			
2025.68	Ransomware	Strengthening	2021-2024	TV2; TV3; TV5	TR2		NRJ
2025.69	Destruction of Biosphere Reserves	Wild card	2029-2039				NRJ
2025.71	Taboo of Senior Sex	Weakening	2024-2028	TV3			
2025.72	AR-Assisted Surgery	Strengthening	2024-2028		TR2	HE4	
2025.73	Robot Couriers	Strengthening	2023-2028	TV1	TR1; TR2; TR3		NRJ
2025.74	Health Monitoring Spaces	Strengthening	2024-2028	TV4			
2025.75	Wood-Based Textiles	Strengthening	2024-2028	TV4			EN4
2025.77	Brick-Laying Robot	Strengthening	2024-2028				NRJ
2025.78	North European Currency	Wild card	2024-2028				
2025.8	AI in Healthcare	Strengthening	2024-2028	TV3; TV4			
2025.81	Increasing Health Requirements	Strengthening	2024-2028				
2025.82	Robotics in Healthcare	Strengthening	2024-2028				
2025.84	Experiences through Gamification	Strengthening	2023-2028	TV4	TR4		
2025.85	Predictive Fashion	Strengthening	2024-2028	TV1; TV4			NRJ
2025.87	Laser Weapons	Strengthening	2024-2029	TV2			NRJ

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2025.88	Rapid Recycling	Strengthening	2024-2028				NRJ
2025.89	Internet of Hacked Things	Strengthening	2024-2028	TV2; TV3; TV4	TR2; TR4		
2025.9	Chinese Dominance in Africa	Strengthening	2024-2028				
2025.93	Underground Construction	Strengthening	2023-2028		TRA		NRJ
2025.94	Business	Summary	2020-2040	TV1	TR2		NRJ
2025.95	Bioterrorism	Strengthening	2029-2039				
2025.97	Smart Wearables	Strengthening	2024-2028	TV4	TRA	HE	NRJ
2025.98	Forestation	Strengthening	2024-2028	TV5			EN3
2025.99	Drone Revolution	Strengthening	2024-2028	TV2; TV3	TR2; TR3		
2026	Small Nuclear Power Plants	Strengthening	2024-2028	TV5	TR1; TR3		EN2; EN3; EN4
2026.01	Environmental and Pigouvian Taxes	Strengthening	2024-2028		TRA		NRJ
2026.02	Male Power	Weakening	2023-2028				
2026.03	Facilitating Surprises	Weak signal	2020-2023	TV4			
2026.04	Personalised Pricing	Strengthening	2024-2028	TV1; TV4			NRJ
2026.05	Open Source Aviation	Strengthening	2024-2028	TV4	TR2; TR3		
2026.07	Lighter Regulation	Wild card	2024-2028				NRJ
2026.08	Plastic-Eating Larvae and Bacteria	Strengthening	2024-2028				NRJ
2026.09	Communication & Media	Summary	2020-2040	TV2; TV3; TV5			
2026.1	New Economic Thinking	Strengthening	2023-2028	TV4			
2026.11	Ambient Intelligence	Strengthening	2024-2028	TV4; TV5	TR2		NRJ
2026.14	Resource Wars	Wild card	2024-2028		TR1; TR3		NRJ
2026.15	Think to Speak	Strengthening	2029-2039			HE2	
2026.16	Thermoelectric Generator	Wild card	2024-2028	TV4	TR1; TR3		EN3; EN4

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2026.17	Synthetic Biology	Strengthening	2024-2028				NRJ
2026.19	Technology Hype	Wild card	2024-2028	TV3	TR1; TR2; TR3		
2026.2	Piezoelectricity	Wild card	2024-2028		TR1; TR3		EN3; EN4
2026.21	Participatory Democracy	Weak signal	2020-2023	TV3; TV4			
2026.22	LED Lights in Food Production	Strengthening	2023-2028	TV4			NRJ
2026.24	Electronic Skin	Strengthening	2024-2028	TV4		HE	NRJ
2026.25	Robot Cars and Taxis	Strengthening	2029-2039		TR1; TR2		NRJ
2026.27	Immersive Virtual Spaces	Strengthening	2024-2028				
2026.28	Algorithmic Biology	Strengthening	2023-2028	TV4		HE4	
2026.29	Internet of Medical Things	Strengthening	2024-2028	TV3; TV4; TV5		HE	
2026.3	Edible Packaging	Strengthening	2024-2028				
2026.31	Governments Putting Pressure on Companies	Strengthening	2023-2028	TV4; TV5			
2026.32	Latin America's Data Centre Market	Strengthening	2024-2029	TV3; TV4; TV5	TR2		
2026.33	Rare-Earth Elements	Weakening	2024-2028		TR1; TR3		NRJ
2026.35	Seaweed Potential	Strengthening	2024-2028				EN3; EN4
2026.37	Aerial Reforestation	Strengthening	2024-2028				
2026.38	Collapsing Housing Markets	Wild card	2024-2028				
2026.39	Artificial Intelligence	Summary	2020-2040		TR2	HE4	NRJ
2026.42	Print Media in the West	Weakening	2020-2023	TV4			
2026.43	Algae Power	Wild card	2024-2028				EN3; EN4
2026.44	Social Ranking Systems	Wild card	2023-2028	TV3; TV4			
2026.45	Storing Solar Energy in Liquid	Wild card	2024-2028		TR1; TR3		EN3

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2026.46	Greentech Bubble Burst	Wild card	2024-2029		TR1; TR3		EN4
2026.52	Visegrad Group	Strengthening	2020-2023	TV4	TR1		NRJ
2026.53	Farming without Pesticides	Wild card	2024-2028				
2026.54	Invincible Weeds	Strengthening	2024-2029				
2026.59	Hydroelectric Power	Strengthening	2024-2028				EN3; EN4
2026.6	Collapse of Russia	Wild card	2023-2028	TV5			NRJ
2026.61	Cyber Schools	Strengthening	2023-2028				
2026.64	Swarm Work (Micro- and Macrotasking)	Strengthening	2024-2028				
2026.66	Self-Driving Bus	Strengthening	2023-2028	TV2; TV4	TR1; TR2		NRJ
2026.67	Safe Data Havens	Strengthening	2024-2028	TV2; TV3; TV4; TV5	TR2		NRJ
2026.68	Freight & Logistics	Summary	2020-2040	TV1; TV2	TR1; TR2		NRJ
2026.69	Impact Investments	Strengthening	2024-2028				
2026.7	Medical Tourism	Strengthening	2024-2028				
2026.72	Completely Corrupted Internet	Wild card	2024-2028	TV3; TV4			
2026.73	Gig Economy	Strengthening	2024-2028				
2026.74	Road Hackers	Strengthening	2028-2040	TV2; TV3; TV5	TR2; TR4		
2026.78	Arctic Resources Race	Strengthening	2024-2028				NRJ
2026.82	India's Megacities	Strengthening	2029-2039				
2026.85	Hydrogen Economy	Strengthening	2024-2028		TR1; TR3		EN3
2026.88	Carbon-Neutral Cement	Strengthening	2024-2028		TRA		NRJ
2026.9	Offshoring	Weakening	2024-2028				
2026.92	AI Robotics	Strengthening	2023-2028	TV5	TR2		NRJ

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2026.94	Clean Water Solutions	Wild card	2029-2041	TV5	TR1		EN4
2026.96	Flying Industrial Robots	Strengthening	2024-2028	TV2	TR2		NRJ
2026.97	Complaint Bots	Wild card	2024-2028	TV2			
2026.98	Perovskite Solar Panels	Strengthening	2023-2028		TR1; TR3		EN3
2027	Collapse of General Knowledge	Wild card	2024-2028	TV2; TV4			
2027.02	Social Mobility	Weakening	2023-2028	TV4			
2027.03	Social Robots	Strengthening	2028-2040	TV4; TV5			
2027.06	Intelligence Amplification (IA)	Strengthening	2024-2028	TV4	TR2	HE4	
2027.07	Thorium Power Plants	Wild card	2024-2028		TR1; TR3		EN3; EN4
2027.08	3D-Printed Food	Strengthening	2024-2028				
2027.1	Floating Food and Energy Production	Strengthening	2024-2028		TRA		EN3; EN4
2027.13	Extremist Movements	Strengthening	2023-2028	TV2; TV3; TV4			
2027.2	Smart and Connected Countryside	Wild card	2024-2028	TV4; TV5	TR1; TR2		EN2
2027.24	AR in Medical Education	Strengthening	2024-2028		TR2		NRJ
2027.28	Omics for Health	Strengthening	2024-2028			HE3	
2027.33	Fuel Switching	Strengthening	2023-2028		TR1; TR3		EN1; EN3; EN4
2027.34	Digital Twins	Strengthening	2023-2028	TV4; TV5	TR2		NRJ
2027.42	Collapse of China	Wild card	2024-2028				
2027.44	Government Change and Healthcare	Wild card	2024-2028	TV2; TV4			
2027.46	Luxury of Healthy Food and Decreasing Quality of Cheap Food	Strengthening	2029-2041	TV4			
2027.49	VR and AR in Healthcare	Strengthening	2024-2028	TV1; TV4			
2027.53	3D-Bioprinted Ovary	Strengthening	2028-2040				

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2027.68	Car Ownership	Weakening	2028-2040	TV1	TR1; TR2; TR4		NRJ
2027.76	Gesture Control Armband	Weak signal	2020-2023	TV4			
2027.89	3D-Printing Metal	Strengthening	2024-2029		TR3		
2027.92	Non-Arab Rivals Shaping the Middle East	Strengthening	2024-2029	TV2			
2027.94	Industry 5.0	Strengthening	2024-2029				EN5
2028.07	Helsinki Tallinn Tunnel	Wild card	2029-2039		TRA		
2028.39	After Death Services	Wild card	2024-2028	TV4			
2028.56	Emoji Language	Wild card	2029-2039				
2028.72	Right to Disconnect	Strengthening	2021-2024				
2028.83	Bolivian Lithium Reserves	Strengthening	2021-2024		TR1; TR3		NRJ
2028.85	CO2 Capture and Repurposing	Strengthening	2024-2028				EN4
2028.86	Eco-Socialism Becomes Mainstream	Wild card	2023-2028				NRJ
2028.87	Modern Slavery and Migrant Smuggling	Strengthening	2021-2024				
2028.92	Collapse of World Economy	Wild card	2024-2028	TV2			NRJ
2029.42	Floating Cities	Strengthening	2065-2075				NRJ
2029.45	Dependency on Electric Grids and Data Networks	Wild card	2029-2039	TV2; TV5	TR1; TR2; TR3; TR4		NRJ
2029.46	Public-Private Partnerships in Healthcare	Strengthening	2024-2028				
2029.59	Supervolcano Eruption Leads to Nuclear Winter	Wild card	2045-2055				
2029.7	Moon Mining	Wild card	2055-2065				NRJ
2029.76	Wellbeing for All	Wild card	2029-2039				NRJ
2029.78	Transparent Society	Strengthening	2024-2028	TV3; TV4; TV5			
2029.86	Waiting to See Doctor	Weakening	2024-2028				

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2029.88	Decriminalising Drug Use	Strengthening	2029-2039				
2030	Holograms	Wild card	2028-2040				NRJ
2030.03	Biodegradable Electronics	Strengthening	2028-2040				NRJ
2030.06	Hyperloop as a Connector of the World	Wild card	2065-2075		TR1		NRJ
2030.08	Transhumanism as a New Religion	Wild card	2065-2075	TV2			
2030.09	Invisibility Cloak	Wild card	2029-2039			HE4	
2030.11	Human Body Garage	Strengthening	2040-2120			HE4	
2030.15	Data Security of Human Body Under Threat	Wild card	2045-2055	TV2; TV3; TV4		HE; HE1; HE2; HE3	
2030.2	Acceptance of Cyborg Technology	Wild card	2045-2055	TV3		HE1; HE2	
2030.32	Perpetual Bonds	Wild card	2024-2029				
2030.4	Intuitive Intelligence	Weak signal	2020-2023		TR2		NRJ
2030.73	Equal Rights to Robots	Wild card	2045-2055				
2030.74	Melting Antarctica & Rising Sea Levels	Wild card	2040-2120				
2030.79	Out of Batteries	Wild card	2029-2039		TR1; TR3		EN4
2030.82	Human Brain-AI Symbiosis	Wild card	2065-2075			HE2	
2030.83	Weakening Gulf Stream	Wild card	2065-2075				
2030.84	Older than Ever	Strengthening	2029-2039				
2030.91	Oil-Based Plastics	Weakening	2028-2040				NRJ
2030.92	Quantum Computers	Strengthening	2045-2055	TV3	TR2		EN5
2031	China's Super AI	Strengthening	2029-2039	TV1; TV3	TR2		
2031.03	Phosphorus Sufficiency	Weakening	2045-2055				
2031.06	Permafrost	Weakening	2065-2075				

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2031.08	DNA Data Storage	Strengthening	2028-2040	TV4; TV5			NRJ
2031.09	Microbots	Strengthening	2029-2039				EN2
2031.13	Future Without Work	Wild card	2055-2065				
2031.16	Geopolitical Impacts of Coronavirus	Wild card	2020-2023	TV4			NRJ
2031.19	Unfathomable AI	Strengthening	2045-2055		TR2		
2031.22	Solar Radiation Management	Wild card	2045-2055		TR1; TR3		
2031.25	Insect Protein	Strengthening	2028-2040				
2031.27	Apocalyptic AI	Wild card	2065-2075		TR2		
2031.38	Dirty Clothes	Weakening	2024-2028	TV4; TV5			NRJ
2031.44	Microgrids	Strengthening	2028-2040	TV3; TV5	TR1; TR3		EN1; EN2; EN4
2031.57	AI Movie Screenwriter	Wild card	2029-2039				
2031.58	Collapse of Language Learning	Wild card	2029-2039	TV4			
2031.6	New Types of Retirement Plans	Strengthening	2029-2039	TV3			
2031.61	End of Nation States	Wild card	2045-2055	TV3			
2031.62	Transparent Wood	Strengthening	2028-2040				NRJ
2031.65	Megaprojects in the Middle East	Strengthening	2021-2024				NRJ
2031.66	AI Bubble	Strengthening	2029-2039	TV4			
2031.68	Space Elevator	Wild card	2065-2075		TRA		
2031.71	Technology-free Zones	Wild card	2029-2039	TV4; TV5			
2031.78	Phage Therapy	Strengthening	2028-2040				
2031.8	Self-Maintaining Buildings	Wild card	2065-2075		TRA		
2031.85	Cryogenic Sleep Chamber	Weak signal	2020-2023		TRA		
2031.86	Solar Satellites	Wild card	2065-2075		TR1; TR3		EN3

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2031.88	Predictive Crime Prevention	Wild card	2029-2039	TV4			
2031.89	Relevance of Low Wages	Weakening	2029-2039				
2031.92	Abundance	Wild card	2045-2055				
2031.93	Escape from Reality	Wild card	2029-2039	TV4			
2031.94	Intelligent Augmented Reality (IAR)	Strengthening	2029-2039				
2031.96	SkyPod Elevator	Wild card	2029-2039		TRA		
2031.99	New Era in Logistics	Strengthening	2029-2039	TV1	TR2; TR3		NRJ
2032.06	Transferring Data Directly into Brain	Wild card	2055-2065			HE2	
2032.07	Flying Goods and People in Cities	Strengthening	2029-2041	TV3	TR2; TR3		
2032.1	Cargo Ports Become Unnecessary	Wild card	2029-2039	TV4	TR1; TR2		NRJ
2032.14	Quantum Levitation	Strengthening	2045-2055		TR3		NRJ
2032.18	Driving as a Job	Weakening	2029-2039		TR2		
2032.23	Whole Life Inside City Interiors	Strengthening	2029-2039	TV4			NRJ
2032.32	Industry 4.0	Strengthening	2021-2024	TV3; TV4; TV5	TR2		EN5
2032.33	AI in Warfare	Strengthening	2029-2041	TV2; TV3; TV4			
2032.42	Generation Z Enters Work Markets	Strengthening	2023-2028	TV4			
2032.44	Universal Basic Income	Strengthening	2029-2039				
2032.46	Fusion Power - Helium 3	Wild card	2065-2075				EN3; EN4
2032.47	Global Water Crisis	Strengthening	2024-2029				NRJ
2032.5	Medical Tricorder from Star Trek	Wild card	2045-2055	TV4			
2032.52	City Self-Sufficiency	Wild card	2029-2039	TV4			NRJ
2032.53	4D Printing	Strengthening	2029-2039				
2032.55	Memory Manipulation	Strengthening	2029-2039				EN5

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2032.56	Asteroid Mining	Wild card	2075-2085		TR1		NRJ
2032.59	Pensioner Tourism to Become the Largest Sector of Economy	Wild card	2029-2039	TV4	TRA		
2032.62	Exponential Times	Strengthening	2029-2040	TV3; TV4; TV5			EN5
2032.63	High Speed Travel	Strengthening	2029-2039		TRA		NRJ
2032.65	Incurable & Widespread Diseases	Weakening	2029-2039				
2032.68	Desert as Bread Basket	Wild card	2029-2039				NRJ
2032.71	Cyborg Plants	Strengthening	2029-2039				NRJ
2032.72	World's Megacities	Strengthening	2028-2040		TR4		NRJ
2032.75	Solar Panel Roads	Strengthening	2029-2039	TV5	TR1; TR2; TR3		EN3; EN4
2032.76	Climate Refugees and Migration	Wild card	2029-2039				
2032.77	City-States	Wild card	2029-2039				NRJ
2032.85	Kurdish Independence	Wild card	2029-2041				
2032.88	Forever Rechargeable Battery	Wild card	2029-2039		TR1; TR2; TR3		EN4
2032.89	Portable Homes	Strengthening	2029-2039	TV4			
2032.9	Disruptions in Finance	Strengthening	2029-2039	TV1; TV3; TV4			NRJ
2032.91	Neom - Saudi Arabia's Future Megacity	Wild card	2028-2040		TR3		NRJ
2032.93	Zero-Emission Countries	Wild card	2029-2039	TV4; TV5			NRJ
2033.02	Living Robots	Strengthening	2029-2039				
2033.04	Mid-Sized Cities Prosper	Wild card	2029-2039				
2033.07	Code Shapes Our Speech	Strengthening	2029-2039	TV4			
2033.08	Autonomous Weapons Ban	Wild card	2024-2028	TV2	TR2		
2033.09	Parking	Weakening	2029-2039	TV1	TR1; TR2; TR4		

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2033.13	Euthanasia	Wild card	2029-2039				
2033.17	Ecosystems amidst Climate Change	Strengthening	2029-2039				
2033.22	Artificial Meat	Strengthening	2029-2039				
2033.25	Africa's Rise	Strengthening	2029-2041	TV5			NRJ
2033.27	Colonising Mars	Wild card	2085-2095		TRA		NRJ
2033.31	Blanket Medicine for Viruses	Wild card	2029-2039				
2033.35	Coronal Mass Ejection of the Sun	Wild card	2029-2039		TR3		NRJ
2033.42	AI Deep Learning	Strengthening	2029-2039	TV4	TR2		EN5
2033.44	Flying Cars	Strengthening	2029-2039		TR1; TR2; TR3		NRJ
2033.58	Space Tourism	Wild card	2029-2039		TRA		
2033.62	Data Centres in Space	Wild card	2029-2041	TV3; TV5	TR2		NRJ
2033.86	Driving and Driver's License	Weakening	2029-2039	TV2	TR2		
2033.91	Artificial Photosynthesis	Strengthening	2029-2039		TRA		EN3; EN4
2034	Warp Drive As Seen in Star Trek	Wild card	2095-2105	TV3	TRA		NRJ
2034.08	Organ Printing	Strengthening	2029-2039				
2034.1	6G Wireless Network	Strengthening	2029-2039	TV3; TV4	TR2		NRJ
2034.12	Thought-Reading from a Distance	Wild card	2029-2039				
2034.14	Car-Free City Centres	Strengthening	2029-2039		TR4		NRJ
2034.26	Passenger Cabins on Robot Platforms	Wild card	2029-2039		TR1; TR2; TR3		NRJ
2034.29	Collective Intelligence	Strengthening	2029-2039	TV4			NRJ
2034.35	Road Deaths and Car Repairs	Weakening	2029-2039		TR1; TR2		NRJ
2034.36	Federalisation of the European Union	Wild card	2028-2040	TV5			NRJ
2034.38	Electric Aeroplanes	Strengthening	2028-2040		TR1; TR3		NRJ

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2034.44	Community Microgrids	Strengthening	2029-2039	TV5	TR1; TR3		EN1; EN2; EN4
2034.8	Light from Graphene	Strengthening	2028-2040		TR1; TR3		EN4
2034.82	Artificial Intelligence's Third Wave	Strengthening	2028-2040				
2035.04	Forest Towns	Strengthening	2029-2040	TV5	TR1; TR2		EN4
2035.07	Climate Change and Energy Systems	Strengthening	2029-2041		TR1; TR3		EN1
2035.2	Enhanced Soldiers	Wild card	2029-2041	TV2		HE1; HE2	
2035.41	Downloading the Human Brain	Wild card	2065-2075				NRJ
2035.43	Lifelogging	Wild card	2028-2040	TV4		HE; HE2	
2035.49	Robotic Deep-Sea Mining	Wild card	2029-2041		TR1; TR2; TR3		EN4
2035.52	High-Tech Ecovillages	Strengthening	2028-2040	TV3; TV4; TV5			NRJ
2035.53	Artificial Creativity	Strengthening	2029-2039	TV4		HE4	
2035.61	Uninhabitable Hothouse Earth	Wild card	2085-2095				NRJ
2035.62	Self-Healing Robots	Strengthening	2028-2040		TR2		
2035.71	Controlling Machines with Thoughts	Wild card	2055-2065	TV4		HE2	
2035.78	E-Work Visas and E-Residency	Strengthening	2021-2024				
2035.84	Super Hurricanes	Wild card	2045-2055				
2035.91	Programmers Out of Work	Wild card	2028-2040	TV3			
2036.49	Acoustic Levitation	Weak signal	2020-2023		TR3		NRJ
2037.59	Global Brain	Wild card	2040-2120	TV3; TV4		HE2	
2037.69	Global Famine	Wild card	2040-2120				
2051.32	Doubling the Number of Buildings	Strengthening	2040-2120	TV4			EN1; EN4
2021.11_Bis	Financial Technology	Strengthening	2020-2023	TV1; TV2; TV3; TV4; TV5			

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2021.17_Bis	Adaptability and Modifiability	Strengthening	2020-2023				
2021.19_Bis	Young Retirees	Weak signal	2020-2023	TV2; TV3			
2021.3_Bis	Superficial Positivity	Weak signal	2020-2023				
2021.35_Bis	Immigration Disputes	Strengthening	2020-2023				
2021.37_Bis	Pollinators	Weakening	2020-2023				
2021.47_Bis	Major War in the Middle East	Wild card	2020-2023				NRJ
2021.49_Bis	Industrial Internet	Strengthening	2020-2023	TV4; TV5	TR2		NRJ
2021.5_Bis	Point Clouds & LiDAR	Strengthening	2021-2024	TV4	TR1; TR2; TR3		
2021.57_Bis	Platform Economy	Strengthening	2020-2023	TV4	TR4		
2021.59_Bis	Hyped for Nothing	Strengthening	2020-2023		TR1; TR3		EN4
2021.6_Bis	Populism	Strengthening	2020-2023				
2021.6_Ter	Malfunctioning Communication	Weak signal	2020-2023	TV4			
2021.61_Bis	Screen-Blocking Glasses	Weak signal	2020-2023	TV5			
2021.62_Bis	Construction Search Engine	Weak signal	2020-2023	TV4			
2021.64_Bis	Personal Finance Apps	Strengthening	2020-2023	TV1; TV3; TV4			
2021.64_Ter	Invisible Online Surveillance	Strengthening	2020-2023				
2021.66_Bis	Ethics of AI	Strengthening	2020-2023	TV4	TR2		
2021.67_Bis	Era of Elites	Weakening	2020-2023				
2021.7_Bis	International Competition	Strengthening	2020-2023				NRJ
2021.73_Bis	New Payment Methods	Strengthening	2020-2023	TV2; TV3; TV5			
2021.74_Bis	Apps for Socially Responsible Investment	Weak signal	2020-2023				
2021.83_Bis	CO_2 to Fuel through Solar Power	Weak signal	2020-2023		TRA		EN3; EN4
2021.84_Bis	Sharing Economy	Strengthening	2020-2023	TV2; TV4	TR4		

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2021.84_Ter	Straddling Bus	Weak signal	2020-2023		TRA		
2021.9_Bis	Ageing China	Strengthening	2029-2041				
2021.91_Bis	Deepfake Videos	Strengthening	2021-2024	TV2; TV3; TV4			
2021.93_Bis	Real-Time Translation Software	Strengthening	2020-2023	TV4			
2021.95_Bis	Haptic VR Controllers	Strengthening	2023-2028		TR2		
2021.99_Bis	Semantic Web	Weakening	2020-2023	TV3; TV4			
2021.99_Ter	Digital Real Estate Business	Strengthening	2020-2023	TV3; TV4; TV5			EN4
2022.07_Bis	Sharing as Work and Culture	Strengthening	2020-2023	TV2; TV4			
2022.09_Bis	Luxury Camping	Strengthening	2020-2023				
2022.1_Bis	Slowbalisation	Strengthening	2020-2023				
2022.11_Bis	Drone Terrorist Attacks	Strengthening	2020-2023	TV2			NRJ
2022.13_Bis	Facial Recognition Filter	Weak signal	2020-2023	TV4			
2022.15_Bis	Arab-Israeli Normalisation of Relations	Strengthening	2021-2024				
2022.16_Bis	Rise of Nationalism	Strengthening	2020-2023				
2022.26_Bis	AI That Writes Itself	Weak signal	2020-2023		TR2		
2022.27_Bis	Nature and Food as Remedies	Strengthening	2020-2023				
2022.27_Ter	Dialogue-Based Knowledge	Strengthening	2020-2023	TV4; TV5			NRJ
2022.33_Bis	Polymorphic Encryption	Weak signal	2020-2023	TV1; TV2; TV3; TV4	TR2		NRJ
2022.34_Bis	Birth Rates	Weakening	2020-2023				
2022.36_Bis	Edge Computing	Strengthening	2020-2023	TV3; TV4; TV5	TR2		EN5
2022.47_Bis	Animal-Free Dairy Products	Strengthening	2020-2023				
2022.51_Bis	Wonder Substance Borophene	Weak signal	2020-2023		TR1; TR3		NRJ

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2022.54_Bis	Quantum State Teleportation	Weak signal	2020-2023	TV1; TV2; TV3; TV4	TR2		EN5
2022.56_Bis	Rule of Law	Weakening	2020-2023				
2022.56_Ter	Pokemon Go Mania	Weakening	2020-2023				
2022.57_Bis	Alienated Young Men	Strengthening	2020-2023	TV2			
2022.59_Bis	Attention Economy	Strengthening	2020-2023	TV4			
2022.61_Bis	Northern Lights and Arctic Area Tourism	Strengthening	2020-2023	TV5			NRJ
2022.61_Quater	Target Price Contract for Building Construction	Weak signal	2020-2023				
2022.61_Ter	Natural Resources of Afghanistan	Weak signal	2020-2023				
2022.62_Bis	Clash of Social Bubbles	Wild card	2020-2023	TV2; TV4			
2022.66_Bis	Health & Wellness Coaching	Weak signal	2020-2023	TV4			
2022.66_Ter	Big Five Dominance (GAFAM)	Strengthening	2020-2023	TV1; TV4; TV5			
2022.7_Bis	Life-Long Learning	Strengthening	2020-2023				
2022.7_Ter	SpiNNAker Supercomputer	Weak signal	2020-2023	TV3; TV4			EN5
2022.71_Bis	Social Burnout	Strengthening	2020-2023	TV4			
2022.74_Bis	California's Mass Exodus	Wild card	2024-2029				NRJ
2022.83_Bis	Teaching and Learning 2.0	Strengthening	2020-2023	TV4			
2022.86_Bis	Censorship of Historical Productions	Strengthening	2020-2023				
2022.95_Bis	Values & Ethics	Summary	2020-2040	TV4			NRJ
2022_Bis	Multidisciplinary Artists	Strengthening	2020-2023	TV4			
2023.01_Bis	Tires for Flying Cars	Weak signal	2020-2023		TR3		
2023.34_Bis	3D Printing with Light	Weak signal	2020-2023				
2023.41_Bis	Crowdsource Your Health	Strengthening	2024-2028	TV4			

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2023.52_Bis	Gamification of Health and Wellness	Strengthening	2020-2023	TV3; TV4			
2023.56_Bis	Middle Class in Asia	Strengthening	2024-2029				
2023.61_Bis	Worsening US-EU Relations	Wild card	2023-2028				
2023.68_Bis	Gut Bacteria Affects Mood	Weak signal	2020-2023				
2023.68_Ter	Sex Robots	Strengthening	2024-2028	TV2			
2023.72_Bis	Separate Monitors	Weakening	2024-2028	TV4; TV5			
2023.74_Ter	Extended Reality VR / AR	Summary	2020-2040	TV4; TV5			
2023.78_Bis	Food	Summary	2020-2040				NRJ
2023.86_Bis	Telediagnostics & Remote Maintenance & Remote Upkeep	Strengthening	2024-2028	TV4; TV5	TR1		NRJ
2023.91_Bis	Social Media Money Transfers	Strengthening	2024-2028	TV3; TV4; TV5			
2023.95_Bis	Significance of Design	Strengthening	2023-2028				
2023.97_Bis	Need for Regional-Level Expertise	Weakening	2024-2028	TV1; TV4			
2024.01_Bis	Digital Humanities	Strengthening	2024-2028	TV3; TV4			NRJ
2024.01_Ter	VR Cameras	Strengthening	2023-2028	TV4			
2024.05_Bis	Roommate Tinder	Weak signal	2020-2023				
2024.05_Ter	Zero-Emission Data Centres	Strengthening	2024-2029	TV4; TV5			EN4; EN5
2024.07_bis	Animal Rights	Strengthening	2024-2028				
2024.26_Bis	Sustainability & Recycling	Summary	2020-2040				NRJ
2024.41_Bis	From Stores to Showrooms	Strengthening	2024-2028				
2024.42_Bis	China's Car Market	Strengthening	2024-2028		TR1; TR2		NRJ
2024.42_Ter	AI Beauty	Strengthening	2024-2028	TV1; TV4			
2024.51_Bis	Antibiotic Resistance	Strengthening	2024-2028				

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2024.55_Bis	Global Economy	Summary	2020-2040	TV3			
2024.57_Bis	Education & Knowledge	Summary	2020-2040	TV4; TV5			EN5
2024.6_Bis	Need for the Culture of Preparedness	Strengthening	2024-2028				
2024.7_Bis	Digitalisation of Legal Work	Strengthening	2024-2029				
2024.76_Bis	AI & Robot Music	Strengthening	2024-2028	TV3			
2024.77_Bis	Neo-Generalists	Strengthening	2024-2028	TV4			
2024.77_Ter	Passwords	Weakening	2024-2028	TV2; TV3			
2024.81_Bis	Identify Everything	Strengthening	2023-2028	TV4	TR2		NRJ
2024.86_Bis	State of Emergency Becoming the New Normal	Strengthening	2020-2023				
2024.89_Bis	Smart Helmets	Strengthening	2024-2028	TV4; TV5	TRA		NRJ
2024.89_Quater	Copyright	Weakening	2024-2028	TV4			
2024.89_Ter	Crowdsourcing	Strengthening	2024-2028	TV4	TR2		
2024.91_Bis	Hyperspectral Food Quality	Strengthening	2024-2028				
2024.93_Bis	Augmented Urban Reality	Strengthening	2024-2028				
2024.93_Ter	Robot Chef	Strengthening	2024-2028	TV4; TV5			
2024.94_Bis	Industry & Manufacturing	Summary	2020-2040	TV2; TV3; TV4			NRJ
2025.02_bis	Retail in Brick and Mortar Stores	Weakening	2024-2028	TV1; TV4; TV5			
2025.16_Bis	Adapted Ethnicity	Strengthening	2023-2028	TV4; TV5			NRJ
2025.17_Bis	Liberal Democracy	Weakening	2024-2028				
2025.17_Ter	Finance & Ownership	Summary	2020-2040	TV3; TV4; TV5			
2025.18_Bis	World's Smallest Camera	Weak signal	2020-2023	TV4			NRJ
2025.19_Bis	Population	Summary	2020-2040	TV4			EN2

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2025.24_Bis	Plant-Based Diets in Latin America	Strengthening	2024-2029				
2025.3_Bis	Ageing World Population	Strengthening	2028-2040				
2025.37_Bis	Scottish Independence	Wild card	2024-2028	TV4			NRJ
2025.37_Ter	Increasing Religiousness	Wild card	2024-2028	TV4			
2025.39_Bis	New Democracy	Strengthening	2024-2028	TV4			
2025.39_Quater	Management & HR	Summary	2020-2040				
2025.39_Ter	CRISPR	Strengthening	2024-2028			HE3	
2025.45_Bis	BRICS Countries	Strengthening	2023-2028				NRJ
2025.5_Bis	Industry Disruptors	Strengthening	2024-2028	TV1; TV3; TV5	TR2		
2025.51_Bis	Surface Media	Strengthening	2023-2028	TV4	TRA		
2025.56_Bis	Better World	Strengthening	2024-2028	TV4			
2025.56_Ter	Smartphone Era	Weakening	2024-2029	TV4		HE2	
2025.6_Bis	Return of Heavy Industry	Wild card	2024-2029	TV4	TR1; TR3		NRJ
2025.62_Bis	Smart Packaging	Strengthening	2024-2028	TV3			
2025.63_Bis	Dark Web	Strengthening	2024-2028	TV2; TV3; TV5			
2025.64_Bis	War in Europe	Wild card	2024-2028				
2025.65_Bis	Importance of Significance	Strengthening	2024-2028	TV5			NRJ
2025.65_Ter	Data Centre Expansion	Strengthening	2024-2029	TV3; TV4; TV5	TR2		NRJ
2025.71_Bis	Carbon Farming and Emission Trading	Strengthening	2024-2029				NRJ
2025.72_Bis	Artificial & Robot Co-Workers	Strengthening	2024-2028	TV4			
2025.73_Bis	Health & Wellbeing	Summary	2020-2040			HE; HE3	NRJ
2025.74_Bis	Virtual Influencers?	Strengthening	2024-2028	TV4			

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2025.85_Bis	Cybercrime in Latin America	Strengthening	2024-2029	TV2; TV3; TV5	TR2		NRJ
2025.87_Bis	Collapse of the Dollar	Wild card	2023-2028				
2025.88_Bis	Nature	Summary	2020-2040				NRJ
2025.97_Bis	Return of the Zeppelin	Strengthening	2024-2028	TV2	TR3		NRJ
2025.97_Ter	Wellbeing Centres	Strengthening	2024-2028				
2025.98_Bis	Nation within a Nation	Strengthening	2024-2028				
2025.99_Bis	Blockchain Revolution	Strengthening	2023-2028	TV3; TV4; TV5	TR2		
2025.99_Ter	Concentration of Wealth	Strengthening	2024-2028				
2026.01_Bis	Change of Expertise	Strengthening	2024-2028	TV3; TV4			
2026.02_Bis	Importance of Religion in Arab Countries	Weakening	2024-2028				
2026.04_Bis	Work & Income	Summary	2020-2040	TV3			NRJ
2026.05_Bis	Collapse of Eurozone	Wild card	2024-2028	TV4			
2026.07_Bis	Alien Impact on Earth	Wild card	2023-2099				NRJ
2026.1_Bis	Rise of Global Oligarchs	Wild card	2024-2028				
2026.14_Bis	Capitalism in Crisis	Strengthening	2024-2028				
2026.16_Bis	Augmented Reality	Strengthening	2024-2028	TV1			
2026.17_Bis	Robotics and Automation	Strengthening	2023-2028		TR2		
2026.17_Ter	Liberal Individualism	Strengthening	2024-2028	TV4			
2026.19_Bis	Working Poor in Sharing Economy	Strengthening	2024-2028				
2026.19_Ter	Growing Inequality in the Labour Market	Strengthening	2024-2029				
2026.2_Bis	Cleantech Revolution of China	Strengthening	2024-2028	TV1	TR1		NRJ
2026.21_Bis	Superbus	Weak signal	2020-2023		TRA		
2026.22_Bis	Powered Exoskeleton	Strengthening	2024-2028	TV5		HE1	EN4

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2026.22_Quater	Construction & Urbanisation	Summary	2020-2040	TV4	TR2		NRJ
2026.22_Quinquies	Climate Change and North American Economy	Strengthening	2029-2041		TRA		EN4
2026.22_Ter	Web 3.0	Strengthening	2023-2028	TV3; TV4; TV5			
2026.24_Bis	Vegetarian Areas	Strengthening	2024-2028				
2026.25_Bis	Hobbit Eco-Houses	Weak signal	2020-2023				NRJ
2026.3_Bis	Distributed Ledger Technologies (DLT)	Strengthening	2023-2028	TV2; TV3	TR4		
2026.33_Bis	Personalised Medicine	Strengthening	2024-2028				
2026.33_Ter	Open Source	Strengthening	2024-2028	TV3; TV4			
2026.35_Bis	Gold-Backed Currency	Wild card	2024-2028	TV3; TV4; TV5			
2026.39_Bis	Migrant and Refugee Crisis	Strengthening	2024-2029	TV4			
2026.43_Bis	Schools without Teachers	Wild card	2024-2028				
2026.46_Bis	Youth Bulge	Strengthening	2024-2028				
2026.69_Bis	Road Traffic as Software	Strengthening	2028-2040		TR2		
2026.78_Bis	Tightening Geopolitical Competition	Wild card	2023-2028				NRJ
2026.78_Ter	Sciences & Research	Summary	2020-2040	TV3	TRA		NRJ
2026.94_Bis	Smart Grids	Strengthening	2024-2028	TV5	TR1; TR3		EN2; EN4
2026.96_Bis	Swarm Printing	Strengthening	2023-2028		TR2		
2026_Bis	Cashless Societies	Strengthening	2029-2041	TV4; TV5			
2027.33_Bis	Manipulated Taste Experience	Strengthening	2023-2028	TV4			
2027.89_Bis	Artificial Alcohol	Wild card	2024-2028				
2027.89_Ter	Diseases of Affluence	Strengthening	2021-2024				
2028.83_Bis	Precision Care	Strengthening	2029-2039				

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2030.82_Bis	Perfect Baby	Wild card	2045-2055			HE3	
2031.13_Bis	Internet of Everything (IoE)	Strengthening	2029-2039	TV2; TV4; TV5	TRA		NRJ
2031.99_Bis	3D-Printed Houses	Strengthening	2029-2040	TV4; TV5			NRJ
2032.06_Ter	Beating Death Itself	Wild card	2065-2075				
2032.07_Bis	Ecoskyscrapers Built from Recycled Material	Wild card	2029-2039				NRJ
2032.18_Bis	Dataism as a New Religion	Wild card	2065-2075	TV2; TV4; TV5			
2032.42_Bis	Privacy Invasion 24/7	Wild card	2029-2039	TV4; TV5			
2032.52_Bis	Underwater Life	Wild card	2040-2120				NRJ
2032.59_Bis	Automated Health Spaces	Wild card	2029-2039	TV4			
2032.71_Bis	Graphene Revolution	Strengthening	2029-2039	TV3	TR1; TR3		NRJ
2032.72_Ter	Global Citizenship	Strengthening	2029-2039				
2032.75_Bis	World Population Growth	Strengthening	2029-2039	TV4			
2032.77_Bis	Use of Fossil Fuels	Weakening	2029-2039		TRA		EN1; EN3
2033.44_Bis	Widespread Web Addiction	Strengthening	2029-2039	TV4; TV5			
2034.14_Bis	Rise of Liberal Arts	Wild card	2029-2039				
2034.8_Bis	Virtual Reality	Strengthening	2029-2039				
2035.04_Bis	School as a Mega Corporation	Wild card	2028-2040				
XXXX.XX	San Francisco Bay Area Population	Strengthening	2029-2041				
YYYY.YY	Amazon Rainforest Destruction	Strengthening	2024-2029				
ZZZZ.ZZ	Nigerian Population Growth	Strengthening	2041-2051				NRJ

Source: Authors, based on Futures Platform content.

Annex 3. Supplementary information for the energy theme

By Alain Marmier (JRC.C.7).

Annex 3.1. Approach for the allocation of Futures Platform phenomena to energy topics

This section describes the approach followed for the text-mining of the phenomena description with keywords (strings of characters) related to the given energy topics:

1. Specific keywords are searched into the text for each topic (e.g., 'esilien', 'system', 'architecture' and 'infrastructure' for 'resilient energy systems').
2. The sentences containing the keywords are retrieved and collated.
3. The result of the text mining is formatted in a matrix. This matrix has the 712 phenomena as rows and a column for each keyword. The cells (intersecting phenomena and keywords) are either empty (when the keyword cannot be found in the phenomena description) or contains sentences of the phenomena description bearing the keywords.
4. The matrix is then manually reviewed to exclude false positive.
5. The matrix is duplicated to keep trace of the original mining.
6. On the copy, the content is treated per column, first filtering blank cells out.
7. The content is then read and off topic content (eventually referring to the phenomenon description, background or impact to capture the context) is deleted.
8. Phenomena / lines with 'on topic' content may be highlighted, flagging the relevance of these lines for the next keywords/columns.
9. Once reaching the bottom of the column, the process is repeated with another keyword/column.
10. Once all the columns/keywords are processed, the relevant phenomena are aggregated at topic level, as displayed in Annex 2 and on the network graphs.

Disclaimer: Over 80 keywords were used to text-mine various aspects in the phenomena descriptions. This list is not exhaustive, allowing specific phenomena to escape the text-mining and the referencing to the energy system, e.g., keyword 'vulnerability' may enhance the search for resilient energy system, while keywords referring to electric voltage or current (e.g., volt, ampere, KV) could enhance the mapping of phenomena referring to the different scales of the energy system.

Resilient energy systems (EN1)

For this topic, the following keywords are text-mined: 'esilien', 'system', 'architecture' and 'infrastructure'. The objective here is to focus on 'energy' systems, architectures and infrastructures, which is at the core of phenomenon 'climate change and energy systems' [2035.07].

For the sake of this pilot, this topic focuses on 'energy' systems, architectures and infrastructures. However any systems, architectures and infrastructures requires energy. Therefore this exercise could be enhanced by looking such 'other' resilient systems, architectures and infrastructures and their energy needs.

(De)centralised/distributed energy systems (EN2)

For this topic, 'central' and 'distribute' are text-mined. Phenomenon 'smart grids' [2026.94_Bis] highlights the concept of a decentralised (smart) grid, in which the delivery of electricity between producers and consumers flows in two directions. Further phenomenon 'smart and connected countryside' [2027.2] presents the distributed generation (DG) concept, resulting from an increased the use of renewable sources.

Energy sources (EN3)

The list of keywords, text-mined for this topic, is the result of iterations:

1. In a first instance, the following keywords are mined: 'energ', 'renewable', 'power', 'efficien', 'electri', 'acoustic', 'cinematic', ' heat', ' therm', 'atom', 'magnetic', 'mechanic'.
2. Looking into the results of this mining, the following keywords are extracted and mined: 'brine water', 'algae', 'seaweed', 'body heat', 'heat', 'kinetic energy', 'anaerobic digestion', 'electricity from', 'kinetic', 'microbial fuel cell', 'fuel cell', 'photosynthesis', 'synthesis', 'thermoelectric', 'piezoelectric', 'energy harvest', 'capacitor', 'waste', 'formic', 'metallic hydrogen', 'hydrogen', 'methan', 'ammonia', 'ethanol',

'dimethyl', 'gas', 'oil', 'coal', 'LPG', 'diesel', 'fossil fuel', 'thorium', 'uranium', 'fusion', 'nuclear', 'wind', 'solar', 'geothermal', 'biomass', 'biogas', 'biofuel', 'bioenergy', 'ocean energy', 'tidal power', 'tidal lagoon', 'tidal', 'hydropower', 'hydroelectric', 'energy storage', 'energy mass storage', 'water reservoir', 'batter', 'thermal energy storage', 'electrochemical energy storage', 'magnetic energy storage'.

Annex 3.2 (below) displays all phenomena referencing the keywords of the latter list. The table below only lists phenomena which focus on primary energy sources, energy vectors or energy supply technologies.

Table 1. Phenomena focused on primary energy sources, energy vectors or energy supply technologies.

JRC_ID	Phenomena Title	JRC_ID	Phenomena Title
2021	Luminous Pathways	2026.2	Piezoelectricity
2022	Formic Acid Fuel	2026.35	Seaweed Potential
2022	Rectenna Solar Cells	2026.43	Algae Power
2022.4	Solar Panel Windows	2026.45	Storing Solar Energy in Liquid
2022.5	Electricity-Producing Bacteria	2026.59	Hydroelectric Power
2022.9	Use of Wind Power	2026.85	Hydrogen Economy
2023.3	Body-Heat Harvesting Wearables	2026.98	Perovskite Solar Panels
2024.6	Biofuels	2027.07	Thorium Power Plants
2024.7	Solar Roof	2027.1	Floating Food and Energy Production
2024.9	Geothermal Energy	2027.33	Fuel Switching
2025.2	Energy	2031.86	Solar Satellites
2025.5	Solar Power	2032.46	Fusion Power – Helium 3
2025.5	Synthetic Fuels	2032.75	Solar Panel Roads
2026	Forestation	2033.91	Artificial Photosynthesis
2026	Small Nuclear Power Plants	2021.83_Bis	CO2 to Fuel through Solar Power
2026.2	Thermoelectric Generator	2032.77_Bis	Use of Fossil Fuels

Source: Authors, based on Futures Platform content.

Scales of energy (EN4)

For this topic, keywords 'scal' and 'watt' are text-mined. Phenomenon 'molecular machines' [2023.02] flags a news item on the development of a nano-scale motor powered by near-infrared light. At the opposite end of the spectrum, phenomenon 'small nuclear power plants' [2026] recalls the ongoing developments of modular nuclear reactors, of 100th of megawatts.

Energy in itself has no purpose. Once consumed however it can fulfil human needs. There is thus the need to align energy sources, with energy demand. The digital sector, providing for numerous human needs, is thus at the intersection.

New chip technologies (EN5)

Keyword 'comput' is used to identify phenomena for this topic: The digital world consumes an ever-increasing amount of energy: By 2030, Nature estimates the total ICT energy demand will be between 8 and 21% of all electricity consumed ['cloud computing', 2023.86]. Computing power accounts for a fair share and is poised to further increase, though limited by current (transistor-based) technology. Alternative technologies - based on quantum mechanics, DNA, brain emulation, nano-sized solutions, or structurally and functionally more advanced transistor-based microchips - are in development. Additionally, alternative architectures such as for example cloud computing, could also provide a solution ['exponential times', 2032.62]. And these improvements are not limited to 'crunching numbers': Fast, energy-efficient, future computing systems uses light instead of electrons to process and store information ['spinnaker supercomputer', 2022.7_Ter], thereby possibly impacting further the energy system.

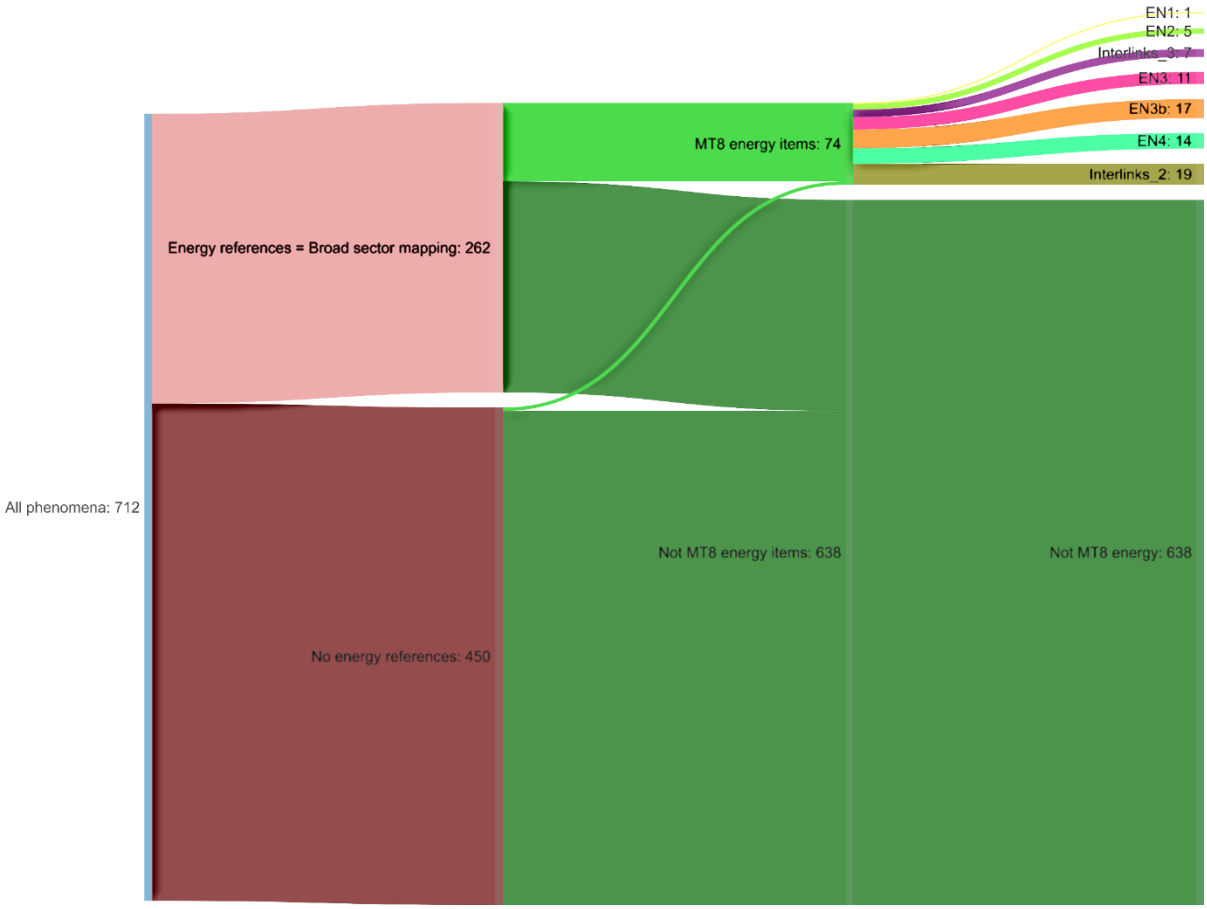
As indicated in 3.3, three of the relevant phenomena do not bear explicit reference to the energy system. On one hand, this may hint at – still to be established – consequences of these developments on the energy system. On the other hand, this observation justifies the investigation, beyond 'energy' systems, architectures and infrastructures, of 'other' systems, architectures and infrastructures, as suggested in 'resilient energy systems' above: Such (exogenous) systems, powered by energy, do impact the energy system.

Annex 3.2. Broader analysis of phenomena relevance to the topics to which there are allocated

This section looks deeper into the phenomena referencing each topic. To this end connections, readily present in the phenomena description of Futures Platform with the energy topics investigated in this report, are presented below.

As mentioned in Section 3.3.2, 71 core phenomena are allocated to one or more specific energy topics, together with three phenomena, deemed not energy relevant though of relevance to topic EN5 'new chip technology', as shown in the second coloured column of the Sankey diagram (**Figure 53**). Of these 74 unique phenomena, 19 are allocated to two topics and seven to three topics, as shown in the third coloured column of the Sankey diagram (**Figure 53**).

Figure 53. Futures Platform phenomena of relevance to energy topics investigated in this report



Source: Authors, based on Futures Platform material.

Resilient energy systems (EN1)

Resilience of energy systems is at the core of phenomena 'Climate Change and Energy Systems' [2035.07], in which climate change is expected to drive extreme weather events, challenging energy systems. This phenomenon relates to two scenarios, in which actions towards more resilient energy systems are undertaken. Scenario 1 assumes a global response and a strong implementation, while scenario 2 considers geographical disparities depending on risk exposure.

This latter approach is already evidenced in news items noting ongoing developments towards resilience energy systems at small scale ['community microgrids', 2034.44 and 'microgrids', 2031.44]. More in detail, grid resilience could benefit from the introduction of grid-scale batteries, stimulating a transition to net-zero electrical generation ['use of fossil fuels', 2032.77_Bis].

In addition to grids, investing in other infrastructures may improve the resilience of the energy system: investments in the building sector mitigates emissions but also enhances resilience against the effects of climate change ['doubling the number of buildings', 2051.32].

(De)centralised energy systems (EN2)

At the core of the 'smart grids' phenomena [2026.94_Bis] lays the paradigm shift in grid operation: from unidirectional to bidirectional electricity transmission and distribution. This shift enables the decentralisation of electricity production.

Coupled with this development, the recent increase in the use of renewable sources in electrical systems has transformed the electrical distribution network with the subsequent implementation of the distributed generation concept ['smart and connected countryside', 2027.2; 'use of wind power', 2022.93].

This however challenges the management of the power distribution system, calling for automation systems ['cleantech', 2024.57]. The need for control is also important for microgrids, electric systems that can operate independently from the central energy grid ['community microgrids', 2034.44].

Distributed energy can then power microgrids at municipality level ['community microgrids', 2034.44] or reach higher installed capacity and geographic coverage ['population', 2025.19_Bis; 'energy', 2025.15].

This diversity in scale enables the use of alternative energy sources, such as:

— 'Decentralized anaerobic co-digestion for the treatment of municipal organic waste with energy recovery' ['dumps to mines', 2021.25].

— Or mixed of central and decentralised systems: The bioliq® process consists of decentralized pretreatment by fast pyrolysis plants for biomass energy densification, and of a central gasification and synthesis step for synthesis of gas and synthetic fuel production ['synthetic fuels', 2025.54].

Energy sources (EN3)

Primary energy source, energy vector or renewable energy sources: Futures Platform provides plethora of phenomena centred on energy supply. Phenomena 'energy' [2025.15] looks at the future of the energy system in detail. In short:

— Global energy consumption has more than doubled in the past 50 years, and will further grow.

— On longer term, the supply of energy production will diversify.

— According to an assessment from Stanford University, renewable energy sources could potentially cover up to 80% of the world's energy consumption by 2030 and 100% by 2050.

Fossil fuel resources, such as oil, natural gas and coal have proved to be much larger than previously estimated, and their prices have remained at a very competitive level ['use of fossil fuels', 2032.77_Bis].

As industries need to replace carbon-intensive fossil fuels with cleaner alternatives to meet decarbonisation requirements, fuel switching will become increasingly widespread in the coming years ['fuel switching', 2027.33].

Synthetic fuels can be produced from various carbon sources and are similar to fossil fuels in terms of volume and energy density, meaning that they can easily replace existing fuels in engines without major infrastructural changes. Thus, synthetic fuels can be a sustainable alternative for cars with combustion engines as well as in aviation, maritime and heavy-freight industries, where full-scale adoption of electrification is not technically feasible ['synthetic fuels', 2025.54].

Among synthetic fuels, hydrogen has the potential to replace liquid fuels for vehicles as well as heating systems and replace batteries as the primary form of energy storage ['hydrogen economy', 2026.85]. A new process increases energy conversion efficiency for the production of liquid formic acid fuels ['formic acid fuel', 2022]. This process captures carbon dioxide for the production of fuel, sharing this objective with a Finish a pilot project, powered by solar energy ['CO_2 to fuel through solar power', 2021.83_Bis]. As such, this technology exemplify the concept of artificial photosynthesis, a concept that mimics one of nature's most powerful phenomena solves two issues at once: it inexhaustibly creates pure energy while capturing carbon dioxide from the atmosphere ['artificial photosynthesis', 2033.91]. This enables the long-term storage of solar energy in (alternative) liquid fuels ['storing solar energy in liquid', 2026.45].

The sun is our prime source of energy, either transformed and consumed instantly as electricity or stored in various forms:

— Solar power is rapidly gaining popularity ['solar power', 2025.45]. And prospects are bright, with several avenues to decrease costs: Perovskite is a mineral which can be found abundantly on the planet. Recently, this material has emerged as the future alternative to conventional silicon solar cells ['perovskite solar

panels', 2026.98]; A solar roof consists of roof tiles acting as solar cells and a Powerwall-battery which is used to store the generated electricity ['solar roof', 2024.66]; Integration of completely see-through or semi-transparent solar cells into window glass is now on track to possibly transform architecture and electricity production ['solar panel windows', 2022.36]; Testing for using solar panels as surface material for roads, streets, and parking lots is underway ['solar panel roads', 2032.75]; It is possible that solar panels installed on satellites will meet most of the future energy needs ['solar satellites', 2031.86].

— Wind power is emerging as one of the cheapest ways to generate energy ['use of wind power', 2022.93].

— Geothermal energy, tapping on earth heat, can be used for both heating and electricity production ['geothermal energy', 2024.89].

— Hydroelectric power is based on utilizing water's kinetic energy, and it is one of the oldest known ways of producing energy ['hydroelectric power', 2026.59]. Hydropower also serves as an energy storage option.

— Ongoing efforts to increase forest coverage support the production of raw materials in the form of biomass ['forestation', 2025.98]. The raw material can be used either directly by burning or it can be further processed into other materials, such as motor fuels ['biofuels', 2024.6]. While other ocean and tidal energy technologies are not the subject of a dedicated phenomenon, the seas are expected to provide bioenergy in the form of algae or seaweed ['algae power', 2026.43; 'seaweed potential', 2026.35].

With awareness raising around the climate emergency, nuclear energy is positioned as a decarbonised source of energy possibly available 'en masse', from the short to the longest time horizons:

— Several concepts of small nuclear reactors are under development, with powers varying from a few dozens of megawatts to 300 megawatts. This range is enough to meet the energy needs of a medium-sized city. These designs enable plants to be made ready at a factory and transported as one piece on a lorry, thereby driving price down ['small nuclear power plants', 2026].

— Besides uranium fuel scheme, designs relying on thorium are also under investigations ['thorium power plants', 2027.07.

— Last, relying on abundant elements, fusion power could fill all the humanity's energy needs without causing pollution or sparking any worries of resources running out. With the timescale of commercial energy production by 2040, UK's proposal is so far one of the most ambitious among the national-scale projects ['fusion power – Helium 3', 2032.46].

Whether powered by renewable energy or nuclear, floating constructions may integrate food and energy production in the future, co-producing both more environmentally friendly, efficiently and locally ['floating food and energy production, 2027.1]. Similar integration of power demand and supply are multiplying:

— Luminous road surfaces enable advancements in traffic safety without the need for separate street lights or power sources ['luminous pathways', 2021.04].

— New, carbon-based thermoelectric materials can convert heat into electricity, and flexible, 3D-printed thermoelectric generators can also withstand heavy use. Wearable technology, medical technology and the Internet of Things offer multiple solutions for utilising this technology ['body-heat harvesting wearables', 2023.34; 'thermoelectric generator', 2026.16].

From niche applications to potential major disruption, new and emerging energy technologies are under development:

— Utilizing electricity-producing bacteria ['electricity-producing bacteria', 2022.49].

— Converting pressure or mechanical stress in piezoelectricity ['piezoelectricity', 2026.2].

— Converting light through rectenna (rectifying antenna), possibly replacing present-day solar cells. ['rectenna solar cells', 2022.01].

Scales of energy (EN4)

Plethora of phenomena provide indications of the power sizing of various products:

— A thermoelectronic textile can produce a small amount of electricity when the textile is heated on one side, for example by a person's body heat - typically 0.2 microwatt at a temperature difference of 37 degrees Celsius ['wood-based textiles', 2025.75].

— The use of an exoskeleton that strategically removes kinetic energy during the swing period of the gait cycle reduces the metabolic cost of walking by 2.5 ± 0.8% for healthy male users while converting the removed energy into 0.25 ± 0.02 watts of electrical power ['powered exoskeleton', 2026.22_Bis].

— Low-power wireless chargers with under 100 watts power are among the most popular options ['wireless power transmission', 2022.62].

— The PEM fuel cells, of a Hybrid Power Systems Based on Photovoltaic, Wind, Electrolyzer, and PEM Fuel Cells, were analysed and designed to cover the electricity demand in the Bahr AL-Najaf region of 1.5 MW ['use of wind power', 2022.93].

— 150-kilowatt-hour battery pack (and a next-generation battery-swapping system) will be rolled out in 2022 ['forever rechargeable battery', 2032.88].

— First floating solar plant in Albania starts commercial operations: The first unit, comprising 1536 solar panels, has an installed capacity of 0.5 MWp. Additional three floating units will be installed in 2021, with a combined additional capacity of 1.5 MWp ['floating food and energy production', 2027.1].

— Florida's largest Tesla Solar Roof is a giant 44-kilowatt installation ['solar roof', 2024.66].

— The largest wind turbines on the market are expected to grow in size to up to 300 metres and be able to produce 15 megawatts by 2024 ['use of wind power', 2022.93].

— The power of one small reactor varies from a few dozens of megawatts to 300 megawatts, which is enough to meet the energy needs of a medium-sized city ['small nuclear power plants', 2026].

— A new pre-feasibility study exploring the potential application of carbon dioxide (CO_2) capture on 750-megawatt coal-fired power plants ['CO_2 capture and repurposing', 2028.85].

— The three hydroelectric plants EDP Energias do Brasil put up for sale. The plants are located in the Brazilian states of Espirito Santo and Amapa, with a total capacity of 800 megawatts ['hydroelectric power', 2026.59].

— Manhattan Solar Partners plans to build crypto data centres utilizing over a gigawatt of renewable energy in Texas ['zero-emission data centres', 2024.05_Ter].

— Voltus, Inc., the leading distributed energy resource (DER) platform, announces today that it will provide over 2,000 megawatts (MWs) of DERs to the North American electric grid this summer ['energy', 2025.15].

In many cases, **the power of technologies** can vary, as already evidenced by the SMR above: hydroelectric power may become a much more popular large-scale as well as small-scale power solution ['hydroelectric power', 2026.59]. Yet, besides power, 'scale' entails different notions when it comes to energy technologies:

It may be a reference to the geometrical dimension of product: scientists are developing a nano-scale motor for molecular machines, to be powered by near-infrared light ['molecular machines', 2023.02].

It may also refer to the scalability of the production process, for instance when it comes to the sustainable production of formic acid ['formic acid fuel', 2022] or solar panel window production ['solar panel windows', 2022.36].

Further, scale may refer to a geographical zone of application:

— Grids can operate at facility ['microgrids', 2031.44] or at large-scale industry level ['community microgrids', 2034.44].

— Energy storage may be rolled-out at utility-scale level ['out of batteries', 2030.79].

— While the evaluation of wind power technical potential is performed at the national scale ['use of wind power', 2022.93].

Last, some phenomena hint at the (potential) scale or scalability of the market: A large-scale utilization of the waste energy created by pressure, voltage and temperature differences, through the use of thermo- and piezoelectric generators, may take place in real estate ['digital real estate business', 2021.99_Ter].

New chip technologies (EN5)

Futures Platform 'data & digitalisation' summary [2025.06] looks in detail at the ongoing development in the digital world. In short:

— Digitalisation is an ongoing growing concept that has the potential to disrupt and revolutionise many industries and aspects of day-to-day life.

— Among others, roll-out on the medium term (late 2020), would require switching to cheap and energy-efficient solutions.

— Beyond 2030, the development of quantum computers, storage on quantum neural networks and DNA data storage will drive the future of information technology.

All of these developments are driven, among others, by the needs for such digital services:

— The quick growth of information technology has necessitated the need for developing novel electronic devices capable of performing novel neuromorphic computations with low power consumption and a high degree of accuracy ['memory manipulation', 2032.55].

— Machine learning is an important branch in Artificial Intelligence computing ['AI machine learning', 2024.01]. It works best when enormous quantity of data requires fast, reliable and accurate computing power.

— The next wave of the industrial revolution foresees robots helping humans work better, faster, and safer by leveraging cognitive computing power ['industry 5.0', 2027.94].

In the meantime, the digital world consumes an ever-increasing amount of energy: By 2030, Nature estimates the total ICT energy demand will be between 8 and 21% of all electricity consumed ['cloud computing', 2023.86]. Computing power accounts for a fair share and is poised to further increase, though limited by current (transistor-based) technology. Alternative technologies - based on quantum mechanics, DNA, brain emulation, nano-sized solutions, or structurally and functionally more advanced transistor-based microchips - are in development. Additionally, alternative architectures such as for example cloud computing, could also provide a solution ['exponential times', 2032.62]. And these improvements are not limited to 'crunching numbers': Fast, energy-efficient, future computing systems uses light instead of electrons to process and store information ['education & knowledge', 2024.57_Bis; 'spinnaker supercomputer', 2022.7_Ter], thereby possibly impacting further the energy system.

Quantum computers can use simultaneously binary digits in forms of zeros and ones. That allows a real quantum computer to conduct simultaneously tasks and operations that amount to all existing calculation power of today ['quantum computers', 2030.92]. Beyond quantum computation, quantum teleportation is technology that transports the quantum state of a particle, not actual matter. The experiment proved that it would be possible to construct a super-safe quantum communications system impossible to eavesdrop without the participants knowing ['quantum state teleportation', 2022.54_Bis]. This enables a new method for helping quantum computers communicate more efficiently with each other, representing a step toward a quantum Internet and next-generation computing speeds ['quantum internet', 2022.13].

Stimulated by additional computing power, data centres' global electricity usage will continue to grow. Therefore, the expansion of green data centres will likely play a significant role in mitigating global emissions. Various companies and governments are working towards decarbonising their data centres by shifting to renewable-powered data centres and different cooling strategies, such as underwater data centres and snow-cooling systems ['zero-emission data centres', 2024.05_Ter].

Edge computing refers to the processing and storing of data near its point of origin. The data is not transferred to an external data centre but a server located, for example, next to a base station will take care of the handling and warehousing. This reduces latency, improves data security and possibly also lowers costs. ['Edge computing', 2022.36_Bis]. Architectures derived from this concept possibly improve on resilience when the (then local) energy needs are ensured through smart uninterrupted power ['industry 4.0', 2032.32].

Annex 3.3. Overview of phenomena relevant to 'energy sources' and 'scales of energy' keywords

The following list provides some keywords, and the relevant phenomena, mined for topics EN3 'energy sources' and EN4 'scales of energy'. This list serves as a quick start for anyone interested in Futures Platform material for specific energy aspects.

For each bullet, the left part shows the search term (corresponding to specific energy technologies) of interest, while the right part refers to the JRC_ID (listed in Annex 2) of Futures Platform phenomena which do bear occurrence(s) of this search term.

The search terms were retrieved through the text-mining of Futures Platform phenomena descriptions, a process described in Annex 3.1 leading to the extraction and analyst's review of relevant sentences: This text-mining process has been applied in an iterative manner, starting from the broad keyword of energy, towards specific forms of energy, to finally end with the energy technologies or sources of interest listed below. Though covering close to 60 search terms, this list is not intended to be exhaustive as some technologies/sources may have escaped this process.

Very specific search terms do appear in one phenomenon, such as microbial fuel cells in phenomenon ['electricity-producing bacteria', 2022.49] and anaerobic digestion ['dumps to mines', 2021.25]. Fuel cell is also unequivocal but more general. It is indeed retrieved in 20 phenomena.

Analogously, photosynthesis was retrieved in three phenomena ['formic acid fuel', 2022; 'business', 2025.94; 'artificial photosynthesis', 2033.91] while synthesis was retrieved eight times, for phenomena ranging from ['biofuels', 2024.6; 'synthetic fuels', 2025.54; 'sciences & research', 2026.78_Ter; 'graphene revolution', 2032.71_Bis and 'world population growth', 2032.75_Bis].

- 'brine water': 2033.27.
- 'algae': 2024.6; 2024.75; 2026.43; 2032.91.
- 'seaweed': 2025.24; 2026.35; 2026.43; 2033.91.
- 'body heat': 2023.34; 2025.75; 2026.16.
- 'heat': 2022.01; 2023.34; 2024.89; 2026; 2026.16; 2026.94.
- 'kinetic energy': 2021.74; 2026.59; 2031.38; 2026.22_Bis.
- 'anaerobic digestion': 2021.25.
- 'electricity from': 2021.19; 2021.87; 2022.01; 2026.59; 2032.46; 2034.44.
- 'kinetic': 2021.74; 2026.2; 2026.59; 2031.38; 2026.22_Bis.
- 'microbial fuel cell': 2022.49.
- 'fuel cell': 2021.87; 2022; 2022.49; 2022.89; 2022.93; 2023.74; 2024.61; 2025.15; 2025.54; 2026.43; 2026.85; 2027.33; 2032.1; 2032.56; 2032.91; 2032.93; 2034.38; 2034.44; 2021.99_Ter; 2032.71_Bis.
- 'photosynthesis': 2022; 2025.94; 2033.91.
- 'synthesis': 2022; 2024.6; 2025.54; 2025.94; 2033.91; 2026.78_Ter; 2032.71_Bis; 2032.75_Bis.
- 'thermoelectric': 2022.01; 2023.34; 2025.88; 2026.16; 2032.77_Bis.
- 'piezoelectric': 2025.15; 2026.2; 2026.88; 2021.99_Ter.
- 'energy harvest': 2021.19; 2022.01; 2023.34; 2024.29; 2025.45; 2026.16; 2026.2; 2026.98; 2031.38; 2032.71_Bis.
- 'capacitor': 2021.62; 2026.16; 2032.71; 2032.71_Bis.
- 'waste': 2021.25; 2022.01; 2022.49; 2024.6; 2025.24; 2025.88; 2026.16; 2026.94; 2051.32; 2032.77_Bis.
- 'formic': 2022; 2023.74; 2024.6; 2025.54; 2026.85; 2027.33.
- 'metallic hydrogen': 2021.64; 2026.85; 2027.33; 2021.99_Ter.
- 'hydrogen': 2021.64; 2021.73; 2021.84; 2021.87; 2022; 2022.89; 2022.93; 2023.74; 2024.57; 2024.6; 2024.61; 2025.15; 2025.19; 2025.36; 2025.54; 2026.43; 2026.45; 2026.68; 2026.85; 2027.1; 2027.33;

2032.1; 2032.56; 2032.72; 2032.91; 2032.93; 2033.27; 2033.91; 2034.36; 2034.38; 2021.83_Bis; 2021.99_Ter; 2024.42_Bis; 2025.97_Bis; 2026.78_Ter; 2032.71_Bis; 2032.77_Bis.

— ‘methan’: 2021.87; 2022; 2023.74; 2024.6; 2025.54; 2026.35; 2026.43; 2026.85; 2027.33; 2031.06; 2033.91; 2021.83_Bis; 2023.78_Bis; 2026.78_Ter.

— ‘ammonia’: 2023.74; 2024.6; 2025.54; 2026.85; 2027.33.

— ‘ethanol’: 2021.86; 2024.57; 2024.6; 2025.15; 2025.34; 2026.94; 2027.33; 2028.85.

— ‘dimethyl’: 2024.57; 2024.6.

— ‘gas’: 2021.19; 2021.25; 2021.66; 2021.87; 2022; 2022.39; 2022.49; 2022.57; 2022.89; 2022.93; 2023.66; 2024.57; 2024.6; 2024.89; 2025.19; 2025.24; 2025.45; 2025.5; 2025.54; 2025.69; 2025.88; 2026.43; 2026.66; 2026.78; 2026.85; 2026.94; 2027.07; 2027.2; 2027.33; 2028.86; 2030.79; 2030.92; 2031.44; 2032.56; 2033.42; 2034.29; 2035.49; 2051.32; 2021.49_Bis; 2021.83_Bis; 2022.74_Bis; 2022.95_Bis; 2024.81_Bis; 2025.73_Bis; 2025.97_Bis; 2032.77_Bis.

— ‘oil’: 2021.66; 2022.49; 2022.52; 2022.57; 2022.89; 2023.44; 2023.66; 2023.68; 2024.02; 2024.42; 2024.51; 2024.6; 2024.81; 2024.89; 2025.15; 2025.34; 2025.45; 2025.5; 2025.54; 2025.56; 2025.69; 2026.04; 2026.07; 2026.08; 2026.43; 2026.45; 2026.78; 2027.07; 2027.33; 2028.85; 2028.86; 2029.76; 2030.79; 2030.91; 2030.92; 2031.65; 2032.14; 2032.47; 2032.72; 2032.91; 2034.14; 2034.29; 2034.35; 2035.49; 2051.32; 2021.47_Bis; 2021.49_Bis; 2022.11_Bis; 2022.95_Bis; 2024.26_Bis; 2025.37_Bis; 2025.45_Bis; 2025.88_Bis; 2026.2_Bis; 2026.78_Bis; 2032.77_Bis; ZZZZ.ZZ.

— ‘coal’: 2021.84; 2022.52; 2023.66; 2025.15; 2025.16; 2025.5; 2025.54; 2025.69; 2026.46; 2027.07; 2027.1; 2028.85; 2028.86; 2035.61; 2022.95_Bis; 2026.2_Bis; 2032.77_Bis.

— ‘LPG’: 2024.57; 2024.6.

— ‘diesel’: 2022.89; 2023.44; 2023.74; 2024.57; 2024.6; 2024.61; 2024.75; 2025.15; 2025.34; 2025.54; 2025.69; 2027.33; 2034.44.

— ‘fossil fuel’: 2021.66; 2022; 2022.36; 2022.49; 2022.83; 2022.93; 2023.1; 2023.74; 2024.29; 2024.57; 2024.6; 2024.75; 2024.89; 2025.15; 2025.24; 2025.31; 2025.45; 2025.54; 2025.69; 2025.75; 2026.01; 2026.45; 2026.46; 2026.59; 2026.78; 2026.85; 2027.1; 2027.33; 2028.85; 2028.86; 2030.79; 2030.91; 2031.44; 2032.46; 2032.63; 2032.68; 2032.88; 2032.93; 2033.25; 2033.91; 2034.38; 2035.49; 2035.61; 2051.32; 2025.71_Bis; 2026.2_Bis; 2026.22_Quinquies; 2026.94_Bis; 2031.13_Bis; 2032.77_Bis.

— ‘thorium’: 2024.51; 2025.15; 2027.07; 2032.77_Bis.

— ‘uranium’: 2027.07; 2025.65_Bis.

— ‘fusion’: 2021.58; 2025.15; 2027.07; 2029.7; 2032.46; 2032.56; 2032.71_Bis; 2032.77_Bis.

— ‘nuclear’: 2021.33; 2021.58; 2023.66; 2024.5; 2025.15; 2025.5; 2026; 2027.07; 2032.46; 2032.77; 2032.77_Bis.

— ‘wind’: 2021.58; 2022; 2022.36; 2022.93; 2023.66; 2024.63; 2024.89; 2024.97; 2025.15; 2025.45; 2025.69; 2025.77; 2026.22; 2026.33; 2026.39; 2026.46; 2026.59; 2026.98; 2027.1; 2027.34; 2029.42; 2030.79; 2031.44; 2032.56; 2032.91; 2034.44; 2034.8; 2035.07; 2035.61; 2021.99_Ter; 2024.05_Ter; 2024.57_Bis; 2025.97_Bis; 2026.04_Bis; 2026.2_Bis; 2026.78_Ter; 2026.94_Bis; 2032.07_Bis.

— ‘solar’: 2021.04; 2021.3; 2021.58; 2021.62; 2021.72; 2021.93; 2022.01; 2022.36; 2022.4; 2022.55; 2022.57; 2022.93; 2023.3; 2023.74; 2024.46; 2024.61; 2024.66; 2024.76; 2024.89; 2025.15; 2025.19; 2025.45; 2025.63; 2025.69; 2025.97; 2026.16; 2026.22; 2026.35; 2026.43; 2026.45; 2026.46; 2026.59; 2026.85; 2026.94; 2026.98; 2027.1; 2027.34; 2029.42; 2029.76; 2030.03; 2030.06; 2030.79; 2031.44; 2031.62; 2031.86; 2032.23; 2032.68; 2032.75; 2032.9; 2032.91; 2033.62; 2033.91; 2034.44; 2034.8; 2035.49; 2035.61; 2021.83_Bis; 2021.99_Ter; 2024.05_Ter; 2024.89_Bis; 2025.19_Bis; 2025.65_Ter; 2025.97_Bis; 2026.2_Bis; 2026.22_Quinquies; 2026.94_Bis; 2031.99_Bis; 2032.71_Bis; 2032.75_Bis.

— ‘geothermal’: 2022.01; 2024.89; 2025.15; 2026.85; 2027.33; 2024.26_Bis.

— ‘biomass’: 2021.72; 2022.04; 2024.57; 2024.6; 2024.75; 2025.24; 2025.54; 2025.98; 2026.43; 2027.33; 2032.91; 2032.71_Bis.

— ‘biogas’: 2021.19; 2021.25; 2024.6; 2026.43.

— ‘biofuel’: 2022.49; 2024.57; 2024.6; 2024.75; 2025.15; 2025.24; 2025.54; 2026.35; 2026.43; 2027.33; 2033.42; 2033.91; 2051.32; 2021.83_Bis; 2032.71_Bis; 2032.77_Bis.

— ‘bioenergy’: 2024.6; 2024.75; 2025.15; 2021.99_Ter.

— ‘ocean energy’: 2026.59.

— ‘tidal power’: 2026.59.

— ‘tidal lagoon’: 2026.59.

— ‘tidal’: 2026.59; 2031.44.

— ‘hydropower’: 2025.15; 2026.59; 2022.27_Ter.

— ‘hydroelectric’: 2024.89; 2025.45; 2026.59; 2035.07.

— ‘energy storage’: 2021.58; 2022.39; 2022.45; 2022.93; 2023.34; 2025.15; 2026.59; 2026.85; 2030.79; 2032.52; 2032.71; 2032.93; 2033.42; 2035.52; 2026.94_Bis; 2032.71_Bis.

— ‘energy mass storage’: 2030.79.

— ‘water reservoir’: 2030.79.

— ‘batter’: 2019.42; 2020.47; 2020.49; 2021.14; 2021.19; 2021.28; 2021.62; 2021.73; 2022; 2022.01; 2022.39; 2022.4; 2022.45; 2022.49; 2022.62; 2022.89; 2022.93; 2023.34; 2023.74; 2024.29; 2024.51; 2024.57; 2024.61; 2024.66; 2025.15; 2025.19; 2025.54; 2025.62; 2025.87; 2026.16; 2026.25; 2026.33; 2026.45; 2026.46; 2026.68; 2026.85; 2026.92; 2027.33; 2028.83; 2029.76; 2030.03; 2030.79; 2031.09; 2031.44; 2031.99; 2032.23; 2032.56; 2032.88; 2033.44; 2034.26; 2034.38; 2034.44; 2035.41; 2035.49; 2021.59_Bis; 2021.99_Ter; 2022.51_Bis; 2023.86_Bis; 2024.42_Bis; 2024.89_Bis; 2025.6_Bis; 2026.2_Bis; 2026.22_Quater; 2026.94_Bis; 2031.99_Bis; 2032.71_Bis; 2032.77_Bis.

— ‘thermal energy storage’: 2033.42.

— ‘electrochemical energy storage’: 2032.71_Bis.

— ‘magnetic energy storage’: 2021.58.

— ‘scal’: 2022; 2022.36; 2022.93; 2023.02; 2024.66; 2024.89; 2025.24; 2025.54; 2026; 2026.16; 2026.2; 2026.35; 2026.37; 2026.43; 2026.46; 2026.59; 2026.94; 2027.07; 2027.33; 2030.79; 2031.44; 2032.46; 2032.75; 2032.88; 2033.91; 2034.44; 2034.8; 2035.04; 2035.49; 2051.32; 2021.59_Bis; 2021.83_Bis; 2021.99_Ter; 2026.22_Quinquies; 2026.94_Bis.

— ‘watt’; 2022.62; 2022.93; 2024.66; 2024.89; 2025.15; 2025.75; 2026; 2026.59; 2027.1; 2028.85; 2032.88; 2024.05_Ter; 2026.22_Bis.

Annex 3.4. Different types of interlinkages within the energy theme

As introduced in Section 2.3.6, the table below summarises interlinkages within the energy theme, beyond the core to core interlinkages already discussed. The idea here is to test an approach to identify fainter types of connections within the energy theme, for possible reproduction in other themes or across themes.

To this end, the authors look here how the core or related phenomena of one topic are allocated to other topics, either as core, as related or as not relevant phenomena. This leads to three types of connections:

- 'Core to core' connections (one example is highlighted in light green). These connections are already addressed in Section 3.3.3 of the report.
- 'Core to related' or 'related to core' connections (one example is highlighted in orange).
- 'Related to related' connections (one example is highlighted in dark green).

An example of how to read this table is to look at the intersections of EN1 and EN2:

- Regarding EN1 six core phenomena: two of them are also core phenomena of EN2 (indicating two 'core to core' relations); two are shared as related to core phenomena of EN2 (indicating two 'core to related' relations) and two are not related to EN2 phenomena.
- Regarding EN1 23 related phenomena: three of them are also core phenomena of EN2 (indicating three 'related to core' relations); nine are shared as related to core phenomena of EN2 (indicating nine 'related to related' relations) and eleven are not related to EN2 phenomena.

Focusing now on 'core to related' connections, the orange highlights below show the highest number of connections between EN2 (related) and EN3 (Core): eleven phenomena core to EN3 are also related to core phenomena of EN2. The orange colour appears twice, also showing the reciprocal relation of eleven related phenomena of EN2 that are core to EN3.

Looking more in details into this one intersection, of the 32 core phenomena to EN3 'new sources of energy', eleven are related to EN2 '(de)centralised energy systems' (i.e., Futures Platform identifies these eleven phenomena as related to phenomena deemed core to '(de)centralised energy systems'). These eleven phenomena are 'formic acid fuel'; 'electricity-producing bacteria'; 'biofuels'; 'solar roof'; 'solar power'; 'hydrogen economy'; 'thorium power plants'; 'fuel switching'; 'solar satellites'; 'fusion power - Helium 3'; 'use of fossil Fuels'. These (new) sources of energy (thus dully core of EN3) have indeed the potential to affect energy production and thus – depending on their roll-out - the management of the energy system in a geographical sense (thus related to EN2).

Focusing now on 'related to related' connections, the dark green highlights below show the highest number of connections between EN3 'new sources of energy' and EN4 'scales of energy': Both share 29 related phenomena. This information mirrors to some extent the 'core to core' connections between those two topics (highlighted in light green): should topics share core phenomena, the related phenomena to these shared core phenomena are obviously shared by the topics.

Looking more in details into this one intersection, the 20 core phenomena jointly allocated to EN3 and to EN4 lead to 26 joint related phenomena in EN3 and EN4. The remaining three joint related phenomena in EN3 and EN4 are:

- 'untouched nature', related to core phenomena 'forestation' in EN3 and 'robotic deep-sea mining' in EN4.
- 'biotech and bioeconomy', related to core phenomena 'biofuels' in EN3 and 'wood-based textiles' in EN4.
- 'graphene revolution', related to core phenomena 'body-heat harvesting wearables' in EN3 and 'clean water solutions' and 'light from graphene' in EN4.

These three phenomena have indirect impacts on both EN3 'new sources of energy' and EN4 'scales of energy', though made reasonable through the above mentioned core phenomena to the said topics.

Table 2. Counts of phenomena retrieved from Futures Platform per topic and type of allocation.

	EN1 *Resilient energy systems*				EN2 *(De)centralised systems*				EN3 *New sources of energy*				EN4 *Scales of energy*				EN5 *New chip technology*			
Counts of core phenomena	6				12				32				42				15			
Shared with	EN2	EN3	EN4	EN5	EN1	EN3	EN4	EN5	EN1	EN2	EN4	EN5	EN1	EN2	EN3	EN5	EN1	EN2	EN3	EN5
As core	2	2	4	0	2	4	7	0	2	4	20	0	4	7	20	1	0	0	0	1
As related	2	2	1	0	2	4	2	2	7	11	8	0	7	8	8	0	0	0	0	1
Not relevant	2	2	1	6	8	4	3	10	23	17	4	32	31	27	14	41	15	15	15	13
Counts related phenomena	23				44				44				82				51			
Shared with	EN2	EN3	EN4	EN5	EN1	EN3	EN4	EN5	EN1	EN2	EN4	EN5	EN1	EN2	EN3	EN5	EN1	EN2	EN3	EN5
As core	3	7	7	0	2	11	8	0	2	4	8	0	1	2	8	1	0	2	0	0
As related	9	6	14	2	9	8	20	1	6	8	29	5	14	20	29	11	2	1	5	11
Not relevant	11	10	2	21	33	25	16	43	37	33	8	40	67	60	45	70	49	48	46	40

Annex 4. Approach for allocating Futures Platform phenomena to tech-vulnerability topics

By Amalia Muñoz Piñeiro (JRC.F.7).

This section describes the approach followed for the text-mining of the phenomena description with keywords (strings of characters) related to the given 'Tech vulnerability' topics:

- Specific keywords are searched into the text for each topic (e.g., 'hacked', 'phishing', 'malware').
- The sentences containing the keywords are retrieved and collated.
- The outcome of the text mining is formatted in the form of a matrix. This matrix has the 712 phenomena as rows and a column for each keyword. The cells (intersecting phenomena and keywords) are either empty (when the keyword cannot be found in the phenomena description) or contains sentences of the phenomena description bearing the keywords.
- The matrix is then manually reviewed to exclude false positive, that is phenomena having the keyword but off topic regarding the content.
- Phenomena for which no-keyword was found but clearly related to the topic were manually added.
- Once all the columns/keywords are processed, the relevant phenomena are aggregated at topic level, so allocation to one or more topics can take place.

Figure 54. Keyword-based allocation of phenomena to the different topics of the Tech-vulnerability theme

Phenomen_Title	AdTec	Cyber A	Cyber Se	Big Data5	Fragility6	TechVuln_
Dark Web		1	1		1	Mix
Data & Digitalisation			3	6		BigData
Data Centre Expansion			1	6	3	BigData
Data Centres in Space			1		1	Mix
Data Consumption	1			3	2	BigData
Data Security of Human		1	1	2		BigData
Dataism as a New Religi		1		1	1	Mix
Harmful Functionality in F		3	1	1		CyberAttacks
Health & Wellness Coachi				1		BigData
Health Monitoring Spaces				2		BigData
High-Tech Ecovillages			1	2	1	BigData
Hijacking a Hospital		4	1	1		CyberAttacks
Home Robots	1			1		Mix
Hybrid Warfare		2				CyberAttacks

Source: Authors, based on Futures Platform material.

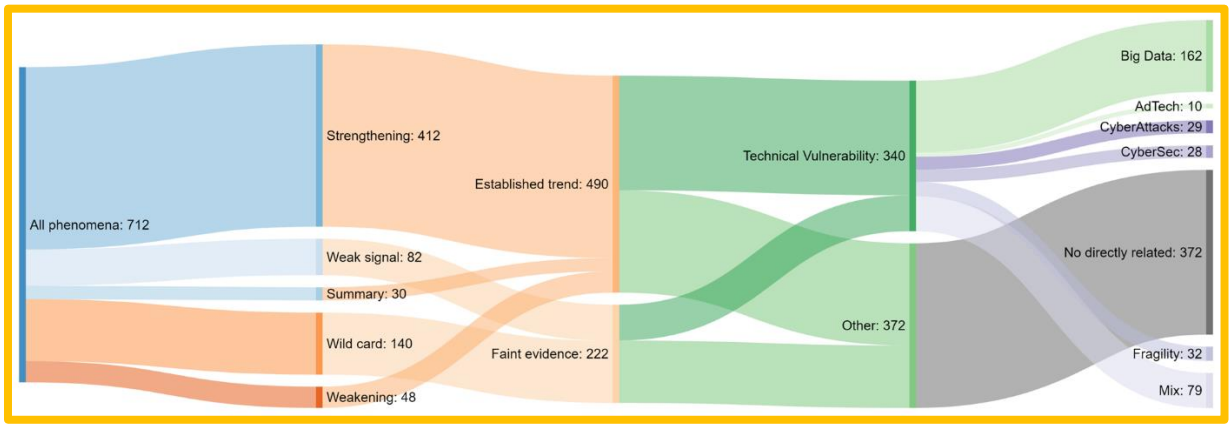
Figure 54 shows two screenshots of the resulting matrix. The table shows how many times keywords, from a list of search terms defined by the authors for that topic, were found in the text of the phenomena. This matrix is on the bases of phenomena allocation. Phenomena are allocated to a topic when:

- It contains only keywords from one topic (i.e., 'Health Monitoring Spaces', 'Health & Wellness coaching' or 'Hybrid Warfare').
- It contains more keywords from one of the topics (i.e., 'Data & Digitalisation' contains 3 keywords from 'Cyber Security' and 6 keywords from 'Big Data', therefore it is assigned to 'Big Data'; 'Hijacking a Hospital' contains 4 keywords from 'Cyber Attacks', 1 from 'Cyber Security' and 1 from 'Big Data', therefore it is allocated to 'Cyber Attacks').

For some phenomenon descriptions, there may be equal counts of keywords retrieved for several topics, making it impossible to allocate these phenomena unequivocally to a single topic. These phenomena are allocated to a group designated as 'Mix'. 'Dark Web', 'Data Centres in Space', 'Dataism as a new religion' and 'Home Robots' are a few examples.

Figure 55 shows the final allocation of phenomena to the different topics applying the above described approach. Of the 340 phenomena allocated to the theme 'Tech vulnerability', 162 were allocated to the topic 'Big Data', 10 to 'Ad Tech', 29 to 'Cyber Attacks', 28 to 'Cyber Security', 32 to 'Fragility' and 79 were defined as 'Mix' since it was not possible to clearly assign to one of the topics.

Figure 55. Sankey representation of the phenomena as resulting from their assigned allocation based on the text mining of topic related keywords



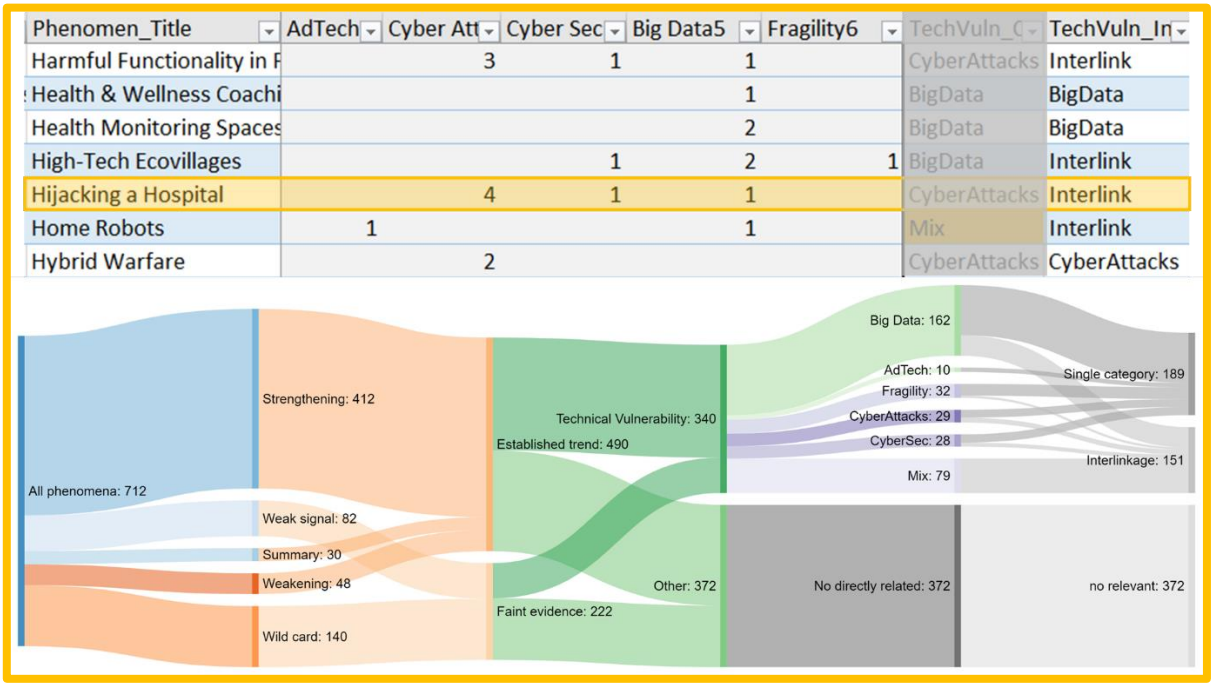
Source of the Sankey diagrams in this Annex: Authors, based on Futures Platform material.

This allocation of phenomena to a topic is based on analysis and interpretation of relations among phenomena as defined by Futures Platform.

However, another basis for retrieving interlinkages is to assume that phenomenon descriptions containing keywords defined by the authors for more than one topic are, by definition, linking two or more topics. This is an important assumption, which underlies an approach for defining interlinkages other than those defined by Futures Platform). In this second approach, a phenomenon is allocated to a topic, only if containing exclusively keywords from the topic. Those phenomena containing keywords from two or more topics are classified as '**Interlinks**'. An screenshot of the resulting table is shown in **Figure 56** top where 'Health & Wellness Coaching' and 'Health Monitoring Spaces' were allocated to 'Big Data', 'Hybrid Warfare' to 'Cyber Attacks', while 'Harmful functionality in Products', 'High-Tech Ecovillages', 'Hijacking a Hospital' and 'Home Robots' were assigned as Interlinkages since containing keywords from different topics.

About 55% of the phenomena from the theme 'Tech vulnerability' were allocated to a single topic, while about 45% were assigned as interlinkages, as shown in **Figure 56** bottom.

Figure 56. Top: Screenshot of the table showing phenomena allocation and interlink allocations. Bottom: Sankey representation of the interlinkages and affiliation analysis based on the keywords found in each phenomenon

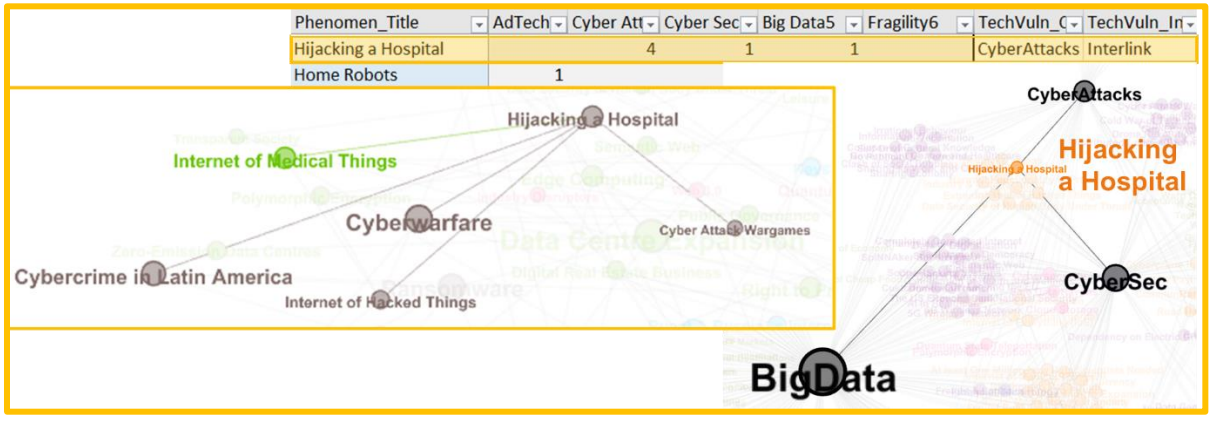


Source: Authors, based on Futures Platform material.

This latest approach, purely based on keyword co-occurrence, allows to integrate in the analysis the outcome of the expert-workshop (i.e. topics and themes) in the network graph. As an example, **Figure 57** shows on the left a network sub-graph based on interlinkages defined by futurist of Futures Platform as related. The 'hijacking a hospital' node appears connected to phenomena containing 'cyber' and 'internet of things' in their titles. On the right network sub-graph, the interlinkages show to which topics defined by JRC experts in the workshop was allocated. Both analyses, as expected, show that 'Hijacking a Hospital' is a phenomena associated to Big Data and Cyber Attacks and indirectly to Cyber Security. The difference is that this is explicit in the right sub-network, where topics defined in the megatrend workshop were included. In the left graph, directly extracted from Futures Platform, this is only underlying information.

This example illustrates the complexities involved in defining, retrieving and indeed untangling interlinkages. There is no single clear-cut 'answer', and subjectivity plays a role also when applying computer-assisted procedures.

Figure 57. Sub-network showing the differences when applying the two approaches to the phenomena 'hijacking a hospital'



Source: Authors, based on data text-mined from Futures Platform and visualised in Gephi.
Annex 2 provides a tabular overview of the Futures Platform phenomena and their Interlinkages.

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