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EQUALITY

Efficient QUantum ALgorithms for IndusTrY

WP6 Impact creation

D6.5 Market analysis, business model and upscaling

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Document description	This deliverable will present a thorough market assessment (market dynamics, volume, value, growth, segmentation, competitor analysis) and a solution-based business model, considering the upscaling to other countries.

[1]R: Document, report (excluding the periodic and final reports); DEM: Demonstrator, pilot, prototype, plan designs; DEC: Websites, patents filing, press & media actions, videos, etc.; DATA: Data sets, microdata, etc.; DMP: Data management plan; ETHICS: Deliverables related to ethics issues.; SECURITY: Deliverables related to security issues; OTHER: Software, technical diagram, algorithms, models, etc.

[2]PU – Public, fully open, e.g., web (Deliverables flagged as public will be automatically published in CORDIS project's page); SEN – Sensitive, limited under the conditions of the Grant Agreement; Classified R-UE/EU-R – EU RESTRICTED under the Commission Decision No2015/444; Classified C-UE/EU-C – EU CONFIDENTIAL under the Commission Decision No2015/444; Classified S-UE/EU-S – EU SECRET under the Commission Decision No2015/444

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Abstract

A quantum revolution is unfolding, and European scientists are in the lead. It is time to take decisive action and transform our scientific potential into a competitive advantage. Achieving this goal will be critical to ensuring Europe's technological sovereignty in the coming decades. EQUALITY brings together scientists, innovators, and prominent industrial players with the mission of developing cutting-edge quantum algorithms to solve strategic industrial problems. The consortium will develop a set of algorithmic primitives applicable to various industry-specific workflows. These primitives include differential-equation solvers, material-simulation algorithms, quantum optimisers, and quantum machine learning. To focus our efforts, we target eight paradigmatic industrial problems. These problems will likely yield early quantum advantage and pertain to the aerospace and energy-storage industries. They include aerodynamics simulation, battery- and fuel-cell design and optimisation, battery-material discovery, space-mission optimisation, and space-data analysis.

We aim to develop quantum algorithms for industrial problems using real quantum hardware. This requires grappling with the limitations of present-day quantum hardware. Thus, we will devote much of our efforts to developing strategies for optimal hardware exploitation. These low-level implementations will account for the effects of noise and topology and will optimise algorithms to run on limited hardware. EQUALITY will build synergies with Quantum-Flagship projects and Europe's thriving ecosystem of quantum start-ups. Use cases will be tested on quantum hardware from three of Europe's leading vendors and two HPC centres. The applications targeted have the potential to create billions of euros for end-users and technology providers over the coming decades. With EQUALITY, we aim to play a role in unlocking this value and placing Europe at the centre of this development. The project gathers nine partners and has a budget of €6M over three years.

Consortium

The EQUALITY consortium members are listed below.

Legal Name on Grant Agreement	Short name	Country
CAPGEMINI DEUTSCHLAND GMBH	CAP	DE
QU & CO AI BV	QC	FR
AIRBUS OPERATIONS GMBH	AOG	DE
DEUTSCHES ZENTRUM FUR LUFT - UND RAUMFAHRT EV (DLR)	DLR	DE
FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV (FHG)	ENAS	DE
INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET AUTOMATIQUE (INRIA)	INRIA	FR
UNIVERSITEIT LEIDEN (ULEI)	ULEI	NL
DA VINCI LABS	DVL	FR

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Disclaimer

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List of Abbreviations

WP	Work package
1D + 1D	1 dimensional + 1 dimensional
AG	Aktiengesellschaft
AI	Artificial Intelligence
B2B	Business-to-Business
B2C	Business-to-Customer
BMC	Business Model Canvas
BMWK	Federal Ministry for Economic Affairs and Climate Action of Germany (Bundesministerium für Wirtschaft und Klimaschutz)
BMBF	Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung)
CAGR	Compound Annual Growth Rate
CapEx	Capital Expenses
CFD	Computational Fluid Dynamic
DFT	Density functional theory
EU	European Union
EUR	Euro (Currency)
FCI	Full configuration interaction
GmbH	Gesellschaft mit beschränkter Haftung
HPC	High Performance Computing
IP	Intellectual Property
IT	Information Technology
LIB	Lithium-ion battery
ML	Machine Learning
NISQ	Noisy Intermediate-Scale Quantum
OpEx	Operating Expenses
PC	Personal computer
PESTEL	Political, Economic, Sociological, Technological, Legal and Environmental
PoC	Proof of Concept
QA	Quantum Annealing
QAOA	Quantum Alternating Operator Ansatz

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QPSO	Quantum Particle Swarm Optimization
QT	Quantum Technology
R&D	Research and Development
SAR	Synthetic Aperture Radar
SEO	Search Engine Optimization
SME	Small and Medium Enterprise
SOFC	Solid Oxid Fuel Cell
SWOT	Strength, Weakness, Opportunities, Threats
TD-TSP TW	Time-Dependent Traveling Salesman Problem with Time Windows
USD	United States Dollar (Currency)

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1. EXECUTIVE SUMMARY

This document is a deliverable of the EQUALITY project, funded under grant agreement number 101080142.

This deliverable, "D6.5 Market analysis, business model and upscaling", is part of Work Package 6 (WP6) "Impact creation" which presents which "ensures communication and dissemination of EQUALITY project activities to different stakeholders: from researchers, industry, policymakers to the public. The main goal of activities in this WP is improving the impact of the project, its public acceptance and translation. We also implement and monitor the project Open Science activities. The objectives of this work package are to develop the project communication infrastructure, to elaborate and implement a successful dissemination plan, to develop a supporting ecosystem, and to manage open data and open access publications.

This deliverable presents a thorough qualitative and quantitative assessment of the market and business environment of the six use cases, together with the products or services yielding from them. The analysis was conducted methodologically, with more details on the used methodology can be found in Chapter 2 of this report and includes an overall assessment of the positive impact of quantum technologies on the analysed industries and markets. The report describes potential influence of external macro-environmental factors on the solutions or product, resulting from the six use-cases, and provides a general situational assessment, reflecting the strengths of the provided solutions and market opportunities for them, as well as their internal and external weaknesses. This assessment of general business environment can be found in Chapter 3.

The analysis proceeds with a thorough use-case-specific assessment, considering the distinct markets targeted for each of the products or services in the Chapter 4. This thorough investigation should help to adapt these products or services better to the industry requirements and specific customer needs. This report also includes the analysis of the advantageous dynamics, volume, growth and segmentation of the markets, as well as outlines potential barriers, identifies the key actors and competition on the markets.

This deliverable proposes, as well, six solution-based business model scenarios, covering the six use cases. General business model elements were identified on the operational and the cost structure levels (more details in section 3.3). The different use cases were analysed separately, considering distinct products/services per use case and built in separate units highlighting the customer segments, value proposition, and revenue streams. These can be also found in the respective sections of the Chapter 4.

Key words: Market Analysis, Business Model, Value proposition, Competition, SWOT, PESTEL

2. APPLIED METHODOLOGY

In preparation of the market assessment and business model development, numerous work sessions and interviews were conducted with the consortium partners and domain experts to clearly define and specify the problems presented in the six use cases: including the outcomes of the different products or services and the concrete added value offered by these.

Step 1: Macro-environmental/external factors

In this step, the focus is put on the analyses of the external market drivers for the different use cases using the strategic framework PESTEL, which stands for Political, Economic, Social, Technological, Environmental, and Legal factors. The latter of these factors can boost the market uptake, i.e., drive it positively, or inhibit market uptake, i.e., drive it negatively, or some factors are still to be determined as they depend on a yet unknown outcome. Detailed description of all these factors can be found in the section 3.1.

This business environment evaluation covers six dimensions:

- **Political factors** are driven by government actions and policies. They include corporate taxation and various fiscal policy initiatives, free trade disputes, antitrust and other anti-competition issues;
- **Economic factors** are related to the broader economy and finances. They encompass various changes of the Interest rates, Employment rates, Inflation, and Exchange rates;
- **Social factors** are more difficult to quantify than economic ones. They refer to shifts or evolutions in how stakeholders approach life and leisure, which can impact their commercial activity. Examples of social factors include Demographic considerations, Lifestyle trends, Consumer beliefs, and Attitudes around working conditions;
- **Technological factors**: The speed and scale of technological disruption in the present business environment are unprecedented, and it has had a devastating impact on many traditional businesses and sectors. Consequently, understanding of how technological factors may impact an organisation or an industry is essential for a correct estimation of its potential for success. Technological factors, which may make an impact costs and competitive advantage, include: Automation, Research and Development (R&D), Technology infrastructure (i.e., 5G, Internet-of-Things, etc.), and Cybersecurity;
- **Environmental factors** emerged as a sensible addition to the original PEST framework as the business community began to recognise that changes to our physical environment can present material risks and opportunities for organisations. Environmental considerations include carbon footprint, climate change impacts, including physical and transition risks, increased incidences of extreme weather events, and stewardship of natural resources, like freshwater;
- **Legal factors** emerge from changes to the regulatory environment, which may affect the broader economy, certain industries, or even individual businesses within a specific sector. They include but are not limited to: Industry regulation, Licenses and permits required to operate, Employment and consumer protection laws, and Protection of the intellectual property.

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Step 2: General situational assessment

The key element of this phase is the assessment of the EQUALITY solutions' competitive position, as a whole and individually per use case, based on the identified added value. Identifying the internal and external elements and discoveries leads to fact-based analysis, fresh perspectives, and new ideas. This assessment is provided in the section 3.2.

The general situational assessment was conducted using the strategic planning technique known as SWOT, which include the following four categories:

- **Strengths** encompass the intrinsic properties of the organisation that it excels at, and which separate it from the competitors: a strong brand, a loyal customer base, a strong balance sheet, a unique technology, etc;
- **Weaknesses** are the internal factors that stop an organisation from performing at its optimum level. These are the areas where the business needs to improve to remain competitive, for example: a weak brand, higher-than-average turnover, high levels of debt, an inadequate supply chain, or lack of capital;
- **Opportunities** refer to favourable external factors that could give an organisation a competitive advantage, such as governmental promotions of some market sector, or favourable conditions for growth and upscaling, like sufficient supply of narrow technical specialists for the specific domain.
- **Threats** refer to the factors that have the potential to harm an organisation. Common threats include rising costs for materials, increasing competition, and tight labour supply, etc.

Step 3: Market assessment and competitive analysis

This step encapsulates the large scope of market analysis, including the qualitative and quantitative assessment. The analysis includes an overall assessment of the impact of quantum technologies development on all combined industries and markets as a first layer.

The analysis proceeds with a thorough use-case-specific assessment, considering the separate targeted markets for each use-case. This granulation should help tailoring and customising the products or services created within each use-case to the requirements of the respective markets and industries. The specific needs of the end-users, or in some cases, the stakeholders, have been considered upfront. However, the long-term viability of the solutions will be addressed in the following stepm with the business model development.

The use-case assessment includes analysis of the market dynamics, volume, growth, segmentation, barriers, and identification of key actors and competition.

Step 4: Business model development

For the business model development, the six use cases were analysed separately, considering distinct products or services per use case, and is built upon individual solution-based business models. Elements of the business model, common though the use-cases, have been identified and considered in details in section 3.3, particularly on the level of the resources, activities, and general cost structure.

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The business model development was conducted using the strategic management tool known as the Business Model Canvas (BMC), which offers a visual chart with key elements describing the product value proposition and aligning the business accordingly. The BMC consists of the following nine blocks:

- **Customer segments** define the distinct groups of people or organisations an enterprise aims to reach and serve. Depending on the specific customer needs, this block may define one or several large or small customer segments. [1] Those segments could be separated if:
    - Their needs require and justify a distinct offer;
    - They are reached through different distribution channels;
    - They require diverse types of relationships;
    - They have different profitability;
    - They are willing to pay for various aspects of the offer.
    - **Value propositions** describe the bundle of products and services that create value for a specific customer segment. in this sense, the value proposition is an aggregation, or bundle, of benefits that a company offers customers. [1] Some value propositions may be innovative and represent a new or disruptive offer. Others may be like existing market offers but with added features and attributes.
- **Channels** describe how a company communicates with its customer segments and reaches to them to deliver a value proposition. Channels are customer touch points that significantly influence the customer experience. Channels serve several functions, including:
    - Raising awareness among customers about a company's products and services;
    - Helping customers evaluate a company's value proposition;
    - Allowing customers to purchase specific products and services;
    - Delivering a value proposition to customers;
    - Providing post-purchase customer support.
    - **Customer relationships** describe the types of relationships a company establishes with specific customer segments. Relationships can range from personal to automated, and may be driven by customer acquisition, retention, or by boosting sales (upselling); [1]
    - **Revenue streams** represent the cash a company generates from each customer segment. Each revenue stream may have different pricing mechanisms, such as fixed list prices, bargaining, auctioning, market-dependent, volume-dependent, or yield management. [1] A business model can generally involve two diverse types of revenue streams:
    - Transaction revenues resulting from one-time customer payments;
    - Recurring revenues resulting from ongoing payments to either deliver a value proposition to customers or provide post-purchase.
- **Key resources** describe the most important assets required to make a business model work. These resources allow an enterprise to create and offer a value proposition, reach markets, maintain relationships with customer segments, and earn revenues. key resources can be physical, financial, intellectual, or human. They can be owned or leased by the company or acquired. [1]

- **Key activities** describe the most important things a company must do to make its business model work. Like key resources, they must create and offer a value proposition, reach markets, maintain customer relationships, and earn revenues. And like key resources, key activities differ depending on business model type. [1]
- **Key partners** describe the network of suppliers and partners that make the business model work. Companies forge partnerships/alliances to optimise their business models, reduce risk, or acquire resources. [1] We can distinguish between four distinct types of partnerships:
  - Strategic alliances between non-competitors;
  - Coopetition: strategic partnerships between competitors;
  - Joint ventures to develop new businesses;
  - Buyer-supplier relationships to ensure reliable supplies.
- **Cost structure** describes all costs incurred to operate a business model: creating and delivering value, maintaining customer relationships, and generating revenue. Such costs can be calculated after defining key resources, key activities, and key partnerships. Some business models, though, are more cost-driven than others. [1]

3. GENERAL BUSINESS ENVIRONMENT ASSESSMENT

This chapter contains a description of the business environment, generalised over all the six use-cases covered by the project.

The chapter starts with a detailed assessment of the external factors in format known as PESTEL analysis. The influence of external factors is mostly governed by the nature of quantum technologies; hence the analysis covers all the six use-cases.

It is continued by so-called SWOT analysis, describing internal and external strengths and weaknesses of the solutions, proposed by the project. First covering the aspects general for all the use-cases, it then focuses on more specific ones, grouped by the use-cases involved. Since the six use-cases will yield in six different solutions, six different business models are built in this document. The chapter covers common aspects through all of them, however, those sections of the business-model canvas, that are very similar through all the six use-cases, are covered in full details in the chapter. Then, the remaining specialities are covered in more detail at the last chapter of this document, at each of the respective use-cases.

3.1. Macro-environmental factors

This section describes in detail the macro-environmental factors, that can influence the solutions, developed within the project. It is built in form of a PESTEL analysis. Each of the subsections covers the factors, applicable for all the use-cases, with the use-case specific ones grouped accordingly at the end of each subsection. The principal aspects are summarised in the Figure 1 below:

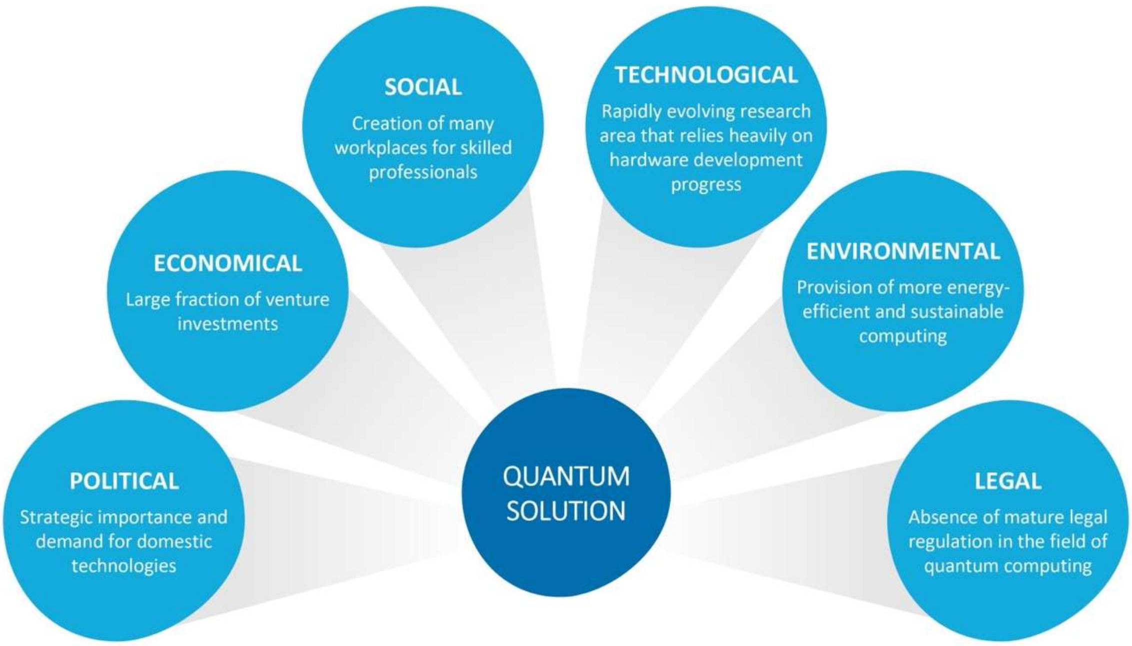

Figure 1: Graphical Overview of the PESTEL analysis general for all six use-cases.

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3.1.1. Political

The disruptive potential of quantum technologies and the large scale of investments necessary to join the field of their development make them an asset of strategic importance. Especially nowadays, at the dawn of the quantum era, since there is still no *single* dominant centre of competencies in the field, each country is trying to develop its own national and European expertise and products, with an aspiration to be among the winners of the quantum race. This gives rise to multiple public-funded initiatives (as is the EQUALITY itself, Quantum Flagship, Horizon quantum, German [2] Quantum Alliance, [3] French Quantum Plan, [4] and many others) and policies promoting such development.

In Politics, the transfer of quantum computing solutions to the industry is strongly encouraged. Funding for projects that support such initiatives is available and will continue to be available in the future. From a political point of view, the early integration of industry in developing usable quantum algorithms or solutions is crucial for competitiveness.

This political scene would eventually enable:

- Large, long-term investments in R&D from the public funds
- Ease of collaboration, finding new partners, etc., within the EU
- Green movements in politics should support the development of multiple domains of application, and the quantum technologies themselves, creating a favourable environment for further development.

However, certain political events and tendencies, together with innate characteristics of the quantum technologies, might present uncertainties and pose threats, like:

- Very tight and competitive market due to both previous points
- International politics may limit the choice of partners, sometimes moderating access to technologies from abroad.
- Quantum technologies may start being hardly regulated by the state due to potential dangers in their use, increasing the costs and developments.

Specific to use-case 1 (Predictive models for battery design and fuel cells):

Especially for battery development, there is a strong effort from politics to push manufacturing and development within Europe since batteries will be one of the key technologies for a sustainable future, and the European Union aims to be independent of raw materials from other countries. Therefore, government policies and regulations can significantly impact the battery modelling market. For example, policies that promote the adoption of electric vehicles and renewable energy systems can drive demand for advanced battery modelling solutions. Conversely, policies restricting certain battery technologies or materials can limit the market's growth.

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Specific to use-case 2 (Materials discovery for battery design):

European Union policies such as the European Battery Alliance, the European Green Deal, and the Circular Economy Action Plan are expected to drive growth in the battery material market by promoting sustainable and environmentally friendly practices.

Political instability in certain regions may also affect the availability of key resources required to produce batteries. E.g., Brexit could impact the availability and cost of raw materials and the regulatory landscape for battery production and disposal.

Specific to use-case 3 (Aerospace simulations):

The use-case does not allow for any specific political influence on the solution, other than mentioned above, due to most of its value and value generation chain lying within a narrow spectrum of specific applications in R&D.

Specific to use-case 4 (Space mission optimisation):

Since the spatial industry, especially – observations of the Earth, has a high impact on international politics and thus is of utter importance to the governments, the political situation may highly influence competitive advantages in this domain at any moment in time. For example, some political powers may promote or halt the development of the domain, accordingly to the strategic balance of powers in the world. This will influence the demand for the proposed solution: business viability. However, the solution (optimisation routine, backed by quantum) is not highly susceptible to political perturbations.

Specific to use-case 5 (Space data analysis and processing):

Upon the same reasoning as for the previous use-case, dramatic advantages in image processing for spatial applications can give a competitive advantage to the intelligence agencies, which can have reciprocal influence on the political situation. Moreover, SAR techniques are extensively used in the Defence sector, which may control the development of related technologies.

Specific to use-case 6 (Solid Oxid Fuel Cell optimisation):

SOFC present a strong approach to the greener energy and mobility, so its development is expected to be strongly promoted by the ecology-aware politics.

3.1.2. Economic

Quantum technologies, being still emergent, require significant investments in research and development and more time until any advantage against business-relevant tasks. As follows, now and in the nearest future the development of quantum computing and simulations relies entirely on venture investments from the public and private sectors. This implies their strong dependence on the overall economic climate.

Moreover, considerable expertise is required to assess the actual worth of the promises made by some companies developing products related to quantum technologies. This is due to a tendency to overpromise, set by numerous emergent companies in strife for the distribution of funds. Occurrent "quantum hype" makes the fair distribution of funds more complex and presents the whole sector less attractive for cautious (non-venture) investors. The uncertainty about the time of arrival of the bespoke Quantum Advantage, and sometimes – whether it will arrive at all, also contributes to the repelling of classical investors.

Prohibitive costs of development in quantum technologies then may imply that:

- Unfavourable economic situations may lead to stagnation in the development process due to the high fraction of state-owned capital in the tech.
- If technology is much less cost-effective than classical ones – it may not attract enough investments.

Specific to use-case 1 (Predictive models for battery design and fuel cells):

The battery market is expected to grow immensely in the following years due to the high demand for batteries in many different industries, modern technologies are needed to meet these needs. Therefore, pressure to find more efficient ways to improve the existing battery technology is increasing.

Nevertheless, economic factors such as inflation and exchange rates can affect the battery modelling market. A strong economy can lead to increased investment in research and development, while economic downturns can lead to decreased funding for battery modelling projects.

Specific to use-case 2 (Materials discovery for battery design):

The battery material market in Europe is heavily influenced by economic factors such as global demand and supply, production costs, and currency exchange rates. Therefore, the adoption of electric vehicles and renewable energy systems in Europe is expected to drive demand for battery materials and research.

Specific to use-case 3 (Aerodynamics simulations):

Since some of the technologies developed for the use-case is niche, the solution relies on the economic situation at the domain of its application.

Specific to use-case 4 (Space mission optimisation):

Optimisation tasks being ubiquitous in technology, business, and operations, ensures certain stability for the business model built around this use-case.

Besides, the market for the direct solution (optimisation of the space missions) is not highly susceptible to economic instabilities (with typical mission duration at the scale of 10 years, which is longer than a typical scale for economic perturbations). Besides, at some point of

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development of quantum technologies the operational expenses are expected to be lower than these of the classical solution, which will also contribute to the independence from the economic situation.

Specific to use-case 5 (Space data analysis and processing):

Since the proposed solution is intended for perpetual use, incurring high CapEx and noticeable OpEx, its long-term success depends on the situation at the market of spatial imaging. (Since the machine will be at the client's side and involved in Defence missions, it is unlikely to be multi-purpose to draw additional cash flows from secondary tasks). Then, any strong economic perturbations, drawing out the venture investments, may interfere with the solution development (if it is still under development).

Specific to use-case 6 (Solid oxide fuel cell optimisation):

SOFC market is expected to grow exponentially for the next years, positively influencing the development of the solution. However, since it is mostly driven by the thrive to the greener economy, any major economic events might slow down this pace, re-directing the investments in more vital sectors of the economy.

3.1.3. Social

Thanks to its high disruptive potential, the notion of quantum technologies has entered different circles, starting from higher education (with multiple programs dedicated to quantum technology appearing in the recent years all around the world), business (according to the number of financial reviews, predictions etc. in the sector), social (notable advances, primarily associated with emerging European start-up's, often get into the news). Here the Quantum Hype helps the dissemination of information and the growth of the domain's popularity. Since the market of quantum workforce is not yet saturated ("only ½ of all the jobs in quantum will be filled by 2025"- McKinsey [5]) – active promotion of Quantum Technologies in the information field creates a positive feedback loop in education, with more students coming into the domain, remaining there after graduation, advancing the technology even further and creating more workplaces for the next generation of graduates. This tendency also attracts cash flows into education and academia, which are essential for providing highly skilled professionals. These tendencies make the domain of quantum technologies attractive in people's eyes and create interest in it, despite the steep and long learning curve.

All these result in the following potential levers to boost the development of the solutions, originating from the social sphere:

- Quantum Hype makes society more aware of the technology, thus making it easier to pave its way to markets.
- Advanced technologies create many workplaces for skilled professionals and supports higher education institutions.
- Quantum Technologies do not hide explicit threats to the social models of nowadays (unlike the AI or VR), so any dramatic innovation should be positively accepted.

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All the previous arguments are applicable to all the use-cases. Some of the use-cases, however, suggest other, more specific aspects, to be taken in consideration:

Specific to use-case 1 (Predictive models for battery design and fuel cells):

Increasing awareness of battery safety and reliability drives the demand for better battery modelling tools. Sociocultural factors such as consumer attitudes towards sustainable energy and the environment can drive demand for battery modelling solutions. For example, growing concern over climate change and air pollution drives demand for electric vehicles, which drives demand for battery modelling software that optimises battery performance.

Specific to use-case 2 (Materials discovery for battery design):

European consumers' growing awareness and concern for the environment and sustainability drives demand for more sustainable and environmentally friendly battery materials.

Specific to use-cases 4 and 5 (Space mission optimisation, Space data analysis and processing):

Aerospace photography has already become ubiquitous and an essential part of people's life (google maps, weather forecasts, etc.). With the uprisal of personal privacy awareness, social movements may appear, which will (through political channels) try to alter the existing market of spatial imaging (by promoting some restrictions). Restrictions on the spatial imaging market will have consequences on the use-case domain. However, for the space mission optimisation use-case, the flexibility of the technology driving the solution and the ubiquity of applications for optimisation, should mitigate this risk. On the other hand, SAR techniques are closely related to Intelligence and Defence, and may be seen in a political context, with the consequent positive or negative connotations.

Specific to use-case 5 (Space data analysis and processing):

Restrictions on the spatial imaging market will span the solution discussed. SAR techniques closely related to Intelligence and Defence may be seen in a political context, with either positive or negative connotations.

Specific to use-case 6 (Solid oxide fuel cell optimisation):

SOFC having a potential to disrupt the economy and ecology of mobility, should receive promotion from any kind of social changes or movements.

3.1.4. Technological

The solution developed by EQUALITY consortium involves a spectrum of different hardware, software, and operational technologies, which are essential for delivering the best value to its clients. This technological richness makes it sensitive to large changes in some domains of technology. For example, dramatic scientific advantages in the field of quantum hardware or algorithms, especially those used in the proposed solutions, may speed up the development process and contribute to the internal expertise.

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On the other hand, dramatic advances of the competitors (both quantum and classical) can present severe threats to the commercial success of the solution, which should be considered. Nonetheless, the quantum-based competition can be mitigated by developing a more flexible (e.g., hardware-agnostic) stack of technologies within the solution. Then, if any rival technology arrives at desired maturity much earlier, the consortium will have a chance for early adoption and adaptation. Another technology-related aspect is the emergence of other disruptive topics, such as AI, Metaverse, Blockchain, etc. – which divert attention and funds from Quantum. Even though they present no direct competition, this resource dispersion can negatively influence the pace of development of Quantum technologies.

The main positive influence from the domain of technology can be found in:

- A lot of research being conducted nowadays in the domain of quantum technologies, increases the chances of technological and commercial success for the solutions developed within the EQUALITY consortium.
- The EQUALITY consortium can conceive the solution flexibly enough (e.g., hardware-agnostic, or hybrid-ready) so that any dramatic technological advancement outside of the consortium could be adapted to the proposed solution before the competitors fully use it.

At the same time, certain negative impact can be faced, such as:

- Success of the whole solution strongly relies on the creation of a suitable operational quantum hardware, which in its term is dependent on the current level of development of technology.
- Quantum Technology (QT) is still challenged by classical and heuristic (incl. AI) technologies. Thus, any dramatic advantages in these domains may set back the advancements in QT (concerning the problem);
- Other emerging domains (AI, Metaverse, Blockchain) may divert the attention and capital of investors.
- Deeply application-specific algorithms can narrow down the application domain for the technology, making it susceptible to dramatic changes within the domain.

All the previous points are valid for all the use-cases. However, for some of them there exist more specific types of impact, such as:

Specific to use-case 1 (Battery fuel cell modelling):

Technological advancements are driving innovation in the battery modelling market. New techniques and technologies being developed, like battery modelling on quantum computers, will improve the accuracy and reliability of battery models, besides machine learning and artificial intelligence.

Specific to use-case 2 (Materials discovery for battery design):

Europe is home to several leading battery technology companies and research institutions that drive innovation and develop new battery materials. Technological advances, such as machine learning, simulation, and automation, are expected to accelerate the discovery and development of new battery materials.

Specific to use-cases 4 and 5 (Space mission optimisation, Space data analysis and processing):

The solution tailored for a use case within a niche market strongly depends on the use-case well-being. In this case, since the space imagery satellites include many complex technologies, any changes in the market of complex scientific instruments, aerospace, or imaging technologies, etc. – may induce changes in the perspectives of the solution's application. However, these changes will be long-term since space technologies take time to mature (at least a decade to develop, build and send a satellite), and the current missions, for example – Pleiades, is planned to be run for at least the next 10 years.

On the other hand, dramatic advantages in the space technologies (e.g.: decrease of weight-to-orbit costs) allowing to send larger machines in space, will dramatically promote the development of an orbit-based quantum computing unit, which will add the momentum to the solution development.

Specific to use-case 5 (Space data analysis and processing):

Any technological substitute to the SAR will influence the solution negatively, as well as any dramatic advantages in its classical counterparts (e.g.: low-power and efficient satellite-based image processors).

Specific to use-case 6 (Solid oxide fuel cell optimisation):

SOFC is not the only novel type of energy convertor, and a strong concurrence is exerted from other "green" technologies, such as Hydrogen Turbines or Electric batteries. The concurrence is exceptionally tough in the domain of mobility. Then, dramatic advancement in the competitive technologies (such as - reduction of the specific weight of the batteries or increase of the turbine efficiency) may shrink the market share of the SOFC solutions, together with the budgets on their development, which will negatively affect commercial viability of the quantum solutions in this domain.

3.1.5. Environmental

Quantum technology is, by design, intended to scale its energy requirements dramatically better with the problem size than its classical counterparts, which puts it in tune with a global orientation towards ecology. To be more specific, since quantum algorithms are by paradigm reversible – their implementation is possible only with non-dissipative processes. Of course, the preparation and operation of quantum states (e.g., in a gate-based paradigm) involve some physical processes, which consume energy (e.g., lasers), and these will scale with the system size. However, the primary power demands in quantum hardware come from completely non-quantum support equipment: vacuum pumps, cooling tubes in refrigerators, magnetic coils, etc. Consumption of these elements does not depend on the size of a quantum system and remains at the scale of a single rack mount in a data centre. Once the quantum advantage is reached against typical HPC use cases (ML, complex supercomputer simulations, etc.) – at scale, it will decrease the ecological footprint of data-rich industries. All these qualities of quantum computing make it attractive for ecology-oriented companies and governments, supporting.

Current solutions, used at all the respective domains, are using HPC and consume a lot of energy. Introduction of quantum technologies in the backend will dramatically shrink the ecological footprint of such computations, which should be positively accepted from the ecological perspective.

This outlines the principal positive influence on the solutions from the Environmental perspective: Since Quantum Technologies should be more efficient (and greener) than its competitors to the solution proposed, ecology-aware companies and governments should prefer and promote quantum-empowered solutions.

For the same reason, any harsh restrictions regarding the ecology of industrial R&D would encourage companies to find more efficient ways to solve the same problems, one of which should be Quantum.

All the previous arguments are applicable to all the use-cases. Some of the use-cases, however, suggest other, more specific aspects, to be taken in consideration:

Specific to use-case 1 (Predictive models for battery design and fuel cells):

The battery industry is under increasing scrutiny due to concerns about the environmental impact of battery production and disposal. The industry is working to develop more sustainable and environmentally friendly battery production methods. New battery types help to reduce consumption of petrol-based fuels in the field of mobility and transportation. This has a high impact on our environment.

Specific to use-case 2 (Materials discovery for battery design):

The battery material market in Europe is heavily influenced by environmental factors such as raw materials' sustainability and environmental impact and the disposal of used batteries. The Circular Economy Action Plan and other EU policies aim to reduce waste and promote sustainable practices throughout the battery value chain. This produces a high demand for investigating technologies to accelerate the battery material discovery.

Specific to use-case 3 (Aerodynamics simulations):

CFD solutions can be applied for aerodynamic simulations, including the domain of ecology: atmospheric, weather and climate simulations are nowadays extremely challenging, so the arrival of a quantum solution might help revolutionising these domains.

Specific to use-case 5 (Space data analysis and processing):

SAR imaging can be extensively used for environmental observations, which should promote the development of the solution.

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3.1.6. Legal

Despite the disruptiveness of the technology, the consortium should be aware of any quantum-specific legal basis, especially considering the potential cryptographic threats of large quantum computers, which may lead to some legal constraints eventually introduced to regulate the domain. Some first recommendations already appear, but still no formal legal regulation was imposed on the field of the quantum computing [6].

However, some issues may arise from the use-cases, where the results obtained with quantum technologies may require posterior verification (due to the recent apparition of the technology and sometimes – probabilistic nature of quantum computing). Once this is impossible, the industry may need certification to ensure the results' quality. Besides, it is essential to consider use-case-specific issues with the legislation, such as specific restrictions of IP exchange between participants, data security, etc.

Despite absence of strict regulation up to date, any favourable or unfavourable laws may dramatically influence the course of development of the domain and even create some roadblocks for particularly disruptive technologies.

All the previous arguments are applicable to all the use-cases. Some of the use-cases, however, suggest other, more specific aspects, to be taken in consideration:

Specific to use-case 1 (Predictive models for battery design and fuel cells):

Legal factors such as patent laws and intellectual property regulations can affect the battery modelling market. Companies and organisations working in the battery modelling industry must navigate complex legal frameworks to protect their intellectual property and avoid infringing on the intellectual property of others.

The European Parliament reached a preliminary agreement on 9.12.2022 about changing the new rules considering the latest technological developments. The agreed rules will cover the entire life cycle of all types of batteries sold within the EU. This includes topics from design to recycling of batteries. There will be stricter requirements for the sustainability of batteries to make them more efficient and longer lasting. This initiative is linked to European Green Deal Economy Action Plan and the new Industrial Strategy.

On the other hand, the improvement of the battery modelling tools should be favoured (by the regulators), as it allows to a decrease the CO_2 footprint of the battery industry by providing more efficient batteries and saving on time and material needed for their development.

Specific to use-case 2 (Materials discovery for battery design):

The battery material market in Europe is subject to various legal and regulatory requirements, including health and safety and environmental regulations. For example, the EU's Battery Regulation, which came into effect in July 2021, sets requirements for the sustainable production, use, and disposal of batteries in Europe.

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Specific to use-cases 3-5 (Aerospace simulations, Space mission optimisation, Space data analysis and processing):

Aerospace-related use cases may not bring up any dilemmas (like data protection or verification of the results) that would require establishing some legal basis.

The proposed solution is not opening new markets or dramatically changing the use case. The use case is quite long-established, so all the underlying legal basis is already stable. One should not expect dramatic changes in the state of this situation, which makes the solution feebly dependent from the legal context.

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3.2. General situational assessment

The maturity of quantum technologies defines principal strengths and weaknesses of the solutions, while the domains of their applications govern the main opportunities and threats.

Internally, the main strengths of the solution are its disruptiveness and adaptability, while the main weakness is low technological maturity. Considering external analysis, primary opportunity for the growth of the solution is a large market for the added value, while ambiguity of technological promises comprises the main threat. The analysis is summarized in Figure 2 below.

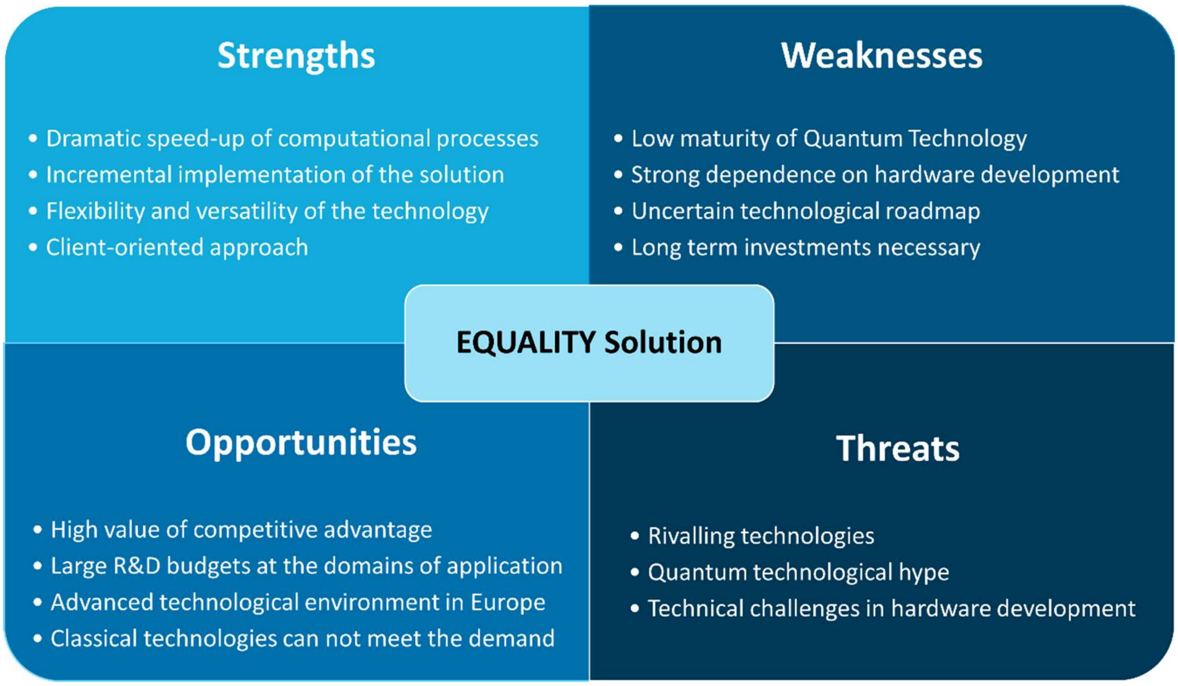

Figure 2: Brief of SWOT analysis for Equality solutions.

3.2.1. Strengths

The solutions being empowered by quantum, and capable to bring large advantages to the domain of applications, remaining nonetheless complex and multi-layered – thus adaptable to other problems.

Through all six use-cases, covered within this project, several common strengths can be identified:

- **Disruptiveness:** capacities of the solution to dramatically increase performance of the current processes for each of the given use-cases.
- **Versatile usage:** flexibility of the full technological stack, allowing it to be adapted to solve various problems in other domains, like novel energy sources, product design, defence, etc.

- **Incremental implementation:** solution can be progressively introduced in the adopters' environment according to the evolution of market-ready quantum technologies. They can be presented as a hybrid classical-quantum framework to leverage the best value from the near-term devices.
- **Readiness of Human Resources:** most of the use-cases lay within long-developed domains of technology, including active research, multiple elaborate techniques, and highly qualified specialists. The latter facilitates the transition towards the modern technologies.
- **Client-oriented approach:** The solution can be tailored for each early adopter and proper workflow, enabling a favourable environment for a smooth transition from the current technology stack to the novel one.

Specific to use-cases 1, 2 and 6 (Predictive models for battery design and fuel cells, Materials discovery for battery design, Solid oxide fuel cell optimisation):

All energy storage related use cases offer a range of benefits, including cost-effectiveness, time-efficiency, and flexibility, making them a valuable tool in the development of energy storage systems.

- **Provides an efficient and cost-effective method** for identifying new materials and designs for fuel cells and batteries without the need for extensive experimental testing.
- **Market potential:** Growing demand for advanced power sources for mobility, like batteries for electric vehicles, renewable energy systems, and portable electronics is driving the growth of the respective markets.
- **Economic efficiency:** The solution can bring a dramatic competitive advantage by saving much working time and workforce in R&D.
- **Feasibility:** Enabling complex simulations, not feasible on classical computers.
- **Quality:** Increasing the quality and lifetime of products due to a better understanding of processes within the electrochemical cell enables more precise control and optimisation of battery systems. Because the solution provides valuable insights into the properties and performance of new materials, allowing for better design and optimisation of battery systems.
- **Accuracy:** Due to the possibility of using high-level quantum chemical methods for parametrisation of the solution, the solution delivers more accurate results compared to classical methods. Precise simulations considering the use-case specificities can help achieve the goals by using new materials and designs to fit the energy storage systems to required requirements.

Specific to use-case 3 (Aerodynamics simulations):

The solution will be developed in close interaction with large clients (direct and indirect), and quantum technologies developed by the consortium will power it.

Specific to use-case 4 (Space mission optimisation):

Hardware-agnosticism: Most optimisation tasks can be implemented natively on most quantum hardware types. This is a strong point of the technology overall. Still, it remains of undetermined use to the commercial viability of the solution: on the one hand, adding the flexibility to adapt to the most developed backend at any time. On the other hand, a consortium restricting the development of a single hardware technology may leave the solution vulnerable to its competitors.

Specific to use-case 5 (Space data analysis and processing):

Multiple quantum approaches: a plurality of quantum and quantum-inspired approaches to SAR image processing, that can be augmented with quantum technologies. This paves the way for parallel exploration of several techniques (e.g.: some for short-term benefits using NISQ, other – for long-term projections, preparing for the fault-tolerant or large-scale quantum computing), making the solution more versatile and flexible.

Specific to use-case 6 (Solid oxide fuel cell optimisation):

Applying quantum methods to SOFC development can dramatically speed up the development processes and the market exit of the technology. Besides, the methods developed for this solution can be expanded to other domains of material design and R&D, impacting the industry. In add the generic benefits, associated with quantum computing in comparison to the classical HPC, the solution presented here is aimed to provide precise simulations considering the use-case specificities, which can help achieving the goals of introducing the lighter materials into the SOFC design, alleviating one of the main bottlenecks of zero-emission mobility – high specific weight of the solutions.

3.2.2. Weaknesses

The main common weaknesses of the solutions, developed within this project, are:

- **Low technological maturity:** Quantum Computing is yet in its active development. Rapidly evolving market includes many players with each building its own PoC and demonstrators and proposing different technology roadmaps. All of these create some uncertainty about the future of the technology.
- **Choice of the leading technology:** Some quantum algorithms can efficiently run exclusively on certain hardware architecture (e.g., [7]). While it is hard to predict when the necessary technology will be ready and if any other will surpass it. Then, restricting the solution to a singular use case and a specific provider, despite the tailored advantages, is sharpening its viability segment.
- **Time till maturity:** Uncertainties in the timeline of the quantum technology development present commercial risks and may not enable reliable long-term planning (e.g., stable hardware equipment may be released to the market as late as in the following years/ decades).
- **Large long-term investments needed:** The quantum computing approaches still need improvement to compete with long-established classical rivals, but the R&D activities for quantum technology have significant costs. This implies additional years of development and the necessity of large, long-term investments.

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Specific to use-case 1 (Predictive models for battery design and fuel cells):

Highly competitive pressure: many vendors offer comparable products, making it difficult for new entrants to establish themselves. Many simulation tools are already available for classical computers; the solution must be faster than the existing tools to be competitive.

The market is still in the initial stages of development, and there needs to be more standardisation in battery models and testing methods, which can create confusion and make it difficult for customers to compare various products.

The complexity of battery systems can limit the accuracy and reliability of battery models, making it challenging to develop models that accurately capture all relevant factors.

Specific to use-case 2 (Materials discovery for battery design):

There needs to be more standardization in the testing and evaluating new battery materials, which can make it difficult to compare varied materials and assess their performance accurately. This makes it difficult to validate the quality of the simulation.

Solution requires significant expertise and training to use effectively, which can limit accessibility to non-experts.

With quantum technology nowadays, the system size that can be tackled in the simulation is limited; therefore, not all relevant physics or chemical phenomena can be captured in the solution, leading to errors or inaccurate predictions. Still the accuracy of the simulation can be limited by the complexity and variability of real-world battery systems. Furthermore, the quality of input data and assumptions made in the modelling process could impact the solution's reliability. The prediction quality can also be worse by the lack of experimental data on new battery materials.

Specific to use-case 3 (Aerodynamics simulations):

Commercial applications of quantum computing are yet at their dawn, weighing in for the weaknesses of the solution. Plus, once quantum supremacy is reached, some results will be hard to verify, which may have consequences:

Complex verification of the results: The absence of an alternative proof for quantum-enabled simulations includes certain risks in the development framework: if the quantum simulation were erroneous, it would be noticeable after building a wing console and placing it in a wind tunnel.

Specific to use-case 5 (Space data analysis and processing):

Lesser flexibility: Some algorithms driving the solution are highly tailored to the specific problem. Means of delivery will also be often adapted to clients, especially those in the Defence sector. All these aspects make adapting ready solutions to different problems, domains, or clients complex, leaving it less flexible.

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3.2.3. Opportunities

Main opportunities are presented by the development of the markets for each of the use-case. Most of them are highly technological, and the improvements brought by the quantum computing can boost the respective markets even more.

Some common opportunities are:

- **Market opportunities:** High R&D budgets of the industry enabled ventures like quantum to explore new applications. The increasing demand for batteries for renewable energy and electric vehicles is expected to continue to drive growth in the battery modelling market.
- **Investments opportunities:** High competitiveness [8] in the aerospace and energy domain, along with high stakes in creation (for example, grants from governmental agencies, e.g. 101 gifts of a total value of 225 M GBP [9], 26 M € [10], [11] make a very fertile soil for disruptive ventures, such as quantum: prohibitive costs of innovation are covered by even higher revenues from competitive advantages. This tendency would consequently create many potential clients for the consortium.
- **Choice of potential partners:** Many players in the market of quantum services are SMEs, and most of the technologies still need to mature for the standalone provision of business value to their clients. Moreover, there is a tendency for different technologies to perform at different use cases, suggesting that strategic partnerships may be the best way for companies to scale. These reasons endorse the creation of partnerships and alliances on the market, which is how the consortium follows.
- **European technologies:** Numerous Quantum software and hardware companies originate from the EU. This gives the advantage of selecting the most suitable partners and providers and retaining the strategic benefit of “domestic” providers at the EU scale.
- **Demand on Data-Driven approaches:** according to Moore’s law (et al.) – advances in classical computation techniques are unlikely to satisfy ever-growing computational power demands. Amounts of data collected in experiments and advances in manufacturing techniques push the industry to seek new concepts to process these amounts of data. Some techniques developed within this project can be applied to more generic data processing schemes, not closely tied with the initial use-cases. Successful implementation of such approaches can stem more advances in the classical domains or Optimisation, Simulations, Image Processing and Data Science.

Specific to use-case 1 (Predictive models for battery design and fuel cells):

The battery market in Europe is behind China's production capacity, and it is hard to gain the same capacity level in Europe as in China. However, the potential for the European battery business lies in developing a high-quality battery with a high-security standard. Therefore, the innovation pressure of finding new battery technologies and materials is remarkably high in Germany and Europe. The emergence of new battery chemistries and technologies, such as solid-state and flow batteries, presents an opportunity to develop new and more advanced modelling tools. This inducted a substantial chance of a solution to improve the battery development process.

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Specific to use-case 2 (Materials discovery for battery design):

Advances in computational power like quantum computers are enabling the development of more sophisticated battery material discovery simulation tools.

The growth of renewable energy sources and electric vehicles is driving increased demand for high-performance battery materials, creating new opportunities for innovation and investment in this field. As well as the demand for Sustainable materials in the battery development, is an increasing market for new technological solutions on the battery modelling area.

The emergence of new battery chemistries, such as solid-state batteries, presents an opportunity for researchers to develop new materials that can enhance the performance and safety of these systems. And accelerate the discovery of new materials by developing more efficient and accurate computational methods and simulation tools and reduce the cost and time required for experimentation.

Since the problematic in the battery material discovery area is comparable to other material research areas and the concepts are comparable, algorithms developed for the battery material discovery solution can be transferred to other areas for material research. Potential industries can be Pharmaceutical and chemical industry, especially drug discovery, catalysis processes. Another target area is the development of solar cells, computer chips or in the field of nanotechnology.

Specific to use-case 3 (Aerodynamics simulations):

The landscape of opportunities for the solution is defined by the domain of application (aerospace technologies, with large budgets and strong demands for technological breakthroughs), and by the domain of quantum technologies (plethora of prominent SME's having high influence on the domain):

Exceptionally large market: High R&D budgets of industry-enabled ventures like quantum. The total research and development budget for the leading aerospace actors Airbus and Boeing in 2021 were respectively of Airbus [12] – was 2.75 Bn€ and Boeing's [13] 2.25 Bn$. The entire EU quantum [14] budget is around 1 Bn€.

Absence of established leaders on the market of quantum-empowered technologies: Being still emergent, the call for quantum-empowered solutions has yet to reach saturation, while classical solutions are already facing their limits. Moreover, despite a few large players (like IBM, Microsoft, Amazon, Alibaba, etc.) – there is no sign of solid dominance or oligopoly in the market.

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Specific to use-cases 4, 5 (Space mission optimisation, Space data analysis and processing):

Ever-growing demands on satellite data acquisition is a strong motive force for the use-cases imply: [15]

- With no breakthrough in the optimisation technique, constant increase of the number of tasks within constant satellite productivity leaves a single way out – launching more satellites, which is expensive.
- Any breakthrough in the image-processing techniques, such as SAR, could noticeably expand the capabilities of existent technologies without dramatic expenses on changing the satellite constellations (if processing is still done on ground).
- Domestic technologies**:** Europe is currently taking leading positions in the market of applied quantum technologies and research, with many competitive start-ups and governmental initiatives stemming in recent years. This point is exceptionally valuable for customers from the Defence sector.

Specific to use-case 6 (Solid oxide fuel cell optimisation):

Boosting the Energy sector R&D with the power of quantum computing will open the gates for many subsequent discoveries. More efficient electrochemistry simulations can revolutionize the domain, and finding its success in the adjacent ones, such as more generic chemistry, pharmaceutical, etc.

The use-case itself is expected to receive high appraisal, since the topics of green energy and mobility are of utmost importance nowadays. Any new ecological restrictions, especially in the mobility sector, will add the momentum to the use-case applications.

3.2.4. Threats

Major threats for the solutions covered by the project originate from rivalling techniques (classical or AI):

- **Rivalling technologies:** Classical solutions are well-developed and have a long history of improvement – it may be hard to surpass them in terms of performance, cost, or both. ML-based techniques are presenting another strong rival.
- **Quantum technological hype:** Many emerging technologies, initiatives, and start-ups in the quantum domain nurture uncertainty for developers and users. The abundance of SMEs on the market and an overall tendency to overpromise to attract venture capital make it complex for the companies to form consortiums with reliable partners and carry-on information campaigns. A certain number of direct rivals may create much concurrence to all the in-house developments, rendering any long-term investment riskier.
- **Technical Challenges:** There are many technical challenges associated with the development of simulation tools using quantum computers, including the need for specialized hardware and software, which may slow down progress in the field.

Specific to use-case 1 (Predictive models for battery design and fuel cells):

The prohibitive cost of the solution and the low awareness of their benefits among some potential customers may limit the market's growth.

The increasing focus on sustainability and circular economy may shift towards battery recycling and second-life applications, which may require different modelling tools and approaches.

Specific to use-case 2 (Materials discovery for battery design):

Competition from alternative approaches to battery material discovery, such as experimental testing and high-throughput screening, may limit the growth and adoption of quantum simulation solution.

The potential for intellectual property disputes and patent infringement claims may limit the ability of companies to commercialize new battery materials discovered through simulation tools.

The prohibitive cost and long development time associated with battery material discovery may limit the number of players in the market, leading to limited innovation and slow progress.

Regulatory barriers and safety concerns related to the use of new materials in batteries could slow down the adoption of these materials in commercial products.

Specific to use-cases 4, 5 (Space mission optimisation, Space data analysis and processing):

Technical obscurity: Quantum-powered solution in the mid-term remains exceptionally complex technology, with the requirements for operation often being stringent. Without extensive informational campaigns the Defence sector may not be among the first technology adopters. High requirements on operation and maintenance personnel qualification make the adoption decision even harder. Then, any dramatic failure (of any other Quantum solution) may stain the reputation of quantum technologies and repel potential customers from sensitive domains.

Specific to use-case 6 (Solid oxide fuel cell optimisation):

High competitiveness in the alternative energy sector from alternative energy converters (hydrogen turbines, batteries, etc) sets a high bar on the way to commercialising the developments using complex and long-perspective solutions, such as quantum.

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3.3. General business model elements

This section describes common features of the business models proposed for commercialisation of the solutions resulting from this project.

Many common points have been identified among the business models created for the six different use-cases. Most of these points stem from different properties of the quantum technologies, that bring the competitive advantage for all use-cases and are thus common for all the use-cases. This section describes in detail those blocks of the Business Model Canvas, that would repeat from one use-case to the other. Those parts are highlighted in the Figure 3 below. For the other blocks of the BMC (namely, the customer segments, value propositions and the revenue streams), this section gives a general overview of the principal constituent parts, while a more in-depth description is given in the case-by-case study in the following chapter of this document.

The Business Model Canvas, as in Figure 3 below consists of 9 building blocks, described in the previous chapter of this document. It is filled with the tiles, grouped by the customer segments addressed, and can be understood as a superposition of a few Business-Models, one for each customer segments. Tiles coloured in green are applied to all the customer segments. Some of the tiles have double colour, resembling two stickers one on top of the other – such tiles address just two customer segments, according to their colour. For example, in the figure below, block Channels has one channel addressing the customers coloured yellow and blue, one addressing all the customer segments, one – exclusively for the customer marked in blue, and finally two tiles addressing blue and violet customer segments, with some degree of priority attributed to the principal colour of the tile.

Generalised through the six use-cases, the business model is centred around bringing computational advantage to various customers involved in highly technological R&D processes, is to be delivered primarily as a cloud service with an opportunity for on-premises hardware allocation. However, the main distribution channel is one-to-one, with multiple possibilities for automated platforms. The main customer relationship is a dedicated long-term assistance. Principal resources are Intellectual property and Infrastructure. Main partners are providers of dedicated software, quantum hardware and infrastructure. Dominant revenue stream is the fees for the usage of solution, while principal costs are associated with developing the hardware and software technology stack.

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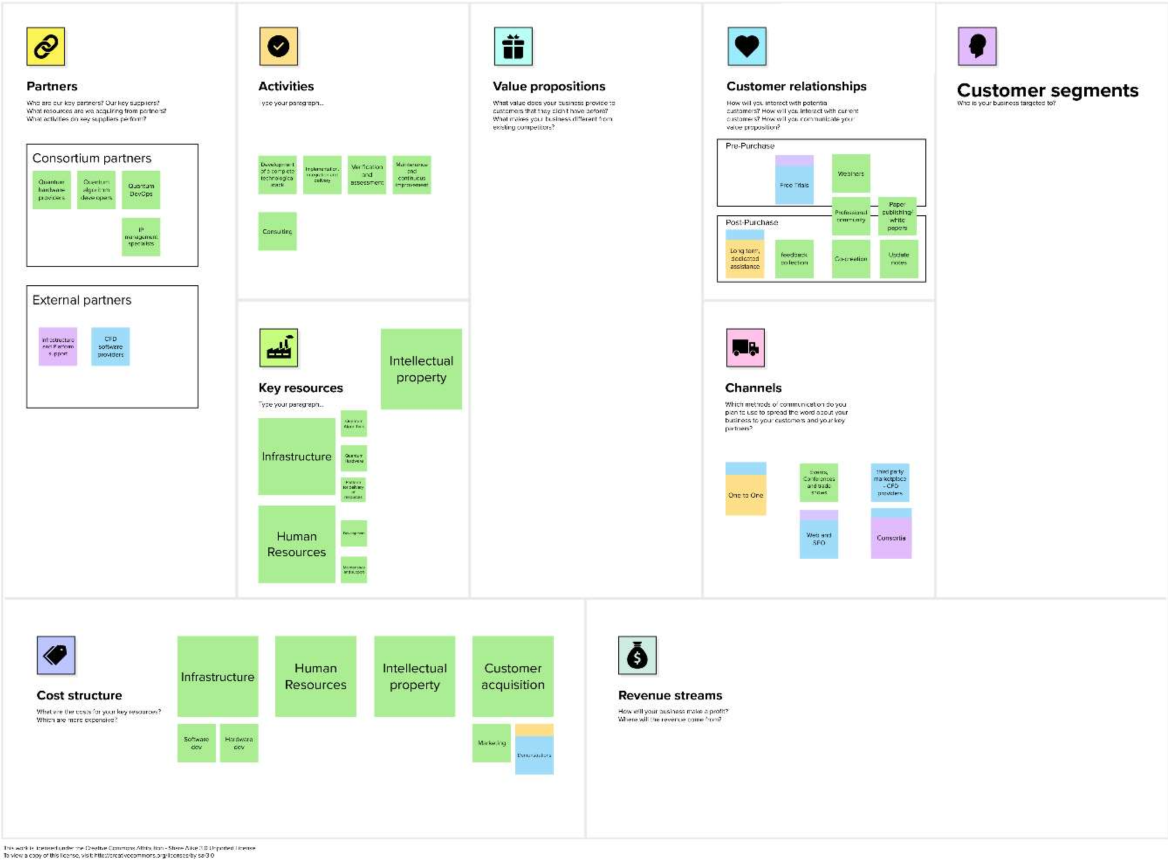

Figure 3: Business model canvas with shared elements. Empty blocks are use-case specific.

3.3.1. Customer segments

Each use-case, being technically specific and narrow, defines its own client segment. However, we can distinguish between several generic types of client segments for most of the use-cases.

- **Industrial clients**: the end-clients for the whole R&D value chain. Companies, that develop, produce, or operate certain technologies or equipment, defined in the use-case. Like: battery manufactures, satellite operators.
- **Simulation and modelling providers**: companies, providing tools (usually – software), essential in the workflow of the respective industry. Providers benefit from the solutions proposed by the consortium to deliver better services and results to their clients and ensure proper integration and delivery of the solution. Consequently, this segment can be involved in the business model as customers, but also as partners.
- **Public Research Institutions (Academia):** multiple use cases covered by the project can result in improvement of the tools essential for industrial research activities, but these tools can also be used in fundamental research. Then, minimal adaptation in the business model can allow addressing a new domain of clients: academia. The main return from this segment is expected to be not monetary, but rather in additional values, such as brand loyalty, preparation of highly skilled professionals, co-operated

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research, etc. However, taking part in public-funded activities is also included in the business models.

- **Adjacent sectors** – in many cases, the main components of the solution delivered by the consortium rely on concepts, that can find use far beyond the specified use-case. For example, various optimisation algorithms can find application in almost any business. In such cases, minor adaptations to the product can open large new markets for the solution, which makes this sector essential to be mentioned in the business models.

Finer details about customer profiles are use-case specific and can be found in the respective sections of the use-case business models.

3.3.2. Value propositions

The whole project is based on development solutions for revolutionising certain industrial workflows using quantum computing. Accordingly, there is a common value proposition through all the business models – **improvement of existing computational processes**. This will create use-case specific final values for each use-case and client segment (like, lower R&D costs, developing better products or reaching higher capacity utilisation), but the origins always lie in a computational advantage provided by the quantum computers.

Besides, some of the use-cases can benefit from the strategic significance of future-proof computational methods.

More detailed descriptions of the value added by the solutions, as well as secondary values brought to the customers because of application of the solutions proposed in this project, can be found in the respective section of use-case business models.

3.3.3. Channels

The technically complex nature of the solution and prohibitive costs of its development suggest two most efficient approaches to reach the current and prominent customers: **one-to-one**, and **third-party marketplaces**, like the platforms of the simulation software providers. The former is aimed principally at the larger industry players, with expected high utilisation of the solution, while the latter is aimed primarily at a wider audience of users, and even these from related disciplines. Software provider marketplaces present an exceptionally potent channel, since it is highly scalable and allows for the simplest integration into the customers existent processes, dramatically expanding the potential coverage of the market. On the other hand, the consortium has the least control over this channel, relying highly on the partners (software providers) for distribution, marketing, and customer experience. This adds certain risk to the channel, suggesting accompanying it with other means of reaching the customers.

Domain specific **conferences and trade shows** present a strong channel to reach a wide range of customers within a given technology domain. Coupled with successful co-creation customer relationships, it can enforce the leading position at the market. Conferences are also a fruitful ground for the first contact and decision-making related to more dedicated one-to-one channel.

Web and SEO can be a great means of reaching for the cloud-based solutions, which is a common variant among the six use-cases described in the Equality project. This channel covers the most audience, and together with the *pay-per-usage* pricing strategy can open multiple opportunities for SME to enhance their business with quantum solutions. Besides, it can serve as an additional attractor for the clients from academia.

Finally, participation in various **consortia** represent a highly flexible channel, allowing to cover the customers in the *developer* and *academic* segments, at the same time mutually beneficial for both the partners and the quantum solution developers. An example of this channel can be participation in public funded projects aimed at exploring the application of quantum computing in new domains of technology. Another type of such channel may find its way in a partnership with some multiphysics simulations providers, like Ansys or COMSOL, and a development of a quantum-empowered plugin for these platforms.

Below, all types of channels, that can be used in the six use-cases described in this project are enlisted, structured in different ways:

Channels by types:

1. **Direct, own**: Solution as a service directly for clients.
   A solution-based business model promotes direct interaction with the clients. This will ensure the optimal tailoring of the solution to the customer's workflow.
2. **Indirect, partner**: Solution as a computational backend for computation providers. Another feasible way of distribution is to install the solution at the providers of battery modelling tools like MathWorks/Simulink. This will ensure maximal integration into the R&D processes of the final customer and delivery of maximal added value by the solution. Besides, since the providers can re-market the solution as a pay-per-use service by themselves, it can dramatically expand sales into the domain of SMEs that do not operate the budgets to integrate the solution permanently but could still profit from its occasional use. Alternative to provider-based sales is selling the solution to the service provider directly. At the same time, they combine the solution with expertise in the field and resell the service to the end user, the battery manufacturer.
3. **Indirect, own:** Solution as a plug-in into the use-case-specific software.
   Having developed state-of-the-art combinatorial optimisation solutions, the consortium can keep the exclusive rights and role of provision of these solutions on-demand for a broad market. This will transform the consortium into a direct provider of quantum services at a global scale.

Channels by phases:

Awareness: Networks and interest groups of use-case ecosystems provide a channel to contact many potential customers, due to high level of connectedness between different research and development teams and organisations. There is a broad, interconnected research landscape in Europe, which can be used to raise awareness about the products. Typical activities at this phase are publishing the results in papers, presenting research results at conferences, active online networking on Social Networks like LinkedIn, maintaining a project web page including a demonstration of results or a whitepaper.

Evaluation: Due to various policies for handling sensitive data and IP management, customers are unlikely to do trials on actual use cases. This makes the technological demonstrators the most promising way of primary evaluation of the technology. Once the solution is ready, the consortium should conduct and publish its assessment on some realistic yet – open data. As a more profound level of evaluation, the consortium can select a service model, providing solutions to customers' tasks via secure data exchange and handling channels.

Purchase: The solution-based model (channel 1) suggests that the solution is developed together with the customer, and the customer pays for its installation, operation, maintenance, and upgrade. When sold as a service via partners (channel 2) – the consortium charges the partners accordingly to the value sold by them. When provided as a service (channel 3) – the purchase is conducted directly from the consortium via a dedicated platform.

Delivery: The Solution proposed here is interesting for the R&D of companies in the battery sector. Usually, data in this area is overly sensitive due to the potential competitive advantage. Therefore, the solution should run on the customers and within their security systems. The value proposition can be delivered as a Solution as a Service, and the actual simulation is done externally on our side. Therefore, a safe and secure data transfer is required. A solution-based business model promotes direct interaction with the clients. This will ensure the optimal tailoring of the solution to the customer's workflow.

After-Sales: After-sales support and improvement are key advantages of the developed solution. Primarily – even after the delivery of the solution, the consortium will continue developing the technological stack, improving the solution's performance. This will uphold the leading position of the solution on the market, increasing its value for the clients.

With Quantum Technologies advancing year-to-year, the most significant improvement would be on the side of the quantum processing unit. For this, one can envisage two models of provision:

1) Rolling release model:
   The client's hardware and software are updated perpetually, following the advancements of the R&D process. Customers' on-site hardware and software can be upgraded during regular maintenance sessions. This will always allow for maintaining the state-of-the-art performance of the solution, giving competitive advantages to the customer at every point in time. The price of the regular updates (according to the roadmap) will then be included in the charges for solution maintenance, bringing in the benefits of the subscription charging model. This makes budget planning simpler for both the customer and the consortium. This model may be more economically beneficial for customers with critical demands on performance.
   When distributed to broader markets (optimisation-as-a-service), this mode retains its benefits of state-of-the-art. However, since the provision is more transaction-like (pay-per-resource, e.g., for a problem, computation times, etc.), the after-sales reduce to keep the client current with current capabilities and pricing to stimulate the following orders. When distributed to broader markets (optimisation-as-a-service), this model retains its benefits of state-of-the-art.

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2) Fixed-version model:
The client subscribes for or buys a fixed version of the solution (hardware + stack). Significant upgrades are to be made on specific customer demands, with transaction-based prices re-evaluated according to the market situation and the increase in value. This model may be more cost-effective, since the customer can purchase the solution with optimal capabilities according to its needs and avoid overspending on the computing powers it does not use. This makes it more suitable for smaller and less dynamic enterprises. Without the need to perpetually upgrade the solution, self–maintenance costs can also be decreased for the consortium. However, this model inconveniences the provider, as it is necessary to support a few different versions, and there are no continuous cash flows to support further R&D activities. This makes the model less attractive for the 2nd and third sales channels.

For the solution delivered via (channel 1), the after-sales should also include intensive maintenance and support on the solution-related issues from the part of the consortium (consultation on artefacts of simulations and capabilities of optimisation, etc. Targeted support may be complicated for the indirect channels (2 and 3). However, if a large enterprise is an intermediary provider of the solution (channel 2), a consortium can help this partner. In contrast, the partner will propagate it to the rest of the value delivery chain until the end customer.
Globally, the tendency of the after-sales for the provided solution is the following: the broader and more diverse the market – the more generic and "backend"-oriented the aftersales. The more significant the client is, the more the solution is tailored – the more targeted and precise the support.

3.3.4. Customer relationships

The customer relationships can be structured respective to the stage of interaction with the client into *pre-purchase* and *post-purchase* ones. Due to the disruptiveness of the solution in its fields of application and the development costs involved, the pre-purchase relationships should be aimed at demonstrating the advantages brought by the solution, while the post-purchase ones should be aimed at maximising the value brought to the customers by the solution.

As follows, the main pre-purchase relationships for the solutions developed in the six use-cases covered by the project are:

- Organising **webinars** with detailed descriptions of the solution, potential cases that it can disrupt, and tutorials on how to get the best out of the solution. These webinars can be aimed for open public, as well as organised after the demand from a specific company. They will help to explain the potential customers all the functions and caveats of the solution, leading them to become the customers.
- **Free trials** can serve a strong instrument to help the clients assess the added value of the solution. These trials may incur additional costs, such as provision of a separate (trial) licensing modules via a cloud platform or taking care of the unsanctioned use, however, assuming the solution is the state-of-the-art on the market at a given time – existence of a trial version should dramatically simplify the access for the potential

clients, especially among SME, as well as serve a convincing argument in leading them to purchase.
- To cover the customers in the fundamental research, provision of special (free or dramatically cheaper) **academic or educational access** to the solution may be a large step towards the acceptance of the solution by the market. Firstly, academia is the primary source of the human resources for such deep technologies as those, improved by the quantum solutions, so introducing the specialists with the new tools during the educational and research phase of their career will be a strong driver for wide acceptance of the solution throughout the market. Besides, empowering the fundamental research with the state-of-the-art tools should speed up overall growth of the applied research in the market segment.

In the post-purchase phase, the consortium would build the following relationships, to enhance the added value of the solution:

- Primarily, the relationship to establish for such involved and expensive solution, as the quantum computation, should be **long-term dedicated assistance**, especially for larger clients in the software providers and developers/producers' segments. It will allow to tailor the solution features to match the customers' demands at any time, as well as solving the problems occurring while using the technology.
- Continuous collection of the customer's **feedback**, personally or by automated solutions, is essential to ensure the high customer's satisfaction in the rapidly evolving market of high technologies.
- Always keeping the customers updated with the solution's new features should engage them and guide them to extract the maximal value from the solution. One of the ways to do this is by sending **update notes** with every improvement of the quantum solution.
- **Co-creation** is a great approach to dramatically improve the added value of the solution with minimal direct costs. Supporting different exchange platforms, such as forums dedicated to the users of the solution, should ease the transition of expertise between the customers in different domains. This should be very fruitful, given the presence of academic customers in almost every use case.

Finally, creating **professional communities**, on- and off-line, and **paper publishing** can help at both pre-and post-purchase phases. These will help to increase the interest of the potential customers and give a valuable way of sharing their achievements with the existing ones.

3.3.5. Revenue streams

The revenue models for each of the proposed use cases depend strongly on the way of provision of the solution (personalised or one-fits-all, on-premises, or cloud, etc.), major customers, and specificities of the domain of application. However, the general structure of revenue sources can be outlined based on the type of value received and the level of client involvement:

Consulting services are included in most business models as a non-principal, yet – valid revenue stream, with the broadest coverage of the client domains. Consulting includes assessment of current workflow of the clients, suggestions on its improvement with or without quantum computing, and similar. These activities can be performed at the lowest level of customer involvement, allowing for the highest flexibility.

Besides, after-sales consulting can be technical assistance or user training. This can make part of the usage fees or form an independent revenue stream.

Usage fees, in various forms and pricing approaches, present the principal income stream in most of the business models proposed within this project. This stream necessitates the solution developed and delivered to the client and encompasses the charges for the main values delivered to the client: improving the current customer's computational processes. They can be based on different approaches, like pay-per-use or subscription models. This is the major source of revenue for delivering the *solution* via the *cloud,* but it is also valid for other approaches. This incurs a prominent level of client involvement (purchase) but still does not impose long-term contributions.

Hardware assets, including several types of sales, leasing, delivery, installation, and maintenance, present an important (and the main, for some use-cases) source of income for various use-cases. Due to the emergent nature of quantum technologies, highly valuable IP involved and prohibitive costs of production and set-up of the equipment, this source is most suited for customers with exceptional data protection and high usage requirements, prepared for long-term collaborations and investments.

Participation in various **public funding and grants** can present another stream of revenues for some use cases. It is highly aimed at clients within the academic sectors, as well as some start-ups in the domain of development/manufacturing. It is not expected to be the main source of the cash flow for the solution providers; however, it will be the most fruitful in terms of non-monetary value: enhancing relationships with other clients by co-creation, publishing and support of the professional community; preparing the ground for the creation of new channels via *consortia* and *conferences;* internal R&D and improvement of the quantum solution itself.

3.3.6. Key resources

The main resources needed for successful solution realisation are highly common through all the use cases since they are defined mostly by the underlying technology (quantum computing) and the means of its delivery (described above in channels).

Intellectual property is essential for the successful creation of the solution, as well as its constant improvement. It needs to be created or acquired and responsibly managed further. This point will become important for the commercial viability of the whole solution when the computational advantage of quantum computing comes into play since some algorithms can be easily ported on different hardware platforms, opening paths for strong concurrence for similar technologies.

Infrastructure for providing the value by solution, including the quantum hardware, quantum algorithms and means to deliver it to customers, are of existential importance for the whole quantum-empowered solution because they define the existence of its added value and its successful reaching the customers.

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Human Resources – highly qualified specialists are indispensable for the creation, perpetual improvement, and maintenance of the sophisticated solution. Besides, client relationships, consulting services and training, as well as incorporating the solution in the workflow of the larger customers, require extensive knowledge in the domain of quantum computing and the applications, making human resources of utmost importance.

3.3.7. Key activities

The key activities involved in the business model are similar throughout all the use cases and they consist of:

- Development of a complete technological stack (primarily, quantum hardware and algorithms).
- Implementation, integration, and delivery of the technology to the customers in form of a solution or (a cloud) service.
- Verification and assessment of the solution running at the customer, to ensure completeness of the value added by the solution and correctness of its operation.
- Continuous improvement of the solution, including the quantum backend as well as the application-specific parts of the solution.
- Maintenance of the technological stack of the solution or training of the maintenance personnel.
- Provision of the consulting services to the clients.

3.3.8. Key partners

Since the solution is developed by a consortium, it is important to distinguish between internal and external partners.

Internal ones comprise the EQUALITY consortium and are responsible for the backbone of the solution, thus remaining through all the use cases. Such partners can be segmented according to the parts of the resources and activities they provide as quantum hardware providers, quantum algorithm developers, maintenance and operation, and business development (marketing, sales, customer relationships, etc.).

Besides the extensive network of competencies within the consortium, some external partners might be involved in the complete value chain.

Use-case-specific **software providers** present an important class of partners since they can enable one of the most fruitful channels for multiple use cases. Strong dependence on the success of the solution in the form of service increases the importance of building solid partnerships with certain software providers. *They represent a segment of customers as well, creating an alternative within the business model*. The difference between the two models (software provider as a customer and as a partner) can be subtle, but in any scenario, providers play a key role on the way to commercial success.

For the solutions provided by the cloud, the consortium might need assistance with the **support of the cloud platform** or other delivery infrastructure, like software plug-ins.

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Receiving this support from external partners may turn out more cost-efficient than organising specific competencies internally.

Besides, assistance with **IP management** might be needed for successful long-term concurrence of a disruptive solution in tight and highly competitive markets.

3.3.9. Cost structure

The structure of the principal costs also remains similar throughout all the use cases, as it is governed by the resources and activities necessary. It can be segmented according to the nature of the expenses:

Infrastructure costs, comprising the dominant part of the whole costs and can be treated as capital expenses. This includes direct costs for the development of the quantum hardware and software, as well as the distribution platform. This category also includes the expenses associated with the delivery and installation of hardware, if any, to be distributed to the premises of the customers. Besides, for the use cases with the cloud platform model of distribution, operational expenses associated with the delivery platform are to be included.

Human resources comprise a notable part of the whole expenses due to the highly technical nature of the solution. Besides, this category includes training of operation and maintenance personnel.

Intellectual property is an essential resource, and certain expenses are associated with its creation or acquisition, like patenting or publishing activities. Besides, it involves recurrent expenses on its correct management.

Finally, **customer acquisition** will always be among the indispensable costs. It includes all kinds of marketing, but also the expenses associated with technical demonstrators of the solution to the customers and other outreach activities, such as webinars or participation in conferences/exhibitors, essential for the expansion of the market share.

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4. SPECIFIC USE-CASE ASSESSMENT

4.1. First use-case: Predictive models for battery design and fuel cells

The development of novel battery technologies presents a significant industrial challenge today, with the total potential market of novel battery solutions adding up to 250€ billion by 2025. [16] The future will be electric to benefit from more sustainable technological solutions like cleaner vehicles and renewable energies. As well as a better and more durable battery development will be critical for transitioning towards a carbon-neutral economy. However, there is an increasing demand for improving battery technologies to provide a higher energy density, longer lifetime, faster recharge rate and lower cost. The cross-industry impact of a significant improvement in any of these metrics would be huge and would lead to a step change in progress towards decarbonisation.

Meanwhile, advances in high-energy battery storage enable novel applications like frequency stabilisation for power grids and heavy-duty transportation. One important route to these necessary improvements is R&D investment in discovering new cell types and improving electrochemical cell lifetime and energy density prediction. Therefore, developing accurate predictive modelling tools will be vital to achieving these objectives. This project will bring quantum capabilities to their workflows.

A set of technologies on Battery Cell Simulation is an indispensable propulsor of advancements of the R&D in this domain. Thus, market breakthroughs will inevitably follow any significant improvement in simulation techniques. Today, the main bottleneck of these technologies hides in the computational complexity of rigorous optimisation, which requires considering physical phenomena on multiple scales, each with its own set of mathematical techniques. Some specific simulations of battery cells necessary for the whole workflow remain beyond the reach of current computing platforms.

The solution provides quantum mechanical solvers for differential equations to model whole battery cells at the continuum level. It supports researchers in creating comprehensive models of lithium-sulphur battery cells. The Solution is to be developed in two stages. The first stage is based on a simple 1D model, where the transport of charge carriers, such as electrons and ions, through the electrode material along the thickness of the electrode is described. At the same time, the second step is based on a more advanced, 1D +1D version. It involves two one-dimensional models: one for the electrode and one for the electrolyte. The electrode model describes the transport of charge carriers, such as electrons and ions, through the electrode material along the thickness of the electrode. The electrolyte model describes the transport of charge carriers through the electrolyte along the length of the battery cell. This problem formulation will correspond to a coupled set of differential and algebraic equations describing the transport of charge carriers in the electrode and electrolyte and include initial and boundary conditions.

The development of quantum-computer-driven partial differential equation solvers for battery design is expected to exploit at the same time the strong potential of Quantum Computing at optimisation tasks, as well as the physical nature underlying both phenomena.

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4.1.1. Market assessment

The battery industry is a rapidly evolving sector with a complex market dynamic involving many factors, such as technological advancements, government policies, consumer demand, and global economic conditions. The market for simulation tools for battery modelling is intricately linked to the growth of battery production; we will first give an overview of the market dynamics of the battery industry in Europe.

Volume and dynamics

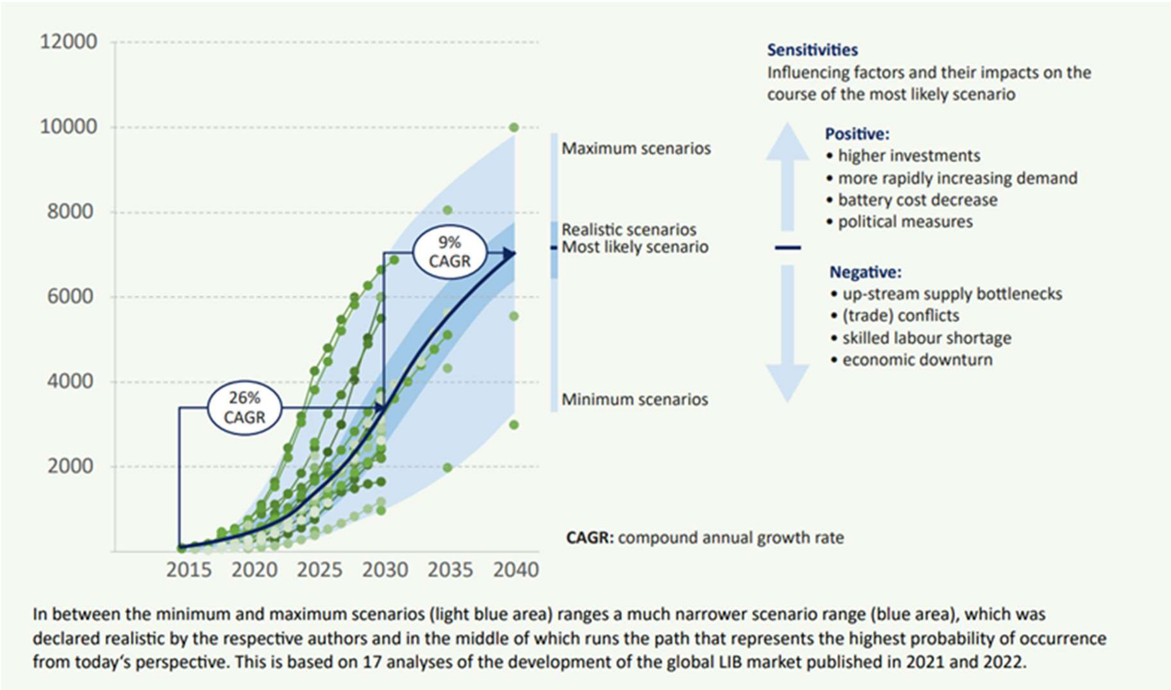
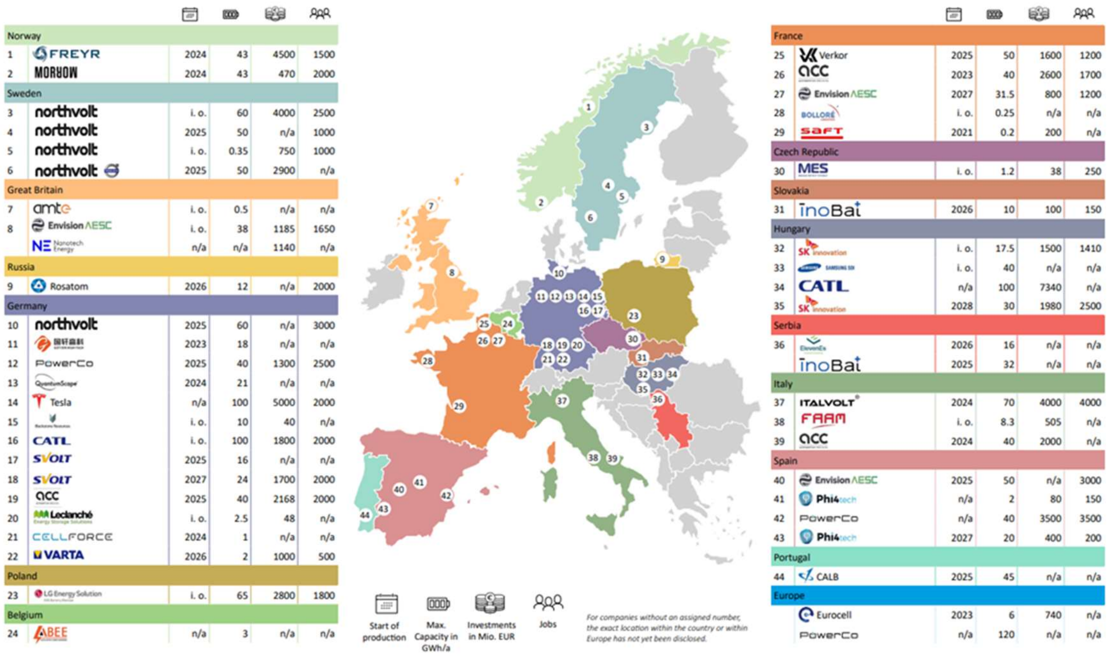


Figure 4: Global Li-ion battery market dev. Scenario until 2040 in GWh/a. [17]

The battery industry in Europe is expected to experience significant market growth in the coming years. The demand for batteries is projected to increase tremendously, with the requirement for batteries estimated to reach 3.2 terawatt-hours per year (TWh/a) by 2030 and 7.1 TWh/a by 2040 (see Figure 4: Global Li-ion battery market dev. Scenario until 2040 in GWh/a.). However, the automotive industry is the primary driver for this trend, as it will make up 80% of the demand for battery cells in 2030. A substantial increase in production capacity (see Figure 5) will follow this growing demand for battery resources. Currently, there are around 50 battery production sites planned in Europe, with an estimated annual production capacity of between 920 and 1,600 gigawatt-hours per year (GWh/a) by 2030. However, the real production capacity in Europe is expected to be between 850 and 1,300 GWh/a, considering full utilisation and no wastage. [17]



No.	Company	Start of production	Max. Capacity in GWh/a	Investments in Mio. EUR	Jobs
Norway					
1	FREYR	2024	43	4500	1500
2	MORROW	2024	43	470	2000
Sweden					
3	northvolt	i. o.	60	4000	2500
4	northvolt	2025	50	n/a	1000
5	northvolt	i. o.	0.35	750	1000
6	northvolt	2025	50	2900	n/a
Great Britain					
7	amte	i. o.	0.5	n/a	n/a
8	Envision AESC	i. o.	38	1185	1650
	NE Nanotech Energy	n/a	n/a	1140	n/a
Russia					
9	Rosatom	2026	12	n/a	2000
Germany					
10	northvolt	2025	60	n/a	3000
11	国轩高科	2023	18	n/a	n/a
12	PowerCo	2025	40	1300	2500
13	QuantumScape	2024	21	n/a	n/a
14	Tesla	n/a	100	5000	2000
15	[illegible]	i. o.	10	40	n/a
16	CATL	i. o.	100	1800	2000
17	SVOLT	2025	16	n/a	n/a
18	SVOLT	2027	24	1700	2000
19	acc	2025	40	2168	2000
20	Leclanché	i. o.	2.5	48	n/a
21	CELLFORCE	2024	1	n/a	n/a
22	VARTA	2026	2	1000	500
Poland					
23	LG Energy Solution	i. o.	65	2800	1800
Belgium					
24	ABEE	n/a	3	n/a	n/a
France					
25	Verkor	2025	50	1600	1200
26	acc	2023	40	2600	1700
27	Envision AESC	2027	31.5	800	1200
28	BOLLORÉ	i. o.	0.25	n/a	n/a
29	saft	2021	0.2	200	n/a
Czech Republic					
30	MES	i. o.	1.2	38	250
Slovakia					
31	InoBat	2026	10	100	150
Hungary					
32	SK innovation	i. o.	17.5	1500	1410
33	SAMSUNG SDI	i. o.	40	n/a	n/a
34	CATL	n/a	100	7340	n/a
35	SK innovation	2028	30	1980	2500
Serbia					
36	ElevenEs	2026	16	n/a	n/a
	InoBat	2025	32	n/a	n/a
Italy					
37	ITALVOLT	2024	70	4000	4000
38	FAAM	i. o.	8.3	505	n/a
39	acc	2024	40	2000	n/a
Spain					
40	Envision AESC	2025	50	n/a	3000
41	Phi4tech	n/a	2	80	150
42	PowerCo	n/a	40	3500	3500
43	Phi4tech	2027	20	400	200
Portugal					
44	CALB	2025	45	n/a	n/a
Europe					
	Eurocell	2023	6	740	n/a
	PowerCo	n/a	120	n/a	n/a

Figure 5: Battery cell production sites in Europe that are planning, under construction or partly already in operation. [17]

Two "Important Projects of Common European Interest" (IPCEI) for battery cell production form the core of the funding effort. The private sector is contributing over €67 billion in self-investments towards building a European battery ecosystem by 2030. These efforts are expected to meet the demand for battery cells with European production. The BMWK and BMBF are also implementing complementary funding measures to consolidate the industrial nucleus of the battery ecosystem. Numerous European and international initiatives are contributing to the networking of relevant actors and the development of a sustainable battery value chain in Europe. [18]

Despite the expected growth in the battery industry, there are also significant challenges. Increasing competition from other regions, such as China and the United States, puts the European market under increasing pressure. Additionally, concerns about sustainability and ethical sourcing of raw materials could hinder the industry's growth.

The primary driver of this increased demand for batteries is the production of battery-electric vehicles. In 2022, it was expected that the sales of electric vehicles for personal use would surpass 10 million units, a significant increase from the 6.6 million units sold in 2021.

European automotive manufacturers and other investors invested approximately 60 billion euros in electromobility in 2019, driven by the CO_2 targets set by the EU for vehicle fleets. This amount is approximately 3.5 times more than the investment made in China. [19]

Customers and segmentation

Battery market

The market for batteries can be segmented based on different perspectives, including battery usage and technology. One way to segment the battery market is based on battery usage. This can include categories such as electric vehicles, stationary storage, and consumer electronics. Electric vehicles require high-capacity batteries that can deliver enough energy to run the car for long distances. Stationary storage batteries, on the other hand, are used to store excess electricity from renewable energy sources like solar or wind. Consumer electronics, including smartphones, laptops, and tablets, require small and lightweight batteries that can deliver power for a long time.

Another way to segment the battery market is based on battery technology. The most popular battery technologies in the market include lithium-ion batteries, lead-acid batteries, and nickel-metal hybrid batteries. Lithium-ion batteries are widely used in consumer electronics and electric vehicles due to their high energy density and long life. Lead-acid batteries are commonly used in backup power systems and stationary storage due to their low cost and reliability. Nickel-metal hybrid batteries are commonly used in hybrid vehicles and medical devices. In addition to these technologies, there are other emerging battery technologies that are being developed, such as solid-state batteries, flow batteries, and sodium-ion batteries. These new battery technologies are expected to deliver higher energy density, longer life, and better safety compared to the existing battery technologies.

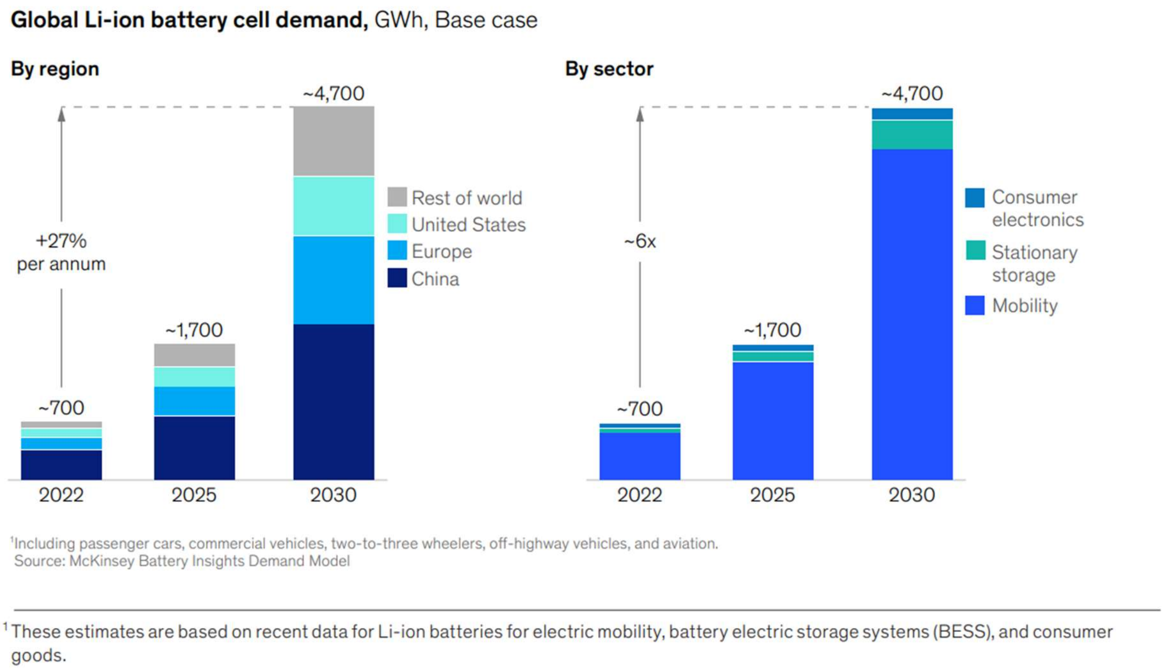


Figure 6: Global Li-ion battery cell demand. [20]

As the demand for batteries continues to rise as it is reflected in

Figure 6, the requirements on the battery software become more stringent. Software Modelling tools are required, that can accurately predict battery performance and behaviour in various applications. This is fuelling the growth of the battery modelling industry as more companies and organisations seek advanced software solutions to optimise battery design and performance. Furthermore, the battery modelling industry is continually evolving, with modern technologies and techniques being developed to enhance the accuracy and reliability of battery models. This includes the application of machine learning, artificial intelligence, and quantum computing to generate more advanced battery models and simulations. As well as the growing adoption of electric vehicles and renewable energy systems is creating demand for advanced battery modelling solutions that can optimise battery performance and efficiency in these applications.

Many governments worldwide are investing heavily in battery research and development, providing funding for companies and organisations operating in the battery modelling industry, for example, Horizon Europe [21] is the EU's research and innovation funding program for the period 2021-2027. Its budget is 95.5€ billion and aims to support research and innovation in a wide range of areas, including energy storage and battery technology. Another example is the Important Project of Common European Interest ("IPCEI") initiative, a research and innovation initiative launched by the European Union in 2019. Its aim is to develop a competitive and sustainable battery industry in Europe. The initiative has a budget of 3.2 € billion and is funded by the European Commission, national governments, and industry. This fosters industry growth and innovation as companies seek to capitalise on these funding opportunities to develop more advanced battery modelling solutions. [22]

Battery modelling tool market

The battery modelling industry is highly competitive, with many companies and organisations striving for market share. This competition is driving innovation and investment in modern technologies as companies try to differentiate themselves from their rivals and offer more advanced and comprehensive battery modelling solutions.

The market of battery simulation tools for the battery development industry can be segmented either based on the Deployment, the End-User, or the Application of the batteries:

- Based on the Deployment
    - Cloud solutions
    - On-premises solutions
- Based on End-User
    - Automotive
    - Aerospace & defence
    - Industrial electronics
- Based on application
    - Engineering, Research & development
    - Modelling & simulated testing

A few market leaders in the battery simulation software industry have stood out from the rest, setting the benchmark for reliable, accurate, and efficient battery modelling. The next section provides a closer look on the segmentation by industry, highlighting the specific needs of simulation tools and market leaders in each segment.

Automotive Industry

Battery and fuel cell modelling is widely used in the automotive industry for the development of electric and hydrogen-powered vehicles. These models help to optimise the performance of the batteries and fuel cells, improve their durability, and enhance the overall efficiency of the vehicles. These are the market leaders in this segment: COMSOL, Siemens, Dassault Systèmes SE

Energy Storage Industry

The energy storage industry uses battery and fuel cell models to optimise the performance of energy storage systems, such as those used in renewable energy applications. These models can also help to identify potential safety issues and optimise the design of energy storage systems. The market leaders in this segment are: COMSOL, and EDF R&D.

Aerospace Industry

Battery and fuel cell modelling is also used in the aerospace industry for the development of advanced propulsion systems for space vehicles. These models help to optimise the performance of the batteries and fuel cells used in these systems and ensure their reliability and safety in extreme environments. The market of this segment is led by: COMSOL, Siemens, and Dassault Systèmes SE.

Materials Science

Battery and fuel cell modelling is also used in materials science research to better understand the behaviour of the materials used in these systems. This can help to identify new materials that could improve the performance and durability of batteries and fuel cells. This segment has a complex market landscape, with the companies like Schrödinger and Materials Design Inc being in the lead.

Research Institutions

Simulation tools for battery and fuel cell modelling are also used in various research institutions and academic organisations to study the fundamental principles underlying the behaviour of these systems and to develop new models and simulation techniques. Solutions for this market come from various companies, like COMSOL, Siemens, EDF R&D.

Overall, the battery modelling industry is a dynamic and rapidly growing market, fuelled by strong demand for advanced battery modelling software and technology. The industry is expected to continue evolving and expanding in the years ahead, driven by technological advancements, intense competition among market players, and rising demand for batteries in diverse applications.

4.1.2. Competitive analysis

In this section, the focus is on the competition the business of battery modelling solutions faces when entering the market. The main competitors in this field focus on developing accurate and efficient models to predict the behaviour of batteries under various conditions. This includes developing models for individual cells and larger battery systems and incorporating factors such as temperature, charging and discharging rates, and cycling history. Some companies may focus on specific applications of battery models, such as electric vehicles, renewable energy storage, or consumer electronics. Others may focus on developing software or tools that enable users to easily incorporate battery models into their designs or simulations. Overall, the main goal for companies in the battery modelling business is to help their customers optimise the performance and lifespan of batteries while also reducing costs and minimising the environmental impact of battery production and disposal.

Technological competition

The battery modelling and simulation market is highly competitive, with companies constantly developing new and innovative technologies to gain an edge. First, it is important to outline the main metrics, that each of the competitors needs to improve to gain an advantage over others. These metrics are:

- **Accuracy of models** - One of the key competitions in battery modelling is the accuracy of the models used to predict battery performance, such as thermal effects, ageing, and degradation.
- **Computational efficiency** - As battery systems become more complex, the computational requirements for modelling and simulation increase. Companies are developing new algorithms and techniques to improve the computational efficiency of their tools, allowing for faster and more detailed simulations.
- **Integration with design tools** - Battery modelling and simulation tools are most effective when integrated with design tools used in battery development. Companies are working to develop seamless workflows between modelling and design tools to streamline the design and optimisation process.

The main technological approaches used for battery development are:

- **Multiphysics modelling** - Battery systems are complex and involve multiple physical phenomena, such as electrochemical reactions, heat transfer, and mechanical stresses. Modelling and understanding different properties of batteries will provide a complete picture of the battery behaviour.
- **Artificial intelligence and machine learning** are increasingly being used in battery modelling and simulation to improve the accuracy and efficiency of models to help automate the modelling and simulation process and to identify patterns and insights in large datasets.
- **Cloud-based simulation** is a growing trend in battery modelling and simulation. Companies are developing tools that allow users to run simulations on remote servers, enabling faster and more efficient simulations without expensive hardware.

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Business competition

Using quantum technology

While quantum computing has the potential to revolutionise the field of battery modelling and simulation by enabling faster and more accurate simulations, quantum computing could help to accelerate the development of new battery materials and designs, leading to better-performing and more efficient batteries. Quantum computing can perform complex calculations and simulations much faster than classical computers, making it potentially well-suited for battery modelling.

- Cambridge Quantum Computing (CQC) is exploring the use of quantum computing for battery modelling. CQC is developing a quantum algorithm for simulating the behaviour of lithium-ion batteries, which could help to accelerate the development of new battery materials and designs.
- Zapata Computing develops a quantum software platform that includes tools for quantum chemistry simulations, which could be used to model the behaviour of battery materials at the molecular level.
- Beneath this, Volkswagen already reaches out to hardware developers of quantum computers like D-Wave or Xanadu to work with them on developing new algorithms on quantum computers to simulate the behaviour of lithium-ion batteries. [23]
- IBM and Daimler have joined forces to develop advanced battery technology for electric vehicles, with a particular focus on lithium-sulphur (Li-S) battery technology. The collaboration aims to accelerate the discovery of new materials and processes that can improve the performance, safety, and cost-effectiveness of Li-S batteries by using Quantum Technology. [24]
- PsiQuantum is working together with Mercedes Benz on the processes of electrochemical cells. They demonstrate that quantum computing can provide valuable insights into the reaction mechanisms of Li-O2 batteries, which can help in the design of more efficient and durable batteries. [25]

Using classical modelling and AI solutions

The battery modelling market in Europe is highly competitive, with many companies and organisations offering battery modelling software and services. Here are some of the main competitors in the European battery modelling market:

- AVL is a global company based in Austria that specialises in developing advanced battery modelling and simulation solutions. Their solutions are used in the automotive, aerospace, and renewable energy industries.
- COMSOL is a Swedish software company providing Multiphysics modelling and simulation software. Their software includes battery modelling and simulation modules, which can be used to model electrochemical reactions, heat transfer, and mechanical stress.
- ESI Group, a French company, provides simulation software and services for various industries, including automotive and energy. ESI Group offers battery modelling tools, such as ESI Virtual Performance Solution (VPS), which can be used to simulate battery performance and optimise battery design.

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- Siemens, a global company based in Germany, provides various engineering and technology solutions. They offer battery modelling and simulation software that can be used to model electrochemical reactions, thermal behaviour, and mechanical stress.
- Dassault Systèmes SE is a French multinational software company that provides solutions for the aerospace, automotive, and life sciences industries. The company offers battery modelling software solutions such as CATIA Systems and SIMULIA Power FLOW.

Regarding the competition, Europe is a strong player in the global battery modelling and simulation tools market. However, there is significant competition from companies in North America and Asia, particularly in countries such as China, Japan, and South Korea, which are essential players in the global battery industry. The competition is fierce, and companies are constantly developing new and innovative tools to stay ahead in this rapidly evolving industry. Furthermore, outside Europe, there are many companies developing battery simulation tools, including:

- ANSYS is a US-based company that develops simulation software for various industries, including the battery industry. Its battery simulation tools enable users to design and optimize battery systems, predict performance, and evaluate safety concerns.
- Battery Design LLC is another US-based company that offers battery simulation software, including tools for electrochemical analysis, battery pack design, and thermal analysis. The company focuses on providing high-quality simulation tools to help users develop better battery systems.
- Keysight Technologies is a US-based company that offers test and measurement solutions for a range of industries, including the battery industry. Its battery simulation tools enable users to perform electrical and thermal simulations to evaluate the performance and safety of battery systems.
- Beijing E-Grid Energy Technology Co., Ltd. is a Chinese company that specializes in the development of lithium-ion battery simulation software. Its software offers tools for electrochemical modelling, thermal modelling, and battery management system (BMS) design.
- Dongguan Zhongli Energy Technology Co., Ltd. is another Chinese provider of battery simulation software. Its software includes tools for cell design, BMS design, and system simulation.
- Murata Manufacturing Co., Ltd. is a Japanese company that develops and produces electronic components and devices, including batteries. Its battery simulation tools enable users to optimize battery performance and evaluate battery safety.
- Hitachi Chemical Co., Ltd. is a Japanese company producing a range of products, including battery materials and systems. Its tools for battery simulations include essential functions to evaluate battery performance and optimize battery systems.
- Samsung SDI Co., Ltd. is a South Korean company that produces batteries for various industries, including electric vehicles and consumer electronics. Its battery simulation tools allow the clients to optimize battery performance and evaluate battery safety, which is an important aspect for the market.
- LG Chem is another South Korean company that produces batteries for various industries. Battery simulation tools provided by Samsung are used in design and

optimisation of battery systems, prediction of their performance, and evaluation of safety concerns.

Besides many companies also, applied research institutes provide services for battery modelling:

- Fraunhofer Institute for Chemical Technology (ICT) is a research organisation that develops advanced battery modelling and simulation tools. They offer diverse services, including battery testing, characterisation, and modelling. Together with its partnering organisation, the Fraunhofer Institute for Systems, and Innovation Research (ISI), that focuses on energy storage solutions, the institute offers battery modelling and simulation software solutions such as JAMSIM.
- EDF R&D is a research and development subsidiary of the French energy company EDF. The department specialises in developing advanced battery modelling solutions for electric vehicle applications.
- RWTH Aachen University is a German research university that carries out applied research in various domains of engineering, natural sciences, and medicine. The university provides battery modelling and simulation software solutions such as JBAT and J-EcoLiB.

Additional to the service providers, large enterprises, especially in the automotive sector (e.g., BMW Group, Daimler AG), established their battery modelling services in-house within their R&D department.

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4.1.3. Business model

Developing a solution-based business model for the use case of battery and fuel cell modelling is proposed. The solution consists of the provision, integration, maintenance and rolling improvement of a simulation tool by using Quantum Computing for the simulation of properties like life cycles and performance of batteries on a continuum level. A BMC attributed to this use-case is displayed below in the Figure 7, with the use-case specific blocks being highlighted, while the faded blocks remaining the same as in the General BMC overview.

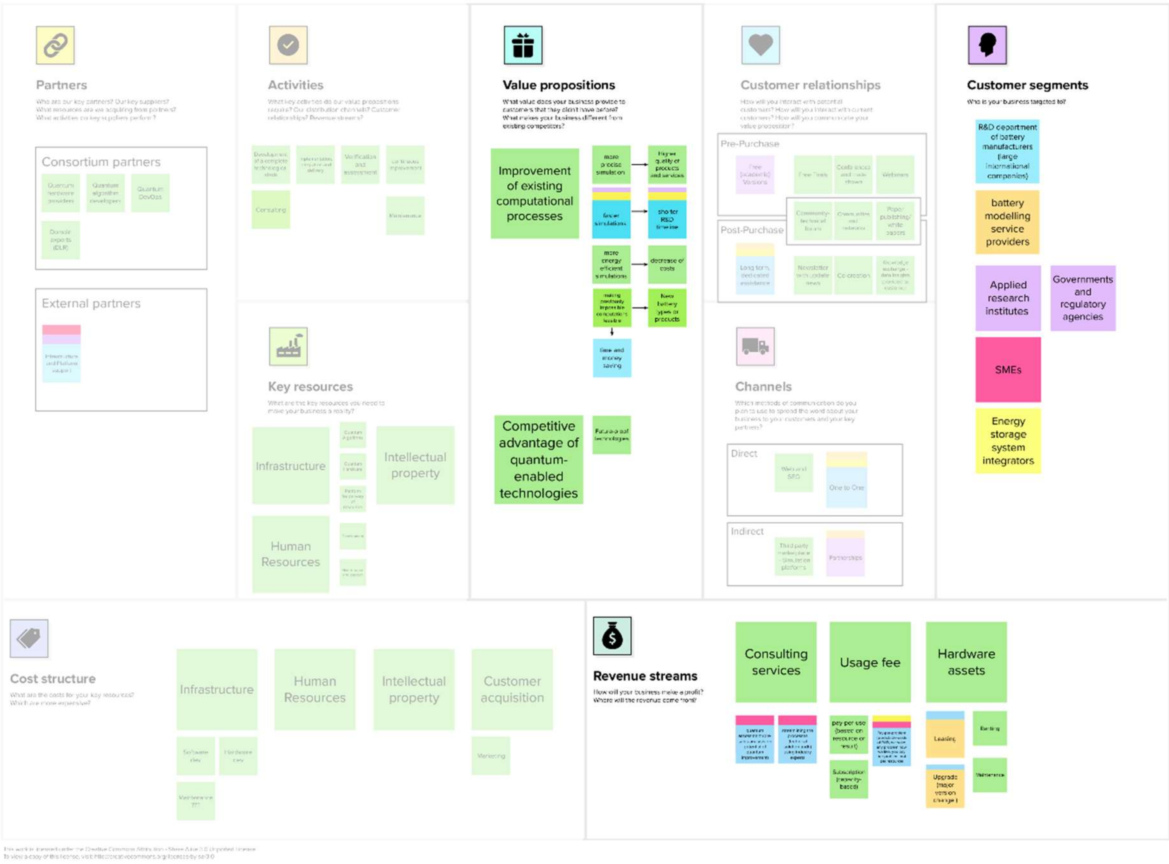

Figure 7: BMC of use-case 1: Predictive models for battery design and fuel cells (bigger in annexe).

Customer segments

The solution discussed here aims to bring a dramatic advantage to battery development due to the simulation of properties, potentially speeding up the time from development to market. Therefore, the solution seeks companies (67%) and research institutes 29%, [19] performing in the battery research area, e.g., the battery manufacturing industry (Webasto, Continental), the automotive sector (BMW, VW, etc.) or from the applied research institutes like for example Fraunhofer institutes. The group of companies consists of large and medium size up to small enterprises (SMEs). Customer segments for our solution can be categorised into five groups:

- **Battery manufacturers** are a key customer segment for simulation tools for battery modelling. These companies use simulation tools to optimise battery design, performance, and safety and to reduce the time-to-market and development costs for

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new battery products. Battery manufacturers require simulation tools that are easy to use, accurate, and can handle complex battery models.

- **SMEs in the field of battery manufacturing:** SMEs in the business area of battery manufacturers are a niche customer segment for simulation tools for battery modelling. These companies may have limited resources and may require simulation tools that are affordable, easy to use, and can deliver accurate results. Simulation tools can help SMEs to optimise their battery designs, improve performance, and reduce development costs. This customer segment may require simulation tools that are tailored to their specific needs and may benefit from flexible licensing and pricing options. Developing simulation tools that are accessible and affordable to SMEs can help to drive innovation in the battery industry and expand the customer base for simulation tools for battery modelling. Examples are companies like: VoltStorage GmbH, Voltabox AG, Akasol AG
- **Battery modelling service providers** comprise another important customer segment. These companies offer customised battery design and simulation services to their clients, which can include battery manufacturers, energy storage system integrators, and other businesses. Battery modelling service providers require simulation tools that are flexible, adaptable, and can be customised to meet the specific needs of their clients.
- **Energy storage system integrators** present a growing customer segment for simulation tools for battery modelling. These companies use simulation tools to optimise the performance and efficiency of energy storage systems for renewable energy applications. Energy storage system integrators require simulation tools that can handle a range of battery chemistries and can model complex system architectures.
- **Applied Research Institutions** are an important customer segment for simulation tools for battery modelling. These institutions use simulation tools to study the fundamental principles underlying battery behaviour and to develop new models and simulation techniques. Applied research institutions require simulation tools that are highly accurate, adaptable, and can be customised to meet the specific needs of their research projects.

Value propositions

Improving existing computational processes and infrastructures can yield significant benefits for companies engaged in high-tech research and development. By leveraging the power of simulations, these companies can better predict battery cell properties and create battery and fuel cells with higher energy density. Additionally, the use of simulations can speed up the R&D process by allowing for more variations of cell types to be tried out, resulting in a faster product-development pipeline and a significant competitive advantage.

One of the key advantages of improving computational processes and infrastructures is the potential decrease in R&D costs. By using simulations, companies can reduce the need for expensive physical prototyping and testing, resulting in significant savings. Additionally, more energy-efficient calculations can decrease the ecological impact of R&D, making it easier for companies to comply with increasingly stringent global standards for the industry. The improvement can also provide companies with the potential for the development of deep niche expertise that can be further valorised. By leveraging the strategic value of the implementation of quantum technologies, companies can improve their company image and build a reputation as leaders in the field of high-tech R&D.

In addition to the benefits already mentioned, improving computational processes and infrastructures can also lead to more precise calculations, resulting in higher quality and safety of new battery types. With simulations, companies can better understand the behaviour of battery and its properties, allowing for more accurate predictions of battery performance and potential risks. By identifying potential issues before they arise, companies can develop safer, more reliable, and higher-quality battery products. This not only reduces the risk of failure and liability but also improves customer satisfaction and loyalty. With higher quality and safer products, companies can strengthen their position in the market and further enhance their competitive advantage.

With the rapid pace of technological advancements in the field of batteries, it is crucial for companies to stay ahead of the curve to remain relevant and competitive. By investing in state-of-the-art simulation tools and computational processes, companies can not only improve the quality and safety of their battery products but also future proof their technology. This means they will be better positioned to adapt to emerging trends and changing customer needs, as well as to take advantage of new opportunities as they arise. This can lead to increased revenue, market share, and profitability in the long run. Additionally, having a reputation for cutting-edge technology and innovation can help attract top talent and strengthen partnerships with other companies in the industry. Overall, the added value of a competitive advantage in future-proof technology cannot be overstated and is a critical component of success in the battery modelling and simulation industry. [19]

Revenue streams

The revenue streams for a battery simulation tool can come from various sources. One such source is the provision of consulting services. This stream is mainly targeted to the big companies and SMEs in the battery manufacturing sector. Here, a pre-sales analysis on the potential of quantum improvement for battery modelling can be offered to interested parties. Additionally, streamlining processes through the audits of technical solution using industry experts can be provided to help companies maximize the usage of the battery simulation tool. Furthermore, the experience and insights in using quantum for battery property simulation can be one strong revenue stream.

Another potential revenue stream comes from usage fees. A cloud solution can be offered to provide access to the simulation tool, and two possible revenue models can be set up here. The first option is pay-per-use, which is based on resource or result usage. The second option is a subscription-based model, which is based on capacity. These options are mainly interesting for all customer segments. While a pay-per-problem model, where predictable costs of R&D are charged based on the specific problems being solved, rather than based on resources, is a good revenue stream for customer segments which have well defined problems to be simulated like the battery manufacturers or energy storage integrators.

Hardware assets can also be used as a revenue stream for a battery simulation tool. Companies can lease their own secure hardware via cloud available infrastructures (e.g., Amazon Web Services). This option can be interesting for battery service providers or battery

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manufacturers. Alternatively, renting the machines that are physically located on their side can also be offered, so that there is no data traffic outside of the company network (secure data and confidential data). The upgrade to the newest improvements and updates can also be sold separately, which is interesting for battery service providers or battery manufacturers. Finally, maintenance can be sold separately when renting or buying hardware and solutions, as it is crucial to ensure the tool is always in good working condition.

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4.2. Second use-case: Battery materials discovery

Developing new battery materials is a critical challenge for researchers and scientists in energy storage. While traditional battery materials, such as lithium-ion and lead-acid, have been widely used for many years, they have limitations. These limitations include low energy density, limited lifespan, prohibitive cost, and environmental concerns. As such, there is a growing need to investigate and develop new battery materials to address these limitations and improve battery performance, safety, and sustainability. The development of new battery materials is critical for advancing the field of energy storage and enabling the widespread adoption of clean energy technologies. Energy storage is essential for increasing the use of renewable energy, improving grid stability, enabling the adoption of electric vehicles, providing backup power, and expanding access to energy in off-grid communities.

However, developing new battery materials is a complex and challenging process that requires expertise in materials science, chemistry, physics, and engineering. It involves identifying new materials with the desired properties, optimising their properties for battery applications, and testing their performance in real-world conditions. Therefore, computational solutions can be advantageous by helping researchers understand batteries' inner workings and physicochemical processes at interfaces.

The current simulation techniques have limitations in achieving precision and scale, leading to a trade-off between the two. Scalable methods, such as Density functional theory (DFT), are often unable to capture the complex behaviour of the system fully. For example, DFT methods struggle to describe electrolyte interactions Batteries rely on the interaction between solid electrode materials and liquid electrolytes. Modelling the interface between these materials and accurately representing the interactions between them is challenging for DFT, which is primarily designed for studying the electronic structure of isolated molecules or solids. Likewise, DFT calculations involve many adjustable parameters, such as exchange-correlation functionals and van der Waals interactions, that must be carefully calibrated to reproduce experimental data accurately. This can be challenging for complex systems such as batteries, where the accuracy of DFT simulations can be sensitive to these parameters. Understanding quantum mechanical effects in batteries requires simulation of electron transfer and charge distribution within the materials; these effects are challenging to simulate accurately in DFT.

In contrast, more precise methods such as Full Configuration Interaction (FCI) or Coupled Cluster (CC) scale poorly with the size of the system, making simulations computationally demanding and unfeasible.

To overcome the challenges of simulating battery materials with DFT, it is necessary to develop simulation tools that balance precision and scalability. One potential solution is to utilise quantum computers, which can represent chemical systems more naturally than classical computers. However, achieving quantum advantage for battery simulations has proven to be difficult. To address this challenge, in the solution, various techniques are combined, including Variational Quantum Algorithms (VQAs) and hardware exploitation strategies, to move closer to quantum advantage. The solution has been developed to simulate complete charging and discharging profiles for the battery system, focusing on the simulation of the interaction of combined mono-/bi-electrolyte components with electrodes and understanding various ground state properties such as binding energies, charge distribution, electron and ionic mobility, and dipole moment within the electrochemical cell.

4.2.1. Market assessment

As well as in the battery modelling use case, the battery material discovery market is growing and evolving rapidly, driven by the increasing demand for high-performance and sustainable batteries for a range of applications, including electric vehicles, consumer electronics, and renewable energy storage. Therefore, the market dynamics of the industry for battery material discovery is highly dependent on the battery market itself. The battery market is predicted to increase exponentially until 2040 (see Figure 4) due to the high demand of LIBs for mobility and energy storage (see Figure 6).

Developing a solution-based business model for the use case of battery material discovery is proposed. The solution consists of the provision, integration, maintenance and rolling improvement of a simulation tool by using Quantum Computing for the simulation of battery material properties for the discovery and validation of new materials used in batteries.

Volume and dynamics

An overview of the market for battery material is given in this section. The battery materials market is expected to see substantial growth of USD 62 billion in the coming years by registering a CAGR of 8.75% in the forecast 2030. [26] The global battery materials market size was valued at $45.6 billion in 2020, and is projected to reach $80.5 billion by 2030, growing at a CAGR of 5.9% from 2021 to 2030. [27]

One of the key trends in the battery material discovery market is the focus on developing sustainable and environmentally friendly materials. This includes the development of materials that are less harmful to the environment, and that can be recycled at the end of their useful life. Furthermore, Europe is facing a vulnerable supply of raw materials due to the increasing demand for materials such as nickel, graphite, and lithium for LIBs (Lithium-ion batteries). In Figure 8, Figure 9 and Figure 10 the global demand of raw materials and the supply capacity is shown for 2030. It is projected that the demand for these materials will rise by 8, 7, and 5 times respectively, by the year 2030 compared to 2020. Unfortunately, most of these raw materials are not sourced from Europe. Therefore, Europe remains dependent on international cooperation, which is becoming increasingly challenging considering growing geopolitical and trade tensions. [17] [20]

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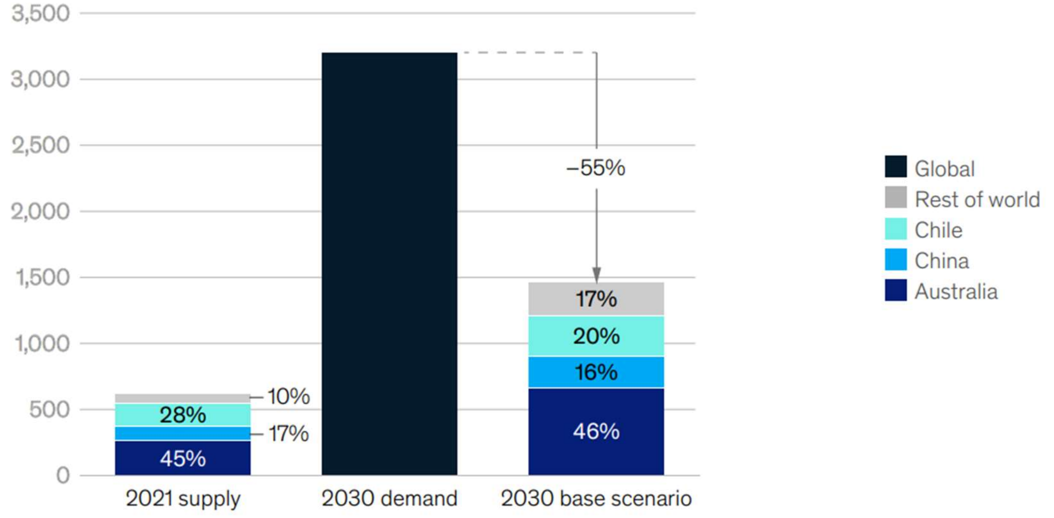
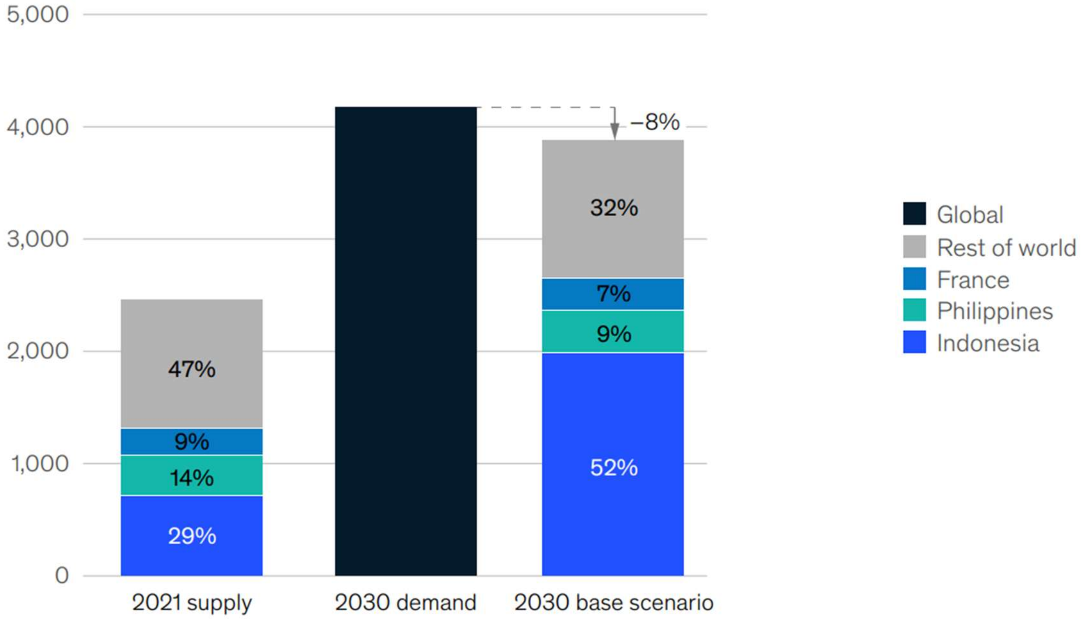


Source: McKinsey MineSpans, 2022



Source: McKinsey MineSpans, 2022

Figure 9: Nickel global demand 2030, supply 2021 and 2030 by country [20]

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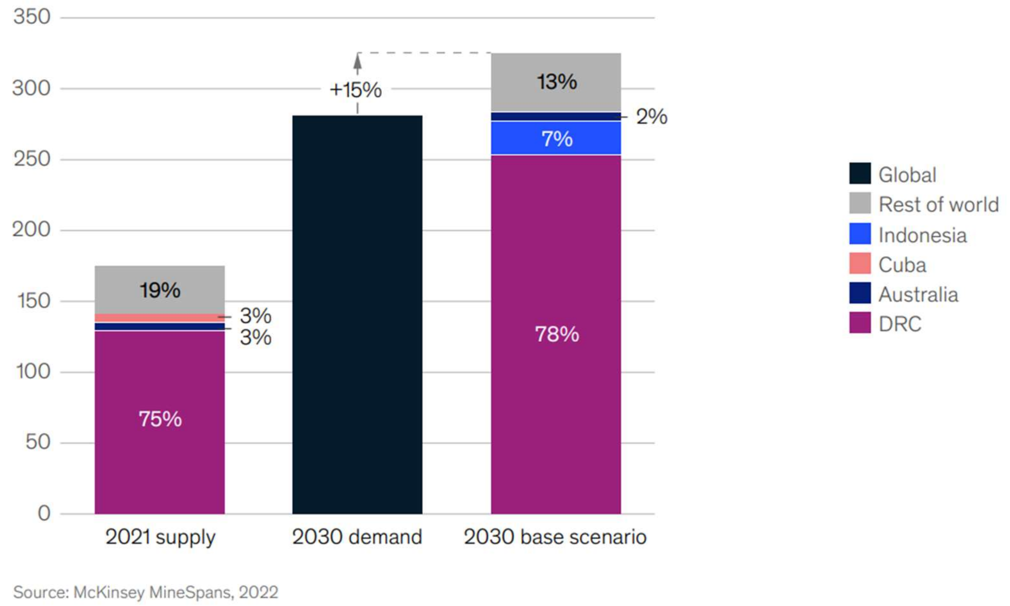

Figure 10: Cobalt global demand 2030 supply and 2030 by country [20].

When focusing on the market for simulation tools for battery material discovery, there are several key factors driving the market. The demand for high-performance batteries is growing rapidly, driven by the increasing adoption of electric vehicles, renewable energy storage systems, and portable electronic devices. [17] Simulation tools can help researchers discover and design new battery materials that offer higher energy densities, longer cycle lives, and faster charging times. Recent advancements in simulation technology, such as machine learning and artificial intelligence, have improved the accuracy and efficiency of battery material simulations. These advancements have also made simulation tools more accessible to researchers and companies, driving demand for these tools. Governments and companies around the world are investing heavily in battery research and development, with a particular focus on improving the performance and sustainability of batteries. This investment is driving demand for simulation tools that can accelerate the discovery and design of new battery materials. There are some initiatives in Europe that aim to develop an innovative, competitive, and sustainable battery value chain in Europe such as European Battery Alliance. [16]

Customers and segmentation

The battery material discovery market is currently experiencing intense competition as established manufacturers, startups, and research organizations vie to develop new and improved battery technologies. With the increasing demand for more efficient and sustainable energy storage solutions, the growth is likely to remain strong in the coming years as more companies and organizations enter the market and focus on developing innovative new battery materials and technologies.

Battery material market

In terms of key players in the market, there are several established companies as well as start-ups and research institutions. These companies are actively involved in the research and development of new battery materials and are also involved in partnerships and collaborations with other companies and research institutions in Europe and around the world to drive innovation in this field. Some of the major players in the market in Europe are:

- BASF SE: A German chemical company that offers a range of battery materials such as active cathode materials, electrolytes, and anodes.
- Umicore N.V.: A Belgian company that specialises in the recycling and refining of metals and offers a range of battery materials such as cathodes, anodes, and electrolytes.
- Johnson Matthey plc: A British company that produces cathode materials, anode materials, electrolytes, and other components for batteries.
- Solvay S.A.: A Belgian chemical company that offers a range of speciality polymers and other materials for use in batteries.
- Arkema S.A.: A French company that produces a range of materials for lithium-ion batteries, including electrolytes and separator membranes.
- Elkem ASA: A Norwegian company that produces silicon materials for use in lithium-ion batteries.

These companies are examples of potential customers for solutions about atomistic modelling for battery materials.

Market for battery material simulation

Within the area of battery material industry potential markets can be segmented into three areas:

Battery manufacturers

In this area, the market leaders in the field of simulation tools for battery material discovery, when focusing on battery manufacturers, are likely to be commercial software packages that offer advanced simulation capabilities tailored specifically for battery design and optimization. These packages provide a prominent level of accuracy and detail in simulating the behaviour of batteries and their components and are widely used in the battery industry for research and development purposes. Examples of such companies are: COMSOL, ANSYS, Synopsys

Besides the software providers, Consulting Firms contributing into this sector. They provide services related to battery material discovery, such as simulation software customization, training, and analysis. They provide high-quality and cost-effective services to their clients. Examples of consulting firms include Total Battery Consulting, On Scale or institutes like Fraunhofer ICT.

Research Institutes

Focusing on the segment of research institutes, the market leaders are likely to be DFT and MD software packages, as these are widely used in the field and provide a prominent level of accuracy and detail in simulating the behaviour of materials. Examples are Gromacs and LAMMPS.

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Material Science Companies and Startups

Companies that supply raw materials for batteries, such as Albemarle, Umicore, and BASF, are also investing in developing simulation tools to improve the properties of their products. They are either developing their own simulation tools for Wildcat Discovery Technologies or using commercial software packages like Schrödinger, Biovia, and ANSYS.

4.2.2. Competitive analysis

Technological Competition

The technological competition in tools for simulations on the molecular level in battery material discovery is intense and rapidly evolving. The demand for advanced simulation tools increases in parallel with the growing need for more efficient, cost-effective, and sustainable energy storage solutions. As a result, many companies and institutions have invested in developing innovative simulation tools for battery material discovery.

One of the major areas of technological competition in this field is the development of more accurate and comprehensive models for simulating battery materials. Companies and institutions are working to develop models that can accurately predict the behaviour of complex battery materials, including the complex interactions on different interfaces like electrode-electrolyte interface and the effects of environmental factors. They are also working to develop models that can simulate the behaviour of batteries at different scales, from the atomic to the macroscopic level, like continuum models for battery modelling and design.

But there is also competition in developing more user-friendly and accessible simulation tools. Many companies are working to develop tools that are easy to use and can be integrated into existing workflows. They are also working to develop tools that can handle substantial amounts of data and run-on various hardware platforms.

Therefore, companies and institutions are investing in emerging technologies, such as quantum computing and machine learning, to develop tools that can more quickly and accurately predict the behaviour of battery materials. This competition is driving innovation and leading to the development of more advanced and effective simulation tools for battery material discovery.

Overall, the technological competition in battery material discovery is intense, and many companies and institutions are pushing the boundaries of what is possible in this area. This competition is driving innovation and leading to the development of more advanced and effective simulation solutions for battery material discovery.

Business competition

Using Quantum Technology

Quantum computing has the potential to significantly accelerate the development of new materials and molecules, including those for batteries. Here are a few examples of companies and institutions that are using quantum computing for battery material discovery:

IBM has developed various tools for materials science and chemistry, including batteries. Their Qiskit software offers a range of quantum chemistry and materials science tools.

Cambridge Quantum Computing is a quantum software company that develops tools for quantum chemistry and materials science, including batteries. Their EUMEN platform offers a range of tools for simulating and optimizing battery materials using quantum computing.

Xanadu is a quantum software company and develops tools for quantum computing and machine learning, including for battery material discovery. Xanadu has created a PennyLane software package, which offers a range of quantum chemistry and materials science tools.

Zapata Computing is a software company specializing in quantum technologies, which develops software tools for quantum chemistry and materials science, including those for battery material discovery. Their product, Orquestra platform, provides an assortment of tools designed for simulating and refining battery materials with the help of quantum computing.

Using Classical Solutions

Fraunhofer Institute for Ceramic Technologies and Systems (IKTS) is a German research institute focused on developing modern technologies in ceramics and materials science. They use atomistic simulations to design and optimise new battery materials.

CIC energiGUNE is a Spanish research centre, using atomistic simulations to study the behaviour of battery materials at the atomic level, with a focus on developing new materials and technologies for energy storage.

Synopsys is a software development company that creates simulation tools for a variety of industries, including those involved in battery material discovery. Their QuantumATK tools enable a broad range of functionalities, including the ability to simulate novel materials for cathode, anode, electrolyte, and additives.

Dassault Systèmes is a French company that acquired Accelrys in 2014 with its brand BIOVIA. BIOVIA offers several software tools that can be used for simulation and modelling in the field of battery material discovery. Particularly, the Materials Studio software is well-suited for battery material research and development. It provides a comprehensive suite of simulation tools for studying materials' structure, properties, and performance, including batteries.

4.2.3. Business model

Developing a solution-based business model for the use case of battery material discovery is proposed. The solution consists of the provision, integration, maintenance and rolling improvement of a simulation tool by using Quantum Computing to simulate battery material properties for the discovery and validation of new materials used in batteries. A BMC attributed to this use-case is displayed below in the Figure 11, with the use-case specific blocks being highlighted, while the faded blocks remaining the same as in the General BMC overview.

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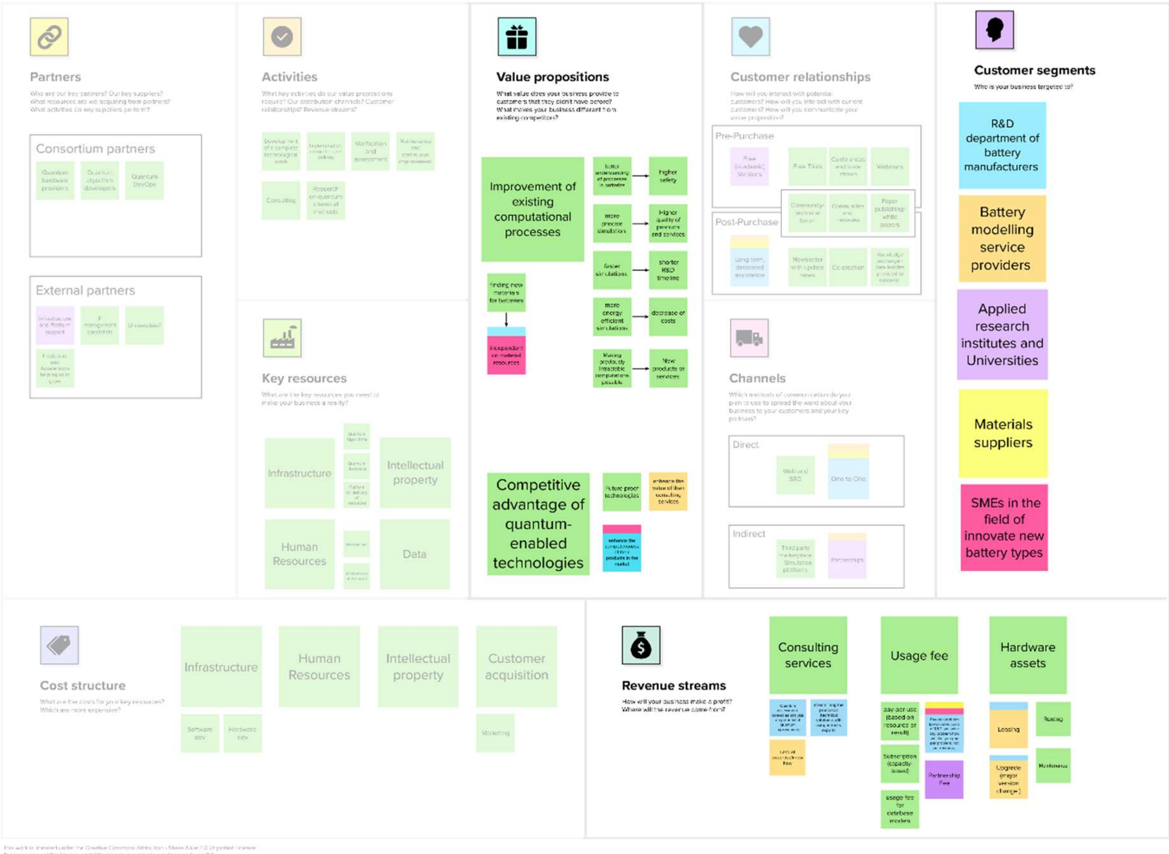

Figure 11: BMC of use-case 2: Materials discovery for battery design.

Customer segments

The group of Battery modelling providers includes companies that provide battery modelling and simulation services to other businesses. By incorporating quantum simulation tools into their services, these providers can offer more accurate and detailed simulations that can help their clients make better decisions about the materials and designs to use in their batteries. Additionally, these providers can leverage quantum simulation tools to streamline their own processes and reduce costs.

Material suppliers are companies, which supply materials to battery manufacturers. By using quantum simulation tools, these suppliers can discover new materials that can be used in batteries and enhance the performance and safety of their products. Additionally, these tools can help material suppliers collaborate with battery manufacturers and research institutions to develop and test new materials more efficiently.

And finally, there are small and medium-sized enterprises (SMEs) in the field of innovative new battery types. This group includes startups and small businesses focused on developing new types of batteries such as solid-state batteries, flow batteries, and other emerging technologies. Quantum simulation tools can help these companies discover new materials and optimize their designs more efficiently, giving them a competitive edge in the market.

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Additionally, these tools can help SMEs collaborate with other businesses and institutions in the battery industry to advance the development of new technologies.

Value propositions

Simulation tools have emerged as an asset for battery material discovery, enabling researchers to understand battery processes better and develop new materials that can enhance the performance and safety of batteries. Here are some key points on the value proposition of simulation tools for battery material discovery.

Firstly, simulation tools enable researchers to gain a deeper understanding of the underlying processes involved in battery performance, which can lead to higher levels of safety and the potential to discover new materials. By simulating battery behaviour in different scenarios, researchers can identify potential risks and develop mitigation strategies, making batteries safer for consumers and users. Additionally, simulation tools can help researchers explore new materials that may have been overlooked in traditional experimental approaches. This is important for the battery manufacturing industry as it reduces their dependence on specific materials resources.

Secondly, simulation tools allow the possibility of making previously intractable computations possible, providing companies with a dramatic competitive advantage in specific products, particularly those that rely on new materials without resource dependency from outside the EU. By investing in developing these technologies, companies can position themselves as innovative and gain a strategic advantage in the market. Researchers can use simulation tools to analyse battery behaviour under various conditions, enabling them to develop new products and services that meet specific customer needs.

Quantum simulation tools can use quantum chemical methods on a higher level, which leads to a greater precision than classical approaches. This can lead to higher quality products and services. By simulating battery behaviour at a microscopic level, researchers can understand the underlying mechanisms that govern performance, enabling them to optimize battery design and improve product quality.

Quantum simulation tools can be designed to be more energy-efficient, which can lead to significant cost savings. By reducing the amount of energy required to simulate battery behaviour, researchers can reduce the cost of R&D and increase the efficiency of their operations.

Furthermore, the use of quantum solutions can provide a competitive advantage for battery manufacturers and service providers. It offers a future-proof technology that can be used to develop new, innovative types of batteries, which can enhance the value of consulting firms that work with battery service providers. By providing a more complete understanding of battery behaviour, simulation tools can help battery manufacturers and SMEs develop more competitive products that meet the needs of their customers.

In summary, atomistic quantum simulation tool has a significant value proposition for battery material discovery. They enable researchers to gain a deeper understanding of battery processes, discover new materials, develop new products and services, and enhance the

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quality and safety of batteries. By using simulation tools, battery manufacturers and service providers can gain a competitive advantage in the market, develop future-proof technology, and reduce the cost and timeline of R&D.

Revenue streams

The revenue streams for a business model of quantum simulation tools for battery material discovery can be classified into three main categories: consulting service, usage fee, and hardware assets.

Firstly, **consulting services** can be offered to provide a pre-sales analysis on the potential quantum improvement for quantum chemical simulations for battery materials. This will allow clients to evaluate the potential of quantum simulation tools before investing in them. The service can also streamline processes by providing technical solution audits using industry experts to consult on the usage of the simulation tool. Additionally, expertise and know-how can be lent by using quantum chemical simulations for battery material discovery.

Secondly, a **usage fee** can be charged for accessing the simulation tool, which can be offered through a cloud solution. There are two possible revenue models that can be set up: pay-per-use, based on resource or result, and subscription, capacity-based. Pay-per-problem can also be offered, where predictable costs of R&D are determined, and companies pay per problem, not per resource. This is particularly interesting for companies in the battery manufacturing sector, especially their R&D departments and material suppliers. A usage fee for database models within the solution can also be charged, and predefined database models could be used for the simulations. Another revenue stream could be Partnership fees, especially with academic partners, which lead to an exchange with academia partners and an improvement of the solution itself.

Thirdly, **hardware assets** can be **leased or rented**, allowing companies to lease their secure hardware, which is physically based on a different place, like with Amazon Web Services, or rent machines physically located on their side, ensuring that there is no data traffic outside of the company network. This is particularly interesting for battery service providers or manufacturers. Upgrades, such as major version changes, can also be sold separately, allowing companies to have the newest technological solution ready to use. The providing of hardware to customers requires maintenance services on the hardware. This can be offered to maintain the hardware and solution, which can be sold separately from the consortium.

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4.3. Third use-case: Aerodynamics simulations

Research and innovation activities in Aerospace Engineering rely significantly on numerical simulations. Computational Fluid Dynamic (CFD) simulations are one of the main instruments for the entire domain of Aerospace Engineering. These simulations are currently performed on supercomputer clusters, capabilities of which have already found their limits in complex simulation problems, such as the optimisation of a wing console shape. To improve the results, it is necessary to increase the size of the problem: splitting the mesh into finer voxels or expanding the search space. Such problems' size often increases exponentially their time, cost, and energy consumption. To achieve notably better results, there is a need for more efficient ways to simulate fluid dynamics.

The algorithms developed in this solution would be capable of speeding up the development and optimisation of critical aerospace problems by leveraging the power of quantum computing. The speedup is achieved by leveraging the property of the Differential Quantum Circuits paradigm to resolve the differential equations systems. An intrinsic property of clear differentiation of these quantum circuits is expected to yield a dramatic increase in the speed and precision of CFD calculations. On top of that, the strong potential of Quantum Computers against various optimisation tasks can be leveraged in muti-disciplinary design optimisation problems, such as the optimisation of load-bearing structures' design.

Use-case specific advantage for aerodynamic simulations is to be demonstrated on two paradigmatic CFD problems — the inviscid Burgers' equation and transonic flow around an airfoil. At the same time, Airbus' Multi-Disciplinary Design Optimization (MDO) framework will challenge the potential of a hybrid quantum-classical approach.

4.3.1. Market assessment

The solution is aimed to disrupt the Computational Fluid Dynamics, improving its performance. This will influence the whole domain of CFD, the market situation of which is explored below.

The main driver for the market of CFD solutions, as shown in the Figure 12 below is the increasing penetration of CFD approaches into different domains together with the continuous rise of the demands for processing power, as more and more complex problems are to be solved.

Figure 12: Key trends at the Market of Aerodynamic Simulations

Volume and dynamics

Forecast of the global market of CFD solutions is shown in Figure 13 below. The data varies noticeably between different sources: EMR [28], IMARC [29] marketresearch.com [30] due to different methods of assessment, with the global market volume can be estimated around 1.8 B in 2020, 2.3 in 2022, 3.5-3.6 in 2026-2028, growing with a CAGR of 8-12 %.

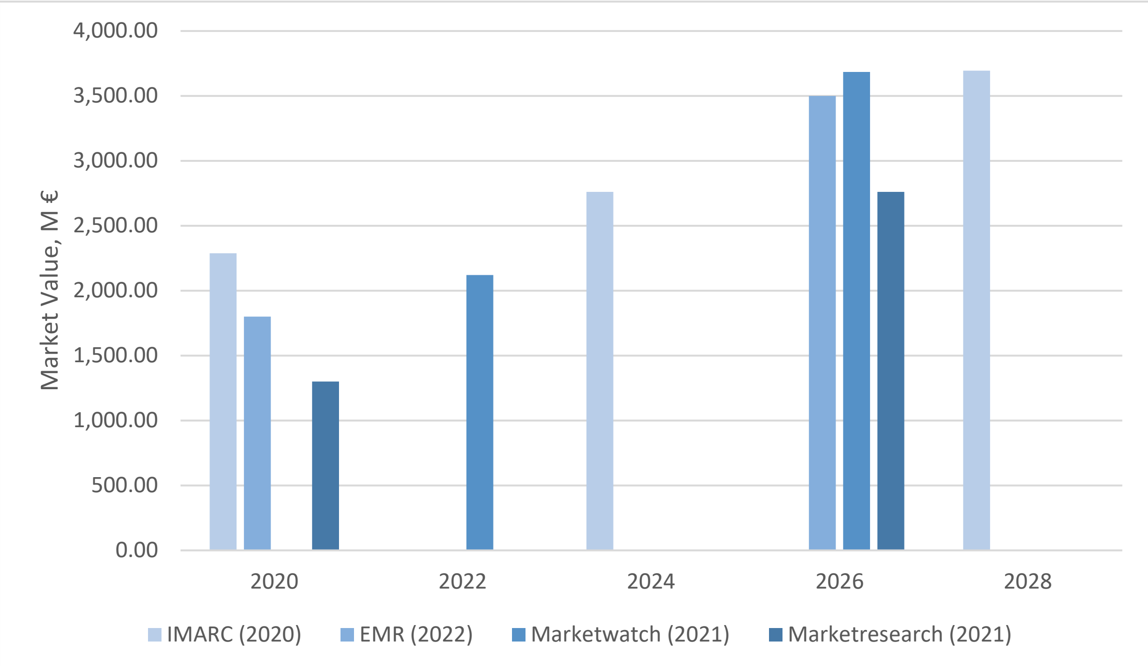

Figure 13: Forecast for the global market of CFD solutions, grouped by sources (in M €).

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The large spread between the market estimations from diverse sources originates from different methods of assessment, however, all the analytical reports present stable market growth in the nearest years.

The market steadily expands to developing countries, such as South Korea, China, Brazil, and India. The rise of outsourcing activities to emerging countries is boosting the manufacturing industry there.

Customers and segmentation

The global market of CFD solutions can be segmented by the deployment model, region, and end-customers. In terms of the deployment model, it can be grouped in either on-premises or cloud-based. Currently, the on-premises model accounts for the largest market share. The end-users for the solutions can be found in the domains of aerospace, energy, automotive, defence and electronics. Among these, the aerospace and defence industry currently hold most of the market share. [30] [31]

Another particularity of the market of CFD solutions is the existence of open-source offers, and a tendency of larger customers to build in-house solutions based on the open-source core algorithms. This expands the potential market for the quantum improvement to CFD beyond the current market figures since the solution can augment the in-house algorithms as well as the commercial ones.

4.3.2. Competitive analysis

This chapter describes the competition in the market of CFD solutions, with a focus on different approaches to bring similar business value as the solution developed.

Developed classical solutions and promising AI techniques present the main technological competition. The main competitors to the solution proposed are large technological enterprises with large market shares and research budgets.

The first section segments competitors by technologies used. The strong and weak points common within each category are enlisted for each of them.

The second section outlines a portrait of a typical competitor company and is summarized by a table of examples.

Technological competition

The main advantage brought in by the solution is the speedup of computational processes involved in the CFD workflow. This value can be delivered by other technologies, which are described here to outline the technological competition to the proposed solution.

The main rivalling technologies are:

- **Classical solvers:** A variety of supercomputer-driven techniques for CFD that are ubiquitously used in the Aerospace industry.
  - **Advantages**
    - Classical algorithms are constantly improving, setting a high bar for the development pace of any alternative solution.
    - Computing resources become more and more affordable, enabling more significant problems to be solved with the existing methods.
  - **Drawbacks**
    - Hardware capabilities surfaced their limits, and there are no reasons to expect dramatic improvements in hardware performance.
    - Large-scale computation is energy demanding.
- **AI-driven techniques:** Alternative and heuristic-based techniques, such as AI, have succeeded at large-scale industrial tasks, like defect-recognition in semiconductor technology, and are expanding to different domains simultaneously. CFD is not [32] an exception: AI has [33] already paved its way in the field and is expected [34] to improve performance compared to classical methods. Following the disruption they have brought into various domains of IT, AI-driven technologies may supersede established procedures of CFD ahead of quantum.
  - **Advantages**
    - No requirement for novel types of backend: it can be run on conventional hardware, available in abundance, which is favourable for the fast exit of the technologies on the market.
    - The high rate of development of AI-driven technologies nowadays, supported by extensive human resources in the domain, makes a favourable climate for its expansion in CFD and aviation.
  - **Drawbacks**
    - As deeply heuristic, there is no definite proof of the advantage brought by this approach. Neither the quantitative predictions are possible. These factors may play a significant role in accepting technology in the aerospace domain. Since the algorithms still rely on classical hardware – training of large models will remain energy-demanding, and it is hard to predict how these demands will scale.
- **Quantum Technologies:** many new quantum initiatives are surfacing in the last few years, adopting different approaches and mechanisms, and claiming different maturity levels making the technology assessment and the market entry estimation challenging. A few techniques and alternatives to the proposed solution have already been announced. (E.g., Differentiable [35] and Variational [36] quantum circuits, Matrix decomposition [37], quantum Amplitude Estimation [38], Hybrid [39]). A primary difference between all the algorithms in this category, in the context of the CFD problems, is the demands on hardware: whether a particular hardware architecture is preferred or the correlation of the demand on size and fidelity of the system scale with the problem size. Another parameter to compare the solutions is the promised speed-up. These quantum-based technologies have strong and weak points compared to the one proposed here:
  - **Advantages:** Future-proof technology, promising dramatic computational advantages. The simultaneous development of multiple different approaches makes it resilient against some local technological roadblocks.
  - **Drawbacks:** Require specific hardware that is yet under development.

Business competition

This section outlines the main competitors on the market, structured by the underlying technology in accordance with the classification above.

Classical approaches

These approaches belong to a well-established domain of classical CFD solutions, relying on the HPC for large computations. It is presented by the large companies, operating both in B2B and B2C segments.

They can be clustered according to the type of resource provision into the on-premises solutions, and the cloud ones. The former provides only software packages, that need to be deployed on the customer hardware, while the latter provide the solution powered with their own backend via cloud, effectively delivering CFD computations as a service to their clients. The main players in every segment (accordingly with their software) are:

On-site software solutions:

- COMSOL, with *COMSOL Multiphysics*: a simulation software that allows users to model and solve fluid flow, heat transfer, and other engineering problems using the finite element method. COMSOL Multiphysics is one of the most modular and polyvalent solutions, covering different domains of finite element simulations with separate add-on packages. The solution is delivered as a software package, with each module (like CFD) licensed separately.
- Siemens, with *STAR-CCM+:* a CFD software package that uses the finite volume method to solve fluid flow problems. Solution allows modelling and analysis of various engineering problems involving fluid flow, particulate flow, heat transfer, stress, electromagnetics, and related phenomena.
- CFD solutions from Autodesk is another strong player at the market of CFD solutions.
- Cadence *Fidelity CFD Software*: another software package, providing state-of-the-art performance and extensive parallelisation to be run on customer owned HPC clusters.
- OpenFOAM: a free, open-source CFD software developed by the eponymous company since 2004 and popular in both commercial and academic organisations.

Cloud-based solutions:

- Ansys, with *ANSYS Fluent*: a popular cloud based CFD solution, that uses the finite volume method to solve fluid flow problems.
- SimScale: a full-cloud CAE simulation software capable to perform CFD, FEA, and thermal simulations for CAD models in the cloud.
- OnScale (now owned by Ansys) with *OnScale Solve*: a cloud-based platform for various Multiphysics simulations, including CFD, aimed to solve engineering problems for large and intricate systems, involving various physical domains.
- Rescale: a cloud-based platform that offers access to a variety of CFD software solutions, including ANSYS Fluent and OpenFOAM.

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- Cadence, with *NUMECA*: Cadence offers complete solutions for flow and multiphysics simulation, design and optimization, via providing fully-cloud solutions based on the Fidelity package.

AI-driven approaches

Multiple commercial CFD tools apply the power of Artificial Intelligence techniques to improve the quality or speed of simulations. The most notable examples of such solutions are:

- Ansys actively employs [40] AI techniques to improve the simulation techniques, as well as an additional instrument for various design optimisation routines.
- Siemens provides [34] AI tools to improve the whole CFD workflow, primarily in pre-simulation analysis and Design of Experiments.
- ByteLAKE CFD Suite leverages [33] the advantage of AI to speed up the whole CFD pipeline. Their custom AI solution is incorporated into the client's existing CFD workflow, helping to leverage the computational bottlenecks by AI-produced predictive analytics, thus dramatically speeding up the workflow. [32]
- Monolith AI have presented a case study, where they employ AI techniques to speed-up a design process involving CFD initially driven by Simcenter STAR-CCM+., where they employ AI techniques to speed-up a design process involving CFD initially driven by Simcenter STAR-CCM+.
- CFMS, a provider of engineering services, employs [41] AI to improve the CFD routines performed by them for their customers. They rely on AI for verification of input data for CAD, mesh refinement, and optimising rigorous CFD computations.
- Altair is an engineering software company that offers AI-driven CFD solutions through its AcuSolve software. AcuSolve uses machine learning techniques to improve simulation accuracy and reduce simulation time.

Quantum approaches

Quantum approaches to CFD simulations are yet under development since the effective size of quantum computers and quantum simulators does not yet allow for CFD simulations of industrially relevant size. However, several hybrid techniques, making use of the joint power of quantum and classical algorithms to bring commercial advantage sooner, are currently being developed by:

- Zapata computing is suggesting [42] its hybrid Quantum-AI solution in Aerospace and Automotive industries, including CFD.
- Classiq, a Tel-Aviv-based startup recently announced its collaboration with Rolls-Royce, aiming to implement novel computational fluid dynamics algorithms using the platform provided by Classiq. [43]

Besides purely technological competition, the proposed solution may face concurrence to other solutions, offering similar kinds of value for the client with other advantages than purely technological: in the economy, delivery, or additional services. This requires a more detailed analysis of competitors' business models.

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4.3.3. Business model

Developing a solution-based business model for the given use case is proposed. The solution consists of the provision, integration, maintenance and rolling improvement of Quantum Computing into customer business processes (in particular, product design and complex aerodynamic simulations).

The proposed solution serves the teams with computationally intensive R&D processes by bringing dramatic speedup and expansion of the tangible problem sizes in aerodynamic simulations. A BMC attributed to this use-case is displayed below in the Figure 14, with the use-case specific blocks being highlighted, while the faded blocks remaining the same as in the General BMC overview.

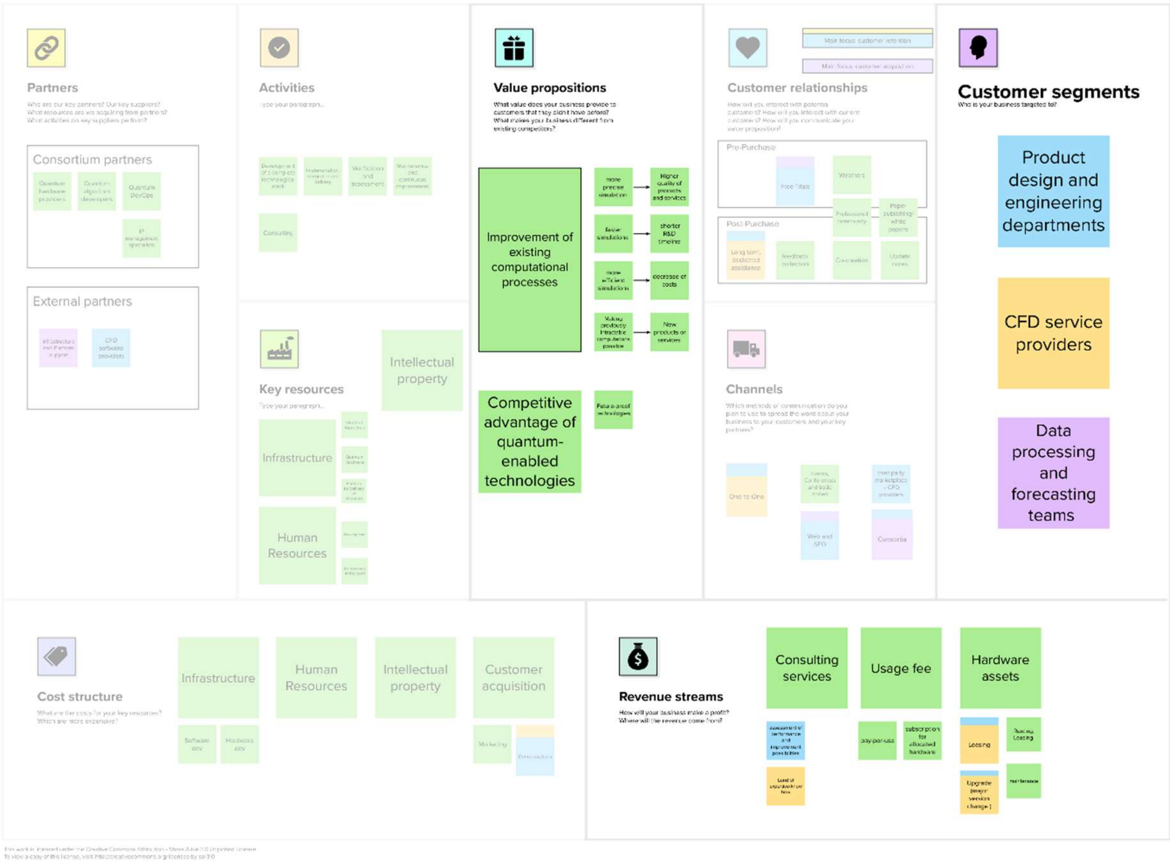

Figure 14: BMC of use-case 3: Aerodynamics Simulation

Customer segments

This solution will primarily serve organisations that need to use complex CFD or similar computations in their processes to create customer value. Early adopters would be the innovation-driven organisations with the most significant R&D budget.

Typical customers for the solution can be found in three large segments:

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- **Product design and engineering departments**, involved in conception and design of complex products and using commercial CFD solutions as their main tool. This customer segment is typically presented in the domains of Aviation (Boeing, Rolls Royce, etc), Aerospace (Safran, Mitsubishi Heavy Industries, Lockheed Martin, etc), Heavy Machinery, especially producing various equipment for energy market, like Hydro- Steam– Aeolo- turbines (General Electrics, etc). This domain includes large enterprises as well as SMEs, however, with accommodated channels and throughputs.
- **Providers of CFD services** together with a backend, such as cloud CFD platforms or design-as-a-service providers, comprise an important customer base for the solution. Since CFD computations are the main activity and source of income for these companies, they would benefit a lot from the improvements offered by the solution. Typical examples of such customers are the cloud solutions provided by Ansys and Cadence.
- **Data processing and forecasting teams** in different domains can benefit from an adapted version of the solution, developed for this use-case. The algorithms driving the CFD computation can be generalised to cover many other problems involving Partial Differential Equations, which opens a wide domain of applications for the solution, making this customer segment the widest and the most fluid one. Typical examples of such customers include various Data-Science or HPC teams in the domains extensively using PDEs. For example, even with minimal adaptation, the CFD algorithms can be used for atmospheric simulations in Meteorology or even in Finance. [44]

Value Proposition

For all client segments, the primary value proposition consists of the revolutionary improvement of computational processes. This will improve the quality of the products and services the client delivers.

Besides, for the product design and engineering companies, it will lead to shrinkage of the R&D timeline and a decrease in R&D costs.

Improvement of existing computational processes will bring secondary values, added to the customer's value chain for all the customer segments. Here they are, structured accordingly by their origins:

- More precise simulations will help the customers to achieve higher quality of their products and services.
- Faster simulations will yield in shorter R&D timelines for the customers leading such activities, while for the other customer segments the speed-up of simulations will directly yield in higher computational throughputs and more value created.
- More efficient simulations will decrease the computational costs for all the customers. Less energy consumption will also aid the customers in achieving their sustainability goals.
- Making previously intractable computations possible will open the customers ways to new markets, by creation of new products or services.

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The strategic value of the implementation of quantum technologies for the discussed solution consists mainly in the adoption of future-proof technologies.

Revenue streams

Revenue streams of the solution are typical for technology-intensive solution models. They vary slightly for different customer segments but always include two main parts: revenues coming from the operation of the solution at the client, and valorisation of the consortium's expertise and IP.

This use-case includes four primary income streams, mentioned in the General Business Model:

Consulting services for this use-case can present an important stream of monetary and non-monetary revenues, as well as be converted into customer loyalty. For the client segment of R&D and developers, the consortium can perform the assessment of performance for the actual workflow, and suggest possibilities for its improvement, using state-of-the-art quantum or classical technologies. For the customer segment of CFD providers, the consortium can lend the expertise and knowledge obtained during the creation of the solution, to streamline current computational processes.

Usage fees present one of the major income streams for the use-case. The pricing strategies should be adapted to the nature and size of the customer's business. For example, occasional customers in the R&D domain might be the best contented with the pay-per-resource pricing, while CFD providers, requiring a high throughput from the solution might chose a subscription for permanently allocated resource.

Hardware assets can serve an additional source of revenue, targeted mostly at the customers with large throughput and budgets, as well as those with highly sensitive data. Then, renting, leasing and maintenance of the quantum hardware, or the whole technological infrastructure, can be a strong source of recurrent revenue. On top of that, acquisition and installation of this hardware, as well as major technology upgrades, can serve a notable transactional revenue stream.

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4.4. Fourth use-case: Mission optimisation for space

Space image acquisition is in high demand nowadays, with photos taken by satellites used in different industries at different scales to tackle problems in cartography, urban planning, ecology, energy, defence, and many other public and private domains. This technique, empowered by modern image-processing and Data-Science algorithms, will expand even more, from a figure of 3.3 B $ in 2021 to 9.2 B $ in 2031. [15] These figures can be further increased by innovation and technological advances, as described below.

Currently, 906 observation satellites are orbiting the Earth, grouped in constellations according to their providers, capabilities and aims. When a company operating one of these constellations, receives a request for the acquisition of an image of a given part of the Earth at a given time, it faces the problem of resource allocation: which satellite will take the job, when will it be capable of executing the request, and which manoeuvres need to be performed for successful acquisition. The unity of such decisions and procedures is known as a space mission. The complexity of this problem grows dramatically with the number of satellites. With huge costs involved in launching new satellites (for reference, a four-satellite Pleiades program costs Airbus 600 M €, with an expected mission duration of 10 years), every operator would prefer to have the highest utilisation of the machines already in orbit. All of these make optimal mission planning a critical operational procedure for large constellations of satellites.

Mission optimisation can be treated as a complex multi-objective problem involving several conflicting goals and constraints. Particularly, an optimal schedule of a space mission should also take in consideration the priorities and preferences of the customers. The aim is to maximise the number and the quality of planned acquisitions while respecting all technical constraints of the imaging platform. Such constraints are largely defined by the manoeuvring capability of the satellite but also include the considerations for the onboard memory capacity, thermal and power limits, and parameters of optical acquisition. The whole problem is intricate, but it is essential for the satellite operators to approach the optimum at solving it, to ensure the best possible utilisation of the precious space-based resources and satisfaction of the most of customers' demands. Besides, the problems of optimal scheduling with time constraints formulated in this use-case are very interesting from a mathematical standpoint, and the findings can be applied across different industries.

The necessity for a novel approach to optimisation of the space missions is stressed by constantly growing complexity of such problems, due to the following factors:

- Ever-increasing number of satellites in the constellations
- Larger volume of candidate meshes to plan per programming period, appearing due to the smaller instrument footprint, which is allowed by higher resolution of sensors.
- Multiplication of acquisition opportunities, thanks to the enhanced agility of newer satellites
- Introduction of the multi-objective optimisation, aimed to satisfy the acquisition priorities, maximise the surface covered, and account for the acquisition latencies and weather conditions.
- Management of uncertainties, such as errors in weather prediction

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All these factors make the optimisation of space missions a very complex mathematical problem, and consequently - a particularly fruitful use case for quantum technologies.

Currently, such problems are addressed with sub-optimal heuristic algorithms, such as greedy or dynamic programming. There is evidence, that heuristic quantum or hybrid approaches might outperform specific classical approaches in combinatorial optimisation. The most prominent quantum approaches to combinatorial optimisation are the Quantum Annealing (QA) and Quantum Alternating Operator Ansatz (QAOA), as well as quantum versions of multi-objective algorithm solvers, such as the Quantum Particle Swarm Optimization (QPSO).

The consortium has a notable advantage in the development of such technologies. For example, teams from Airbus and DLR have already assessed the performance of quantum annealers for the operational planning of an Earth observation satellite. [45] The work was exploring the problem of acquiring high-value images while obeying the attitude manoeuvring constraint of the satellite and included a benchmark of quantum annealers provided by the D-Wave against the algorithms used in industry. The quality of the solution using QA was found to be comparable to the one yielded from the classical heuristics for the small problems, however, the quality of the QA solutions degraded quickly with the problem size surpassing certain limit, defined by the physical limitations of the annealing chip (at about 40 variables). In the current project, this experience will be promoted on other quantum approaches developed under the umbrella of the Quantum Flagship.

Another unique strength of the consortium is the profound technical insight into space operations. One of the consortium members, Airbus Space Systems, delivers leading space technology and solutions for enterprises and governments around the globe. Its expertise includes versatile telecommunications satellites, very-high-resolution Earth observation instruments, unique deep space missions, International Space Station operations and lunar exploration. Airbus operates the world’s largest Earth observation constellation comprised of the Pléiades Neo, Pléiades, SPOT, DMC Constellation and Vision-1 optical satellites and a Radar Constellation consisting of TerraSAR-X, TanDEM-X and PAZ. Unique industry-specific insights will allow the consortium to conceive an industry-relevant and viable solution.

4.4.1. Market assessment

Volume and dynamics

Space industry nowadays experiences stable growth, with CAGR around 10%. Solution is intended to optimise the route planning of the imagery satellites, however, can be employed to any space missions that require optimisation. Dependence on satellite data is especially growing in the construction and defence sector. The highlights of the market are displayed in the Figure 15 below.

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Figure 15: Key trends at the Market of Commercial Satellite Imaging

The Global Commercial **Satellite Imaging** Market is projected to grow from about USD 4.8 Billion in 2022 to USD 7.08 Billion in 2027 at a CAGR value of 11.25% from 2022 to 2027. [46] Other estimations attribute it 3,76 USD Billion in 2022, and 8,77 USD Billion by 2030 with CAGR of 11,2% [47] or 11.84% [48]

The **satellite data services** market is projected to reach 16.7 billion by 2026 (from 5.9 in 2021) with a CAGR of 23%, which is noticeably higher than most of other domains involved in this study, being between 10 and 14%. [49]

The global space traffic management market was valued at $11.9 billion in 2020 and is projected to reach $22.4 billion by 2030, growing at a CAGR of 7.1% from 2021 to 2030. [50]

The main driver for the market is the growth of Earth observation and analytics volumes, while the main restraint is the stringent government space policies and regulations, the main opportunity is the increased government investment in space agencies, and the main challenge is the concern about the space debris [49].

Customers and segmentation

The market for satellite imagery can be segmented: [47]

By application: geospatial data acquisition and mapping, natural resource management, surveillance and security, conservation and research, disaster management, defence, and intelligence.
Defence accounts for the largest share of the market (45%) with the exploration of Natural Resources being the second largest. A more detailed chart is presented in the Figure 16 below.

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By end-user: government, construction, transportation and planning, military and defence, forestry, and agriculture.

Geographically: US is the largest segment with 42% of global revenue, while APAC is the fastest growing market

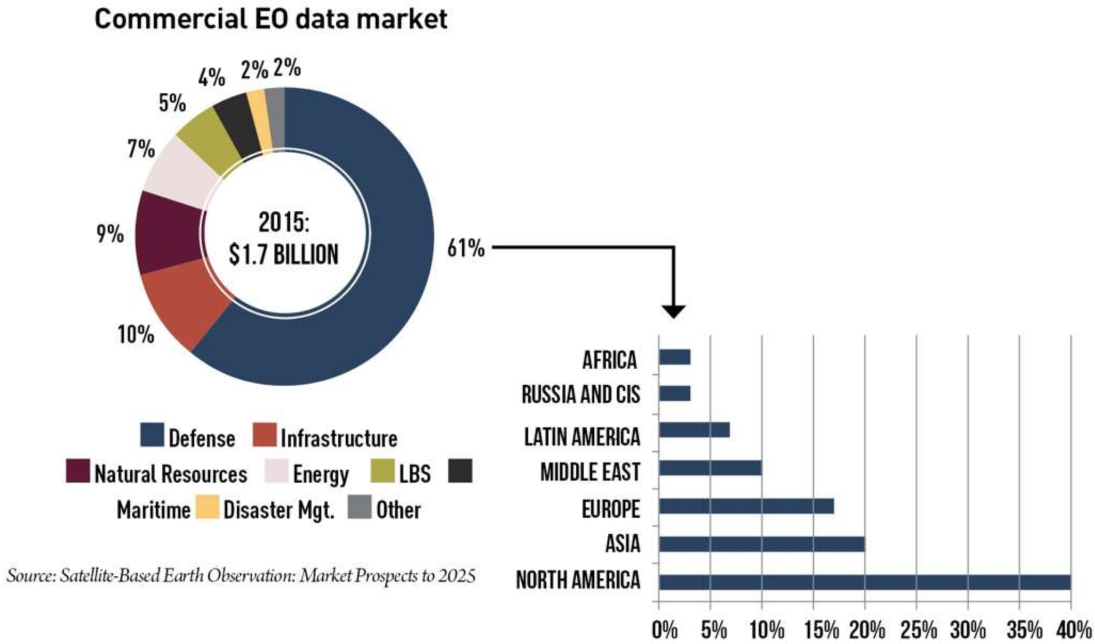

Figure 16: Segmentation of the Commercial Earth Observation market [51]; [52], [53]

The main players on the Satellite Data Services market are: Maxar technologies (US), Planet Labs (US) Satellite Imaging Corporation (US), ICEYE (Finland), Earth-I (UK), Airbus (Netherlands), while the main customers are the governments. [49]

More specifically, the main providers of *Commercial Satellite Imaging* are: DigitalGlobe Inc, Esri, MDA, Airbus, Blacksky Technology, European Space Imaging (EUSI), ImageSat International, Galileo Group, Planet Labs, Skylab Analytics, SpaceKnow. [47]

4.4.2. Competitive analysis

The final value that is created by the solution is the increase in the amount of satellite-acquired data received on Earth per unit of time. This section focuses on alternative ways to reach the same value to estimate the competition.

Technological competition

- **Classical heuristics:** Various heuristic algorithms are currently used ubiquitously for Combinatorial Optimisation across industries. Notable examples of optimisation solvers are Cplex, Gurobi and Xpress.
  - **Advantages:** Classical algorithms are constantly improving, setting a high bar for the development pace of any alternative solution. Computing resources also

become cheaper, eventually allowing larger problems to be run with the existing methods.
    - **Drawbacks:** Hardware capabilities mostly govern current limitations. They have already been reached, and there are no reasons to expect dramatic improvements in the hardware performance. Large-scale computation is also energy demanding. Another aspect is the high price of licenses for commercial usage (~200k € / year).
- **Quantum Technologies:** Optimisation problems can be formulated in a very natural way for solving them with the help of quantum technologies. Multiple quantum optimisation algorithms have already been demonstrated but are still limited severely by the hardware capabilities. A feature of quantum optimisation, that is important for the competitive landscape, is that most algorithms and concepts are "hardware-agnostic", meaning that they can be easily run on any type of quantum computer, leaving the competitive advantage between different quantum computing providers to rely completely on the technological maturity of the backend hardware. Another important aspect to compare different approaches is the promised speed-up.
    - **Advantages:** Future-proof technology, promising dramatic computational advantages. Several different approaches are a strong asset against potential technology-specific roadblocks.
    - **Drawbacks:** Requires specific hardware that is yet under development. (Quantum overall). A multitude of quantum competitors on the market makes direct competition tensile.
- **Launching more satellites:** Besides improving the optimisation scheme for satellite routing, the customer can launch more satellites, yielding more data acquired. This would be a purely business solution since (despite satellites being exquisitely sophisticated machines) as, differently from the approaches listed above, it has low R&D or technological breakthrough requirements. Since this scenario would bring the customer a similar value as the quantum solution of the consortium – it still counts as a competitor. The leading provider of this competition is the client of the solution itself.
    - **Advantages** of this decision are independence on the IT developments (since, building more identical satellites involves much less R&D, than developing novel technologies); predictable roadmap and scaling.
    - However, it has a few **Drawbacks** as well. The primary is the costs: the four-satellite Pleiades program cost Airbus 600M€, with an expected mission duration of 10 years. (½ of the whole European Quantum Budget. Costs of the whole Equality program is 6M€). Another aspect is sustainability – avoiding cluttering the orbit with extra satellites is preferable. Finally, increasing the number of satellites in a constellation will make spatial routing even more complex (for example, to evade collisions between satellites), so it should be avoided if possible.

Business competition

Nowadays there exist a plethora of providers for various types of optimisation problems. This section presents an overview of different commercial solutions, that would fit the best to the types of optimisation problems faced in this use case:

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Classical approaches

- IBM ILOG CPLEX: a commercial optimization software package, including mixed-integer programming and constraint programming solvers, which can be used to solve binary optimization problems subject to constraints. IBM offers both cloud and on-premises deployment options for its software.
- Gurobi Optimization: a commercial optimization software, including mixed-integer programming, linear programming, and quadratic programming solvers, which can be used to solve binary optimization problems subject to constraints. Gurobi offers cloud deployment options, in addition to the on-premises one.
- Google OR-Tools: an open-source optimization software suite that includes mixed-integer programming, constraint programming, and local search solvers, which can be used to solve binary optimization problems subject to constraints. Google OR-Tools can be run on the cloud or on-premises.
- FICO Xpress Optimization: a comprehensive suite of optimization tools, including mixed-integer programming, linear programming, nonlinear programming, and constraint programming solvers, which can be used to solve binary optimization problems subject to constraints. FICO offers both cloud and on-premises deployment options for its software.
- Cognitivescale: an AI-driven optimization platform that includes solvers for combinatorial optimization, network optimization, and other optimization problems, which can be used to solve binary optimization problems subject to constraints. Cognitivescale's software is cloud-based.
- LGO: a commercial optimization software package that specializes in global optimization of nonconvex problems, including binary optimization problems subject to constraints. LGO's software is on-premises, so it necessitates an HPC to run it on.
- OptaPlanner: an open-source optimization software that specializes in vehicle routing, employee rostering, and other combinatorial optimization problems.

Quantum approaches

Optimisation problems are one of the most popular and explored domains of application for quantum computers, due to the promised speedup being theoretically proven for some kinds of tasks. At the same time, the maturity of the technology has not yet arrived at the point of providing commercial services for optimisation. Besides, the problem considered in this use-case (TD-TSP TW) belongs to the class of “constrained” problems, while most of the quantum optimisation approaches are aimed at “unconstrained” problems due to them being closer to natively quantum instances like Ising Hamiltonian. Nonetheless, it is important to outline a few companies that advanced the most on the way to delivering their services to customers:

- D-Wave systems, with their quantum annealer available for commercial use. It has not yet outperformed the state-of-the-art classical heuristics, especially on the large problems. Its established presence on the market and development during the few recent years makes it a potential competitor to the solution proposed in this project. However, it is important to admit, that the annealer is not perfectly suited to the satellite routing problem in its full representation, due to conceptual inability to capture certain constraints, despite still suiting for solving simplified problems.
    - Fujitsu digital annealer is a classical device for executing simulated annealing algorithms extremely efficiently. It is often considered quantum-inspired and

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compared to its quantum counterparts. Despite the limited nature of problems resolvable, its performance is competing with the best heuristic algorithms.

- Zapata computing is offering a hybrid Quantum-Classical-AI approach to a set of optimisation problems, presumably including the constrained ones. [54]
- Solutions from: CQC, Rigetti, 1QBit, Pennylane include software modules aiming at constrained optimisation, which, provided suitable hardware in reasonable time, could present certain competition.

4.4.3. Business model

Developing a solution-based business model for the given use case is proposed. The solution consists of the provision, integration, maintenance and rolling improvement of Quantum Computing into customer business processes (in particular, Space Mission optimisation, or similar problems of combinatorial optimisation).

The proposed solution serves the operators of space imagery satellites by bringing dramatic speedup to the mission planning, allowing for better satellite utilisation. Besides, the solution can be adapted to solve similar optimisation problems across the industries.

A BMC attributed to this use-case is displayed below in the Figure 17, with use-case specific blocks highlighted, and the faded blocks remaining the same as in the General BMC overview.

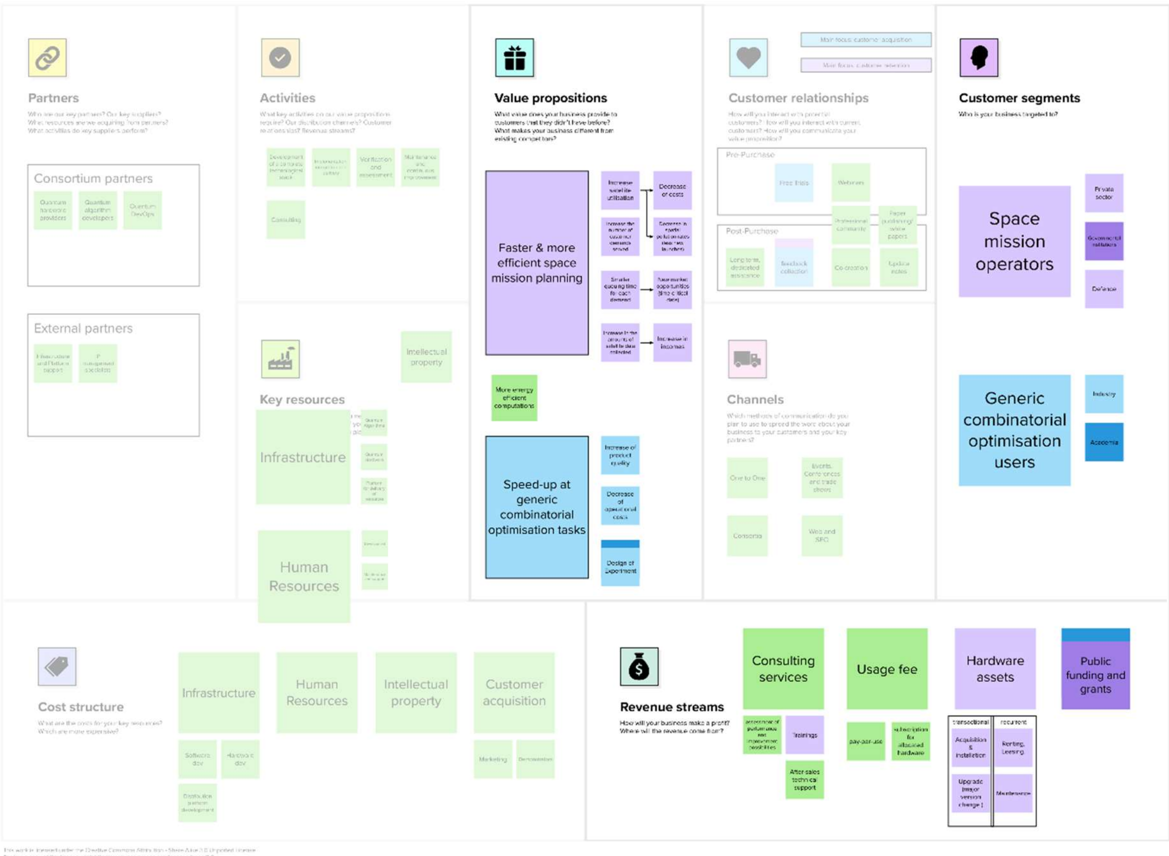

Figure 17: BMC of use-case 4: Space mission optimisation (bigger in annexe).

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Customer segments

Solution developed for this use-case will primarily serve organisations that operate constellations of Earth-observation satellites, alleviating the computational bottleneck at the mission planning. Typical customers for the solution can be found in two large segments:

- **Space mission operators**, from Private, Defence or Governmental sectors, present the principal customers for the solution, which is specifically designed to fit the type of problems arising in the space mission planning. The solution is intended to alleviate the bottlenecks with mission optimisation, which the clients from this sector already face. Typical customers from this sector would be companies like: European Space Imaging (EUSI) and Galileo Group.
- **Generic combinatorial optimisation users** comprise a wide category of clients, that the solution can address with minor changes. Combinatorial optimisation problems arise ubiquitous in industry and academia, so efficient methods to solve them can generate much added value.

Value Proposition

For the customer segment of the space mission operators, the primary value brought by the solution consists in **faster and more efficient planning of space missions**. This yields in many secondary benefits:

- Increase in the amounts of satellite data collected will directly increase the revenues of the space imagery operators.
- More optimal mission planning can increase the satellite utilisation (*currently with the use of sub-optimal heuristic algorithms the capacity of satellite utilisation is limited to 80%)*, leading to decrease in costs for launching new satellites and time-consuming computations. Besides, by launching less satellites, the operators contribute less to the formation of space debris on the orbit.
- Increase the number of client's demands served, by increase in satellite utilisation and allowing for more flexible dynamic planning (e.g., including urgent demands from clients without disrupting the schedule much), will yield in higher revenues, higher client satisfaction and loyalty.
- Faster mission planning and decision-making will decrease the queuing time for each client's demand, paving the space operators a way into the new markets dealing with time-critical data.

For the wide group of customers using combinatorial optimisation, the main value consists in bringing **speed-up at combinatorial optimisation tasks**, with various consequent advantages, such as:

- Decrease of operational costs
- Increase of product or service quality
- Improvement of Design-of-Experiment routines

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Besides, for all the customer segments, augmentation of current computationally demanding processes with quantum solutions, which are more energy efficient, will help to decrease the operational expenses and ecological footprint.

Revenue streams

Revenue streams of the solution are directly following the nature of the principal client groups, including all four primary income streams, mentioned in the General Business Model, with certain specificities:

Consulting services for this use-case present an additional stream of monetary revenues, as well as one of the means of after-sales support. For all the clients, consortium can perform the assessment of performance for the actual workflow, and suggest possibilities for its improvement, using state-of-the-art quantum or classical technologies. It can also provide the after-sales technical support. For customers in the segment of space operators, that have selected the on-premises model of solution deployment, consortium will provide also training of operational and maintenance personnel of the customers, to ensure the maximal utilisation of the solution by the customers.

Usage fees present one of the major income streams for the use-case and are applicable to any customer segment. The pricing strategies should be adapted to the nature and size of the customer's business, but the primary ones are payment based on the resource used, mostly aimed at SMEs or occasional users of optimisation services, and subscription for allocated capacity, favourable for the intensive use, which is expected to be the case of the space mission operators.

Hardware assets present an important source of revenue for this use-case. It is targeted principally at the larger customers in the domain of space mission optimisation, due to the strict demands of the domain on uninterrupted performance and data security. Aimed at such customers renting, leasing and maintenance of the quantum hardware or the whole technological infrastructure can be a strong source of recurrent revenue for the solution. On top of that, acquisition and installation of this hardware, as well as major technology upgrades, can serve a notable transactional revenue stream.

Public funding and grants can generate additional revenue for the solution, when supplied to the governmental space agencies or research centres. Besides, it is one of the additional benefits from participation in academic collaboration, on top of the additional values generated for the consortium in terms of knowledge and IP.

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4.5. Fifth use-case: Space data analysis and processing

Space imagery is in high demand nowadays, with novel applications stemming daily thanks to the advancements of the computation approaches to image data processing, such as Machine Learning or Big Data. Radars provide an extremely powerful domain of space imagery, thanks to their ability to deliver high-quality images regardless of the atmospheric conditions. Among those, a Synthetic Aperture Radar stands out with its by-design high resolution. This resolution, however, comes at the cost of computationally hard post-processing of the acquired data. Various HPC techniques now perform this processing (e.g., Back projection or omega-k transformation). Despite each technique having its strong and weak points, there is a global tendency of mismatch between the high demand for end customers and the insufficiency of current computational power. The key problem addressed within this use-case is schematically expressed as a diagram of the processing power capacities along the value creation chain in the Figure 18 below. The urge for a breakthrough in the domain is also supported by the fact that current space missions can provide a few orders of magnitude more data than it can be processed per unit of time.

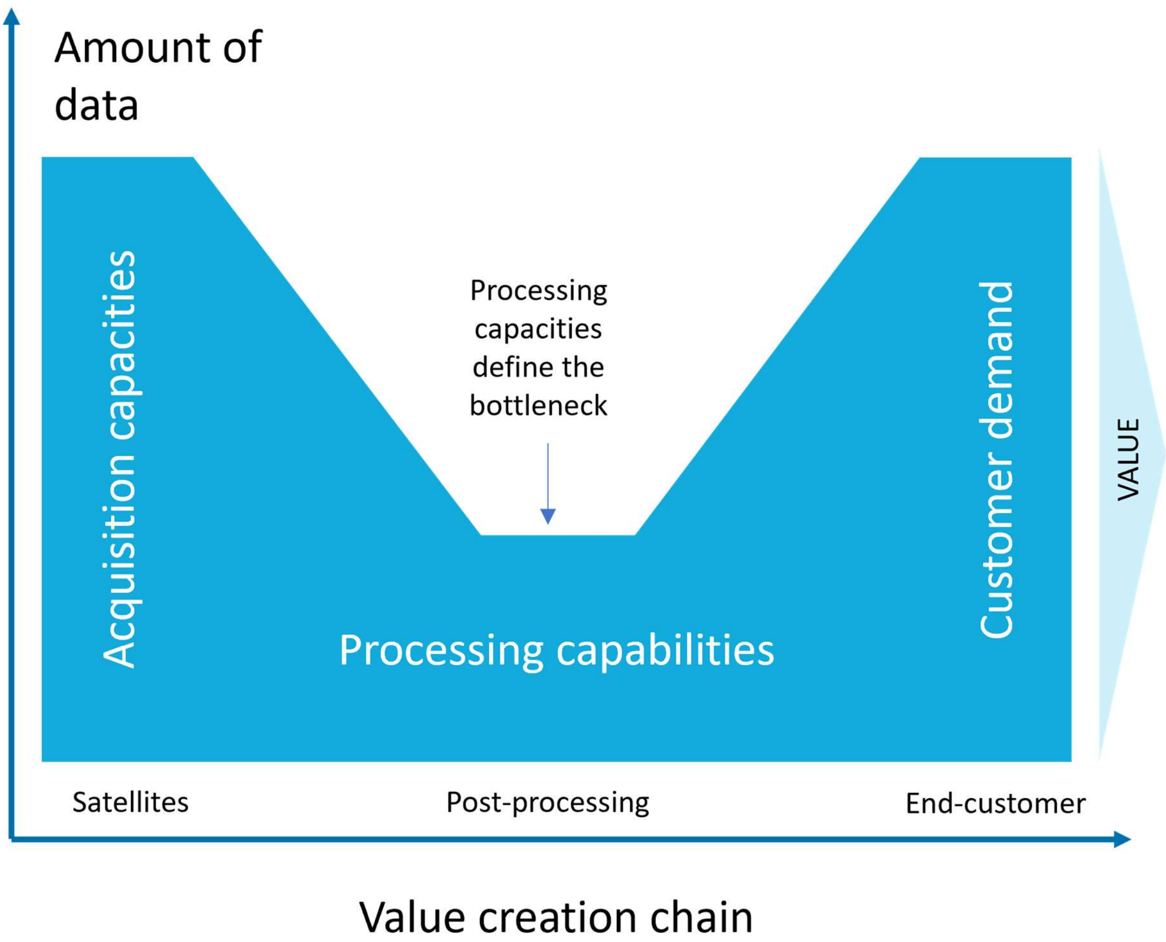

Figure 18: Schematic representation of value generation in the SAR imagery use-case, with a bottleneck in processing capabilities.

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This use case aims to develop algorithms and hardware capable of dramatically speeding up the processing of SAR images, to alleviate the bottleneck problem mentioned above. Potential directions of the research may be:

a) Improvement of classical SAR processing algorithms, substituting computationally intensive parts of classical algorithms with their quantum equivalents
b) Developing a completely novel, quantum or quantum-inspired approach to SAR processing
c) Application of (Quantum) Machine Learning techniques to pre-processing of SAR images (e.g., feature detection on raw data to pre-select data frames for complete SAR processing)
d) Exploration of the potential of (Quantum) Machine Learning against the SAR image processing

The main particularity of this use case is that a high percentage of customers coming from the Defence sector, places tight restrictions on the security of the data processing pipeline. Besides, majority of the customers in both the Defence and Civil sectors are expected to be large enterprises, as operators of satellite constellations.

4.5.1. Market assessment

Most of the SAR processing is performed by Defence and Intelligence agencies or tightly intertwined with them, which makes the market rather obscure, with a large part of classified and in-house technologies. The following market research is performed on open data, hence – is not exhaustive. The highlights of the market are displayed in the Figure 19 below.

Volume and dynamics

Synthetic Aperture Radar (SAR) Market in the space sector market, in terms of revenue, was estimated to be USD 3614.6 million in 2021 and is expected to reach USD 7645.4 million in 2028, growing at a CAGR of 11.30% from 2022 to 2028. [55]

Figure 19: Key trends at the Market of Synthetic Aperture Radar solutions

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Customers and segmentation

The market is considered medium-consolidated, with multiple large players. A few of them are: [56]

- Lockheed Martin Corporation
- Thales Group
- BAE Systems
- Cobham PLC
- Aselsan A.S.

The SAR market can be segmented: by application - into defence, commercial and research; by platform – into space-based, aerial and ground platforms; and based on the frequency bands and modes used.

4.5.2. Competitive analysis

The final value created by the solution in this use case is the speed-up the post-processing of satellite-based image acquisition, specifically for the SAR techniques. The potential use of satellites as a platform for the quantum backend is another strong point of the solution, mutually beneficial to the use case and for quantum technology development in general, although satellites are not the only type of carriers for SAR imagers.

This section focuses on alternative ways to reach the same value to estimate the competitive situation in the domain.

Technological competition

- **Classical algorithms:** Various approaches are currently used for Image Data Processing across industries, especially in the domain of SAR. [57]
    - **Advantages:** Classical algorithms are constantly improving, setting a high bar for the development pace of any alternative solution. Computing resources also become cheaper, eventually allowing larger problems to be run with the existing methods.
    - **Drawbacks:** Hardware capabilities mostly govern current limitations. They have already been reached (the tangibility of their processing governs current limitations in image size), and there are no reasons to expect dramatic improvements in the hardware performance in recent years. Large-scale computation is also energy demanding.
- **Assembly-Specific Integrated Circuits**:
  Another strong approach to Data processing is Assembly-Specific Integrated Circuits - microchips designed for extremely efficient execution of a single algorithm. Their application for SAR problems has already been explored. [58] [59] ASICs excel at high workloads thanks to hardware-programmed algorithm execution. However, they are the least flexible solution and incur high development costs.
    - **Advantages:**
      ASICs can always exceed classical performance and/or energy efficiency solutions since the same algorithms can be executed faster on dedicated chips, rather than on general-purpose processing units. In everyday technology,

Image Processors are often integrated directly into imaging devices, allowing for dramatic improvements in the speed and resolution of SAR. The on-board placement of such may present a technological problem, yet – once solved, it may create a strong adversary to the quantum solutions.

- **Drawbacks:**
  The ASIC approach does not allow flexibility since the algorithm is encoded at the silicon level during design. This may be crucial for some applications (e.g., often changing resolution or imaging mode). ASICs also incur prohibitive costs, since the development and fabrication involve a high budget, which is split over a comparatively small (for semiconductor manufacturing) batch of chips.

- **AI-driven techniques:**
  Alternative, heuristic-based techniques, such as AI, have found industrial success in Image Processing, such as image classification and many other domains. It has already been shown [60] how AI can be applied for Phase unwrapping, which is one of the key procedures of Interferometric SAR signal processing.
  - **Advantages**:
    - No requirement for novel types of backend: the algorithms can be run on conventional hardware, available in abundance. This is favourable for the fast exit of the technologies on the market.
    - The high rate of development of AI-driven technologies nowadays, especially in image processing, creates a favourable climate for development of AI techniques applied to SAR.
  - **Drawbacks**:
    - As deeply heuristic, there is not always definite proof of this approach's advantage; neither is the quantitative predictions possible. Besides, processing raw data from SAR into images requires precise mathematical operations upon large chunks of data, so any heuristic advantage may come at cost of some trade-offs in other aspects (e.g.: resolution, or loss of non-specific features).
    - These factors may play a significant role in accepting technology in the aerospace domain, where the validity of non-specific data is of ultimate value. Moreover, as long as the algorithms still rely on classical hardware – training of large models will remain energy-demanding, and it is hard to predict how these demands will scale with time.
- **Quantum Technologies:**
  Classical SAR can be obtained by different mathematical routines, which can be mapped on quantum computing in diverse ways. (E.g., Fourier Transform vs Back-projection). Each comes with its strong points for the initial algorithm and its quantum realization. A plurality of Quantum-Driven approaches, especially considering better suitability of some hardware for some tasks, make space for more than a single way quantum computing can succeed at SAR. Thus, to obtain an advantage in the field, one must match success at the software stack with notable improvements of the hardware backend, which is a non-trivial task today.
  - **Advantages:**
    Future-proof technology, promising dramatic computational advantages. Technology offers an opportunity to develop simultaneously several independent hardware and software approaches, making it more resilient against local technological roadblocks.

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- **Drawbacks:**
  Quantum Computing requires specific hardware that is yet under development. A multitude of quantum competitors on the market makes direct competition tensile.

Business competition

This section is dedicated to an overview of current competitors on the market of the space data analysis. SAR market is relatively narrow and due to the sensitive nature of data, is mostly limited to the operators of SAR-imaging constellations, as well as Defence and Intelligence. High demands on data throughput and highly sensitive nature of the data push each of these organisations to organise the whole workflow on-premises, with a large part of in-house developments in algorithms and frameworks, as well as the full stack of hardware for SAR image acquisition and processing. At the same time, the nature of the solution proposed in this project is rather augmentative to the existent SAR routines, effectively speeding them up rather than replacing the whole pipeline, which together with the previous point imply that each of the current large players on the SAR market would be either a customer, or a competitor, if not at the same time, for the solution proposed by this project. This is the reason why this chapter is focused on an overview of current main SAR data processing companies, which in many cases are at the same time SAR satellite operators:

- **Airbus**: Airbus is a major player in the SAR processing market, providing SAR data processing services and software for a range of applications. The company offers a variety of SAR processing techniques. Besides relying fully on the in-house algorithms for SAR processing, the company also leverages machine learning techniques for improvement of SAR processing workflow.
- **Capella Space:** Capella Space is a US-based company offering SAR satellite imagery and data processing services. The company uses advanced signal processing techniques to generate high-quality SAR images, including range-Doppler processing, polarimetric processing, and interferometric processing. Besides, the company uses AI for automation of image analysis.
- **ICEYE**: ICEYE is a Finnish provider for satellite SAR imagery. The company uses a set of various SAR techniques, such as spotlight imaging mode for increasing the resolution beyond that supported by the azimuth beamwidth of the antenna, as well as the Interferometric mode (InSAR) to generate 3D images of terrain and to detect changes over time.
- **ESA** (European Space Agency): ESA is a multinational organization that is involved in a range of space-related activities, including SAR processing. ESA has developed a variety of SAR processing techniques, including range-Doppler processing, polarimetric processing, and InSAR processing.
- **GAMMA Remote Sensing**: GAMMA Remote Sensing is a Swiss company that provides a GAMMA software, supporting the entire processing chain from Synthetic Aperture Radar raw data to end products such as digital elevation models, displacement maps and land use maps. The techniques provided by the solution include range-Doppler processing, polarimetric processing, and Interferometric SAR processing. GAMMA also offers software tools for SAR data analysis, including tools for deformation analysis and land cover classification.

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4.5.3. Business model

A BMC attributed to this use-case is displayed below in the Figure 20, with the use-case specific blocks being highlighted, while the faded blocks remaining the same as in the General BMC overview.

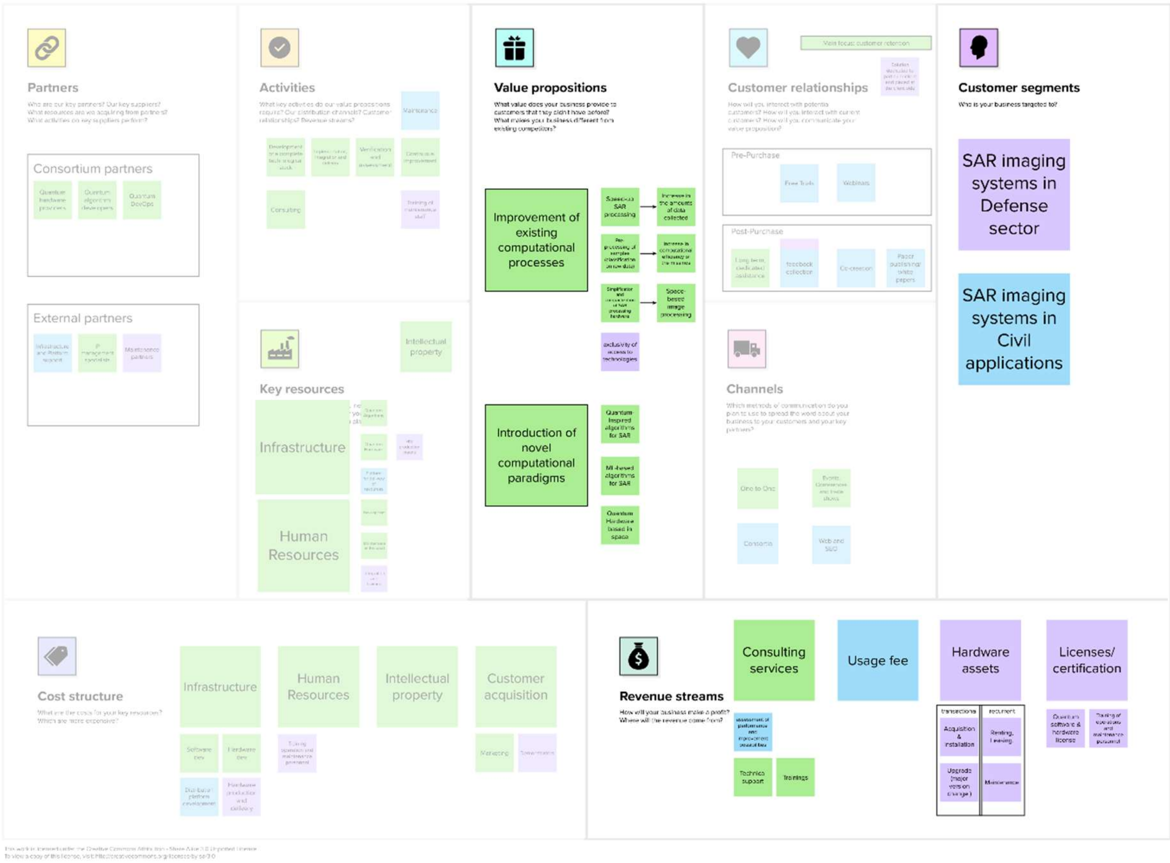

Figure 20: BMC of use-case 5: Space data analysis and processing (bigger in annexe).

Customer segments

Solution developed for this use-case will primarily serve organisations using intensively SAR imaging techniques, alleviating the computational bottleneck at the post-processing of the images obtained by SAR techniques. Present business model distinguishes between two types of customers, according to their nature and with a strong accent on sensitivity of the information processed:

- **Defence sector** comprises a large share of the whole market of SAR systems and operators. Clients from the domain of Defence and Intelligence have high interest in disruptive technologies and would not be repelled by the large costs of the solution. However, they impose strict conditions on the transparency of the underlying technology and on the data security, which must be met by the solution. Proposed solution, as well as this business model take these constraints in consideration.

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- **Civil applications** still exist in the domain of SAR imaging, thanks to international organisations like ESA and public-funded research projects. These customers are expected to be closer to academia and SME, with respective accommodations of the business model. However, they present an important sector to include in the customer base, since much non-monetary value can be extracted in various collaborations, research, and education programmes.

Value Proposition

For all the customers, the primary value brought by the solution consists in **improvement of existing computational processes**. This yields in many secondary benefits:

- Improve in the pre-processing routines, like introducing classification of the raw data, will dramatically increase the computational efficiency of the whole missions, resulting in decrease in costs.
- Speed-up the whole SAR processing pipeline, which will increase the amounts of data and value extracted from the whole technology stack.

Customers from the domain of Defence and Intelligence would greatly value the exclusivity of access to technologies.

Besides the speed-up of existing data pipelines, the introduction of quantum technologies can also create momentum and a knowledge base to propel the **introduction of novel computational paradigms** in the domain, which will lead to:

- Development of quantum-inspired algorithms for SAR
- Deeper introduction of ML-based approaches into SAR processing

Besides, for all the customer segments, augmentation of current computationally demanding processes with quantum solutions, which are more energy efficient, will help to decrease the operational expenses and ecological footprint.

Finally, thanks to the potential customers and partners, this use-case might pave the way for the exploration of space-based quantum hardware, which might be a disruptive step for Quantum Technologies as well as for the use-case itself.

Revenue streams

Revenue streams of the solution are directly following the nature of the principal client groups, including all four primary income streams, mentioned in the General Business Model, with certain specificities:

Consulting services for this use-case present a secondary stream of monetary revenues due to the information protection protocols of majority of potential customers, but they can still present as the means of after-sales support. Especially for customers from the Defence and Intelligence sector, that are expected to select deployment of solution on their premises, consortium will take part in training of operational and maintenance personnel of the customers, to ensure the maximal utilisation of the solution by the customers. Assessment of

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performance then remains as a secondary stream of services reserved to open organisations and academia.

Usage fees present a valuable income stream for the use-case, especially for the Civil segment of customers. The pricing strategies should be adapted to the nature and size of the customers, including opportunities of free academic versions.

Hardware assets is expected to be the dominant source of revenue for this use-case, especially in the Defence and Intelligence sector. Solution will then be adapted for the deployment of the solution on customers' premises, with high degree of isolation and scrupulous protocols of information protection. In this model, renting, leasing and maintenance of the quantum hardware or the whole technological infrastructure can be a strong source of recurrent revenue for the solution. On top of that, acquisition, and installation of this hardware, as well as major technology upgrades, can serve a notable transactional revenue stream.

Licenses and certification can generate additional revenue for the solution, when supplied to the governmental agencies or research centres, as well as to the defence sector. Revenue can be generated by provision of licenses for use of quantum hardware and software, as well as by providing training and certification for the operational and maintenance personnel.

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4.6. Sixth use-case: Solid Oxide Fuel Cell Optimisation

Hydrogen-fed fuel cells are a promising candidate for future energy convertors, being greener and easier to operate than combustion engines, yet – scalable and powerful enough to replace the latter in different applications of autonomous power sources, especially in mobility. An outstanding example is the ZEROe project launched by Airbus to create the world's first zero-emission commercial aircraft. The ZEROe concept aircraft rely on hydrogen as a primary power source, relying on a hybrid-hydrogen configuration featuring modified gas-turbine engines complemented by fuel cells for electrical power.

In this context and beyond, fuel cells have tremendous potential to shape future mobility without harmful emissions. The most promising candidate for this domain of applications in Solid Oxide Fuel Cells (further referred as SOFC), being a more efficient and fuel-versatile alternative to gas turbines. Over the past decade, the power density of SOFCs has doubled. However, there is still a significant amount of work required to make this technology feasible for aviation purposes. The development of novel manufacturing techniques for both metallic and ceramic materials show promise in creating lighter functional layers for SOFCs, which can increase their micro-structured surface area. Nevertheless, to effectively use these new materials and cell concepts, a thorough comprehension of the microscopic chemical processes is essential.

Despite the SOFC presenting a promising candidate for future mobility, there still is a need for improvement before they reach their full potential. Particularly, there is a need to achieve lower operating temperatures of SOFC (current cells function at 600-800 °C), thus enabling cost-competitive materials. Long-term stability also needs to be improved to enable commercial use of the fuel cells. Finally, increasing the power density of the cells and incorporating lighter materials without loss in power can alleviate the main bottleneck of zero-emission mobility: the high specific mass of the energy systems. All these aims can be achieved through a deeper understanding of physical and chemical mechanisms driving the fuel cells and change of materials by optimising the chemical compositions of the electrodes and electrolytes and their microstructure.

This project is aimed to apply Quantum Chemistry modelling to better understand the chemistry of SOFC in operation. The main directions of work are the discovery of new materials, modelling of the electrochemistry of the electrodes, and the resistances and transport properties of the cells. The added value of Quantum Computing in this use case is in bringing novel computational approaches to cover the gap between rapid but rough approximations like DFT and meticulous but computationally demanding ones like FCI.

To gain a deeper understanding of SOFC, novel computational chemistry techniques are necessary. However, commonly used methods like Density Functional Theory lack the required level of detail for the problems at hand, while more precise methods like FCI are too computationally intensive. This project aims to address these challenges by employing innovative variational quantum algorithms that are optimized for hardware utilization. These quantum algorithms will be used to model and optimize various aspects of SOFCs, such as the cathode electrochemistry of oxygen reduction systems, contact resistances, and charge carrier transport in ceramic electrolytes. Additionally, the project will design new materials that can operate at the desired parameters for SOFCs and maintain long-term stability against processes like contact oxidation.

Fraunhofer ENAS, with extensive experience in classical simulation, will provide classical benchmarks for comparing quantum performance. They will create atomistic models to simulate fundamental electrochemical processes at the electrodes and contact resistance models, as part of the fuel cell model workflow. These models will use cutting-edge quantum-chemical and quantum-transport theory. The methodology developed for nanoelectronics will be adapted for fuel cells, allowing the identification of robust material compositions for desired SOFC operating temperatures. Fraunhofer ENAS will perform reference calculations using its own classical HPC cluster for this model.

4.6.1. Market assessment

This use-case is dedicated to improving simulations used in development of SOFC, so the first part of this section focuses on the SOFC market. However, the tools used in simulating SOFC are quite complex and polyvalent, so to fully understand the potential of the solution, the market data for Multiphysics simulations is brought in the second part of this section. This data can also help in understanding the market perspectives for other five use cases described in this document.

The highlights of the global SOFC market are displayed in the Figure 21 below.

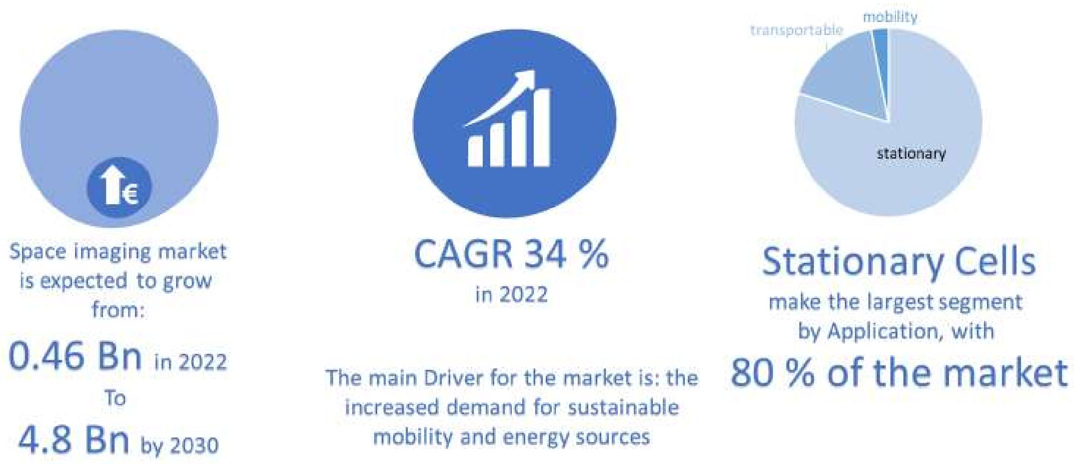

Figure 21: Key trends at the Market of Solid Oxid Fuel Cells

Volume and Dynamics

The global solid oxide fuel cell market size was valued at about 0.5 Bn EUR in 2022 and is predicted to grow dramatically withing the next few years, with CAGR of up to 30-40%. The graph below in the Figure 22 summarizes the estimations of the SOFC solutions market, and presents the predictions of its growth, provided by different market research groups. [61] [62] [63] [64]

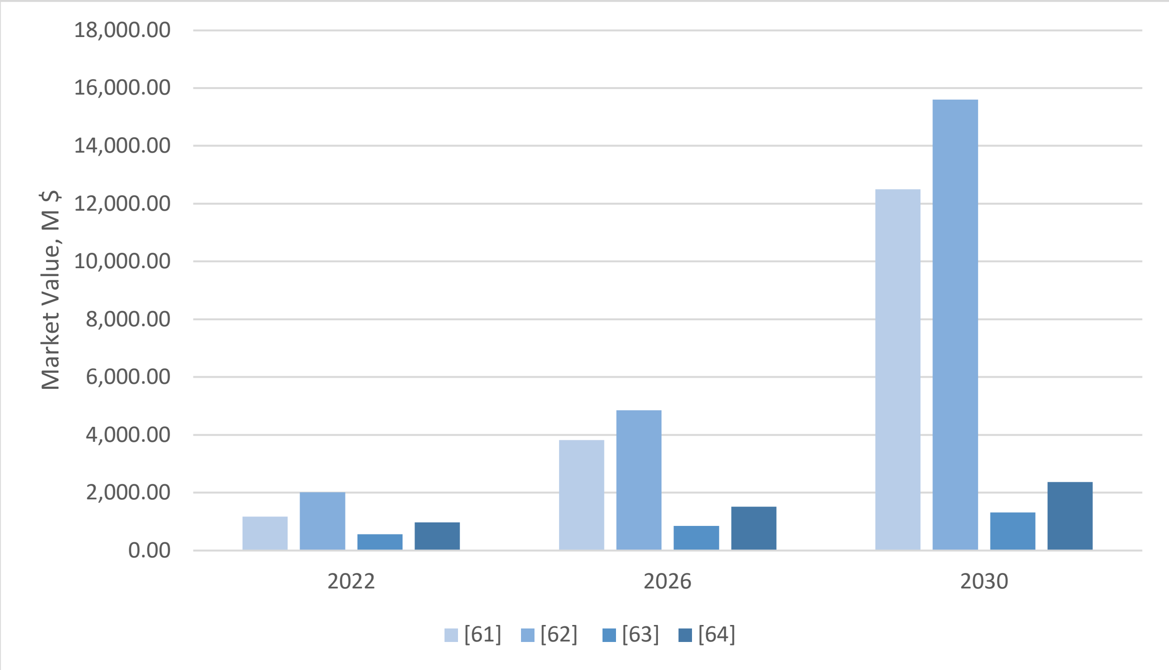

Figure 22: Forecast for the global market of SOFC solutions, grouped by sources of data (in M $)

The graph above demonstrates high spread between different evaluations, originating from different methodologies of research. However, it is important to notice the trend for very large growth of the domain within the next decade. The **main driver** for such explosive growth is the increased demand for sustainable mobility and energy sources.

At the same time, proposed solution is intended to augment or even substitute the Multiphysics simulation tools, currently used for the SOFC development. This is the reason to consider the **market of Multiphysics simulation tools** in this chapter.

The simulation software market was valued at USD 7.80 billion in 2020 and is expected to reach USD 15.09 billion by 2026. The market is expected to witness a CAGR of 11.68% during the forecast period (2021 - 2026). [65]

The global Multiphysics software market is projected to grow from USD 2.77 billion in 2021 to USD 4,57 billion by 2030, at a CAGR of 5.7% from 2021-2030. [66]

Main driver for this market is the increase in demand on simulations, automation, and quality assessment.

Customers and segmentation

Market of the SOFC can be segmented by application in three large groups, accordingly to the domain of application and required portability:

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- Transportation, where the most compact and lightweight cells are needed to disrupt the future of mobility. Extremely high power-to-weight ratio is required, as well as an ability to operate while moving, imposing the resilience to vibrations.
- Portable cells, which are not as compact as the ones from the previous section, yet – are packaged and can be relocated from one operation site to another.
- Stationary cells for various applications not requiring the relocation of once operational unit, for example – a power source in remote areas. Such cells have less requirements on the power-to-weight ratio, but in return are expected to have dramatically longer lifespan and the highest fuel efficiency possible.

Some prominent players in the global solid oxide fuel cell market include:

- Bloom Energy
- Mitsubishi Power Ltd.
- Cummins Inc.
- Ceres
- General Electric
- Fuel Cell Energy Inc.
- Ningbo SOFCMAN Energy
- KYOCERA Corporation
- AVL
- NGK SPARK PLUG CO., LTD.

As mentioned in the previous section, it is important to consider the market of Multiphysics simulation tools. The main **segments** of this market are: commercial, educational and academic software tools. The market is highly differentiated between multiple **companies**, such as: COMSOL, ANSYS, Dassault Systemes, WelSimulation, MotionPort, MAYA HTT, MSC Software, ESI Group, CPFD Software, TEN TECH LLC, SimuTech Group, PTC, Livermore Software Technology.

4.6.2. Competitive analysis

This section includes an overview of competitors for the solution of material design for the market of SOFC.

SOFCs are complex devices which depend on multiple physical and chemical processes. To optimise SOFC design, all these processes must be understood to the highest precision on different scales. Technological competition is coming primarily from long-established classical solutions run on HPC and prominent novel approaches, such as AI [67]. This implies that the main business competitors for the proposed solution are the providers of multi-scale and multi-physics (continuous, molecular, and atomistic) simulators.

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Technological competition

The main technological approaches used for SOFC development are:

- **Multiphysics modelling** - Battery systems are complex and involve multiple physical phenomena, such as electrochemical reactions, heat transfer, and mechanical stresses, to provide a complete picture of battery behaviour.
- **Artificial intelligence and machine learning** are increasingly being used in battery modelling and simulation to improve the accuracy and efficiency of models to help automate the modelling and simulation process and to identify patterns and insights in large datasets.
- **Cloud-based simulation** is a growing trend in battery modelling and simulation. Companies are developing tools that allow users to run simulations on remote servers, enabling faster and more efficient simulations without expensive hardware.

Business competition

The main competition for the solutions developed in this use-case on the market of SOFC development is presented by the:

- **COMSOL** is a provider of Multiphysics simulation software that can be used for SOFC design and optimization. COMSOL's software allows simulation of various aspects of SOFC operation, such as fluid flow, heat transfer, and electrochemistry.
- **Ansys** offers a range of simulation software tools for SOFC design and optimization. These tools include Ansys Fluent for fluid flow analysis, Ansys CFX for multiphase flow analysis, and Ansys AIM for Multiphysics simulations.
- **Siemens** offers a range of software tools for SOFC design and optimization. These include the Simcenter software portfolio, which encompasses a set of tools for Multiphysics simulations. Another offer from Siemens is the STAR-CCM+ software for computational fluid dynamics simulations.
- **ESI Group** offers simulation software tools for SOFC design and optimization, including its flagship OpenFOAM software for CFD simulations. OpenFOAM is an open-source software package that can be used for a wide range of fluid flow simulations, including SOFC design.
- **AVL** provides a simulation software package that can be used for SOFC design and optimization.

Besides, atomistic modelling is extensively used in the development of novel materials for SOFC, and simulation of quantum chemistry with quantum computers may be one of strategic advantages of the quantum-powered solution. Then, one should also consider competition in the domain of atomistic modelling of the materials:

- **VASP**, standing for Vienna Ab-initio Simulation Package is a software package for performing DFT calculations, allowing to obtain approximate results for the large systems that are not tangible for more precise methods, which is a frequent case in applied material science, including the domain of fuel cells.

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- **Quantum Espresso** is an open-source software package using Density Functional Theory (DFT) calculations to investigate the electronic and structural properties of materials at the atomic scale.
- **LAMMPS**, Large-scale Atomic/Molecular Massively Parallel Simulator is an open-source molecular dynamics simulation software package that can be used to simulate the behaviour of materials at the atomic scale. It is used widely in the materials science community to study a wide range of materials, including fuel cells.

4.6.3. Business model

A BMC attributed to this use-case is displayed below in the Figure 23, with the use-case specific blocks being highlighted, while the faded blocks remaining the same as in the General BMC overview

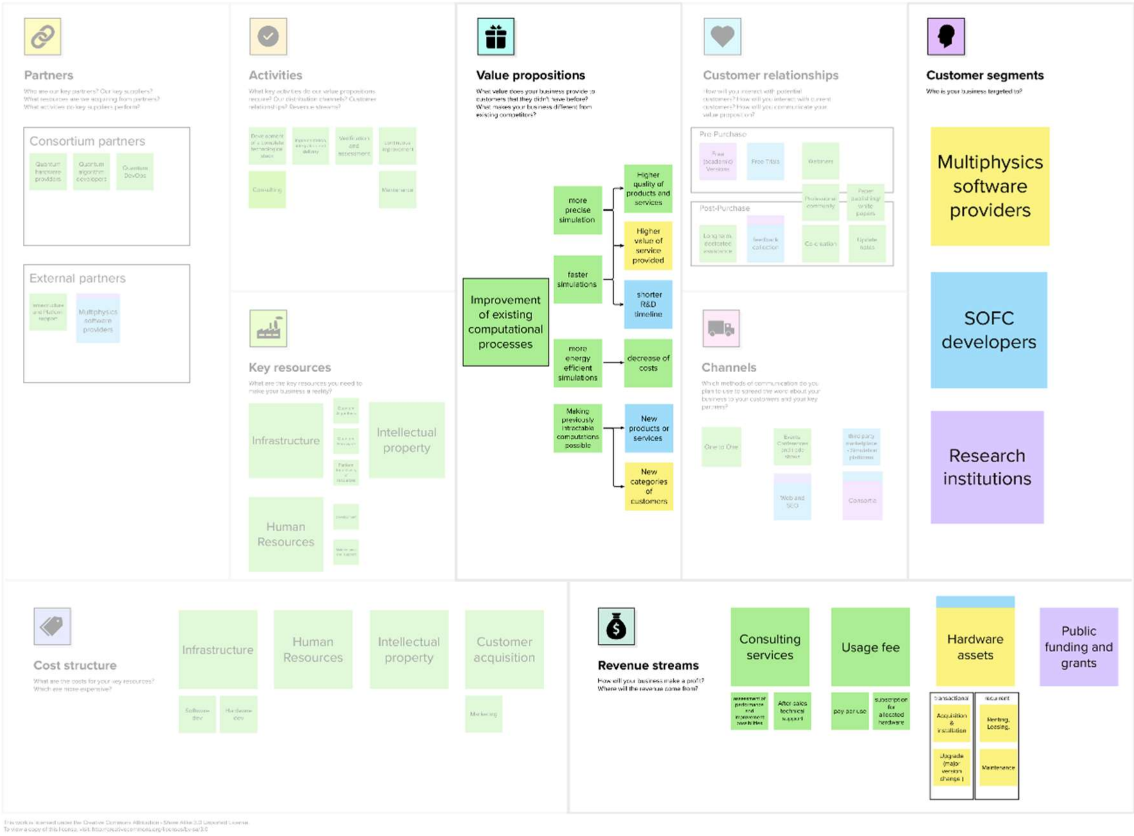

Figure 23: BMC of use-case 6: SOFC optimisation (bigger in annexe).

Customer segments

Customers for the proposed solution can be structured in three large sectors according to the added value they receive from the solution and the structure of their core value chains: Providers of Multiphysics simulation software, R&D departments of SOFC producers, and public research groups working on SOFC.

- **Multiphysics software providers** present an important segment of customers for the solution, thanks to their ubiquitous penetration within the domain. Solution developed

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by the consortium can be used as a computational backend by various providers of simulation software and simulation-as-a-service, increasing the computational power of their solutions. Typical representatives of this class would be companies/solutions like COMSOL, Ansys, and Dassault. This sector stands out by the nature of the tasks performed (hence – value added): execution of large volumes of well-pre-processed tasks. This segment has a high potential for development beyond SOFC simulations, as well as growth in volume. However, accepting this segment as a customer relies on the market expansion of the solution to the customers, which might involve certain potential as well as risks.

- **SOFC developers** form the most natural group of customers for the use-case tailored solution. With the energy sector expanding rapidly, the budgets of R&D departments in the domain of energy solutions grow accordingly, opening multiple opportunities for the provision of "tum-empowered simulation/computation as a service," tailored to the necessities of the SOFC field. Typical representatives of this segment would be the R&D departments of the companies like Bloom Energy, Mitsubishi Power and General Electrics. An important aspect of this domain is the multitude of successful SMEs, like Sunfire Fuel Cells, SOLIDpower or Elcogen, actively contributing to the development of the domain. This has implications on the solution delivery: it should be flexible to respond easily to changes in volume and in customers and allow for adequate dynamic pricing models. Besides, due to the narrow spectrum of applications – more valuable consulting services may be delivered. Marketing and distribution play a more significant role for this segment, than for others.
- **Public research and academia** present many unique opportunities for the consortium as potential clients, as it might bring much value to academia, and public-related research organisations and to consortium reciprocally. Providing access to a state-of-the-art backend, the consortium can add a lot of momentum in the fundamental research (which will have a lot of implications in the commercial applications afterwards), as well as participate in different research activities relying on public funding. This segment is not expected to bring the largest cash flows but can yield the maximal non-monetary benefits, such as co-creation of community databases, publications etc. Specific delivery methods and pricing strategies should be implied for maximal leverage of these benefits.

Value proposition

The key value proposition for this use-case is the improvement of existent computational processes. For customers in any of the segments, using the solution as a backend for SOFC modelling will bring:

- **Faster and more precise simulations** will allow the customers to increase the quality of products developed and services delivered. Besides, it will shrink the R&D timelines for the SOFC developers and ensure a higher value of services delivered by the simulation software providers.
- **More energy efficient simulations**, that will decrease the costs and have an ecological impact for all groups of customers.
- Opportunity to **perform previously intractable calculations**, helping the SOFC developers create new products or services, and attracting new categories of clients to the simulation software providers.

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Revenue streams

Solution specific to this use-case is aimed at a wide range of customers from different sectors, so the flexibility of revenue streams is essential for the business model.

Consulting services are essential in allowing desired flexibility because they can be provided for any segment of the clients, especially those with industrial orientation. For example, the specialists from the consortium can carry out an assessment of the current performance of the client's computational processes, and outline the possibilities for improvement, classical or quantum. These means of providing value to the clients (and generating revenue to the consortium) have an immense potential. First, consulting services can present an additional pre-sales' relationship with the customers, serving as a strong attractor for the new clients. Secondly, they allow to generate income from a broad range of clients, not requiring a strong involvement from them. Finally, provision of the consulting services yields in better understanding of the market needs, allowing to make optimal choices regarding development of the solution. Optional "premium" technical support to the existent users can also serve as an extra revenue stream among other consulting services.

Usage fees remain the main source of revenues for the solution. Different pricing strategies can be created, adapted to the nature of the usage of the solution and the primary business of the clients, like pay-per-use or subscription for allocated hardware.

Hardware resources allocation can be a strong source of revenue for the clients requiring intensive usage of the solution. An example of such clients for this use case are Multiphysics software providers and the larger representatives of the SOFC developers. Dedicated hardware can be deployed for such customers, via acquisition or leasing, on customer premises or remotely. Renting and leasing of the hardware, together with its maintenance, will form the recurrent revenues. At the same time, acquisition and installation of the hardware, as well as the major upgrades to the hardware stack, will present a source of significant transactional revenue.

Public funding and grants present the main source of monetary revenue for the third, academic, segment of the customers. It can be generated via co-participation in publicly funded activities like, grant proposals for applied research. Despite this stream is not expected to contribute to the balance of the solution dramatically, it will come along with multiple non-monetary benefits, such as knowledge, branding and distribution, attraction of new clients and educating prominent specialists in the domain.

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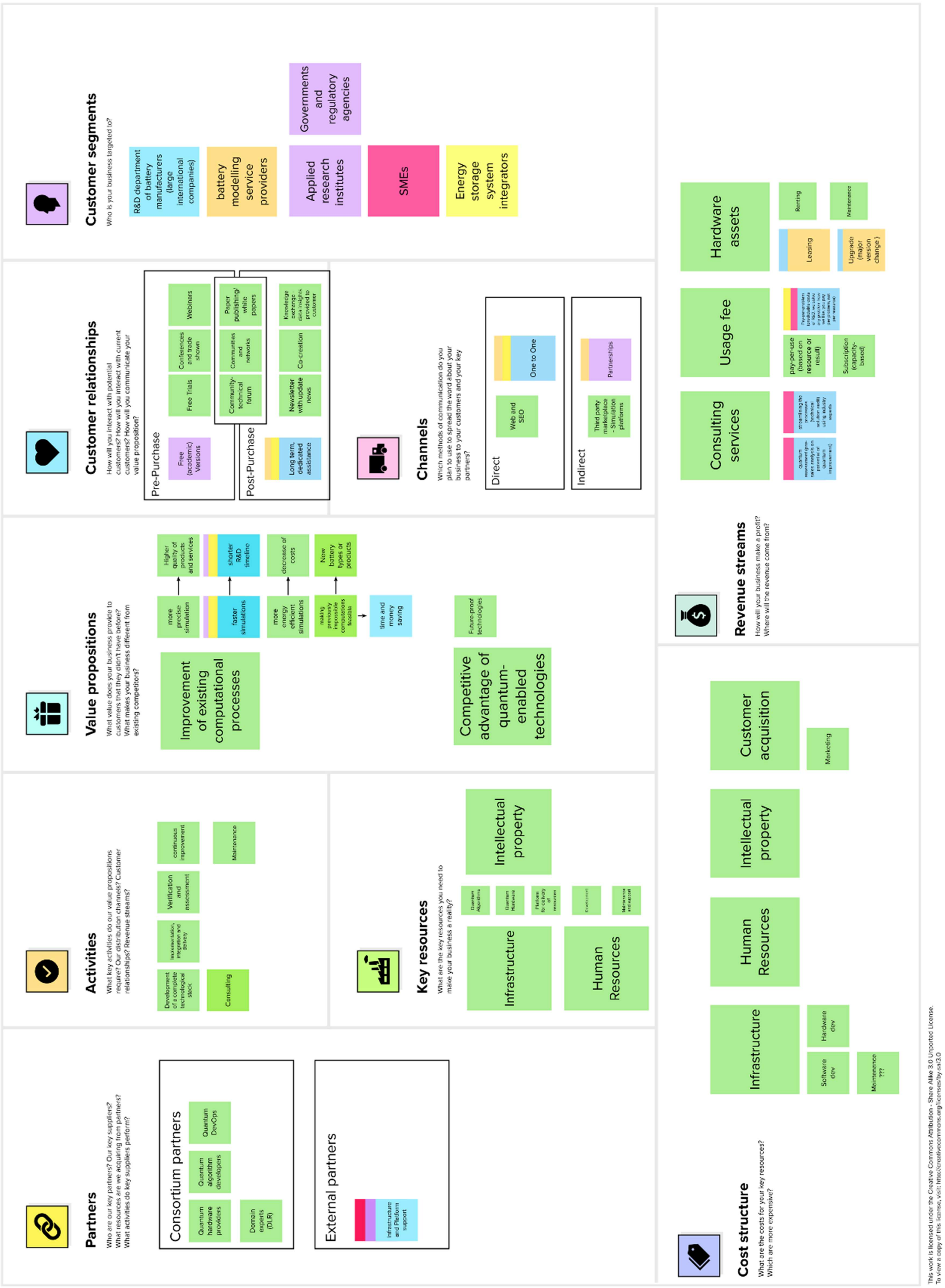
ANNEX

Complete Business Model Canvas for the use-case 1



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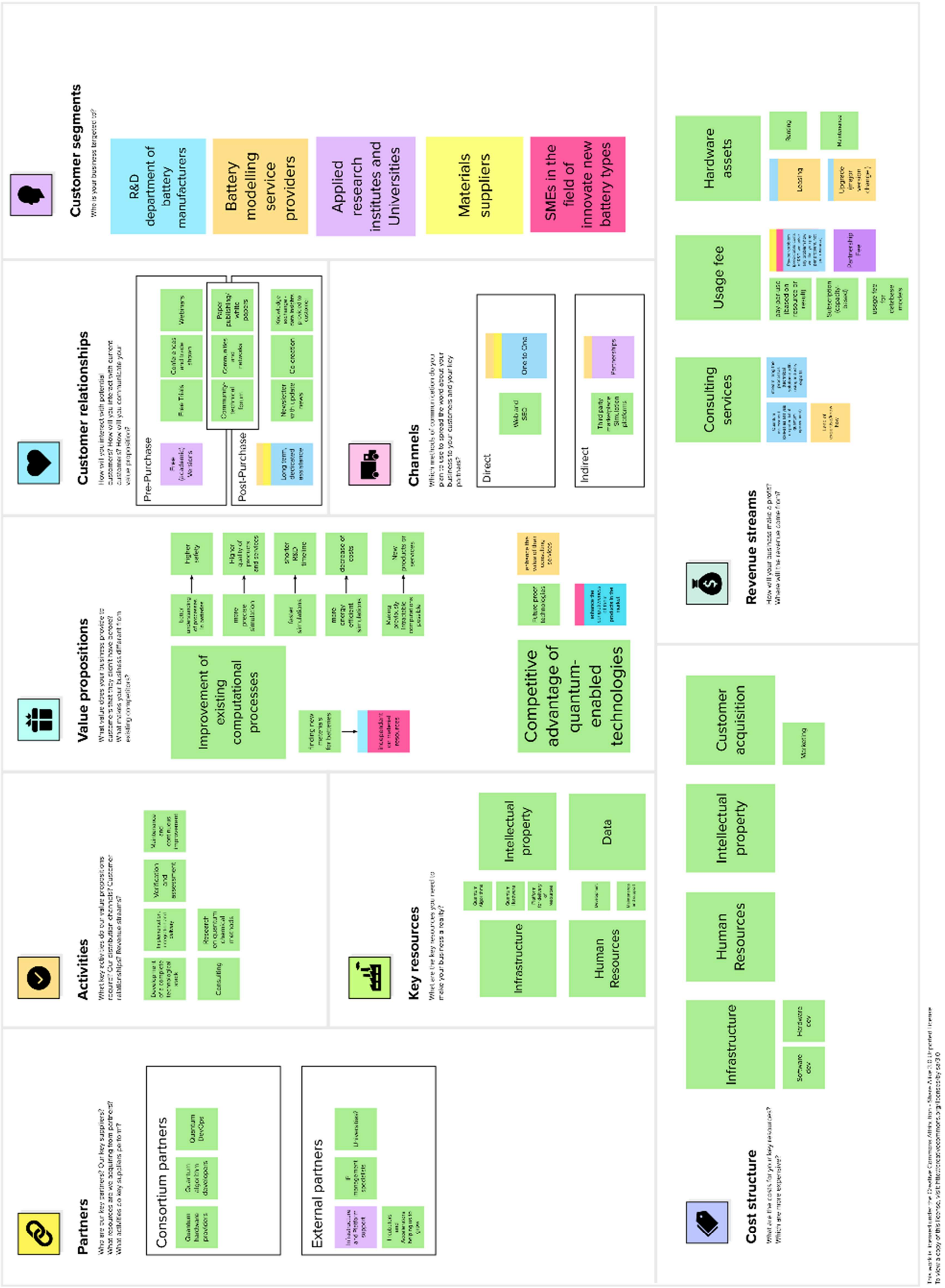
Complete Business Model Canvas for the use-case 2



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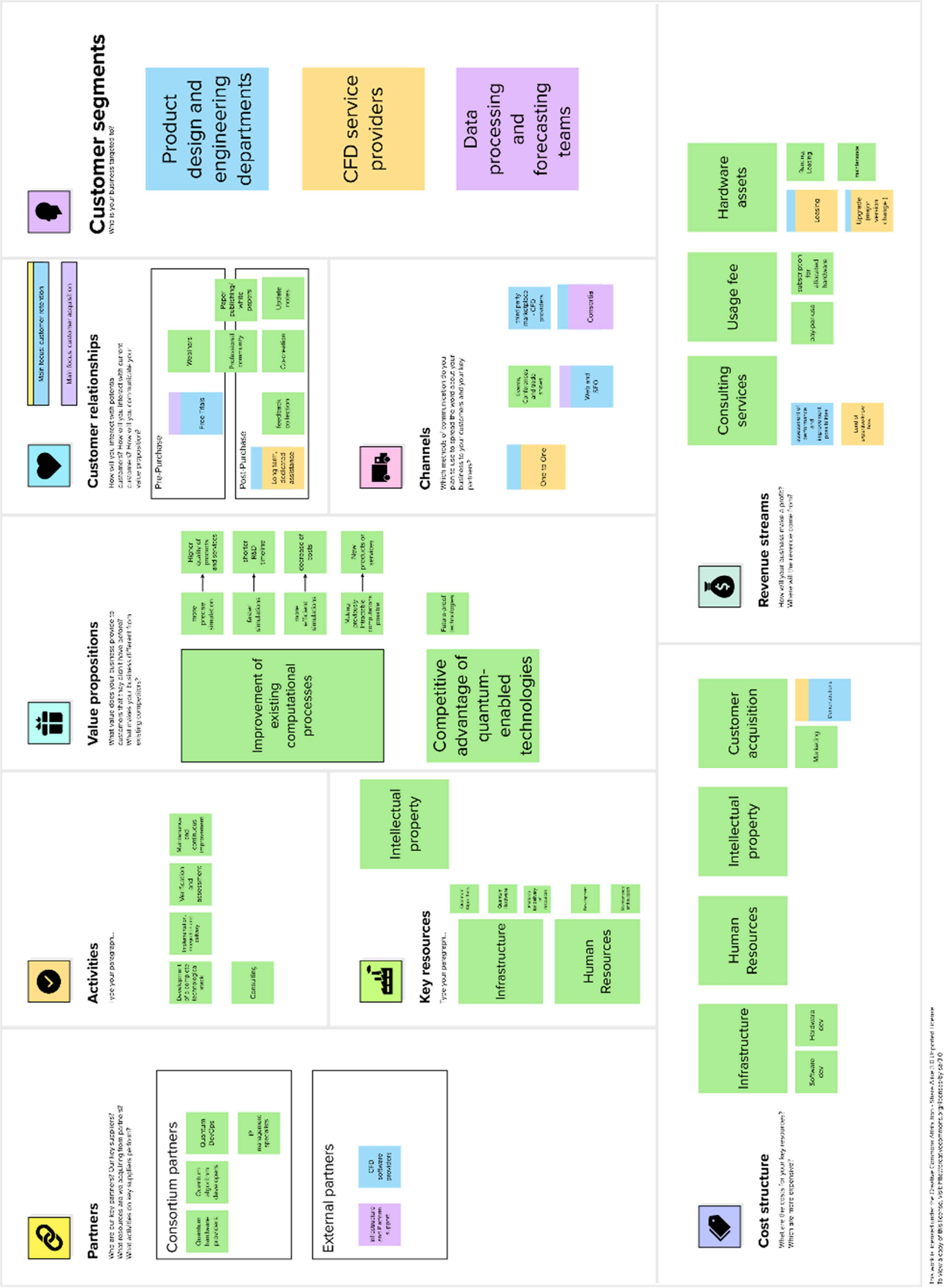
Complete Business Model Canvas for the use-case 3



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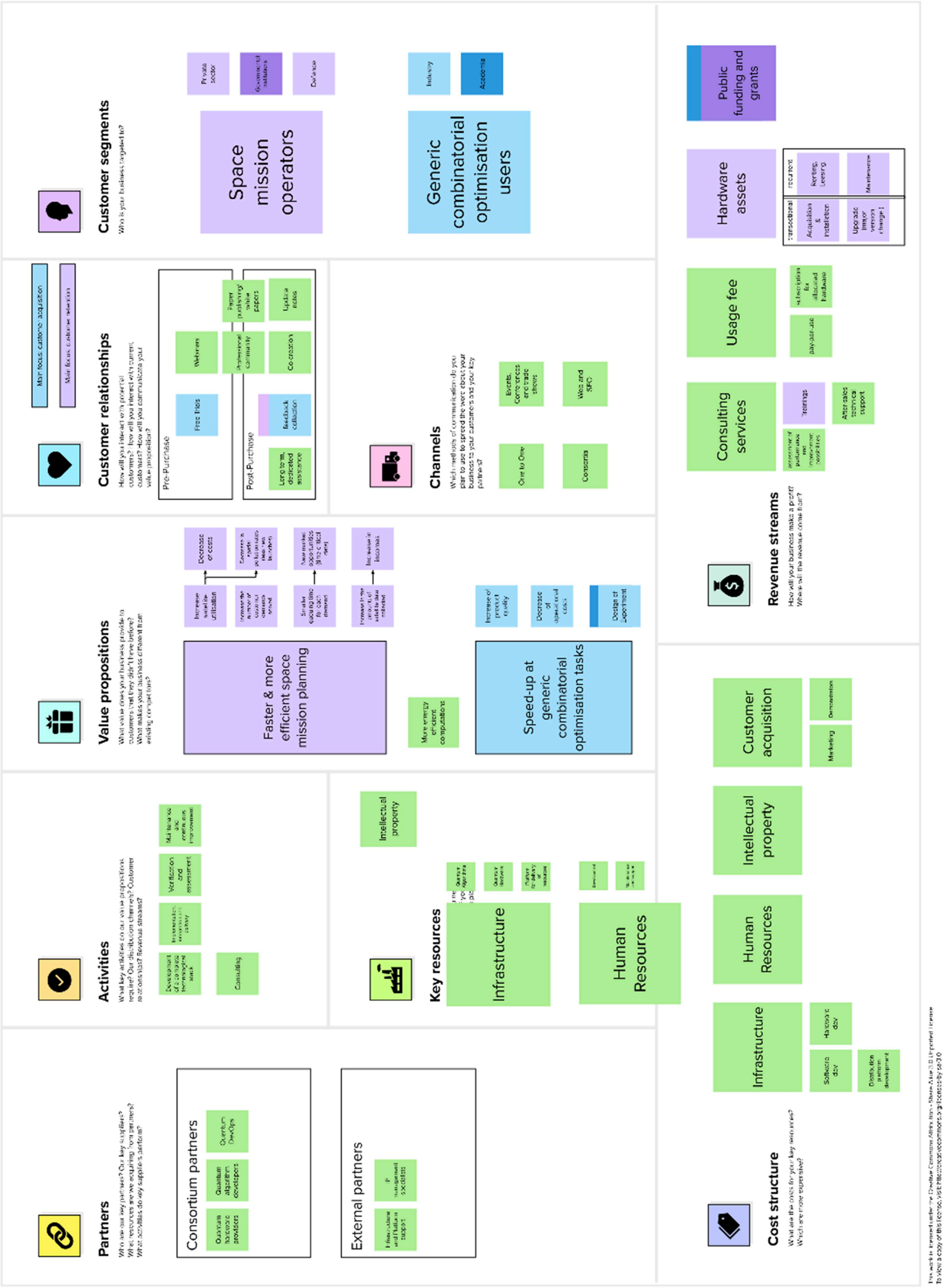
Complete Business Model Canvas for the use-case 4



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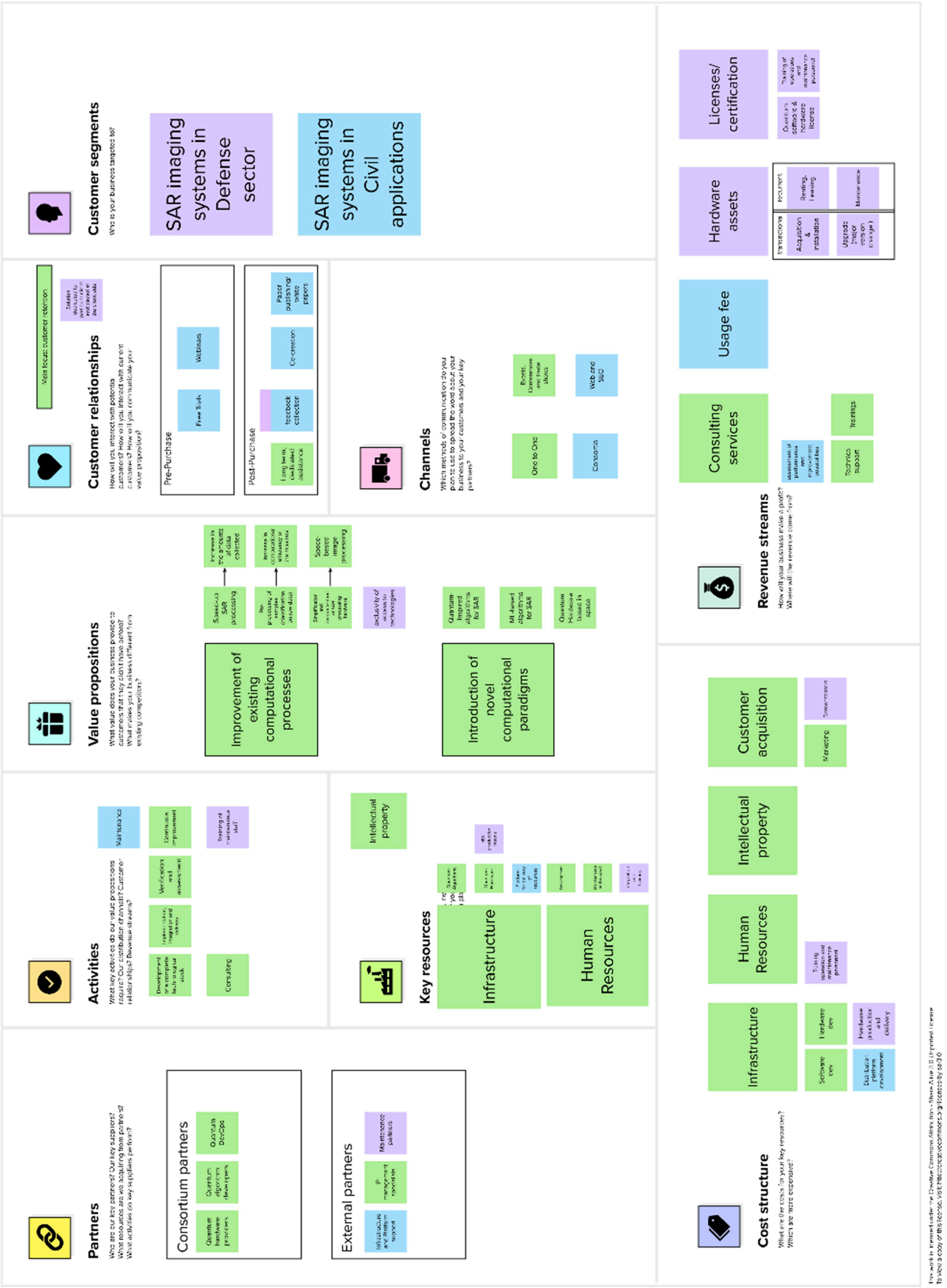
Complete Business Model Canvas for the use-case 5



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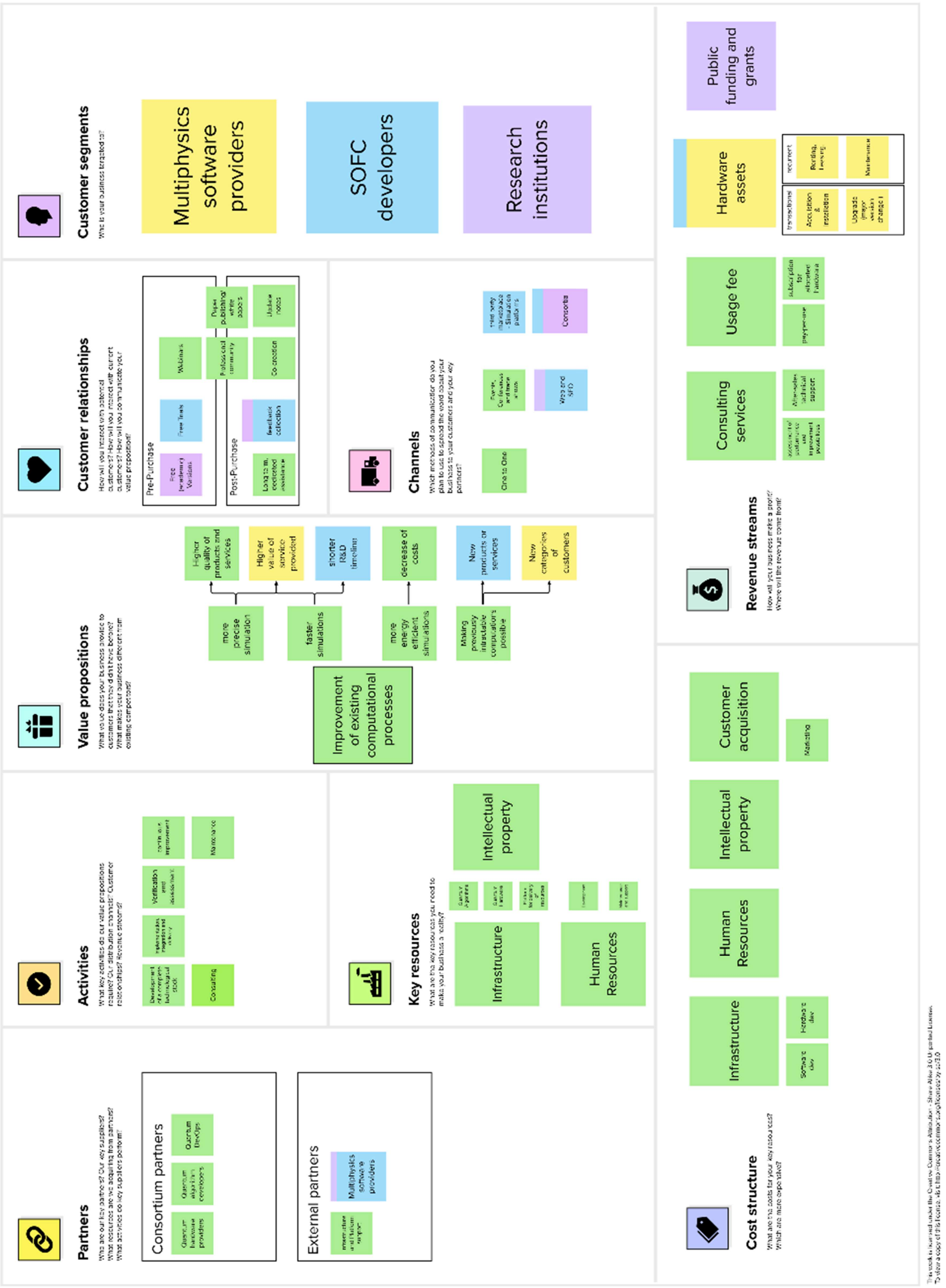
Complete Business Model Canvas for the use-case 6



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