Consultancy Research into the UK Maritime Technology Sector

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London Economics

NLA INTERNATIONAL

MarRI-UK

Department for Transport

About the Consortium

Our consultants are highly qualified economists and maritime specialists with extensive experience in applying a wide variety of best practice analytical techniques to advanced technology sectors and the maritime industry. For this study we provide an experienced team with expertise in advanced technologies, stakeholder consultation and impact assessments in line with government guidance (HMT Green Book / Magenta Book).

The **London Economics** Space Team have pioneered innovative analytical techniques to provide trusted economic advice over more than 100 projects and 10 years. Across the full space value chain and all types of satellites, we advise national governments, space agencies, private and third sector organisations on space policy, economic and market analysis. We offer expertise in market sizing and forecasting, strategic insight, business cases, due diligence, and return-on-investment analysis from launch to applications and across GNSS, EO, Satcom and Science.

NLA International champions the implementation of Blue Economy solutions by enabling the utilisation of innovative technologies, tools, and processes to create sustainable ocean environments for the people and economies that depend upon them. We work on projects around the World, providing a conduit to suppliers of innovation to access wider markets, raising awareness of Blue Economy potential and inspiring engagement of current stakeholders and future generations.

Marine South East is as sector consortium for marine industries, established in 2005, to stimulate maritime companies' investment in innovation and growth improving access to technology, skills, and market intelligence. Based in Southampton, MSE facilitates a cluster of 1,800 companies and suppliers, research organisations, and public sector bodies both in the UK and overseas activities. MSE forges new relationships and consortia to help companies gain market access and promotes the capabilities and growth potential of the marine industries and their supply chains to public authorities and policy makers.

Acknowledgements

We are very grateful to the large number of people and organisations who responded to requests for information. They include trainers, manufacturers, their representative bodies, regulators, Classification Societies and Certifying Authorities, insurers, charterers, national centres of excellence, academics, and other interested parties. Their time in interviews, their provision of additional contacts to engage, and their strong support for this activity are very much appreciated.

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Authors

London Economics:
Moritz Godel, Divisional Director
Rasmus Flytkjaer, Divisional Director
Romain Esteve, Senior Economic Consultant
Daniel Herr, Senior Economic Consultant
Greta Dohler, Economic Analyst
Emily-Jane Murphy, Economic Analyst

NLA International:
Andy Hamflett, Technology & Blue Economy (BE) Expert
Gary Hesling, Technology & BE Expert
Jonathan Williams, Technology & Economic Expert
Simon Powell, Technology Economic Analyst
Chris Pontet, Technology & BE Analyst
Keith Tatman, Technology & BE Analyst
Oliver Stringer-Jakins, Technology & BE Analyst

Marine South East Ltd (subcontractor):
Dr Jonathan Williams, CEO

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Executive Summary

The consortium, composed of London Economics (lead) and NLA International (NLAI), was commissioned by the Maritime Research and Innovation UK (MarRI-UK) to undertake economic research to inform the Department for Transport (DfT) approach to supporting the smart shipping industry (SSI) in the UK. The consortium brings complimentary experts from the maritime and engineering world alongside experts in economic research and analysis.

The research focuses on the UK's strengths in smart shipping technology and provides economic and technology research to inform the Department for Transport (DfT) approach to supporting the smart shipping sector in the UK.

The research considers **4 market segments** which include smart ports technologies, autonomous vessels technologies, on-board technologies, and professional services and try to address four main research questions:

1- What are trends for smart shipping technologies between now and 2050 and which are likely to be delivered by the UK?
2- What is the economic rationale for UK government funding to support the development of smart shipping technologies at this time?
3- What are the estimated social costs and social benefits of smart shipping technologies for the UK?
4- What is the value of being first mover or follower for different smart shipping technologies?

The maritime and smart shipping industries

The maritime industry (**MI**), as defined by Maritime UK[1], contains 5 high-level segments[2]:

- The **shipping industry,** with activities including the transport of freight and passengers;
- The **port industry,** which concerns all warehousing, management, cargo and passenger handling and customs activities;
- The **marine engineering and scientific** (MES) industry responsible for shipbuilding, support engineering, marine science, and other academic activities;
- The **marine business services** (MBS) industry dealing with shipbroking, insurance financial and legal activities;
- The **leisure marine** industry including recreational and boatbuilding activities.

Smart shipping encompasses the automated, partly digitised equipment of today, the remote operation of equipment, and the development of autonomous maritime systems, both at sea and onshore. The UK Government's definition of smart shipping is defined as:

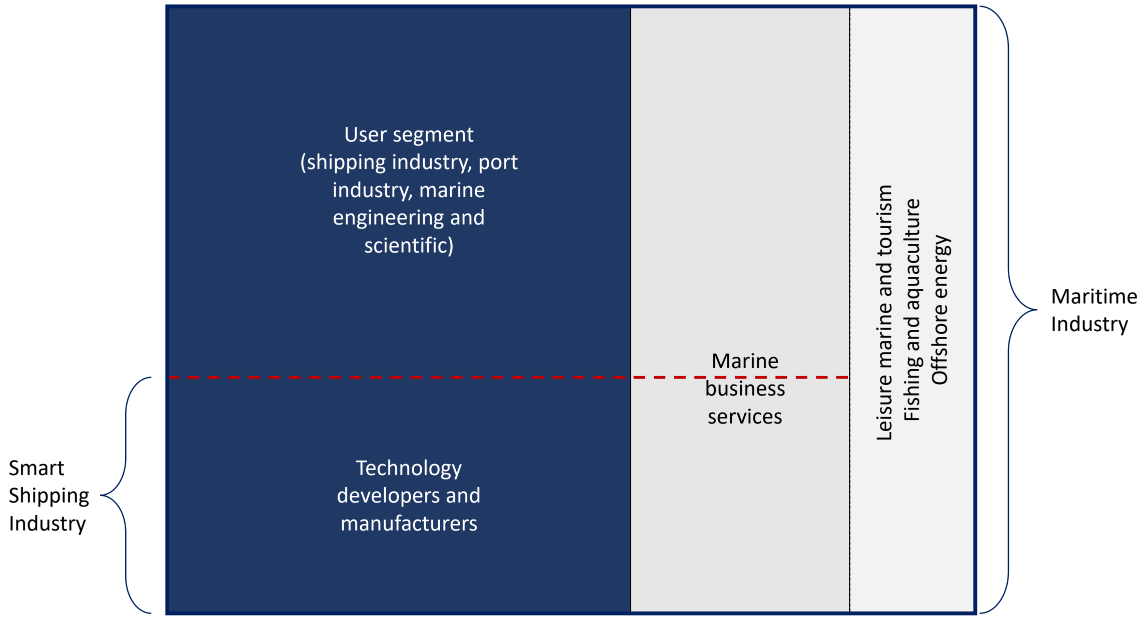
> *a technological pathway for the entire maritime sector. This pathway encompasses the automated, partly-digitised equipment of today, the remote operation of equipment, and the development of autonomous maritime systems, both at sea and onshore. Here, 'shipping' is understood in its broader sense, rather than just referring*

[1] Maritime UK (2019). State of the maritime nation report 2019.
[2] There are alternative definitions of the maritime sector too. For example, the Government Office for Science's definition of the 'ocean economy' also includes fishing and fish processing, marine aquaculture, offshore oil and gas, and offshore renewables – Foresight. (2020).

to seagoing vessels. This broad definition is used because new technologies will have the greatest impact when they are used holistically, as part of a wide-ranging approach that applies to the whole UK supply chain.[3]

We assume that MI companies using advanced technologies belong in some parts of the SSI industry's value chain. The SSI industry consists of **3 technology development and manufacturing segments** namely, smart ports, autonomous vessels, on-board technologies, and **one support segment,** the maritime business service industry. The **user segment** includes potential users from the wider shipping industry, port industry and MBS industry.

Figure 1 The maritime industry value chain



Source: London Economics

According to Maritime UK[1], the UK maritime industry generated estimated business turnover of **£44.5bn in 2017**. This includes 42.5% from the shipping industry, 10.7% from ports, 32.0% from MES and 14.8% from MBS.

The gross value-added (GVA) contribution of the industry to the UK was **£16bn in 2017**. This contribution is led by the shipping industry (38%), MES (32%) and followed by MBS (17%) and ports (12%).

According to interview participants in this project, the most important drivers underpinning the development of smart shipping technologies in the UK are:

- **Improving environmental sustainability and energy efficiency**;
- **Optimising workflows** to increase capacity and efficiency;
- **Digitising transaction** documentation to improve customer service, and increase efficiency through transaction time savings, error reduction, improved security, and added value services;

[3] DfT. (2019). Technology and Innovation in UK Maritime: The case of Autonomy.

- **Brexit.** The UK's departure from the EU may lead to a sharp drop in EU/UK trade with implications for the UK's ports, though there is significant uncertainty round this as it is also argued that a collapse in UK-EU trade is not likely, even if there is no free trade deal;
- **CoVID-19**. Besides issues and delays in accessing funds, the overall impact of the pandemic remains uncertain. The fact that interviewees have not talked about it extensively seems to suggest that the pandemic might not be a key enabler of smart shipping technologies.

Technology trends

The baseline report collated industry news and market intelligence focused on four **smart ports technology** segments:

- Automation;
- Big Data and AI software systems (performing a range of optimisation tasks);
- Power, propulsion, and energy;
- Communications.

Autonomous vessel technologies are expected to reduce maritime emissions, enabling massive fuel savings, and reducing the cost of shipping. Autonomous technology is anticipated to lessen the scope for human error from operations on the vessel's bridge, thereby reducing the risk of accidents.

On-board technologies include **safe navigation, ship performance, maintenance** and more. Despite the shipping industry's apparent or perceived reluctance in embracing technology, the sector still sees technological advancement in several key areas such as **AI, smart ship platforms, alternative propulsion, and connectivity**.

The **service industry** will adapt from the provision of new technologies and applications coming to market by supplying appropriate services and responding to the need for **more training**. The UK offers great opportunities in the field of consulting. Leading universities, maritime colleges and regulatory experts provide much weight to the UK maritime 'brain trust', which is generating value for many projects.

Identification of market failures

To assess the appropriateness and impact of government intervention, a logic model (or Theory of Change)[4] is used and identifies the long-term goals and the rationale for specific intervention.

[4] A logic model helps articulate how various options are expected to work and the strength of the evidence that underpins them – HM Treasury (2020). Magenta Book.

UK's Maritime 2050[5] 10 core strategic ambitions	Long-term goals
Strategic ambition 1	Enhancing UK competitive advantage.
Strategic ambition 2	Leading the way on clean maritime growth.
Strategic ambition 3	Maximising benefits from maritime technology.
Strategic ambition 4	Retaining global leadership in maritime safety and security.
Strategic ambition 5	Growing the maritime workforce and transform their diversity.
Strategic ambition 6	Promoting a liberalised trading regime.
Strategic ambition 7	Supporting continued investment in maritime infrastructure.
Strategic ambition 8	Strengthening and enhancing the UK's reputation as a leading maritime Country.
Strategic ambition 9	Promoting the UK's UK-wide leading maritime cluster offer.
Strategic ambition 10	Showcasing the UK's maritime offer to the world.
Rationale for intervention	**Definition**
Efficiency	Technology enables ports to optimize workflow and efficiently use limited space.
Employment	Investment in technology could create direct, indirect, and induced employment.
Environment	Streamlining logistics, e-noses, and appointment systems to reduce port traffic could reduce greenhouse gasses.
Safety and social capital	Technology could improve safety conditions, enable better informed decisions, and allow seafarers to speak to their family and friends increasing their quality of life.
Security	Linking port security systems, surveillance cameras, sensors, drones and tracking tools could heighten security in ports.
Supporting SMEs	Small and Medium-sized Enterprises (SMEs) could foster innovation, generate employment and increase productivity.
Spillover effects	Knowledge spillovers could benefit other sectors of the economy.
Political	Maintaining the UK's presence as a leading maritime nation.
Growth	Economic growth itself also forms a key driver under which many of the other rationales for intervention fall.

Source: London Economics

However, the existence of market inefficiencies could hinder the ability for the market to operate optimally without intervention. This is the case when market failures are identified within the industry.

These failures appear between the 'activity' and the 'output' steps of the logic model and removes the capacity to achieve long-term goals either by slowing down technology development or completely inhibiting the investment.

Four group of market failures have been identified that are present in the industry:

[5] DfT. (2019). Maritime 2050. Navigating the future.

Market failures	Definition
Coordination failure	Many small parties contribute to a large supply chain resulting in split incentives.
Imperfect information	There is imperfect information and uncertainty surrounding the benefits of investing in developing shipping technologies.
Externalities	Externalities, impacts on uninvolved third parties, are not reflected in the price of the products and services.
Barriers to entry	Barriers include capital requirements, transition costs and minimum efficient scale.

The UK commercial shipping sector seems ‘off the pace’ compared to other nations. There are pockets of innovations from smaller companies and universities, but there is no real trend in the direction of technology development for on-board systems for the commercial shipping fleet.

In the case of maritime technology, there is also **imperfect information** as high costs, long lead times, and uncertain return on investment reduce the incentive for firms to develop new technologies and lead to an underinvestment in research and development (R&D).

Various negative externalities have been identified, such as machine integration and cross-technology integration, human-machine interactions, and environmental externalities. These externalities mean there could be under- or over-investment in maritime technology, as the social costs and benefits do not reflect the private costs and benefits of the technology.

Large capital requirements may act as a barrier to entry in the marine technology sector. The required upfront investment for new entrants is high and firms may not have access to enough capital to establish themselves in the market, providing incumbents with an advantage. While the appetite for smart shipping innovation is high, ports were considered to have **no or very little R&D budget** according to interview participants in this project.

Access to funding is an issue affecting many parts of the industry. The maritime sector is characterised by high transition costs and complex large-scale operations, which create barriers to entry for maritime R&D. This is exacerbated as the levels of **upfront capital investment required and the risk involved in maritime R&D are high**, and loans may not be able to de-risk R&D investments enough to incentivise the desired levels of maritime R&D.

Defining the channels for intervention

A set of interventions that can solve these issues and alleviate market failures to drive the market towards greater efficiency have been identified. We distinguish four main groups of intervention:

Intervention options	Definition
Funding	Providing R&D funding and de-risking innovation investments.
Collaboration	Facilitating collaborations and partnerships.
Skills development	Supporting education and skills development.
Policy & regulation	Policy and regulatory frameworks that foster innovation.

- One option is for the government to **directly provide R&D funding** for the development of new technologies, products or services that could grow the UK maritime sector, help the UK maintain international competitiveness, or help meet UK strategic objectives;
- The government could act as a **guarantor** on loans in order to de-risk investment. Such a scheme has been launched by the Netherlands through its Nesec Shipping Debt Fund

(NSDF). The Fund offers a state guarantee for SMEs to purchase new short sea vessels or make modifications to current vessels in order to meet ballast water requirements, limit sulphur emissions and other emissions[6];

- Tax relief provides an alternative mechanism to incentivise private firms to undertake R&D activities. The UK Government already provides R&D reliefs to support companies that work on innovative projects in science and technology. HMRC's most recent evaluation of the R&D tax credit scheme found that for each £1 of tax foregone, between £1.53 and £2.35 of R&D expenditure is stimulated[7];
- The UK Government could provide similar **capital incentives** by providing specific funding for companies to acquire capital equipment. This reduces the risk to investors by mitigating the high upfront capital requirements;
- Another way to increase maritime R&D is through the facilitation of greater engagement and intra-industry collaboration between maritime companies, as well as collaborations and knowledge exchange with academia. Research collaborations can increase the exchange of ideas, speed up innovation, and reduce friction of technical diffusion;
- Similar to capital incentives and to influence better coordination, the government could **invest in providing supporting infrastructure** to facilitate collaboration. This could take the form of provision of pooled capital equipment, investments in technology, investment in physical locations to facilitate collaboration, or **providing regulatory/legal incentives** to encourage collaboration;
- The establishment of new (or widening/refocusing of existing) **local university enterprise zones** or **local growth hubs** for businesses focussed on maritime technology could also be a great way to support the industry;
- The importance of **skills development** to unlock the benefits of advanced technologies has been widely evidenced. In the maritime sector, facilitating innovation and having advanced shipping technologies on hand is only one part of the story; people with the right skills and an appreciation and understanding of smart shipping technologies are needed in order to make technology adoption a success and reap the maximum benefits from innovation;
- A consistent theme in interviews was that the UK needs to do more to tackle a **lack of joined-up thinking** and working in order to encourage the development and adoption of smart shipping technologies. This is seen as a **key barrier which the government could address**, and contrasts with places such as Finland and Singapore;
- To ensure that existing initiatives and future measures successfully address the challenges of the maritime sector, the government should explore how institutions offering these initiatives can better coordinate (both within the maritime sector and with broader existing measures) and how existing measures can be promoted in the maritime community.

Modelling the effects of government funding

The economic model tries to capture the essential metrics to appraise the impact of government funding for smart shipping technology. This does not appraise the other government intervention options set out above. The indicators used to appraise the government funding are divided into 3 main categories:

- **Industrial impacts** which include turnover, GVA, employment (full time equivalent);

[6] Nesec funding.
[7] HM Revenue & Customs (2015). Evaluation of Research and Development Tax Credit.

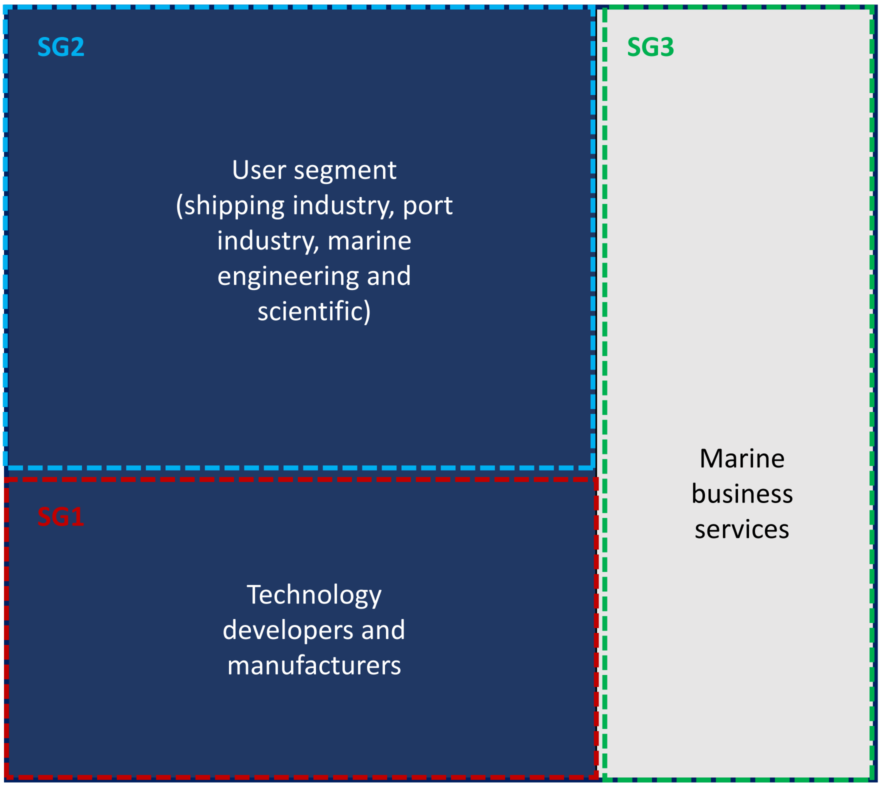
- **Knowledge spillovers** that could benefit other sectors of the economy;
- **Externalities** which consider environmental impacts (e.g. GHG reduction, ecological impacts), and safety and security impacts.

We follow the definition of the value chain presented earlier and work with 3 **stakeholder groups**:

- **SG1:** The **technology providers** who invest in R&D to bring new technologies to the market;
- **SG2:** The **end users** (ports and shipping companies) which may adopt the technologies and improve efficiency;
- **SG3:** The **business services providers** who capture a share of the market by supplying support services such as insurances and shipbroking.

The stakeholder groups are embedded into the value chain as follow:

Figure 2 Stakeholder groups in the Maritime Industry value chain



Source: London Economics

Table 1 combines indicators and stakeholder groups in a matrix to visualise what the model will generate. Each cell contains the main inputs used to compute the required indicator and is explained in detail in the methodology.

Table 1 Analytical framework

Category	Indicator	SG1	SG2	SG3
Industrial effects	**Turnover**	Company matrix – FAME data	Bass diffusion model	Company matrix – FAME data
Industrial effects	**GVA**	Company matrix – ONS data	Bass diffusion model	Bass diffusion model
Industrial effects	**Employment**	Company matrix – FAME	Employees productivity – Maritime UK	Employees productivity – Maritime UK
Spillovers	**Knowledge**	Spillover Model	None	Spillover Model
Externalities	**Environment**	Environmental Model	Environmental Model	Environmental Model
Externalities	**Safety**	Safety Model	Safety Model	Safety Model

Source: London Economics analysis

A scenario-based model is developed to capture the degree of **additionality** generated. Additionality is defined as the difference between the expected outcome in the **primary scenario** *with* the initiative/government intervention and the expected outcome in the **counterfactual scenario** *without* the initiative.

The **counterfactual scenario** represents the case without further government intervention. It uses the industry trends to project the industry growth and estimate the income, GVA and employment over time.

The additionality is measured as the cumulative difference between the primary scenarios (no growth to high growth) and the counterfactual scenario. It also reflects the domestic efforts capturing UK induced additionality.

Industrial impacts

We have identified **215 relevant companies** in the smart shipping industry that are split between the four segments of analysis. For this stakeholder group, we focus on the four relevant technology segments for which **36** companies were identified as active in the smart port segment, **38** in the autonomous vessel segment, **68** provide on-board technologies and **131** deliver professional business services. Note that companies can be active in multiple segments.

Knowledge/Technology spillover effects come from the technological developments associated with the SSI value chains, which are expected to encompass several technical domains such as AI, manufacturing, autonomy, robotics, and data analytics. London Economics developed a model that estimates the potential spillover returns based on the assessment of smart shipping technologies characteristics (investment required, time to Technology Readiness Level 9, potential for spillovers, and more).

For the wider maritime industry (end users), the **Bass diffusion model** is used to project the technology adoption over time. This model factors in various elements of the observed market and builds an S-shaped curve to simulate the adoption. This is a widely used model in various industries.

Environmental impacts

To model environmental impacts and estimate the level of emission reduction and thus external costs savings both while at sea and at berth, we have modelled two separate cases. We use a scenario-based approach simulating various trips for different sizes of container ships.

At sea, emissions depend on vessel size, distance travelled, speed, fuel efficiency, and the engine exhaust factor (measured in tons of CO_2 per tonne of fuel). The result yields CO_2 emissions saved in tonnes per trip, assuming a 1% efficiency gain in fuel and an external cost factor[8] of £65 per tonne of CO_2.[9][10]

In the port, ships still require electricity for hotelling activities. This demand can be met either through power generated by fuel consumption in auxiliary engines or by using **shore power**. Comparing the CO_2 emissions of generating electricity through the auxiliary engine with the CO_2 emissions from the national power grid lets us estimate how much CO_2 can be saved.

Safety impacts

The total saving through the implementation of technology is calculated using the Department for Transports road accident and casualty cost estimations, estimates of the total insurable value (TIV) of vessels and shipping accident data published by the European Maritime Safety Agency (EMSA). The cost estimate considers the value of lives lost, hull and machinery damage, cargo lost and pollution.

Caveats

- Assessment relies on expert judgement and is subject to uncertainties, optimism bias
- The list of companies is non-exhaustive
- Retrospective analysis is not possible, and we assume the share of income that is SSI relevant is constant over time
- The curves derived via the technology adoption model are <u>not</u> forecasts, but rather approximations of where on the adoption curve each sector is likely to be if given adoption forecasts hold true. A significant number of factors influence adoption and actual adoption is therefore likely to be different than the curves derived via this exercise.
- Impacts of the CoVID-19 pandemic and Brexit are not considered explicitly.

The model is built on a wide variety of assumptions and sources. Each assumption presents a variable degree of uncertainty and pulling them together might increase the uncertainty of our results.

However, assumptions were always challenged, and wider research was committed when significant doubt on the estimates existed. The methodology and results were systematically discussed with a steering group to maintain credibility. The steering group provided full support during the modelling process which is reflected in the results of the report.

[8] This does not represent the price on carbon emissions but the offsetting cost i.e. the cost of mitigating CO2 emissions rather than the social cost or shadow price of carbon.
[9] Schneider Electrics. (2018). Study of ship emissions whilst at berth in the UK.
[10] BEIS (2017). Valuation of energy use and greenhouse gas.

Assessment of the benefits

Table 2 Summary of the results (additionality – central scenario)

Investment = £560m	Indicator	SG1	SG2	SG3
Industrial effects	**Turnover**	£540m	£983m	£80m
Industrial effects	**Direct GVA**	£275m	£383m	£70m
Industrial effects	**Direct Employment**	3,986 FTE	6,535 FTE	1,017 FTE
Spillovers	**Knowledge**	£56m	None	£0m
Externalities	**Environment**	Not quantified	Not quantified	Not quantified
Externalities	**Safety**	72% of total costs	72% of total costs	72% of total costs

Note: the central scenario assumes a CAGR of 2.8% per annum and 43% match funding.

Source: London Economics analysis

Table 3 Summary of the results (additionality – lower and upper scenarios)

Investment = £560m	Indicator	SG1	SG2	SG3
Industrial effects	**Turnover**	[£488m; £576m]	[£737m; £1,051m]	[£72m; £85m]
Industrial effects	**Direct GVA**	[£248m; £294m]	[£291m; £408m]	[£59m; £74m]
Industrial effects	**Direct Employment (FTE)**	[3,705; 4,180]	[5,039; 6,954]	[878; 1,064]

Note: the lower scenario assumes no growth and 53% matched funding; the upper scenario assumes a CAGR of 3.5% per annum and 36% matched funding.

Source: London Economics analysis

Industrial effects

The scenario assumes that an initial investment of **£560m** is made over four years and **shared** between the government (**£319m**) and grantees (**£241m**), based on MarRI-UK grants showing that 43% of the total cost of R&D is matched by the participating company/consortium. The initial investment was determined by a detailed assessment of new technologies by NLAI. It corresponds to the investment required to bring the selected technologies to TRL9. Details about these technologies are available in the Annex 5.

The counterfactual scenario assumes the whole investment is borne by companies and the government is not involved in the R&D funding process.

The scenario presented in this section is hypothetical. The level of funding required to bring the technologies to market are based on the assessment of selected technologies. It does not reflect the current strategy of the government[11].

Stakeholder Group 1

The first channel of returns comes from the government funding which acts as **additional income**. The second channel generating wider benefits comes from participating companies (grantees). Access to a grant is assumed to enable faster development of a technology and consequently a faster access to market. This benefit is captured by the additional **leveraged commercial sales**.

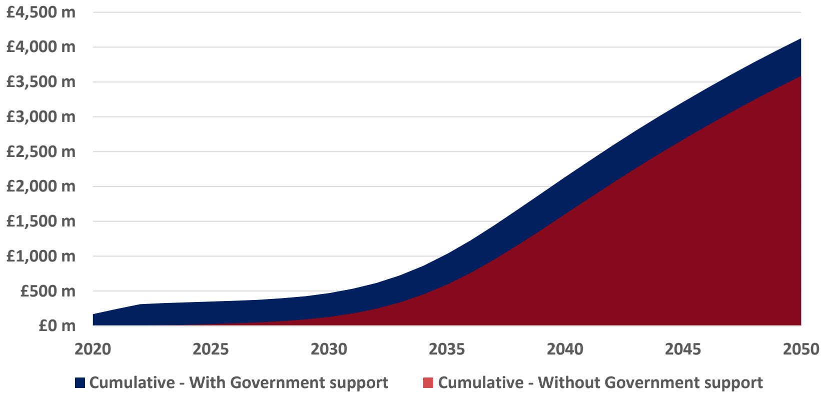
Results show that with government support, the additional sales might start as early as 2022 but substantial additional revenues are expected to start around 2030. The cumulative income in present value terms could reach **£4.1 billion** between 2020 and 2050. Without government support,

[11] UK Innovation Strategy

these benefits are expected to start much later and therefore the cumulative present value would only reach **£3.6 billion** in 2050. This represents an additionality of **£500m**.

Combining the benefits from grant and leveraged sales, the cumulative additionality from financial support amounts to **£540m** in present value terms and over the whole period. This is equivalent to an additional income of **£18m** per year.

Figure 3 Cumulative impact of government intervention (values in £2020)



Source: London Economics

The GVA generated by the additional activities is computed using the within-segment GVA per income ratio. This yields a cumulative and additional GVA of **£276m**.

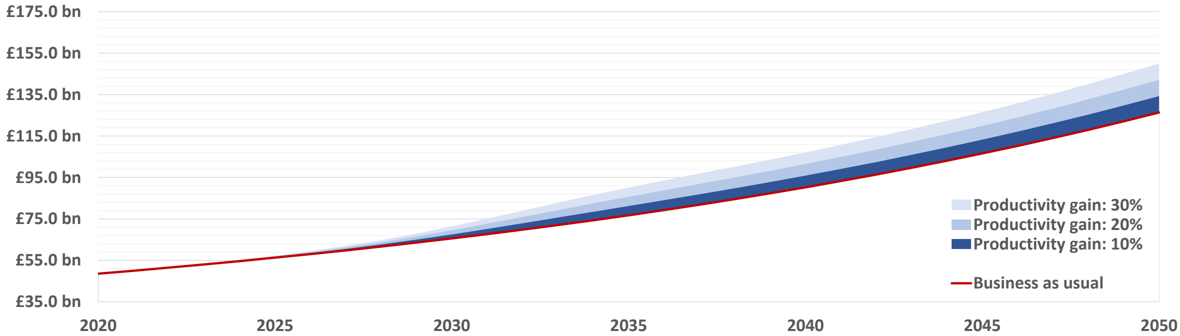
Similarly, using the within segment employee's productivity, results show that over **3,900** additional jobs could be secured from the financial support.

Stakeholder Group 2

The benefits generated by the MI are due to the improved efficiency of their activities. To capture the impact on the wider market, we use the Bass diffusion model. The calibration inputs are presented in the table below. We assume that users who adopt new technologies can improve their efficiency (and their income) by 10% (up to 30%).

In 2020, it was estimated that the MI generated **£48.6bn** in turnover. Using the counterfactual assumption, this would yield a turnover of **£126bn** by 2050. By using the diffusion model, the turnover in 2050 would reach **£134bn** and up to **£150bn** in the 30% growth scenario.

Figure 4 Maritime industry productivity gains



Source: London Economics

In the 10% efficiency gain scenario, the cumulative income additionality that is attributable to government financial support is **£1 billion** while in the 30% gain scenario, this additionality rises to **£2.9 billion**.

In GVA terms, the direct effect in 2020 was estimated around **£17bn** in the maritime industry and in 2050, the GVA is estimated to reach **£56bn**. In cumulative terms, the additional GVA generated by grant support is equal to **£400m** in the 10% gain scenario and up to **£1.1 billion** in the 30% gain scenario.

The employment level also benefits from increased efficiency in the industry. Direct employment was estimated around 200,000 FTE in 2020 which could grow up to 600,000 in 2050 with a 10% efficiency gain. Given the additional impact of an intervention, **6,500 jobs** could be created with government support. By using the maritime employment multiplier of 5.0[12], over **39,000** additional FTE could be supported in the wider economy due to domestic efforts.

Stakeholder Group 3

For the service industry, it is estimated that the total additionality attributed to a government grant support yields a cumulative **£80m** over 30 years whilst the GVA totals **£70m**.

In terms of employment, **3,300 Full-Time Equivalents (FTEs)** have been estimated as of 2020. Using the growth model, this number is expected to grow to **10,000 FTE** by 2050. This represents an additional **1,000 FTE** that the UK government intervention could secure.

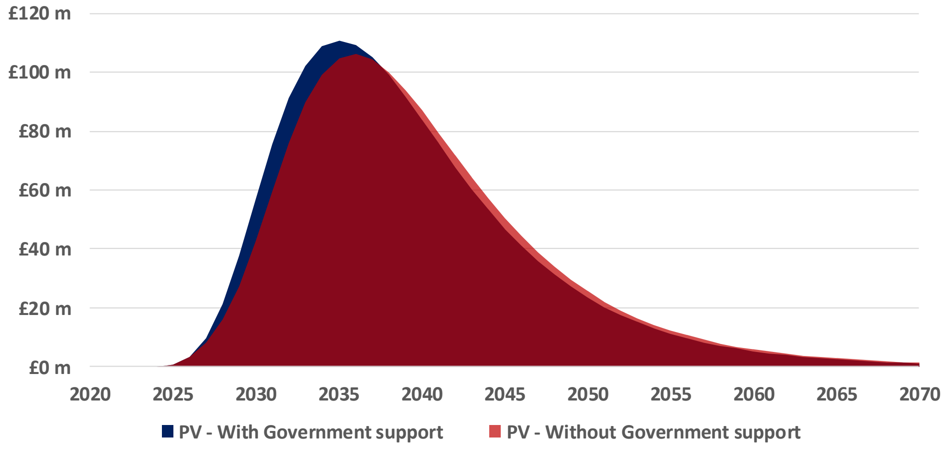
Technology spillovers

The 19 technologies identified have been reviewed by a panel of experts. Consultations and NLAI have identified the minimum requirements for determining the spillovers by assuming the duration of the development to technology readiness level 9 (TRL9), the investment required to bring it to maturity, magnitude of potential spillovers (ranging from very low to very high) and the time until when the technology will be ready.

The distribution of the benefits is shown in Figure 5, which shows the extent of spillover returns with and without the intervention from the government.

[12] Maritime UK (2019). State of the maritime nation report 2019.

Figure 5 Distribution of knowledge spillovers (values in £2020)



Source: London Economics

By 2050, knowledge spillovers are expected to yield **£1.57 billion** and this might drop to **£1.51 billion** in the absence of intervention. This represents an additionality of **£56m** from grant funding.

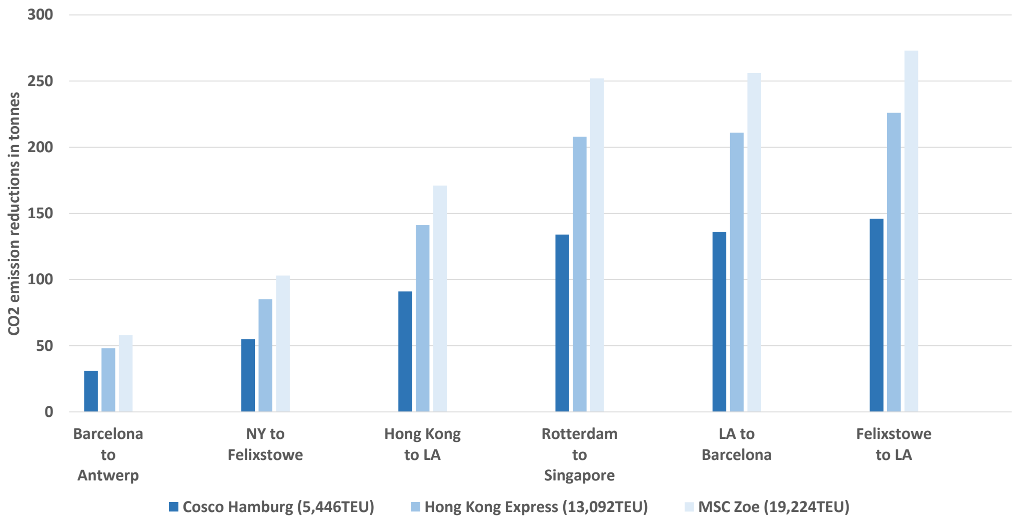
Environmental impacts

At sea, the extent of environmental benefits substantially varies with respect to the trip simulated and the type of ship.

The amount of CO_2 emissions, and hence the external cost that can be saved at sea through efficiency gains, depends on the size of the ship, the speed, and the voyage length. On a shorter journey, i.e. from **Barcelona to Antwerp** (2,146 NM), CO_2 emissions can be reduced by **31 tonnes** for a smaller vessel (5,500TEU[13]) and **58 tonnes** for a large vessel (19,200TEU) for each 1% efficiency gain. On longer journeys, such as the **Europe-East Asia** Trade Route (Rotterdam-Singapore, 9,343 NM), emission reductions range from **134 tonnes** for a smaller vessel to **252 tonnes** of CO_2 for a large vessel (see Figure 6). **This is equivalent to 30 to 55 fewer cars on the road for one year for each 1% fuel saved per trip.**

[13] Twenty foot-equivalent unit is the standard unit of measurement of containerised cargo transportation.

Figure 6 CO2 emission reduction for 1% efficiency gain at 20 knots



Source: London Economics

In ports, the savings highly depend on the type of ship and the emissions from auxiliary engines, the alternative source of energy that is available and the time spend at berth.

The potential CO_2 emissions that can be saved by switching to shore power range from **46 to 119 tonnes for a smaller vessel to 184 to 477 tonnes of CO_2 saved for a very large vessel** based on the duration spent at the port. Depending on the source of electricity used for shore power, the savings may be even larger. If ports use renewable energy, e.g. by generating solar or wind energy, the carbon emissions per kWh will be even lower than those from the national grid.

In addition to air pollution, shipping and the maritime industry contribute to further environmental problems that are out of scope of this research project but could be areas for further research. These include:

- Pollution by **oil** or **bilge water;**
- Noxious substances (e.g. from anti-fouling paint);
- **Sewage** from ships;
- **Garbage** from ships; and
- **Ballast water.**

Safety benefits

According to EMSA, general cargo ships were the main category involved in a marine casualty or incident (43.8%), followed by passenger ships (23.7%) during the 2011-2018 period. These estimates are used to calculate the cost of accidents. All ships which fall outside cargo and passenger ships are categorised as other.

The total cost of accidents depends on the number of injuries, lives lost, seriousness of the accident and the type of vessel involved. At the EU level, the total cost of maritime accidents between January 2012 and September 2019 is estimated to be **£7.2 billion**. This figure represents the cost of 634 very serious casualties[14], 7,790 people injured, 655 lives lost, damages to 26,500 ships, and the total insurable value of the 215 ships sunk.

Estimates of the total value of maritime casualties which could have been prevented by automated mooring systems, autonomous vessels, on-board technology and automated cargo handling is estimated to be worth **£5.1 billion** (72% of total costs) in the EU 28 since 2012.

Strategic choices

The strategic choices for the UK were assessed using the primary and secondary research carried out by NLAI. The assessment of UK capabilities considers the strategic advantages of the UK commercial shipping sector, the barriers to entry, and the state of the competitive landscape. This includes the recognition that foreign competitors may enjoy absolute cost advantages in certain segments of the shipping sector but also that UK competitive advantage in smart shipping may come from suppliers outside the narrow maritime sector and include areas of strength in the broader professional services market.

The conclusions were supplemented with an analysis of the competitive advantage that can be achieved by investing in the selected key technologies as well as a SWOT analysis of the shipping industry as a whole.

The areas in which UK capabilities can be leveraged to achieve substantial and long-lasting benefits from technology and business leadership are:

- The manufacturing and deployment of smaller autonomous vessels;
- Smart shipping sensor development and sensor integration services;
- Smart shipping command and control systems and expertise;
- Smart shipping data and intelligence services;
- Smart shipping cyber security and risk management;
- Training in the adoption and utilisation of smart shipping technologies.

The table below summarises the general assessment of the first-mover advantage durability for each of the selected UK strategic opportunities.

[14] "A very serious marine casualty means a marine casualty involving the total loss of the ship or a death or severe damage to the environment. Note: Severe damage to the environment means a discharge of 50MT or more of pollutant." *UK Marine Accident Investigation Branch*

Table 4 Assessment of first-mover advantage based on market conditions

Market characteristics	Short lived first-mover advantage	Durable first-mover advantage	Smart shipping segments
Technological development: slow Market evolution: slow	Unlikely	Very likely	-
Technological development: slow Market evolution: fast	Very likely	Likely	Training; cyber security & risk management
Technological development: fast Market evolution: slow	Very unlikely	Unlikely	Command & control systems & expertise*.
Technological development: fast Market evolution: fast	Likely	Very unlikely	Small autonomous vessels; sensors & sensor integration services; data & intelligence services

Note: * Scale economies and network effects could create more durable advantage.
Source: Adapted from Suarez and Lanzolla (2005).

1 Introduction

The consortium, composed of London Economics (lead) and NLA International, was commissioned by the Maritime Research and Innovation UK (MarRI-UK) to undertake economic research to inform the Department for Transport (DfT) approach to supporting the smart shipping sector in the UK. The consortium brings complimentary experts from the maritime and engineering world alongside experts in economic research and consultancy.

The research focuses on the UK's strengths in smart shipping technology and provides economic and technology research to inform the Department for Transport (DfT) approach to supporting the smart shipping sector in the UK.

The research considers **4 market segments** which include smart ports technologies, autonomous vessels technologies, on-board technologies, and professional services and try to address four main research questions:

1- What are trends for smart shipping technologies between now and 2050 and which are likely to be delivered by the UK?
2- What is the economic rationale for UK government funding to support the development of smart shipping technologies at this time?
3- What are the estimated social costs and social benefits of smart shipping technologies for the UK?
4- What is the value of being first mover or follower for different smart shipping technologies?

The analysis uses inputs from both primary and secondary research.

- Desk research:
  - A wide review of the literature has been carried by all parties and include reports, conferences, news articles, and research papers
- Market intelligence:
  - NLA International's **Blue Economy Knowledge System** was interrogated to find recent news alerts relevant to the 28 distinct market sub-segments identified across the four smart shipping segments of smart ports, autonomous vessels, on-board technologies, and professional services technologies
- Industry interviews:
  - 64 relevant interviewees were scoped and shortlisted
  - 50 were contacted
  - **26 were interviewed** and their findings included in this report
- Interviewees were aligned to each of the four main sectors (smart ports, autonomous vessels, on-board technologies and professional services technologies) to ensure good coverage of each, though many respondents shared comments and insights that covered more than one of those sectors;
- Key findings of the initial drafts were developed in a cyclical style. Twice-weekly full-team meetings were established, with the Work-In-Progress document shared, interrogated, and challenged alongside the sharing of new insights;
- In particular, these meetings had a focus of making sure that the key insights emerging from the industry interviews were understood and absorbed by all team members; this also

provided other team members with the opportunity to reference additional material or case studies that would support and strengthen emerging findings;

- Assessment of individual companies:
    - 450 candidates were identified by Glass.AI research
    - **215 were judged relevant**

This report is the output of **all of the above work packages** and looks to establish a counterfactual / baseline by analysing trends for smart shipping technologies between now and 2050 and establishing which are likely to be delivered by the UK.

The report is organised as follow:

- **Chapter 2** provides an overview of the maritime economy and the state of the smart shipping industry in the UK;
- **Chapter 3** highlights the theory of change mechanisms with details about the rationale for intervention, market failures and potential channels for intervention;
- **Chapter 4** presents the theory behind the economic modelling;
- **Chapter 5** details the quantitative findings with details about the maritime industry and a specific focus on the smart shipping industry;
- **Chapter 6** drafts the potential strategic choices the UK could make;
- **Chapter 7** concludes with an assessment of the recommendations drawn from the previous chapters.

2 The maritime industry at a glance

This section outlines the wider maritime industry value chain and the smart shipping industry. It also provides preliminary information on the size of the industry.

2.1 Definition of the value chain

The maritime industry (**MI**) as defined by Maritime UK[15] contains 5 high-level segments:

- The **shipping industry,** with activities including the transport of freight and passengers;
- The **port industry,** which concerns all warehousing, management, cargo and passenger handling and customs activities;
- The **marine engineering and scientific** (MES) industry responsible for shipbuilding, support engineering, marine science, and other academic activities;
- The **marine business services** (MBS) industry dealing with shipbroking, insurance financial and legal activities; and
- The **leisure marine** industry including recreational and boatbuilding activities.

This definition slightly diverges from the OECD's 'Ocean Economy'[16] definition and excludes the following segments which are considered out of scope:

- Marine Tourism
- Fishing & Fish Processing
- Marine Aquaculture
- Offshore Oil & Gas
- Offshore Renewables

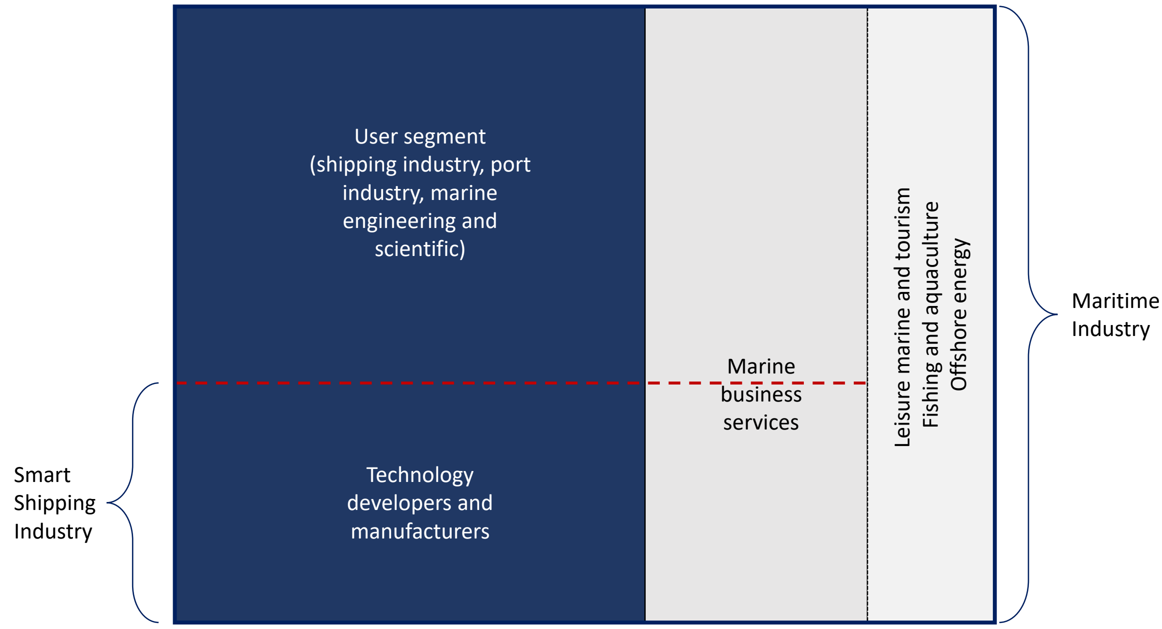
We distinguish the smart shipping industry (**SSI**) from the wider MI based on the list of technologies identified by NLAI (section 2.3). This is a summarised value chain which illustrates how the SSI fits into the wider MI value chain for us to address the potential economic benefits of technology adoption and model a counterfactual scenario.

According to the definition provided by the DfT[17], **smart shipping** encompasses the automated, partly digitised equipment of today, the remote operation of equipment, and the development of autonomous maritime systems, both at sea and onshore. This broad definition is used because new technologies will have the greatest impact when they are used holistically, as part of a wide-ranging approach that applies to the whole UK supply chain.

We assume that MI companies using advanced technologies belong in some parts of the SSI industry's value chain. The SSI industry is defined by **3 technology development and manufacturing segments** namely, smart ports, autonomous vessels, on-board technologies, and **one support segment,** the maritime business service industry. The **user segment** includes potential users from the wider shipping industry, port industry and MBS industry.

[15] Maritime UK (2019). State of the maritime nation report 2019.
[16] OECD (2016). The Ocean Economy in 2030.
[17] Department for Transport (2019). Technology and innovation in UK maritime: The case of autonomy.

Figure 7 The maritime industry value chain



Source: London Economics

2.2 Size and health of the UK maritime industry

The UK maritime industry generated estimated business turnover of **£44.5bn in 2017**. This includes 42.5% from the shipping industry, 10.7% from ports, 32.0% from MES and 14.8% from MBS. Compared with 2010 levels, this represents a compound annual growth rate (CAGR) of **2.8%** per annum (p.a.) at the industry level. The fastest growth has been registered by the shipping industry (**4.3%** p.a.) and followed by the MBS segment with a CAGR of **3.6%**.

The UK gross value-added (GVA) contribution of the industry was **£16bn in 2017**. This contribution is led by the shipping industry (38%), MES (32%) and followed by MBS (17%) and ports (12%). Despite the lower contribution to GVA, ports and MBS have the highest GVA per turnover unit where **£0.43** and **£0.42** are added in gross value terms per £1 or turnover generated, respectively.

In 2017, the four segments supported over **190,000 UK jobs**, of which 42.8% were attributed to MES, 31% to shipping, 14% to ports and 12.3% to services. In absolute terms, employment supported has increased by more than 35,000 since 2010 of which 16,700 are attributed to the shipping industry.

Using internal CAGR as the best predictor for growth, it can be assumed that the UK maritime industry will generate **£48.6bn** in turnover, **£17.7bn** in GVA and support nearly **210,000 jobs** in 2020. Impacts of the global CoVID-19 pandemic and Brexit are not explicitly taken into account.

Based on the wider OECD definition, Go Science estimates that the Ocean Economy in the UK generates £47 billion GVA and employs over 500,000 people[18].

[18] Government Office for Science (2018). Foresight future of the sea: A report from the government chief scientific adviser.

2.3 Smart shipping technology trends

According to *Shipping 2030* (compiled by Lloyd's Register, Qinetiq and University of Southampton) the technologies that are likely to transform shipping are:

- Robotics
- Sensors
- Big data analytics
- Propulsion and powering
- Advanced materials
- Smart ship
- Autonomous systems
- Advanced manufacturing
- Sustainable energy generation
- Shipbuilding
- Carbon capture and storage
- Energy management
- Cyber and electronic warfare
- Marine biotechnology
- Human–computer interaction
- Deep ocean mining
- Human augmentation
- Communication

This report's areas of focus (smart ports, autonomous vessels, on-board technologies, and professional services technologies) touch on and incorporate most of these technologies.

Statistics from 2019 show that 95% of the country's total imports and exports – 500m tonnes of cargo – pass through the UK's ports every year[19]. Interviews flagged that the most important drivers underpinning the development of smart port technologies in the UK are:

- To **improve environmental sustainability and energy efficiency**. The Maritime 2050 Strategy and Clean Air Act (especially for those >1 million tonne ports that are required to provide air quality reports) was specifically referenced;
- To **optimise workflows** to increase capacity and efficiency;
- To **digitise transaction** documentation. Many transactional processes necessary for the movement of goods through the international maritime supply chain are still supported by paper documentation. Against a background of ever-growing global trade volumes, (CoVID-19 and Brexit impacts not withstanding), these analogue systems are not sustainable. The digitisation of information and processes can result in improved customer service, and increased efficiency through transaction time savings, error reduction, improved security, and added value services. Digital systems allow dynamic pricing, online bookings, paperless Bills of Landing, customs, and trade documentation. They can reduce errors, demurrage, detention and storage costs and aid safety by helping identify and track hazardous goods.

[19] International chamber of shipping.

Supported by Maersk and developed by IBM and GTD Solution Inc, the 'TradeLens'[20] supply chain platform is an example of a service designed to deliver this digital transformation;

- **Brexit.** The UK's departure from the EU may lead to a sharp drop in EU/UK trade with implications for the UK's ports, though it was also argued that a collapse in UK-EU trade is not likely, even if there were no free trade deal[21]. With the EU-UK Trade and Cooperation Agreement (TCA), future UK/EU trade will require additional customs declarations and border checks. Before Brexit, the port of Dover handled between 7,000 and 10,500 trucks a day and the Channel Tunnel a further 6,000. Each truck takes less than four minutes to exit the port or terminal. Post Brexit, rapid border management processes will be needed to keep congestion to manageable levels. In February 2020, Michael Gove announced that a full customs, VAT, and regulatory border will be enforced. This would require up to 200 million additional separate declarations each year. If trucks have the correct papers, a small proportion of the border checks could be done away from the ports, however most customs and goods checks happen in the port or terminal areas. Modelling by Imperial College has shown that an extra 2 minutes per truck transiting Dover could create 29-mile-long tailbacks[22]. The changes brought about by Brexit emphasise the need for more efficient processes and act as a catalyst for the trend towards digital transformation.

Each of these elements exist at the same time. While preparing for / implementing Brexit and the need to improve environmental sustainability are the main 'push' focus areas in the sector from a governmental / regulatory perspective, the potential to adopt new technologies to optimise workflows and digitise transaction documentation appear to be the priority areas attracting interest from industry to deliver business benefits.

2.3.1 The rise of maritime innovation

The maritime industry has typically been perceived to be slow at adopting new technologies. This is generally a global phenomenon brought about by a combination of factors including:

- This may stem from a safety perspective where technology failures leading to incidents often make headlines but technology creating a safer and more efficient industry does not;
- IMO can be slow to react because of the way conventions come into force, coupled with the fact that deadlines can be delayed so firms are incentivised to delay investment;
- Shipping is globally competitive and goes through periods of low/negative margins, so vessel owners don't want to invest in assets that may become loss-making;
- Bringing offshore/maritime technology up the higher Technology Readiness Level (TRL) is inherently expensive and the risks of failure can be very high. Asset owners are therefore risk averse.

It has long been considered that significant effort needs to be in place to encourage technology adoption that is not solely legislation driven.

However, this picture is changing. To help mitigate increased infrastructure and resource pressure, and as technology accessibility increases at the same time as costs reduce, the smart shipping sector

[20] TradeLens

[21] Policy Exchange (2018). BREXIT - Prospects for trade and Britain's maritime ports.

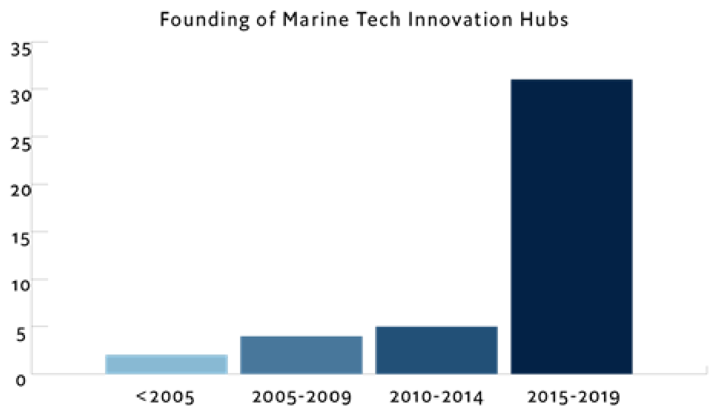
[22] Dr Han, Centre for Transport Studies, Imperial College London, March 2018.

is seeking innovative solutions to optimise efficiency, reduce logistics costs, improve safety, and lessen environmental impacts.

Several segments of the smart shipping industry are projected to exhibit significant growth in the coming decades, and there is growing global competition to maximise these opportunities. **Investment in innovation seems to be a clear current trend** where venture capital investment into maritime software and digital startups has grown from >US$50m in 2015 to over US$1,100m in 2019[23] **.**

To give one example, Figure 7 shows the explosion of marine technology innovation hubs in the USA alone. These hubs act as a marine technology ecosystem which represent a community of stakeholders and innovators in the maritime sector. The hubs act as launchpads for startup companies and encourage collaboration. This level of investment in marine and maritime innovation funds and accelerators is being echoed in all parts of the world, most notably Europe and Asia.

Figure 8 Maritime technology innovation hubs creation (USA)



Source: NLAI

2.3.2 Smart ports

In order to ensure all aspects of the smart ports sector were considered, the NLAI collated industry news / market intelligence focused on nine smart port technology segments, (which were defined within a commercial market research report). These were:

- **Terminal automation and cargo.** E.g.: Two large remote-controlled Ship-to-Shore (STS) cranes in the Red Sea Gateway Terminal (RSGT) – supplied by ZPMC from Shanghai – feature a series of advanced automation technology, including remote control and optical character scanning capability, chassis alignment and automatic landing systems;
- **Port Community Systems.** E.g.: The port call collaboration platform PortXchange has already exhibited a 30% reduction in idle time of ships in the Port of Rotterdam by enabling all parties involved in a port call to plan and optimize together;
- **Traffic management systems.** E.g.: Ports America is currently building what it calls a "turn-time efficiency tool" to speed container pickup at its Port Newark Container Terminal and

[23] Smith, D. (2019). Industry Perspectives: Venture capital investment in maritime technology.

Seagirt Marine Terminal in Baltimore. The system enables a core group of beneficial cargo owners and their trucking providers to pool their containers for each vessel call;

- **Automated information systems.** E.g.: North Sea Port is collaborating with the Flemish Waterways plc, the Port of Antwerp, the Port of Oostende, the Port of Zeebrugge, the Agency for Maritime and Coastal Services, and the Joint Nautical Management to digitise and standardise cargo data sharing on Belgium's inland waterways. In a statement, The SWINg system will allow skippers and inland shipping companies to submit a single, digital report on their route, cargo, and other data to travel;
- **Real-time location systems.** E.g.: Intelligent Cargo Systems' CargoMate platform provides carriers with real-time port call visibility and information such as estimated time of completion, to allow fleet managers to "dynamically manage coastal schedules";
- **Automated mooring systems.** E.g.: Wärtsilä's SmartDock solution was hailed as world's first commercially available auto-docking system, reducing the potential for human error resulting from ship officers having to perform the same manoeuvre many times a day. The ship's captain only must select a destination, after which time the intelligent system takes over and either moves the vessel out of the dock or into the harbour, without the need for human intervention;
- **Gate automation.** E.g.: APM Terminals Aarhus has commenced the construction of phase 1 of its US$3 million automated gate complex, enabled by Optical Camera Recognition (OCR), license plate recognition cameras and CCTV cameras for exception handling by gate clerks;
- **Shore power.** E.g.: The Port of Bremen/Bremerhaven will receive eight shore power supply units for maritime shipping and two additional connections for inland shipping after its local Senate approved plans, as part of its efforts to become a green, carbon-neutral port;
- **Smart energy and environmental solutions.** E.g.: The Port of Los Angeles is now using the world's first zero-emission top handles in daily operations at the Everport Container Terminal. The top handlers run on a one-megawatt battery designed to operate for up to 18 hours between charges and have data loggers for tracking hours of operation, charging frequency, energy usage and other performance indicators.

While this was a useful approach to ensure a breadth of commercial market intelligence was collected, it became clear that there are many cross-over functions across this rigid segmentation, and in fact the key smart port technology clusters may best be viewed as being:

- Automation;
- Big Data and AI software systems (performing a range of optimisation tasks);
- Power, propulsion, and energy;
- Communications.

2.3.3 Autonomous systems

The global autonomous ships market size is estimated to be valued at US$88 billion in 2020, and is projected **to reach US$135 billion by 2030**, registering a CAGR of 4.4% from 2020 to 2030[24].

Autonomous systems in the shipping industry are expected to reduce the maritime emissions, enable fuel savings, and save about 20% of the cost incurred for the shipping operators. According

[24] Allied Market Research.

to the European Maritime Safety Agency (EMSA), 58% of accidental events were attributed to human error and 70% had shipboard operations as a contributing factor. Autonomous technology is anticipated to reduce the scope for human error on the bridges of the vessel thereby reducing the risk of accidents on-board. Stated benefits vary. For example, it is claimed that *Jin Dou Yun 0 Hao*, China's first autonomous cargo ship, will reduce construction costs by 20%, operation costs by 20% and fuel consumption by 15%.

The IMO has identified four degrees of ship autonomy:

- In degree 1, a ship has automated processes and algorithmic decision support, but onboard crew members are still needed to operate the systems (albeit with less supervision);
- In degree 2, ships are controlled remotely, but still with onboard crew members;
- In degree 3, ships are controlled remotely with no seafarers on-board;
- In degree 4, the ship is fully autonomous, but with shore-based emergency over-ride.

Across the IMO definitions, some interviewees thought that the early, market-leading emphasis would be on remote monitoring and control with full autonomous phases of operation in short sea operations. Another interviewee singled out coastal freighters (single flag state) and survey and inspection as being of greatest early interest, while others thought that container ships would be first to adopt autonomy at higher levels, partly because of the nature of the cargo and partly because container terminals are already automated extensively. Respondents were clear in their thinking that IMO autonomy degrees 3 and 4 were still "a long way off", and that smart watchkeeping and decision support were good interim steps.

These views recognised the reportedly strong progress in the adoption of autonomous systems in larger vessels, and live trials with vessels at degrees 3 and 4. They also reflect the industry claims, mainly overseas, that technology will advance apace, and the large amount of information emerging in commercial and academic publications concerning the bright future for autonomous ships. But respondents repeatedly told us that every time a trial of an autonomous vessel is organised, the operator must convince the relevant Maritime Authority that the operation will be safe. This means that exemptions from many national and international maritime safety requirements, including those in UN Conventions have to be obtained for each voyage (e.g. Load Line, SOLAS, COLREGS and Safe Manning).

Trials are normally conducted using a manned escort vessel, or a Notice to Mariners warning sea users of the existence of autonomous trials. Classification Societies and Insurers also need to make special arrangements to assure themselves that the relevant risks are covered. So, until widely adopted standards are agreed for autonomous operations, trials have a **heavy burden of administration** before commencement. The larger the vessel, and the higher the level of autonomy proposed, the more complex this burden becomes because, the more regulations must be accommodated through "equivalence" or "exemption".

Other reasons, less technical or regulatory in nature, include the societal perception of safety at sea, and the need to persuade seafarers and their representative bodies that good careers are still available, in part to prevent a cliff-edge in young recruitment.

It is for these reasons, among others, that respondents told us that degrees 3 and 4 operations might be **five or more years in development**, apart from limited trials.

The two key drivers within the autonomous vessels market as specified in interviews to date are **cost** (savings from reduced staff needs) and **reduction of risk** (minimising the potential for human error). Autonomous and remotely operated vessels were also seen to “break the 1:1 crew-to-vessel relationship, allowing companies to better utilise their technical experts across multiple concurrent projects”.

Complementing the IMO categories set out above, smaller Maritime Autonomous Surface Ships (**MASS**) and Unmanned Underwater Vessels (**UUVs**) are entering the market to undertake a range of tasks. **Sensor development and data fusion technologies** also promise to improve autonomous ship behaviour, feeding better data to AI systems and providing better situational awareness in machine readable formats.

2.3.4 On-board technologies

Ships are becoming more and more laden with technology that assists in **safe navigation, ship performance, maintenance** and more. Despite the shipping industry’s apparent or perceived reticence in embracing technology, the sector still sees technological advancement in several key areas such as **AI, smart ship platforms, alternative propulsion, and connectivity**.

Machine learning and **Artificial Intelligence** (ML/AI) for ship efficiency is a growing area of interest. There are a good number of **vessel optimisation systems** on the market with a healthy mix of new and long-standing players. ML/AI has the ability to assess the impact of various technologies (such as rotor sails or air lubrication) by actively analysing the vessel and providing an accurate picture of how a vessel is performing and create a ‘real’ baseline to compare against. ML/AI is still in its infancy, though, allowing space to build and optimise such systems.

Smart ship platforms create a standard interface for all the ships instrumentation and sensors so holistic analysis and decision support of a ship can be made. This feeds into both ship autonomy and control via Sea Traffic Management (STM) and other land-based systems. The UK Ministry of Defence (MoD) has defined such a platform for its land vehicles with generic vehicle architecture, but no such maritime equivalent standard exists. There are several studies and platforms at various Technology Readiness Levels but **no one platform has emerged yet as the de-facto integration system for a ship.**

Vessel performance optimisation is another growing subject of interest. Although fleet and vessel control centres are taking some responsibility away from ships there are still some on-board systems designed to let the crew take action to improve vessel performance. This can be anything from vessel trim to route optimisation, navigation, or speed planning. Microsoft has invested heavily in one US performance optimisation company as an example of other sectors looking to invest in technology in the maritime sector. It is also a growing requirement for vessels to **report their performance in line with increasing environmental legislation.**

Alternative fuels are being promoted by rising fuel costs, tighter emission regulations and the need for the industry to support Corporate Social Responsibility.

Communication, connectivity, and data transfer are topics of growing interest as systems require ever greater bandwidth to provide optimal performance. Sea traffic management, chart and ECDIS updates, safety notices, crew welfare, remote maintenance, autonomy, and many more will only work effectively with **resilient** communications – the mechanism to enable all other technologies.

2.3.5 Professional business services

Blockchain is seen as a significant opportunity for ports and shipping in the UK. Being able to amalgamate documents (customs, inventory, right to goods), and payments from seller to buyer is seen as a ‘game changer’, offering the potential to cut out the significant cost of banks and other intermediaries in a low margin industry.

With so many new technologies and applications coming to market – in many cases aligned to new regulations and ways of working – the need for **more training** also comes into play. The introduction of ECDIS (Electronic Chart Display and Information System) is a helpful example of where training was mandated alongside the installation of the technology.

The UK offers great opportunity in the field of **consulting**. Leading universities, maritime colleges, regulatory experts, and a well-respected class society provide much weight to the UK maritime ‘brain trust’ which is adding value on many aspects of development projects.

UK shipbrokers continue to **dominate** the international shipping sector where 30-40% of dry bulk and 50% of tanker are managed by UK-based shipbroking firms[25].

Respected academic institutions both for general and maritime education are well placed to capitalise on emerging training and development needs. Significant growth is expected in the use of autonomous surface and sub-surface systems in survey work, not only to offer improved productivity but to **increase the quality of survey results**. This will further increase demand for qualified operators to monitor, manage, and maintain these systems.

[25] Maritime London

3 Theory of Change and rationale for intervention

Theory of Change (ToC)[26] is a comprehensive description and illustration that demonstrates the causal link between **inputs**, **activities**, **outcomes and impacts**, and **enabling assumptions**. It maps out **how** and **why** the strategic and technological objectives are expected to be achieved and under **what** circumstances, assumptions, and subject to what influences. The objective is to bridge the unknown between the creation / elaboration of a program and the outcomes envisaged.

The maritime industry will benefit from the development and adoption of smart shipping technologies. However, to ensure commercial success and support industrial activities, it is important to strategically assess the best channels for government intervention. To this end, the ToC approach provides a useful **framework** that allows the formalisation (via a logic model) of activities and corresponding outcomes/impacts of two possible development paths: **One supported by the government via various channels of intervention whilst the other excludes that support**. It is this feature of the ToC that makes the logic model a useful tool to **structure thinking** around government interventions and makes it a key tool in evaluating policy choices.

The next section (Section 3.1) provides a brief **summary of the main findings** of the ToC analysis for the maritime sector. Section 3.2 then provides further **background** on the key components of a **logic model.** Sections 3.3 to 3.5 set out **the long-term goals** for the UK maritime sector as set out in the Department for Transport's Maritime 2050 strategy, the **rationale for government intervention** in the sector, and evidence the **market failures** inhibiting private players from investing the optimal level of capital in smart shipping technology. Finally, Section 3.6 considers several **intervention options** structured around the four key areas of funding, collaborations, skills, and policy/regulation.

3.1 Summary of findings

The table below provides a brief overview of the main findings of the ToC analysis for the UK maritime sector. It highlights the long-term goals for the sector, the rationale for government intervention, market failures, and the areas in which government interventions can be focused.

[26] HM Treasury (2020). The Magenta Book.

Maritime UK 2050 goals: 10 core strategic ambitions	Long-term goals
Strategic ambition 1	Enhancing UK competitive advantage.
Strategic ambition 2	Leading the way on clean maritime growth.
Strategic ambition 3	Maximising benefits from maritime Technology.
Strategic ambition 4	Retaining global leadership in maritime safety and security.
Strategic ambition 5	Growing the maritime workforce and transform their diversity.
Strategic ambition 6	Promoting a liberalised trading regime.
Strategic ambition 7	Supporting continued investment in maritime infrastructure.
Strategic ambition 8	Strengthening and enhancing the UK's reputation as a leading maritime Country.
Strategic ambition 9	Promoting the UK's UK-wide leading maritime cluster offer.
Strategic ambition 10	Showcasing the UK's maritime offer to the world.
Rationale for intervention	**Definition**
Efficiency	Technology enables ports to optimize workflow and efficiently use limited space.
Employment	Investment in technology could create direct, indirect and induced employment.
Environment	Streamlining logistics, e-noses and appointment systems to reduce port traffic could reduce greenhouse gasses.
Safety and social capital	Technology could improve safety conditions, enable better informed decisions and allow seafarers to speak to their family and friends increasing their quality of life.
Security	Linking port security systems, surveillance cameras, sensors, drones and tracking tools could heighten security in ports
Supporting SMEs	SMEs could foster innovation, generate employment and increase productivity.
Spillover effects	Knowledge spillovers could benefit other sectors of the economy.
Political	Maintaining the UK's presence as a leading maritime nation.
Growth	Economic growth itself also forms a key driver under which many of the other rationales for intervention fall.
Market failures	**Definition**
Coordination failure	Many small parties contribute to a large supply chain resulting in split incentives.
Imperfect information	There is imperfect information and uncertainty surrounding the benefits of investing in developing shipping technologies.
Externalities	Externalities, impacts on uninvolved third parties, are not reflected in the price of the products and services.
Barriers to entry	Barriers include capital requirements, transition costs and minimum efficient scale.
Intervention options	**Definition**
Funding	Providing R&D funding and de-risking innovation investments.
Collaboration	Facilitating collaborations and partnerships.
Skills development	Supporting education and skills development.
Policy & regulation	Policy and regulatory frameworks that foster innovation.

3.2 Background on Logic models

The ToC approach provides a useful tool to structure thinking around government interventions and makes it a key tool in evaluating policy choices. It provides a framework that allowing the formalisation (via a so-called logic model) of activities and corresponding outcomes/impacts of two possible development paths: A path supported by the government via various channels of intervention whilst the other excludes that support.

The main components of the logic model are:

- **Inputs / channels:** public sector resources and expenditure that are committed to deliver the strategic objectives;
- **Activities:** this refers to the actions or interventions which are directly undertaken by the government or other stakeholders;
- **Outputs:** refer to the immediate or desired products of the activity;
- **Outcomes:** refer to the immediate or desired effects of the output, and the change brought about within a given group. The overall **impact** is given by the aggregated net effects of all outcomes;
- **Assumptions:** the conditions that affect the causal link between inputs, activities, outcomes and impacts, including both endogenous factors and exogenous factors that will influence the success of the government's activities. These assumptions need to be made explicit so that they can be scrutinised and tested.

Figure 9 Outline of the logic model

Source: London Economics analysis

The logic model allows us to understand the connections between the activities (in our case, maritime technologies development), the outputs, expected outcomes and impacts. Before designing an intervention, the question of what it aims to achieve must be addressed. The outputs of an intervention represent the long-term goals a project aims to achieve. Outputs include efficiency gains, raising employment level, reducing environmental impact, supporting SMEs, among others. The existence of market inefficiencies impedes the market to achieve optimality without intervention. This is the case when market failures are identified within the industry.

These failures appear between the activity and the output steps and remove the capacity to achieve long-term goals either by slowing down technology development or completely inhibiting the investment and freezing the activities.

Adverse effects such as pollution and externalities on third parties have a negative impact on outcomes due to a market failure between the activity and output. The appropriate response would be an intervention that prevents the negative action taken by the industry stakeholder (e.g. higher fines / better enforcement of environmental regulations).

Figure 10 Market failures create a gap in the logic flow

Source: London Economics analysis

By analysing rationales and market failures under scrutiny, policymakers can design interventions to alleviate the inhibitors and bridge the activities of the industry with expected outputs.

Figure 11 Channels of intervention to address market failures and inefficiencies

Source: London Economics analysis

3.3 UK maritime long-term goals

This section provides an overview of the long-term goals for the UK maritime sector as set out in the Department for Transport's Maritime 2050 strategy[27]:

- Maximise the UK strength in maritime professional services, retaining and enhancing our UK competitive advantage in the provision of maritime law, finance, insurance, management and brokering, and developing our green finance offer;
- Lead the way in acting on clean maritime growth enjoying economic benefits from being an early adopter or fast mover;
- Strengthen the reputation for maritime innovation, maximising benefits to the UK from new maritime technology through world leading universities, maritime small and medium enterprises (SMEs) and global companies;
- Continue to be recognised as the global leader in maritime safety and security standards and expertise worldwide;
- Grow the maritime workforce and transform their diversity enhancing the UK's reputation as the world leader in the provision of maritime education and training;
- Promote a liberalised trading regime that delivers maximum benefit for our maritime sector;
- Support the continued multi-billion-pound commercial investment in maritime infrastructure that makes the UK a globally attractive destination for all maritime business;
- Strengthen and enhance the reputation as a leading country in the International Maritime Organization (IMO), International Labour Organization (ILO) and all international fora working with like-minded countries to take action;
- Promote UK-wide leading maritime cluster offer with government, the maritime sector and academia working in partnership to make the UK the place to do maritime business;
- Showcase the UK maritime offer to the world, promoting all parts of the maritime sector including shipping, services, ports, engineering and leisure marine, and through London International Shipping Week (LISW) maintaining its status as the leading global maritime event.

3.4 Rationale for intervention

This section outlines the **rationale for government intervention** in the smart shipping sector, identifying the **benefits of investment** as well as possible issues which policymakers may encounter.

According to economic theory, intervention can be welfare-improving when markets are not operating efficiently due to market failure(s). Several market failures have been identified in the

[27] Department for Transport (2019). Maritime 2050. Navigating the Future.

maritime sector including barriers to entry, coordination failures, imperfect information and externalities which inhibit the optimal level of investment.

The rationale for intervention can be split into 2 subcategories:

- The **economic rationale** for market intervention aims to address the market inefficiencies using fiscal and/or regulatory intervention. When a market failure[28] is identified, it is the role of the government to combat this by intervening in the market to raise the social surplus[29] and the general economic fairness. Intervention should lead to the optimal allocation of resources such that it is impossible to improve the situation of one person without imposing a cost on another. However, government intervention could result in unintended consequences, further inefficiencies, and a misallocation of resources. We analyse those in section 3.5);
- **Policy objectives** such as economic growth, increasing employment, reducing carbon emissions, improving safety, increasing social capital, improving security, supporting SMEs and the UKs political objectives. These objectives are addressed in the following subsections.

3.4.1 Efficiency

Investing in maritime technology provides opportunities for the shipping sector to become more efficient and cost effective in their operations and drive economic growth in the wider economy. Technologies being implemented in smart ports such as blockchain[30], Artificial Intelligence (AI)[31], drones[32] and Internet of Things (IoT)[33] enable ports to digitalise operations and increase productivity.

There are several indicators which can measure port efficiency, the turnaround time of ships, rate of loading/unloading cargo, quality of the service to inland transport and time taken to process people[34]. The time ships spend at port depends on the operational efficiency of several inputs including ease of berthing, pace at providing ship supplies and efficiency in handling cargo. The table below from the United Nations Conference on Trade and Development (UNCTAD) details the median number of days spent in port according to the number of port calls. As shown in the table below, time spent in port in the UK is greater than the world median in each market segment.

The largest ship to port in the UK in 2019 was 233,000 gross tonnes (gt), the same as China, Germany, and the Netherlands. The average size of a vessel entering a port in China was 2.3 times larger in terms of gt than in the UK. Additionally, Singapore, France and the United States all handled larger

[28] A market failure is defined as inefficient allocation of resources.
[29] Social surplus is the benefit derived from a good or service above what the consumer is willing to pay for that good or service and what a producer is willing to sell a good for. For example, if a consumer pays less that what they were willing to pay for a good or service a consumer surplus is produced. Similarly, if a producer sells a good or service at a higher price that they would have accepted a producer surplus is produced. Social surplus is the combination of consumer surplus and producer surplus.
[30] Blockchain is a digital record of transactions. Transactions are called blocks and linked together in a single list called a chain. Blockchain is spread across many computers which makes it almost impossible to manipulate transactions.
[31] Artificial intelligence (AI) is the ability for a computer to complete tasks commonly associated intelligent beings, such as learning from experience, problem solving, and pattern recognition.
[32] Drones are unmanned aerial vehicle or aircraft systems.
[33] Internet of Things is a network of physical objects embedded with software, sensors and other technology enabling the objects to connect and share data with other devices via the internet.
[34] Comtois, C. and Slack, B. (2019). Ship Turnaround Times in Port: Comparative Analysis of Ocean Container Carriers.

ships than the UK on average. The total number of containers handled by UK ports was lower in all countries apart from Norway and France[35].

Table 5 Median days spent in port by number of port calls and cargo

Economy	Number of port calls	Liquid bulk carriers	Dry bulk carriers	Container ships	Break bulk carriers	Liquefied natural gas carriers	Liquefied petroleum gas carriers
China	205,448	1.1	2	0.62	1.17	1.21	1
Japan	180,400	0.31	0.9	0.35	1.12	0.99	0.32
Netherlands	100,343	0.49	0.84	0.78	0.4	1.3	0.94
United States	72,485	1.64	1.84	1	1.79	1.28	2.03
Singapore	60,712	0.6	0.12	0.77	0.65	2.22	1.12
United Kingdom	58,203	1.06	2.73	0.73	1.46	1.43	1.08
Germany	50,264	0.36	2.48	0.79	0.5	..	0.75
Norway	49,339	0.61	0.87	0.33	0.34	0.32	0.75
France	24,677	1.06	3.14	0.75	1.5	1.2	1.07
World total	1,884,818	0.94	2.05	0.7	1.11	1.11	1.02

Note: Ships of 1,000 gross tonnes and above, not including passenger ships. Roll-on roll-off vessels are included for total number of port calls but not for time spent in ports. Ports with fewer than five calls of this vessel type in **2018** are not included. Complete table of all countries. UNCTAD data was used to be able to compare UK data to that of other countries.
Source: UNCTAD secretariat calculations, based on data from Marine Traffic.

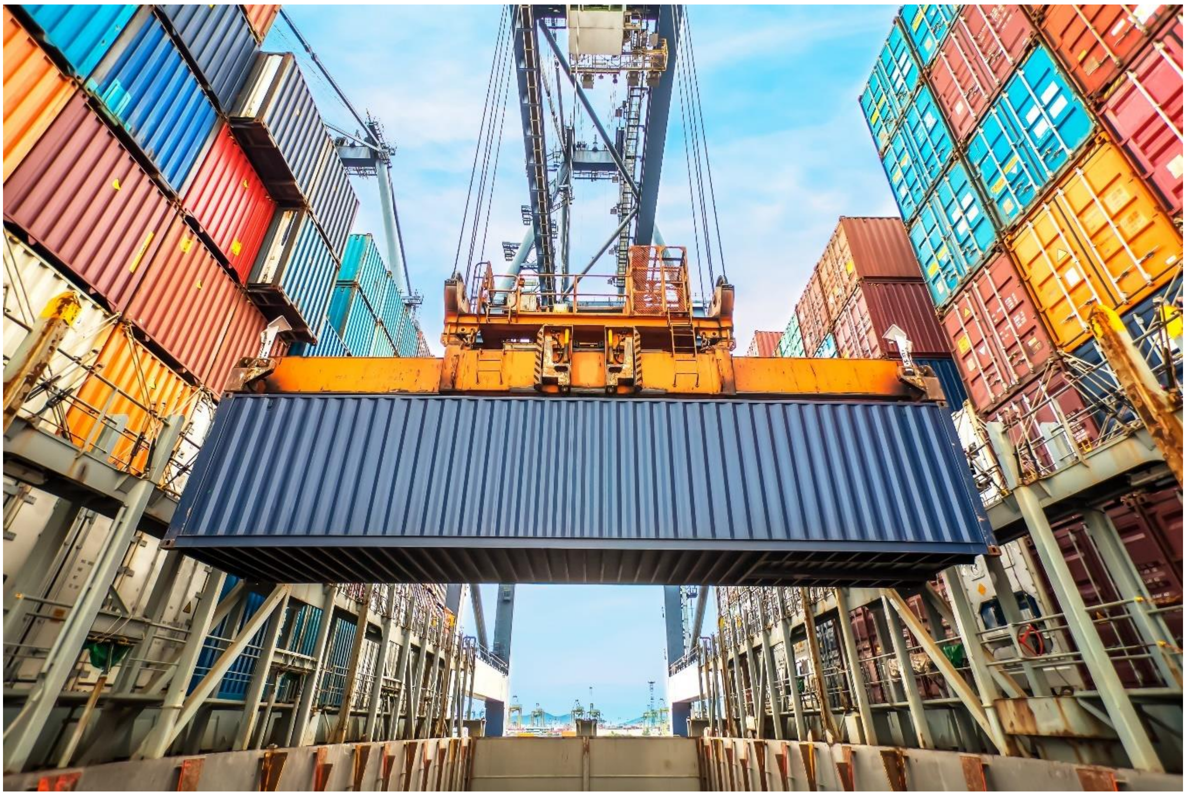
According to UNCTAD (2020), international maritime trade is expected to grow at an average annual rate of 3.5% over the 2019-2024 period, driven by growth in containerized, dry bulk and gas cargo[36]. In the UK, freight traffic in the shipping sector is projected to grow by 3.5% over the same period[37]. The growth in volume of trade as well as the size of container ships[38] is likely to put increasing pressure on turnaround times for ports (assuming no further efficiency or supply increases).

Smart ports are defined as ports that use advanced technologies to increase efficiency and reduce turnaround times in port. Technology is currently being used to optimise berthing, enabling ports to streamline traffic, optimise workflow and efficiently use limited space. This increases capacity of ports without the need to find additional land, which is costly and environmentally damaging.

Box 1 Black boxes in Valencia

The use of monitoring systems in smart ports could present opportunities to enhance cargo handling. In the port of Valencia, a network of 'black boxes' were installed on cranes, straddle carriers, trucks and forklifts.[39] The system collects and transmits real time energy and operating status, enabling terminal staff to identify operating bottlenecks and take appropriate steps to ensure machinery is working efficiently in real time.[40] The prototype's developer estimates operating costs could be reduced by up to 10% by reducing equipment idle time and minimising energy use. Additionally, drones can be used for stock measurement reducing the time spent on counting inventory and resulting in more accurate information.[41]

[35] UNCTAD data
[36] UNCTAD (2020). Review of Maritime Transport 2019.
[37] Department for Transport (2019). UK Port Freight Traffic 2019 Forecasts.
[38] International Transport Forum (2015). The Impact of Mega-Ships Case-Specific Policy Analysis.
[39] Ship Technology (2018). Smart ports: increasing efficiency and cutting costs.
[40] Sea Terminals (n.d.). SEA Terminals.
[41] On the MoS Way. (2019). Blue Innovation – Drones in Port Operations.



Credit: MOLPIX/Shutterstock.com

The smart shipping technologies outlined in section 2.3 can help bring further efficiency gains, for example:

- **Blockchain** – Reducing cargo handling time not only relies on moving cargo more efficiently, but also processing customs information and payments in an efficient manner. India has aimed to make this process more efficient through the Port Community System (PCS). The cost of documentation required to process and administer goods is estimated to represent on average one fifth of the cost of transporting goods.[42] During the CoVID-19 pandemic, MSC Mediterranean Shipping Company accelerated its efforts to introduce Electronic Bills of Landing (e-BL) with selected shippers in India as documents could not be delivered due to quarantine measures[43]. The World Economic Forum estimates that blockchain could boost global trade by US$1 trillion globally with small and medium-sized enterprises (SMEs) and emerging markets being the main beneficiaries;[44]
- **Internet of Things** – Monitoring of infrastructure can be streamlined by using smart sensors, enabling port authorities and terminal operators to better track, operate and maintain infrastructure. Sensors embedded in quay walls, road, railways, and bridges can transmit real time data about the conditions of berths and other infrastructure, reducing the need for inspections and enabling owners to schedule preventative maintenance more precisely;
- **Digitisation and Artificial Intelligence** – Technology in smart ports can monitor the status and health of infrastructure to ensure it operates efficiently, increase productivity by optimising cargo handling operations, improve traffic flow by coordinating vehicle

[42] Port of Rotterdam (2019). How Rotterdam is using blockchain to reinvent global trade.
[43] Smart Maritime Network. (2020). MSC steps up blockchain Bill of Lading efforts in India.
[44] World Economic Forum. (n.d.). Blockchain set to increase global trade by US$1 trillion.

movement between ports and cargo destinations, streamline customs processing through the digitisation of documents, increase security by using early warning systems and monitor and reduce energy consumption and overall environmental impact of operations. Several stakeholders benefit from these enhanced operations, namely, port authorities and operators, terminal operators, shipping lines, logistics companies, cargo owners, rail operators, barge operators and consumers. These stakeholders also benefit from a reduction in the cost of port and terminal operations;

Autonomous vessels have the potential to reduce operating costs in the shipping sector. It is estimated that the present value of the cost of owning an autonomous vessel is US$4.3 million lower than a manned ship over a 25-year period due to savings on fuel consumption, crew supplies and salaries[45]. However, these savings are reduced by the upfront cost of development and the setting up of onshore operations to monitor fleet movements. Ethical considerations will also need to be addressed in the development of autonomous vessels. When autonomous vessels are put in a position to make a decision where all options have a bad outcome it is important to know how the machine decides on which option to choose. Government alongside relevant organisations should be involved on how autonomous vessels are programmed to make decisions. Finally, existing international conventions were created under the assumption that a crew would be on-board, so conventions would need to be updated to reflect the presence of autonomous vessels.

Interviews stressed that one key area for growth or improvement of the UK smart shipping sector is to place greater emphasis on the funding and support for **scaling up**. Many hugely innovative ideas are emerging and progressing at the lower TRL of smart shipping, but the sector faces greater challenges in accessing the resources to commercialise in a highly competitive global market. This is especially important when considering the larger investments being seen in other parts of the world and from larger foreign companies with more resources (e.g. Kongsberg).

A (similar) theme emerged from interviews that “penny packets” of short-term loans, grants, and parcels of R&D support were inefficient. SMEs invest a lot of efforts and repeatedly apply for time-limited support diluting their “front line” efforts. It is a burden, and in some cases a barrier - for example, if a grant is available for 6 months or a year, and a project is estimated to consume 2 years, organisations are less likely to embark on the work knowing that funding will run out at the half way mark. If the report identifies over 200 organisations involved in “Smart” maritime work, and each has 0.5FTE involved in R&D, then many employees’ time is occupied looking for support funding externally.

Supporting **the scaling up of UK smart shipping initiatives** will also help to safeguard against start-ups being bought up by foreign entities just as they start to return normal profits i.e. break-even. It is also important to recognise that there are many mature technologies such as sensors (particularly for decarbonisation) that can be used in the smart shipping sector, but they lack informed business cases. Government investment and encouragement of cross-sector collaboration could help, as could initiatives to make the smart shipping sector **more transparent and accessible** to new market entrants (such as the provision of a directory listing smart shipping technology companies as discussed in Section 3.5.1).

[45] Kretschmann, L., Burmeister, H. and Jahn, C. (2017). Analyzing the economic benefit of unmanned autonomous ships: An exploratory cost-comparison between an autonomous and a conventional bulk carrier. *Research in Transportation Business & Management*.

3.4.2 Employment

Technological transformation in the maritime sector has the potential to radically change and disrupt the type and nature of work within the maritime industry. Investment in maritime technology could create new jobs within the sector and enable individuals to generate additional income. Digitalisation also presents challenges for policymakers surrounding the uncertainty of employment outcomes in the future.

Technology reduces the need for certain jobs, thus replacing labour that is currently employed. For example, according to the Office for National Statistics (ONS), **27,000 jobs** in the water transport sector are **at risk** of automation. At the same time, technology also creates new types of employment, to which labour is better suited than capital[46]. As infrastructure in ports need to be updated with 'smart' technology and autonomous ships need to be built. Smart shipping could thus provide employment in regions with the highest unemployment in the UK (North East, Yorkshire and The Humber).

The overall net impact on employment will depend on which of the two effects will dominate. Comprehensive evidence on which effect is stronger is currently limited. However, recent evidence by Autor and Salomons[47] - using data on 28 industries for 18 OECD countries since 1970 - suggests that automation has *not* been employment-displacing, although it has reduced labour's share in value-added.

Indirect and induced employment is another benefit of investing in smart shipping technology. In 2017, 177,000 jobs were supported by the Marine Scientific and Engineering industry (Cebr ,2019)[48]. Of those 177,000 jobs, 61,000 were through indirect employment (in the supply chain) and 34,000 jobs were induced employment (jobs generated in the wider economy due to spending by direct and indirect employees). Moreover, estimates by the Government Office for Sciences[49] suggest that the UK 'ocean economy' more widely employs more than 500,000 people across the marine tourism; maritime business services; fishing & fish processing; marine aquaculture; offshore oil & gas; offshore renewables; ports; shipbuilding & repairs; and, the shipping sectors. Further investment into the Marine Scientific and Engineering industry could have a spin off effect on the wider economy.

Box 2 Coastal 5G

A 5G high-speed mobile data network will be installed off the coast of Plymouth after receiving a £1.8 million investment. Plymouth's Marine Business Technology Centre (MBTC) has been awarded the grant from the Heart of the South West Local Enterprise Partnership's (HotSW LEP) Growth Deal Digital Extension 2020 programme. The funding will be used to build a modern communication system as part of the MBTC's Smart Sound Plymouth testing and proving ground, known as Smart Sound Connect. The project will create 100 jobs and put the city at the forefront of marine technology innovation[50].

While new jobs will be created, *end of work* scenarios due to the obsolesce of tasks through automation may present problems to policymakers. The changing nature of jobs will transform the skills needed in the maritime sector increasing demand for individuals with information technology

[46] UK Commission for Employment and Skills (2020). The Future of Work Jobs and Skills In 2030.
[47] Autor, D. and Salomons, A. (2018). Is Automation Labor-Displacing? Productivity Growth, Employment, and the Labor Share. BPEA Conference Drafts, March 8–9, 2018
[48] Cebr (2019). The economic contribution of the UK Marine Engineering and Scientific industry.
[49] Government Office for Sciences (2018). Foresight Future of the Sea. A Report from the Government Chief Scientific Adviser.
[50] Telford, W. (2020). Marine tech project set to create 100 jobs after £1.8m investment. Business Live.

knowledge and skills. New entrants into the seafarer role will need advanced technology skills as well as knowledge on how to operate vessels both manually and alongside the new technology with which the vessel is equipped. This change in job scope could further exacerbate shortages of STEM graduates, drone pilots and computer programmers[51]. A lack of workers with the appropriate skills is cited by senior managers of UK businesses in the maritime engineering sector as one of the factors holding back growth[52]. However, it should be noted that there is also evidence to the contrary; i.e. that UK workers are overqualified for their jobs[53].

3.4.3 Environment

The global maritime sector is under pressure to reduce pollution created by the shipping industry. Ports are increasingly expected to align performance with sustainability goals and shipping is being scrutinized to reduce its carbon footprint. New regulations such as the IMO 2020 sulphur limit have been introduced to increase the environmental sustainability of shipping[54]. The new regulations mandate a maximum sulphur content of 0.5% in marine fuels. Global Port State Control (PSC) authorities are responsible for enforcing IMO 2020 presenting authorities with challenges on how best to do so.

Technology is one possible solution that could enable the maritime sector to reach its sustainability goals. Streamlining logistics, using e-noses[55] to detect toxins, deploying sulphur sniffing drones and appointment systems to reduce port traffic are all contributing to the reduction in greenhouse gasses and increasingly sustainable operations.

Traffic congestion can have a significant negative impact on the environment. Congestion on roads increases fuel consumption, which leads to increases in greenhouse gas emissions, outdoor air pollution and poor air quality[56]. Ships being moored at ports can also increase the burden on the local community such as noise pollution. Smart ports can improve the flow of the logistic chain transporting cargo between ports and their final destinations. The introduction of appointment systems which lets logistic carriers reserve specific times when picking up or dropping off shipments can improve traffic flow. Time slots can decrease turnaround times and minimise congestion, which contributes to poor air quality and the inefficient use of worker's time.

Unused shipping container space acts as both a contributor to carbon emission and a driver of rising costs in shipping. Currently around 100 million shipping containers cross the sea almost empty, producing 280 million tons of carbon emissions and reducing revenue by US$25 billion per year. Blockchain is now being used to buy and sell space in shipping containers, lowering the number of empty containers at sea, reducing the cost for exporters and reducing carbon emissions.[57] While 'traditional' blockchains use significant amounts of energy themselves, other secure-ledger architectures aiming to mitigate this problem have been developed (though these may bring other trade-offs)[58].

[51] Ball, C. (2019). Skills shortages in the UK.
[52] Society of Maritime Industries (2019b). Maritime Autonomous Systems Survey 2018.
[53] For example: CIPD (2014). OVER-SKILLED AND UNDERUSED. Investigating the untapped potential of UK skills.
[54] IMO (2020). Sulphur 2020 – Cutting Sulphur Oxide Emissions.
[55] E-noses are electronic noses which identify odors by detecting the chemical compound of gasses using an array of sensors monitored by pattern recognition software.
[56] Bharadwaj, S., Ballare, S., Rohit and Chandel, M.K. (2017). Impact of congestion on greenhouse gas emissions for road transport in Mumbai metropolitan region. Transportation Research Procedia, 25, pp.3538–3551.
[57] World Economic Forum. (n.d.). How can blockchain can save shipping carbon emissions.
[58] A discussion of the advantages and disadvantages of different ledger architectures is beyond the scope of this study. Further discussion on this topic can be found in: Sedlemeir, J. et. al. (2020). The Energy Consumption of Blockchain Technology: Beyond Myth.

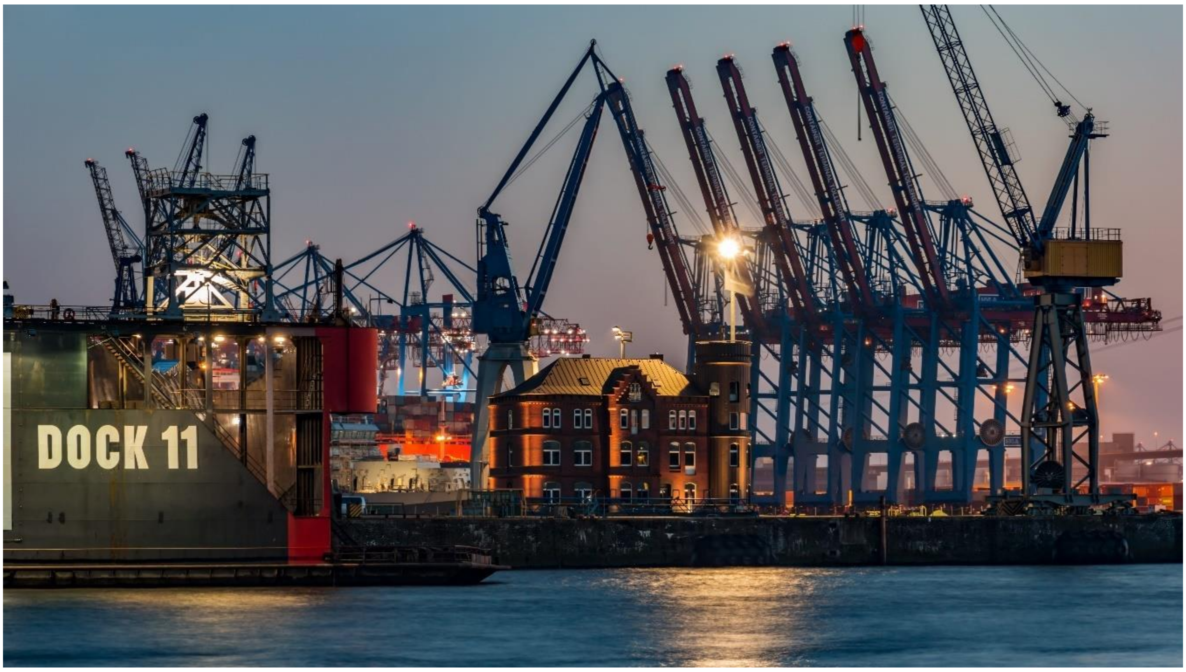
The use of lighting in ports is essential for the safety and security of port operations. Lighting enables individuals to navigate along jetties, docks, and terminals. Smart port technology can reduce greenhouse gasses and light pollution by using smart illumination systems. Smart illumination systems are dynamic lighting solutions that light up areas only when vehicles are in close vicinity. Installed at the ports of Valencia, this technology is said to have cut energy consumption by 80% according to Boston Consulting Group (BCG).

Ports around the globe are implementing new technologies, such as drones, to assist in the enforcement of this new regulation as well as capture data on port emissions. The Danish Maritime Authority (DMA) conducted its first 'sulphur mission' in April 2019 and announced in July 2020 that a new sulphur-sniffing drone will be tested in the airspace above the Great Belt over the next four months. These drones fly into ships' exhaust gas plumes and register the sulphur content in the ship's fuel. This data is then immediately made available to the Danish Environmental Protection Agency who can take action if a ship is emitting too much sulphur.[59]

The sector is not only implementing technology to abide by regulation but also to improve air quality and to respond to dangerous emissions.

Autonomous ships allow for a more efficient use of space when designing ships. Autonomous vessels can also save fuel and reduce carbon emissions by reducing their travel speed. Rødseth and Burmeister (2012) report that a transit speed reduction from 16 to 11 knots on a journey from Porto de Tubarao to Hamburg, should reduce fuel consumption by about 54% and thus avoid about 1,000 tons of CO2 emissions[60]. Technology also enables ships to be fuelled by more sustainable sources of energy. AutoNaut developed an unmanned vessel propelled by the motion of the waves and has shown the ability to operate for weeks on end without the need for carbon-based fuels. Sensors on-board the vessel collecting data are powered by solar energy. Scaling up this technology could greatly reduce the maritime sectors reliance on sulphur-based fuels. However, it is worth noting that the AutoNaut vessels are very small and would require significant scaling up to be able to support full size cargo vessels.

[59] www.dma.dk. (n.d.). New sulphur-sniffing drone patrols above the Great Belt.
[60] Rødseth, Ø.J. and Burmeister, H.C., 2012. Developments toward the unmanned ship. In Proceedings of International Symposium Information on Ships–ISIS (Vol. 201, pp. 30-31).



Port of Hamburg. Source: Pxfuel

Box 3 Environmental case studies

The **Port of Hamburg** is reducing the number of empty truck journeys through the development of a "virtual depot" to optimise the movement of empty containers between packing companies. When a container comes into port the containers are emptied and then filled by a packing company. If there are excess containers, they are then often moved to an empty-container depot. The cloud-based virtual depot system informs participating operators which containers are to be delivered to the empty-container depot. A packing company can then request these containers directly, which results in no unnecessary empty trips to the depot, less greenhouse gas emissions, better air quality and less burden on heavily used roads. As of December 2017, the virtual depot resulted in 4,000 fewer truck trips in the port[61].

The **Port of Rotterdam** uses a network of 'e-noses' (electronic noses) to detect changes in air composition allowing companies, authorities, and the Environmental Protection Agency to response faster to unpleasant or dangerous emissions. There are 250 e-noses in the port and two patrol vessels are also equipped with e-noses. These sensors register changes in the composition of the air and transmit the information via a wireless connection to a central server. The control room then detects the cause of any changes by deploying visits to the location. Precautions can then be taken quickly if the emissions are harmful.[62]

The **Port of Hamburg** is also becoming more efficient by using an intermodal PortTraffic centre that forms the basis for managing the flow of traffic. Anyone driving around the port receives personalised navigation information regarding traffic in and around the port, access to parking and infrastructure information, information on the closures of the moveable bridges, as well as the latest information on important operations. The data collection not only reduces carbon emission and increases efficiencies, it also presents opportunities to ports to sell this data to logistics companies trying to optimise their workflow or commodities traders trying to get information on what to trade.

[61] Hamburg Port Authority (HPA) (2018). Fewer Trucks running empty in the Port – HPA hands Virtual Depot Project over to new Operator.
[62] Port of Rotterdam (n.d.). E-noses for a safe port.

Projections of environmental value are becoming more commonplace within the autonomous shipping sector. For example, Norwegian grocery distributor ASKO's two autonomous, all electric freight ferries on order at India's Cochin Shipyard are estimated to replace 2 million kilometres of truck transport, **saving 5,000 tonnes of CO2 every year**. Norwegian government agency ENOVA is providing NOK 119 million (about US$14 million) in support for the project, including the required port infrastructure, in line with its commitments to reduce emissions and transfer transport from road to the sea where feasible.

3.4.4 Safety and social capital

Maritime workers face a far higher risk of fatality than the average worker[63]. Data published by the Marine Accident Investigation Branch shows that, in 2018, 1,227 accidents, involving 1,339 vessels, were reported to UK vessels or in UK coastal waters[64]. Investment in technology has the potential to improve the safety conditions within this sector. Autonomy for instance, reduces the need for crew and therefore the number of people at risk.

Technology could also contribute to an increase in social capital[65] as seafarers get to spend more time onshore with their friends and family. Human error due to fatigue or bad judgement is one of the biggest causes of fatalities on ships. Between 2011 and 2018, 65.8% of accidents were attributed to human action with shipboard operation being the main contributor[66]. However, the increasing use of technology on-board vessels enables machines to interact and act with more independence which provides the possibility of greater safety in terms of collision avoidance and improved visibility (e.g. under bad weather conditions). Increasing the level of information gathering and communication technology on ships using sensors and AI could enable individuals manning vessels to make **better informed decisions** and allow better coordination between ships. More advanced information systems could lead to safer transit through dangers such as more difficult conditions, e.g. narrow straits, storms, or piracy.

Day to day operations, such as inspecting equipment in ports, can put maritime workers at risk. Drones are increasingly being used as a low-cost means of inspecting hard-to-access navigation markers, equipment, patrolling waterways for oil spills, checking on clean-up efforts and being deployed in emergencies. Drones limit the need for employees to inspect potentially dangerous areas, making the port safer and operations timelier and more cost-efficient.

Inspection of offshore infrastructure, such as oil and gas pipelines or wind farms, is imperative to the safe operations of offshore operating environments. The marine oil and gas industry have already noted the efficiency gains from remote operated vehicles (ROV). ROVs have reduced the number of vehicles and time needed to conduct a survey, reduced cost as well as increased safety. BP for instance, aims to have 100% of their subsea inspections performed using marine autonomous systems (MAS) by 2025.

[63] Roberts, S., Nielsen, D., Kotowski, A. and Jaremin, B., 2014. Fatal accidents and injuries among merchant seafarers worldwide. Occupational Medicine, 64(4), pp.259-266.
[64] Marine Accident Investigation Branch (2019). Annual Report 2018.
[65] Social capital is defined by the OECD as "networks together with shared norms, values and understandings that facilitate co-operation within or among groups". They go on to define networks as "real-world links between groups or individuals such as friends and family networks."
[66]The data includes ships flying a flag of an EU Member State, accidents in territorial sea and internal waters of Member States or wherever there are interests of Member States involved, as reported in EMCIP. [EMSA (2020). Annual Overview Of Marine Casualties And Incidents 2019.

As ROVs still require the support of a manned vessel, Maritime Autonomous Surface Ships (MASS) could offer further efficiency gains in pipeline inspection. Shell and BP have been trailing the use of MASS while Equinor completed a pipeline survey in September 2019 off the east coast of England and north coast of Germany.[67]

While artificial intelligence (AI), big data and automation have the potential to transform the maritime industry, they do not guarantee increased safety and may in fact contribute to accidents. Automation creates new types of errors, introduces cognitive biases which can lead to poor decision making and decreased vigilance amongst crew[68]. A study analysing accident reports issued by Marine Accidents Investigation Branch from 2012 to 2014 shows that 31% of marine accidents are associated with technology[69].

While the systems may be developed by software engineers, input from the maritime sector is imperative for the safety of workers when creating this new technology. The equipment design must be developed in the context of the working environment, **fitting the needs of seafarers**, and fully taking into consideration under what circumstances the technology will be used. In addition, it is imperative that workers have the right skills and training on new technologies to minimise potential errors and risks.

Seafarers on shipping vessels spend between four and six months at sea on average[70], leaving their family and friends onshore while they work 10 to 12-hour days. Autonomous vessels can reduce the negative social impact of shipping by reducing the number of personnel at sea, instead having land-based employees controlling ships. Improvements in communication technology may also enable seafarers to speak to their family and friends more often increasing their quality of life.

3.4.5 Security

Ports are an integral link in the supply chain and are sometimes categorised as critical national infrastructure, but the maritime sector can be an attractive target for criminals who engage in theft, smuggling and drug trafficking. Thieves can break into containers, warehouses and ships berthed in port or in transit where vessels can be overrun by armed gangs[71]. There is also potential for undocumented migrants to enter a port and attempt to stowaway on ships, in containers or in trucks parked in the port area.

Port security must go beyond simply securing fencing to prevent people from accessing the port area. Technology is being implemented in ports across the globe to ensure they operate safely and securely. Drones can be used to survey the port perimeter, ensuring fences are secured and warehouse doors are closed. Drones are also being deployed to patrol waterways and detect drug smuggling as well as illegal border crossings[72]. The port of Boston uses 3D automated cargo inspection system that can detect, locate, and identify contraband at ports. The International Atomic Energy Agency launched a smartphone application to help inspectors scan containers for radioactive

[67] Maslin, E. (2020). Raising the Pipeline Inspection Game. Offshore Engineer Magazine.
[68] Parasuraman, R. and Manzey, D. (2010). Complacency and Bias in Human Use of Automation: An Attentional Integration. Human factors.
[69] Bielic, T., Hasanspahić, N. and Čulin, J. (2017). Preventing marine accidents caused by technology-induced human error. Pomorstvo.
[70] IMO (2020). FAQ On Crew Changes And Repatriation Of Seafarers.
[71] Port Technology International. (2019). Security for Ports of the Future.
[72] Oxford Research Group. (2016). Drones in the war on Drugs: From Surveillance to Smuggling.

materials. The Port of Seville is using the IoT to improve tracking and control of containers passing through.[73]

Ports have identified that combining IP Video Management Systems with other security technology such as access control, intercom, license plate recognition, perimeter intrusion detection, radar and vessel detection can improve security response and the effectiveness of security operations[74].

Companies in ports are responsible for both physical goods and valuable customer data. The International Ship and Port Facility Security Codes maritime regulation details minimum security standards for ships, ports and government agencies. This regulation does not include cyber threats to which smart ports will become increasingly susceptible. Increasing the level of technology and automation in the shipping industry could also create new risks and vulnerabilities. According to the Global Maritime Technology Trends 2030 report, the growth of software-based systems is anticipated to cause an increase in sophisticated malware, in addition to cyber threats. A cyber-attack could disrupt the shipping sector and cause losses in revenue to businesses. Additionally, software can have bugs which may not have been identified in the testing and piloting stages.

In light of the cyber risks faced by ports, the Institution of Engineering and Technology (IET), earlier this year, with help and support from the Department for Transport (DfT), the Defence Science and Technology Laboratory (Dstl) and the National Cyber Security Centre (NCSC) published updated cyber security guidance for ports[75].

3.4.6 Spillover effects

The development of smart shipping not only increases the efficiency of ports but may also cause spin-off effects for other inventions or applications in different sectors. According to a survey sent to senior managers of UK businesses in the maritime engineering sector, Maritime Autonomous Systems (MAS) companies are working in a wide range of applications including defence, oil & gas, marine science research, environmental monitoring, renewable energy, maritime security, deep sea mining, commercial shipping and underwater asset management.

Advancing technologies in the maritime sector may produce knowledge spillovers that could be utilised in other sectors of the economy. The ease of learning and exploiting available information can impact a firm’s decision to invest in R&D[76]. However, as R&D investment into the maritime sector increases, the level of knowledge available to all firms expands and enables other sectors to utilise this knowledge for their own benefit[77]. This knowledge may be transmitted by the movement of labour between sectors; knowledge exchange between workers via conferences, publications and informal exchanges at meetings or networking events[78]; cross-sector collaborations and diversification strategies for suppliers of technology[79].

[73] The port of Seville implemented IoT technology to improve the tracking and remote control of containers passing through the port, optimize rail traffic in the vicinity of the port and optimize traffic on the Guadalquivir River.
[74] Port Technology International. (2014). Unified security to protect critical port infrastructure.
[75] The Institution of Engineering and Technology (2020). Good Practice Guide. Cyber Security for Ports and Port Systems.
[76] Aghion, P. and Jaravel, X. (2015). Knowledge Spillovers, Innovation and Growth. The Economic Journal, 125(583), pp.533–573.
[77] It should be noted that the level of transmission depends on the transmission mechanism. For example, investment in proprietary R&D that is kept secret will yield lower spillover impacts than R&D that is subsequently shared with others, e.g. via publication.
[78] London Economics. (2018). Spillovers In the Space Sector.
[79] Nessie roject (2018). Cross-Sector Knowledge Transfer: North Sea Solutions For Innovation In Corrosion For Energy.

While, to our knowledge, no spillover estimates for the maritime sector exist, spillover effects are evidenced for a range of other sectors, giving an indication of the potential magnitude of maritime spillovers; for example:

- In the **space** sector, research by London Economics[80] (for the UK Space Agency) found that private benefits of R&D to innovators (i.e. ripple effects) appear to be approximately £3-4 in impact for each £1 of public expenditure, with the spillover impacts to the broader public being significantly larger.

Data collection creates the opportunity to generate new revenue streams. Real-time data access and information can enable other parties in the logistic chain to cut costs by sharing information on when ships are leaving ports as well as schedule updates, freight companies can better prepare for incoming vessels, delivery companies can collect cargo in a more timely manner and consumers will have more information on their shipments. New revenue streams could be created as ports could sell this data to third parties such as logistics companies.

3.4.7 Support for SMEs

Currently SMEs contribute 47% of revenue to the UK economy[81]. SMEs, especially digital start-ups, could foster innovation and develop maritime technology, generating employment and increasing productivity across the UK. In Germany, SMEs in the maritime industry are characterised by above average innovation activity when compared against other sectors and are attributed with increasing employment in the sector. The Ports of Rotterdam and Singapore are two of the major ports that have acquired or partnered with digital start-ups to implement smart technology into their ports. The maritime industry which was previously considered low-tech and labour intensive is modernising, enabling firms to be competitive independent of size[82].

Investment in smart shipping technology not only creates opportunities for SMEs within the maritime sector but also improves the competitiveness of SMEs outside of the maritime sector. A recent study conducted by Shipa Freight, an online platform which enables businesses to quote, book, pay and track freight online, noted 42% of SMEs globally[83] say that the costs of shipping internationally are too high, or they do not have an accurate picture of costs; 79% of those that export to Europe found it challenging to get started, and 67% of businesses that export to North America struggled to start exporting there[84]. Smart shipping technology will increase efficiencies and reduce costs of shipping. Additionally, accurate communication technology tracking shipments will enable SMEs to provide a greater level of service to their customers.

3.4.8 Political

Increasing investment in smart technology could help grow the UK's presence as a leading maritime nation, increasing the UK's maritime reputation internationally. A strong international standing in turn can act as a catalyst for further innovation, invention, enterprise and exporting of technology to other nations, enhances the UK's competitive advantage, and attracts foreign direct investment and talent to the UK.

[80] London Economics (2018). Spillovers in the space sector.
[81] UKRI (2016). Boosting UK productivity with SME growth - Economic and Social Research Council.
[82] Bass, Hans & Ernst-Siebert, Robert. (2007). SME in Germany's maritime industry: Innovation, internationalisation, and employment. Int. J. Globalisation and Small Business Int. J. Globalisation and Small Business.
[83] Shipa Freight surveyed a total of 800 SMEs from the UK, USA, Germany, Italy, India, Indonesia, China and UAE
[84] Shipa Freight (2019). Ship For Success: SMEs And International Trade.

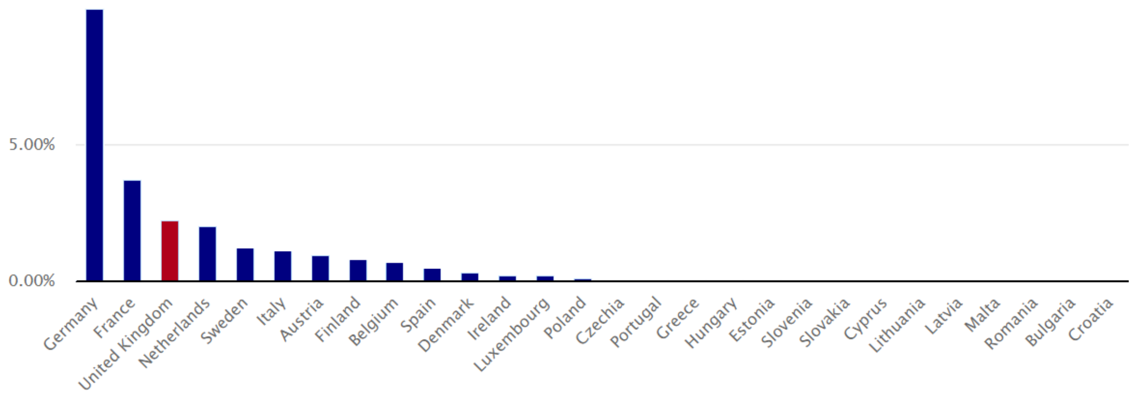
The UK's shipping industry is already performing well globally, with the UK in 10th position, as of Q2 2020, UNCTAD Liner Shipping Connectivity Index (LSCI). The LSCI measures the positions of countries and ports in global liner shipping networks. The index assess ports on five components i) the number of shipping lines servicing a country; ii) the size of the largest vessel used on these services (in Twenty-foot Equivalent Unit (TEU)); iii) the number of services connecting a country to the other countries; iv) the total number of vessels deployed in a country; v) the total capacity of those vessels (in TEU).

At the same time, the UK is 128th in the world in terms of growth since 2016, suggesting other nations are likely to be catching up. The UK can improve its position and growth in the liner shipping by increasing port efficiency and productivity, important factors which contribute to port selection. Increasing investment in technology and tapping into the opportunities which digitisation presents could enable UK ports to be more attractive. Leading ports across Europe such as Rotterdam have invested heavily in port community systems, port call optimization, automation, and other technologies. At the same time, investments in technology alone are unlikely to compensate for wider structural changes, for example due to the UK's exit from the EU, and geographical features.

The UK also performs relatively well in advanced technology innovation more generally, capturing the third highest share in global advanced technology patenting within Europe in 2017. However, this is nevertheless significantly lower than Germany suggesting that there is room for improvement. (Figure 12)

Within smart shipping innovation specifically, research undertaken for this study suggests that whilst there are pockets of innovation within the UK (e.g. the maritime military sector is trialling and using on-board innovations in electronic architectures, radar, combat systems and communications, and there are pockets of innovations, from smaller companies and universities) there are also significant market failures and barriers to entry. These are discussed in further detail in the next section.

Figure 12 European countries' advanced technology country share in global patenting (2017)

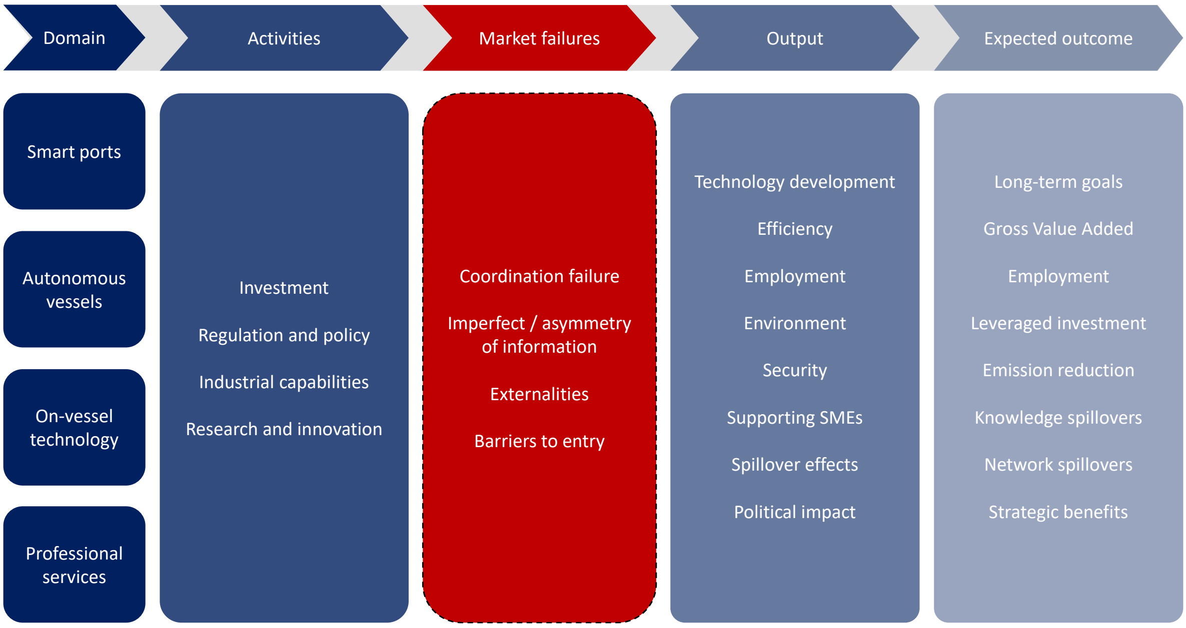


Note: Graph shows the share in global patenting across a range of advanced technologies for the UK compared to other European countries.
Source: European Commission: Advanced Technologies for Industry Data Dashboard

3.5 Identification of market failures or other barriers

A market failure occurs when resources are not allocated efficiently and/or equitably due to a failure in some market mechanism. The presence of a market failure results in the wasting of resources as well as the underconsumption of goods or services. Identification of specific market failures provides rationale for public sector intervention.

Figure 13 Rationale for intervention and identification of market failures



Source: London Economics analysis

3.5.1 Coordination failure

Market suppliers can save costs by cooperating with other market players on investment in information or via promotional activities for collective benefits. However, the existence of free-riding behaviour and the lack of mutual trust can impede the **coordination** of agents and the benefits from collective efforts. This may be true for maritime technology sector, as there are **many small parties** who contribute to a large supply chain[85]. Individual parties may only be incentivised to invest in projects where the benefits are realised by their own business thus **limiting spillover effects** benefitting the wider sector. This coordination failure inhibits investment and major changes in the maritime sector.

Interviewees highlighted that, whilst the UK maritime military sector is trialling and using on-board innovations in electronic architectures, radar, combat systems and communications, **the commercial shipping sector is 'off the pace' compared to other nations.** There are pockets of innovations, generally, from smaller companies and universities but there is no real trend in the direction of technology development for on-board systems for the commercial shipping fleet.

A consistent theme in interviews was that more needs to be done to tackle **a lack of joined-up thinking and working** to encourage the development and adoption of smart shipping technologies in the UK. This is seen as a key barrier, in contrast to the emerging landscape in places such as Finland and Singapore, that the government can do more to overcome.

There is broad agreement that there is a need for clarifying the state of the smart shipping industry within UK. There is an urgent need to create **a UK national directory listing smart shipping technology companies**, which should be free of use to commercial, research and development

[85] Glave, T., Joerss, M. and Saxon, S., (2014). The Hidden Opportunity In Container Shipping. mckinsey.com.

opportunities. This would be a rich ‘shop window’ for the UK smart shipping sector. The right level of detail, perhaps wrapped into a brokerage portal, might provide the global market and / or investors with a sound and detailed overview of the growing number of business opportunities available within the UK smart shipping sector. Of course, possible commercial or legal challenges and constraints (e.g. with regards to data protection) would need to be investigated further. However, it may be possible to mitigate these challenges by allowing maritime companies to self-register themselves in order to be featured on the register.

Such an endeavour may help the various stakeholders (especially new market entrants looking to break in) to understand where they sit within the smart shipping landscape, and identify where they may best target their efforts, and with whom they might most usefully partner.

3.5.2 Asymmetric and imperfect information

Asymmetric information is the situation where the information is uneven between the agents of a market. In this case, an agent has better information than other agents, allowing them to make better informed decisions and providing them with a competitive advantage over other agents.

In the case of maritime technology there is also **imperfect information** as high costs, long lead times, and uncertain return on investment create uncertainty around the future realised benefits of investing in developing shipping technologies. This in turn reduces the incentive for firms to develop new technologies[86] and may lead to an underinvestment in R&D. Moreover, high costs, long lead times, and uncertain returns also make it more difficult to obtain funding from ‘traditional’ institutional investors, thus creating barriers to entry (see Section 3.5.4).

3.5.3 Externalities

The price of a good or service is the mechanism that ensures that resources are allocated efficiently and the optimal quantity of the good or service is produced and consumed. For price mechanisms to work, the true value of the good or service must be priced in. However, some economic activities do not accurate price in the social cost or benefit of their activity.

An externality is a cost or benefit resulting from an economic transaction that is borne or received by parties not directly involved in the transaction. When externalities exist, producers are unable to accurately price their good or service as the costs or benefits of producing the good or service are consumed by parties not directly involved in the transaction. Therefore, in the presence of externalities, the market will not deliver the efficient quantity of the good or service. Smart shipping could have externalities which are not reflected in the price of the service, resulting in the market not delivering the efficient quantity of the service.

Positive externalities

- Market spillovers
    - Innovations can create new producer and consumer surpluses. Wherever the innovating organisation is not able to charge a price fully capturing all the benefits, these benefits will be transferred to those further down the supply chain.
- Network spillovers

[86] Katsomitros, A., 2020. The Shipping Industry Must Adapt If It Is To Survive In The Modern World.

    - Maritime technology could increase the value of other innovations. The economics of networks describes the market dynamics of situations where there are gains from more users on an operating system. Gains that are not immediately obvious to those producing the innovation can often be realised in interlinked markets.
- Environmental externalities
    - The use of smart shipping technologies could reduce the environmental impact of shipping owing to the efficiencies discussed above. Decision makers may not factor this into their purchase decision.

Negative externalities

- Machine integration
    - It is unclear how new technology will affect traditional port infrastructure as advanced technology may not be appropriate for current port infrastructure. For example, autonomous ships can be designed in a more efficient manner, enabling them to carry more cargo due to the lack of crew needed on-board. However, these ships must still fit into port infrastructure.
- Human interaction
    - There exists uncertainty surrounding how autonomous vessels and humans will interact. As technology develops there will be increased interaction between maritime employees and technology. Autonomous vessels could be problematic as it is uncertain how they will coordinate their movement with manned vessels. Humans may take more risks in the presence of autonomous vessels which could lead to more accidents or slower traffic flow[87].
- Environmental externalities
    - The carbon footprint over the lifetime of smart technologies may exceed that of traditional means, resulting in a net adverse effect on the climate.
    - The reduction of operational costs leading to cheaper prices for various goods would increase the demand and therefore the throughput of ships. This may compensate part of the carbon emission saved with greener technologies.
    - Environmental solutions may be subject to optimism bias and bare hidden costs. Fuel cells for instance highly rely on the provision of platinum which mines are often overexploited with carbon intensive technologies. Life cycle assessment of new technologies are widely recommended.

In the case of net positive externalities, the market failure results in underconsumption of the good relative to the social optimum. If the net effect is negative, the market failure results is overconsumption of the good.

3.5.4 Barriers to entry

The existence of barriers to entry can prevent firms from entering a profitable market. The maritime sector is characterised by large capital requirements, transition costs as well as complex operations delivered on a large scale. The inability for firms to enter the market because of this financial threshold could lead to reduced competition and innovation and higher prices for consumers. Recently, there has been a growth in vertical and horizontal market integration in the global

[87] Millard-Ball, A., 2018. Pedestrians, autonomous vehicles, and cities. Journal of planning education and research, 38(1), pp.6-12.

maritime transport sector[88], indicating a potential trend towards market shares being concentrated to a few businesses.

Large capital requirements may act as a barrier to entry in the marine technology sector. To compete in the market, entrants are required to invest a large amount of capital in both research and development as well as product development[89]. Firms may not have access to enough capital to establish themselves in the market providing incumbents with an advantage. Additionally, firms may find it hard to get financing from a third party due to the uncertainty of returns on maritime technology.

Transition costs within the maritime technology sector may be high as new technologies may not be compatible with existing systems in operation within the port. Additionally, bundling of services within operations reduces the ability for new players to enter the market[90]. If, for example, an incumbent has provided the terminal operating system, the towage and intermodal transport, it is difficult to switch one of those operations as it will affect the whole logistic chain.

The minimum efficient scale[91] for providing shipping services is large. In the case of smart ports, in order to provide a smart solution, technology must be integrated into the operations of the port. Due to the scale of port operations, the number of players and the complexity of this working environment, smaller firms may be prohibited from entering the market as they are unable to provide solutions on a sufficient scale.[92]

While appetite for smart shipping innovation is high, ports were considered to have **no or very little R&D budget**. As continental ports are generally publicly owned with access to low-cost capital, facilitating access to capital for private UK ports was deemed important if they are to be competitive in innovation terms. UK ports too have been relying on European grants and have long called for infrastructure investment to match EU grants post Brexit[93]. The UK Government has recently launched a £200 million port infrastructure fund for ports to build new border facilities as the Brexit transition period end draws closer[94]. However, this additional one-off funding must be placed in the context of the £600 million UK port operators invest annually[95]. Shortages in infrastructure funding, due to the loss of EU grants that have not yet been replaced by sovereign UK funding, only exacerbate the difficulties ports face in finding additional money for R&D investments.

Moreover, **access to funding is also a wider issue** with sectoral characteristics such as large capital requirements, transition costs as well as complex large-scale operations creating barriers to entry for maritime R&D. This is exacerbated as the levels of **upfront capital investment required and the risk involved in maritime R&D are high**, and loans may thus not be able to de-risk R&D investments enough to incentivise the desired levels of maritime R&D. Similarly, obtaining institutional funding for complex projects with large upfront capital requirements can also be challenge as the typical ten-year fund horizon of Venture Capitalists is often not well suited to such long-term projects and institutional investors are thus often not prepared to fund these investments. CoVID-19 creates

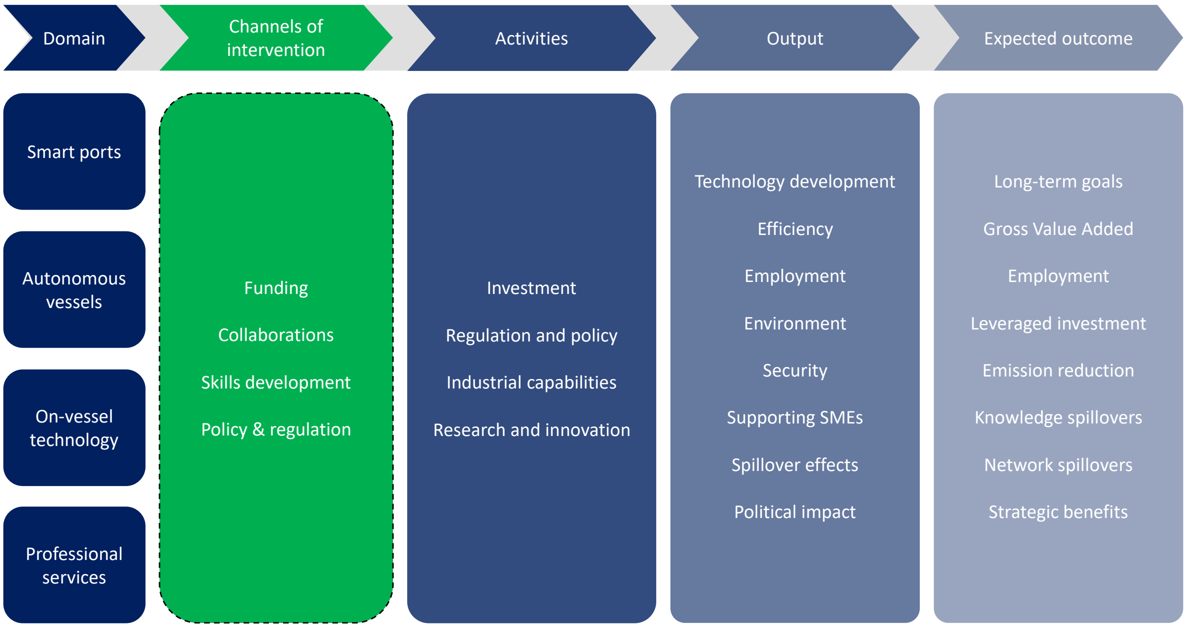
[88] UNCTAD (2019b). Review of maritime transport 2019.
[89] Port Technology International (2017). Successful Delivery Of Terminal Infrastructure.
[90] Acciaro, M. (2010). Bundling Strategies in Global Supply Chains.
[91] The minimum efficient scale is the minimum level of output a firm needs to produce so that the cost per unit of output can decrease no further with increasing scale, and may even start to rise. If the minimum efficient scale is large, firms must produce a high level of output relative to the total industry output to operate at productive efficiency and competitively in the market.
[92] Pallis, T. (2020). Chapter 4.4 Entry Barriers. Port Economics, Management and Policy.
[93] British Ports Association (2018). British ports call for infrastructure investment to match EU grants post-Brexit.
[94] Port Strategy (2020). GB£200M BREXIT PORT INFRASTRUCTURE FUND.
[95] Lloyd's List (2019). UK issues emergency port funding ahead of Brexit.

additional funding challenges, with one interviewee commenting that 'in the CoVID-19 era investment funding has dried up'.

3.6 Intervention options

Market failures discussed in the previous section mean that government interventions may be needed in order to facilitate research and development of marine technology. This section discusses four key areas at which the government could target interventions: Providing R&D funding and de-risking innovation investments; facilitating collaborations & partnerships; supporting education and skills development; and, providing policy and regulatory frameworks that foster innovation.

Figure 14 Identification of the channels of intervention



Source: London Economics analysis

3.6.1 Providing R&D funding and de-risking innovation investments

Investment in innovation can lead to returns for firms who undertake R&D and produce spillover effects as described in the previous section. However, the up-front capital required for R&D of marine technology and the risk involved in the projects means that accessing finance from private sources can be difficult. Government can offer fiscal incentives such as loans, grants, subsidies and taxes to incentivise private firms to conduct R&D or act as a guarantor in order to de-risk investments for private investors.

Evaluating which of these measures would best support innovation is not straightforward. In theory, grants should facilitate higher levels of R&D where the levels of capital investment required and the risk involved are high, as loans may not be able to de-risk R&D investments enough to incentivise R&D. At the same time, grants and tax reliefs may be more prone to abuse or fraud as evidenced by HMRC's recent crackdown on abuse of the R&D tax relief system. However, evaluating the impacts of R&D support is extremely complex, and little robust evidence on the impact of different forms of R&D support (such as grants vs. loans) exists. In practice, a healthy mix of complementary and different fiscal incentives may be needed. Therefore, the following options should be considered in a holistic approach to addressing R&D funding challenges and de-risking innovation investments.

Provision of R&D funding

One option is for the government to directly provide R&D funding for the development of new technologies, products or services that could grow the UK maritime sector, help the UK maintain international competitiveness and help meet UK strategic objectives. The most direct form of this would be for the government / Bank of England to directly provide loans at market or reduced rates to companies seeking to undertake maritime research and development. However, as the level of upfront capital investment and the risk involved in maritime R&D are high, loans may not be able to sufficiently de-risk R&D investments to incentivise the desired levels of maritime R&D.

The government could instead consider the creation of a targeted fund with the aim to facilitate maritime R&D investments. One example of this is **the Dutch National Fund for green investment**. The fund, launched on September 10th 2020, represents a total value of €20 billion and aims to improve the region's green infrastructure and to realise 10% extra economic growth for the Netherlands within the next ten years. It was welcomed by the CEO of the Port of Rotterdam Authority to boost climate change mitigation and economic development and employment.

For the maritime sector more specifically, the Netherlands have also implemented a Green Deal investing €5 million for studies into new technologies to make maritime transport sustainable. Similarly, the Green Shipping Guarantee (GSG) program has been established to engender greater investment in green technologies in European shipping companies. The program is intended to finance shipbuilding projects including new vessels, conversion and retrofitting of vessels that promote sustainable transport and environmental protection. The European Investment Bank has proposed to issue €750 million of financing with the total cost expected to reach €3 billion.

Creating a similar fund dedicated to long term projects, which could lower emission in ports and shipping could also be established in the UK. Such an initiative could help mitigate the environmental impact of the maritime sector, accelerate the implementation of green technologies, and contribute to the governments net zero emissions goal.

An alternative to such a green fund, could be the establishment of a **Maritime innovation fund**. Such a fund could target innovations which help the UK maintain international competitiveness, grow the UK maritime sector, create jobs and increase efficiency of the sector. The innovation fund could be also used by the government to call private firms to tender on projects which are most pertinent to UK ports.

Currently, the MarRI-UK initiative aided by the UK Department for Transport (DfT) supports the development of technological innovation to improve the services and operations of UK maritime. In July 2020, 11 maritime technology projects have been awarded £1.5m for developing innovative technology to help improve the services and operations of the UK maritime sector. However, this funding is only a fraction of what is invested by other maritime nations.

South Korea is investing US$132m over six years on an integrated government task force to develop and commercialise autonomous shipping technologies. The Ministry of Trade, Industry and Energy and the Ministry of Maritime Affairs and Fisheries will establish the task force at the state-run Korea Research Institute of Ships & Ocean Engineering in city of Daejeon[96].

[96] Splash247. (2020). Seoul sets aside US$132m to commercialise autonomous ship tech.

Tariffs and tax relief

Tax relief provides an alternative mechanism to incentive private firms to undertake R&D activities. The government already provides R&D reliefs to support companies that work on innovative projects in science and technology that seek to research or develop an advance in their field[97]. HMRC's most recent evaluation of the R&D tax credit scheme found that for each £1 of tax foregone, between £1.53 and £2.35 of R&D expenditure is stimulated[98].

In addition, to R&D tax relief, the government also operates freeports and tax-free zones around ports where normal tax and customs rules do not apply. Businesses operating inside these zones can manufacture goods using imports (and add value), before exporting again without facing the full tariffs or procedures[99].

However, despite existing schemes, high capital requirements and uncertain returns continue to act as a barrier to research and development in the maritime sector. Additional tax relief targeted at mitigating the issues faced by marine technology R&D could act as an incentive for much needed investment. Similarly, tariffs on outdated machinery combined with grants and/or tax relief on updating marine technology could incentivise firms to invest more into becoming more technologically advanced.

Tariffs on vessel emissions could generate funds for further R&D into green technology. The International Maritime Research Fund (IMRF) is a global fund that proposes to levy US$0.7 on each tonne of CO2 that ships emit (US$2.1 per tonne of fuel). The goal is to generate about US$5 billion in the next 10 years to fund research and development into carbon-free marine technologies that would help to reduce the carbon emissions in the sector. Similarly, as part of the European Green Deal, the European Commission is committed to including the maritime transport sector in its emissions trading system (ETS). Including shipping in ETS would generate about €4 billion per year whilst having a negligible impact on consumer prices[100].

De-risking investments

In addition to direct funding provision or tax incentives, the government could act as a **guarantor** on loans in order to de-risk investments for shipping firms that seek to invest in technology. Such a scheme exists in the Netherlands through its Nesec Shipping Debt Fund (NSDF). The Fund offers a state guarantee for SMEs to purchase new short sea vessels or make modifications to current vessels in order to meet ballast water requirements, limit sulphur emissions and other emissions.

The UK Government could provide similar **capital incentives** by providing specific funding for companies to acquire capital equipment. This funding could take the form of a government backed venture leasing model, with funding secured on the capital assets. Capital equipment could eventually be acquired by companies if they do well, while the government could recoup the assets if necessary. This reduces the risk to investors by mitigating the high upfront capital requirements and would therefore facilitate further R&D investment.

Another way to mitigate the risk of high upfront CAPEX costs of investments could be through **provision of pooled capital equipment**. Existing institutions such as catapults already provide

[97] Current guidance on claiming tax relief can be found on Gov.uk: HM Revenue & Customs (2020). Guidance. Claiming Research and Development tax reliefs.
[98] HM Revenue & Customs (2015). Evaluation of Research and Development Tax Credit.
[99] Institute for Government (2020). Trade: freeports and free zones.
[100] European Commission. (n.d.). Reducing emissions from the shipping sector.

capital equipment in other sectors (e.g. pilot manufacturing labs) that companies can use to develop proof of concept production pilots. The government could explore whether a similar model could also work to de-risk maritime R&D investments.

The government could also provide additional incentives for investors to invest, for example, by providing **matched funding** or mutual contribution funds i.e. where the government matches the funding by investors, under certain conditions. This reduces the high-risk of maritime R&D investments to private investors and thereby facilitates investments.

Supporting companies seeking to scale-up

In the maritime shipping sector, many hugely innovative ideas are emerging and progressing at the lower Technology Readiness Levels (TRL) of smart shipping, but the sector faces greater challenges in accessing the resources to commercialise in a highly competitive global market. This is especially important when considering the larger investments being seen in other parts of the world and from larger foreign companies with more resources.

Therefore, it is important to not forget about the challenges these companies will face once they have obtained first customers and are seeking to scale-up. Recent reports have examined the scale-up challenge. These include the "2019 Scale-up UK: Growing Businesses, Growing our Economy" study by Barclays and Cambridge Judge and Oxford Said business schools (2019) and the ScaleUp Institute's (2019) annual ScaleUp review.

Supporting the scaling up of UK smart shipping initiatives will also help to safeguard against start-ups being bought up by foreign entities just as they start to return useful profits. It is also important to recognise that there are many mature technologies, such as sensors (particularly for decarbonisation) that can be used in the smart shipping sector, but they lack informed business cases. Government investment and encouragement of cross-sector collaboration could help (see Section 3.6.2), as could initiatives to make the smart shipping sector more transparent and accessible to new market entrants.

3.6.2 Facilitating collaborations & partnerships

Another way to increase maritime research and development is through the facilitation of greater engagement and intra-industry collaboration between maritime companies, as well as collaborations and knowledge exchange with academia. Research collaborations can increase the exchange of ideas, speed up innovation, and reduce friction of technical diffusion[101].

Box 4 Examples of development networks

Many **autonomous vessel test beds and R&D centres** are being established globally, such as that established by the non-profit Nippon Foundation in Japan, which brings 40 local companies together – including owners, yards, equipment manufacturers – to trial autonomous ship voyages this year and next on five different ship types.

Eight leading maritime nations have recently formed a new network to encourage the development of Maritime Autonomous Surface Ships (MASS). Called **MASSPorts**, the network will address the challenges of making ports ready for autonomous shipping and involve the flag, coastal and port

[101] Ahuja, G., 2000. Collaboration networks, structural holes, and innovation: A longitudinal study. Administrative science quarterly, 45(3), pp.425-455.

authorities from China, Denmark, Finland, Japan, the Netherlands, Norway, Republic of Korea, and Singapore.

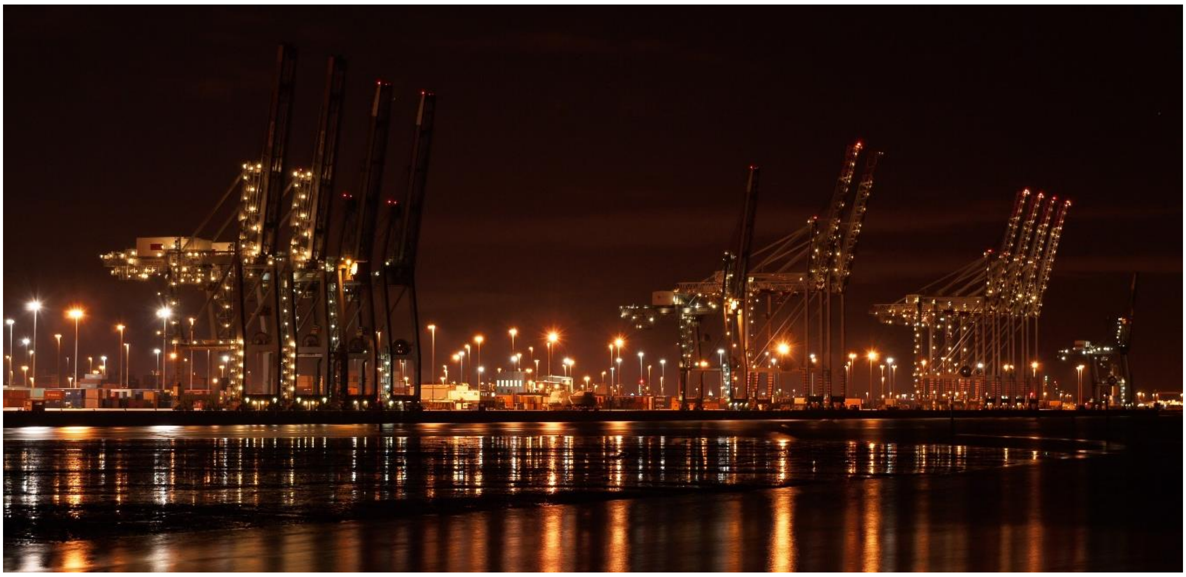
In the UK the most prominent example is **Innovate UK**, the UK's innovation agency. Innovate UK seeks to drive productivity and economic growth by supporting businesses to develop and realise the potential of new ideas, including those from the UK's world-class research base. Innovate UK is part of **UK Research and Innovation** (UKRI), a non-departmental public body funded by a grant-in-aid from the UK government**.** UKRI works with the government to invest over £7 billion a year in research and innovation by partnering with academia and industry.

Connecting and supporting future partners

The government could foster collaboration by providing grants for cross-sector projects or support research and innovation projects with strategic maritime partners.

In addition to connecting future partners, the government can **invest in providing supporting infrastructure** to facilitate collaboration. This could take the form of provision of **pooled capital equipment** (as highlighted in the funding section), **investments in technology** (such as collaboration software, online portals, intranet, etc.), **investment in physical locations** to facilitate collaboration (e.g. shared office space), as well as, **providing regulatory/legal incentives** to encourage collaboration (e.g. redesigning legal/contractual frameworks to incentivise collaboration, rewarding positive outcomes for join projects, strengthening/tweaking IP rights to encourage collaboration).

Utilising local enterprise zones / local growth hubs



Port of Southampton. Credit: Wikipedia

The establishment of new (or widening/refocusing of existing) **local university enterprise zones** or **local growth hubs** for businesses focused on maritime technology could also be a great way to support the industry. A recent example highlighting this approach is the Maritime UK Solent hub, launched by the **Solent Local Enterprise Partnership** to bring together the Solent's marine and maritime strengths and assets and champion the region as a globally significant maritime hub[102].

[102] Solent LEP webpage

Enterprise Zones are part of the government's wider Industrial Strategy to support businesses and enable local economic growth. The government has already launched 24 zones in 2012 and a further 24 new zones were created in 2016 and 2017[103]. They provide tax breaks and economic support for companies located in the zones. In addition, 38 Local Enterprise Partnerships (LEPs) already exist across England. LEPs are business led partnerships between local authorities and local private sector businesses aiming to drive economic growth and job creation, improve infrastructure and raise workforce skills within the local area[104].

Specific maritime enterprise zones or local growth partnerships could be created around existing pockets of expertise in order to develop maritime technology hubs, in the fashion of the Maritime UK Solent hub, which foster collaboration and bolster economic growth. Alternatively, existing schemes could be utilised to create an increased focus on maritime technologies, where feasible. Firms located in the enterprise zones could benefit from increased collaboration with universities, resulting in innovation and local economic growth.

Facilitate collaborations outside the maritime sector

Smart shipping technologies do not exist in isolation but are interdependent with advances in other technologies. For example, many smart shipping technologies rely on or will eventually provide new sources of information to feed into new advanced analytics capabilities. Again, the UK maritime sector has strong resources to draw on within this exponentially growing discipline. Many universities have established Big Data institutes and invested in necessary computing power; IBM has a strong presence in London; bodies such as the Open Data Institute and the Greater London Authorities' London Datastore are pushing for the release of datasets to complement proprietary data in order to provide customer value; bodies such as the UK Hydrographic Office are investing in platforms to make their data more accessible to maritime businesses.

It is important to recognise this interdependence and the added value that partners outside the maritime sector can bring to collaborations. Some promising testbed / collaboration initiatives – such as the **Situational Awareness Information National Technology Service** (SAINTS) – are beginning to show promise in this respect. SAINTS involves the Port of Berwick, Port of Blyth, Port of Sunderland, Teesport and the Port of Tyne and brings together experts from business, universities and the public sector to find ways of using artificial intelligence (AI) to harness data and develop digital solutions for smart ports. Government could explore whether similar projects could be facilitated, either through the channels discussed above or through **targeted measures encouraging collaboration with promising partners outside the maritime sector.**

3.6.3 Education and skills development

The importance of skills development to unlock the benefits of advanced technologies has been widely evidenced, with skills development rightly forming a key part of the government's own industrial strategy[105]. In the maritime sector, facilitating innovation and having advanced shipping technologies on hand is only one part of the story; **people with the right skills and an appreciation and understanding of smart shipping technologies are needed to make technology adoption a success and reap the maximum benefits from innovation**.

[103] UK Enterprises zones website and Universities enterprises zones.
[104] LEPs.
[105] HM Government (2021). Industrial Strategy. Plan for Growth

Identifying the future skills needed in the maritime sector and ensuring that training meets the needs of the sector is critical to ensure that the future workforce in the sector is well equipped to make the most of technological advances. Therefore, **investments in technological developments should be supplemented with efforts to understand, and facilitate development of, the future skills needed to support technology adoption**. As the government's Maritime 2050[106] strategy rightly highlights: the changing skills profile in the maritime sector presents an opportunity to build on the UK's strengths, by developing and expanding the UK's high-quality training programmes and upskilling the existing and future maritime workforce in order to be able to reap maximum benefits of advanced and emerging maritime technologies.

For regulators, this means continuing to take the skills challenge seriously and creating policies that are targeted at meeting the skills requirements of the future. It also means working with education providers to ensure the workforce has the skills needed to exploit the technologies of now and of the future. The UK is already home to universities and other educational institutions, such as the Warsash Maritime Academy and the Glasgow Maritime College, among others, that play a key role in maritime training.

At the same time, it is important that efforts are not solely focused on new entrants, but also to ensure that the existing workforce is able to keep pace with the changing skills requirements and is supported through targeted upskilling efforts. Here, the government should create policies that encourage upskilling, as well as work with education providers and maritime firms, to ensure the right offerings are available and encourage and support upskilling efforts.

3.6.4 Providing policy and regulatory frameworks that foster innovation

Regulation can both be a driver and a barrier to adoption. Lack of regulation and being too slow to adopt regulation can create uncertainty and hinder innovation. Creating the right regulatory frameworks that foster innovation can therefore be a driver that foster adoption and innovation. On the other hand, regulation can also create barriers to innovation, compliance costs and red tape hindering adoption and innovation. Government and regulators should therefore seek to create regulatory certainty while ensuring that they develop regulation that is conducive to innovation without creating additional barriers.

Continue to be a leader in the development of regulatory standards

The UK is already seen to be leading on the development of standards. For example, the Maritime UK Autonomous Systems Regulatory Working Group (MASRWG) has published Version 3 of the UK Industry Code of Practice on autonomous vessels with new sections on inland waterways and an enhanced section on the principles that should underpin the design, manufacture and operation of autonomous vessels. Leadership and collaboration are also offered through the Maritime Autonomous Systems Group Council, a specialist group set up and run through the Society of Maritime Industries. Moreover, the government has already put in a place a strategic ambition for the future of the maritime sector through its Maritime 2050 strategy[107].

The UK government was requested by many to put in place applicable legislation that allows the development and testing of smart ships / autonomous marine capabilities in UK waters for both UK industry and industries from other countries. The government is currently planning to introduce a domestic framework for autonomous vessels to enhance testing in UK waters and the Maritime and

[106] Department for Transport (2019). Maritime 2050. Navigating the Future
[107] Department for Transport (2019). Maritime 2050. Navigating the Future

Coastguard Agency is currently looking at what is needed to ensure the safety of these and other ships[108]. This is one concrete area where legislation can be used as an example of state practice to influence the international legal landscape in this area. The **government should continue this leadership tradition and work pro-actively with members of the maritime industry to create regulatory standards and frameworks that support rather than hinder their innovation efforts.**

Addressing a lack of joined up initiatives

A consistent theme in interviews was that more needs to be done to tackle a lack of joined-up thinking and working to encourage the development and adoption of smart shipping technologies in the UK. This is seen as a key barrier, in contrast to the emerging landscape in places such as Finland and Singapore, that the government can do more to unlock. One interviewee reported that DfT is doing quite well and should press on, and that most elements are working except joined-up investment.

It is also important to place the UK's smart shipping sector within the broader UK innovation landscape. Many related capabilities – or, in some cases, capabilities that have not yet considered the smart shipping sector as a viable market – are being developed at pace within and with support from Innovate UK, Silicon Roundabout and the network of government-sponsored Catapults.

In order to ensure that existing initiatives as well as future measures successfully address the challenges of the maritime sector, the **government should explore how existing institutions and government initiatives can be better joined** (both within the maritime sector and with broader existing measures) **up as well as how existing measures can be further promoted among the maritime community.**

[108] Department for Transport. (2021). Future of transport regulatory review: maritime autonomy and remote operations.

4 Economic model

The economic model tries to capture the essential metrics to evaluate the impact of government intervention. We divide these indicators into 3 main categories:

- **Industrial impacts** which include turnover, GVA, employment (full time equivalent);
- **Knowledge spillovers**; and
- **Externalities** which consider environmental impacts (e.g. GHG reduction, ecological impacts), and safety and security impacts.

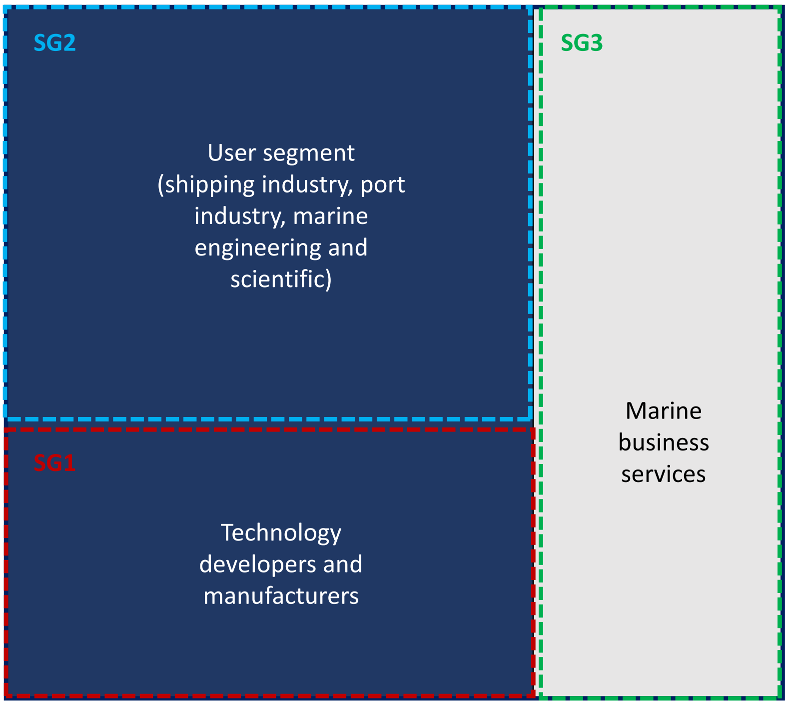
4.1 Scope

We follow the definition of the value chain made in chapter 2 and work with 3 **stakeholder groups**:

- **SG1:** The **technology providers** who invest in R&D to bring new technologies to the market;
- **SG2:** The **end users** (ports and shipping companies) which may adopt the technologies and improve efficiency; and
- **SG3:** The **business services providers** who capture a share of the market by supplying support services such as insurances and shipbroking.

The stakeholder groups are embedded into the value chain as follow:

Figure 15 Stakeholder groups in the Maritime Industry value chain



Source: London Economics

This distinction is important because the various market mechanisms will have different impacts on the 3 groups. This is also relevant for describing the counterfactual scenario necessary to assess the additionality (i.e. additional costs, benefits and risks) due to an intervention.

Table 6 combines indicators and stakeholder groups in a matrix to visualise what the model will generate. Each cell contains the main inputs we use to compute the required indicator and is explained in detail in the methodology.

Table 6 Analytical framework

Category	Indicator	SG1	SG2	SG3
Industrial effects	**Turnover**	Company matrix – FAME data	Bass diffusion model	Company matrix – FAME data
Industrial effects	**GVA**	Company matrix – IOAT (ONS)	Bass diffusion model	Bass diffusion model
Industrial effects	**Employment**	Company matrix – FAME	Employees productivity – (Maritime UK analysis)	Employees productivity – (Maritime UK analysis)
Spillovers	**Knowledge**	Spillover Model	None	Spillover Model
Externalities	**Environment**	Environmental Model	Environmental Model	Environmental Model
Externalities	**Safety**	Safety Model	Safety Model	Safety Model

Source: London Economics analysis

The **period of analysis** is 2020 through 2050 but the results will provide details by decade. The 30 years analysis was chosen for the following reasons:

- It is in line with the Maritime 2050 projections;
- The potential benefits/outcomes are long-lived;
- The diffusion of technology takes time and spillovers are generated until the obsolescence of the technology.

4.2 Scenarios and additionality

In economic analysis, the impact of an initiative depends on the degree of **additionality** generated. Additionality is defined as the difference between the expected outcome in the **primary scenario** *with* the initiative/government intervention and the expected outcome in the **counterfactual scenario** *without* the initiative.

Benefits from smart shipping technologies are estimated with respect to three scenarios. Due to uncertainty in the estimates (CoVID-19, Brexit, delays, etc.), this report presents results from simulations in a central setting / best-guess scenario. However, the impacts of CoVID-19 and Brexit are not specifically modelled.

The model provides estimates from a 'high growth' scenario considered as an 'optimistic' scenario, a business-as-usual scenario (BAU) and a 'low/no growth' scenario. The notable differences between these three configurations are internal growth rates that come from different sources.

The **high growth** scenario assumes that the shipping industry will grow by **3.5%** per annum (in real terms) within the next decade[109]. The **BAU scenario** uses the observed CAGR in the UK maritime industry equal to **2.8%**.[110] A no growth scenario is also considered with a 0% growth over time.

[109] Unctad (2020). Review Of Maritime Transport 2019.
[110] Maritime UK (2019). State of the maritime nation 2019.

The **no growth** scenario assumes that there is no real growth over time and hence incomes are steady for the whole analysis. The interest of such scenario is to illustrate the full range of possibilities between this and an optimistic scenario illustrating the uncertainty associated with possible outcomes. Due to the large number of inputs and assumptions, the uncertainty in the model is large. Looking at the whole range of results can be interpreted as a confidence interval bounded by both scenarios.

In all scenarios, the technology providers benefit from additional government intervention which translates into additional financial support for the development of technologies. This additional investment directly increases the UK smart shipping industry turnover and it is assumed that the industry is able to absorb the increased activity, including through recruitment of skilled staff, as required i.e. supply can meet any given level of demand. This is referred to as **industrial impact**. Additional support may translate into increase in efficiency, adoption, or cost reduction. We discuss these possibilities in section 5.5.

The **counterfactual scenario** represents the case without further government intervention. It uses the industry trends to project the industry growth and estimate the income, GVA and employment over time.

For the maritime industry and the users, we use the CAGR estimates form the maritime industry report which reports turnover growth of **2.8%** per year.[111] It also results in a slower adoption of technologies.

For the smart shipping industry and the technology providers, the baseline trend is the same as above given that the SSI is part of the wider MI. In addition, the absence of government intervention delays the development of technologies. We assume that the development of smart shipping technologies will happen regardless. However, in the counterfactual scenario, companies do not benefit from financial support and therefore must cover the development costs entirely. This procedure increases the struggle to gather investments and creates additional barriers to the participation of smaller companies. The development of technologies is lagged, and therefore, the technology will enter the market at a later stage. Consequently, the benefits from sales and spillovers are shifted in time.

It is probable that the benefits from spillover are not realised at all if the technology fails to be funded or matured to TRL9. Capturing this effect is complex and requires a wider analysis of the additionality of spillovers. Assuming that all technologies are developed, though later due to delays, the results will provide a **lower bound estimate** of the spillovers as well as the leveraged sales.

It is strategically important for the DfT to develop a monitoring and evaluation tool capable of capturing the different returns from public investments. The evidence provided could feed into further research and decision-making regarding intervention strategies.

Assuming the time required to develop a technology is proportional to the investment, the absence of a grant will delay the R&D proportionally to the funding. We show this by using an OLS regression on the project duration with the data from Innovate UK on grant funding. Results show that the project duration is significantly, positively correlated to the proportion of matched funding, meaning that the greater the investment made by a private company, the longer the project. Results are shown in Table 24 (Annex A2.3).

[111] Maritime UK (2019). State of the maritime nation 2019. .

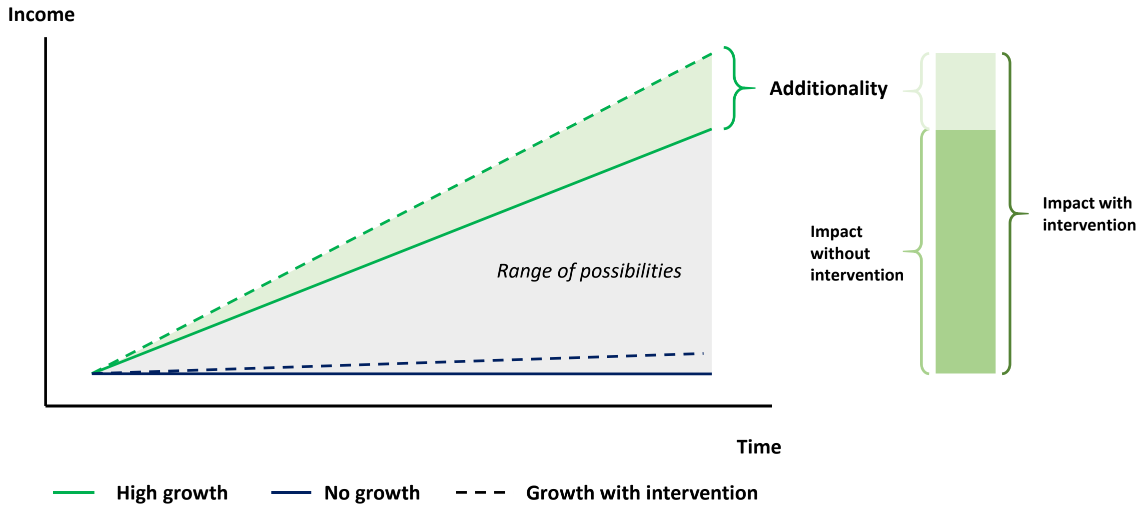
Historical government investment has required matched funding from industry under EU State Aid rules, although this has now been replaced with a UK-wide subsidy control regime[112]. The actual proportions are sourced from MarRI-UK projects. Given the current uncertainty surrounding the UK's future setup at the time of conducting this research, it has been assumed that a similar legal framework will remain in place.

It is further assumed that projects would go ahead without government investment, but that project teams would be able to cover the equivalent of the matched funding in any given time period. The implication is that a two-year project at 50% matched funding would take four years to maturity. The model uses matched funding estimates from MarRI-UK grants in which the average matched funding equates to 43% of the total budget. However, and for sensitivity, we add further estimates of 37% coming from Innovate UK[113] funded projects in 2019 and 53% form International Partnership Programme (IPP) projects[114].

Professional services capture a given proportion of other segments, by supplying business support to other companies. The BAU rules apply to them as well and we assume the proportion of income captured to evolve over time, following the within segments growth rates. It is worth noting that business support companies serve a global user base and that historical growth rates in this segment have been higher than that for other segments.

To summarise, the additionality is therefore measured as the cumulative difference between the primary scenarios (no to high growth) and the counterfactual scenario. The additionality is mainly driven by the presence of government intervention (or not).

Figure 16 Additionality



Source: London Economics

4.3 Caveats

- Assessment relies on expert judgement and is subject to uncertainties, optimism bias;
- The list of companies is non-exhaustive;

[112] HMG. (2021). Subsidy control bill.
[113] Innovate UK funded projects since 2004.
[114] London Economics (2019). Economic evaluation of the International Partnership Programme (IPP) – Economic return to the UK.

- Retrospective analysis is not possible, and we assume the share of income that is SSI relevant is constant over time;
- The curves derived via the technology adoption model are not forecasts, but rather approximations of where on the adoption curve each sector is likely to be if given adoption forecasts hold true. A significant number of factors influence adoption and actual adoption is therefore likely to be different than the curves derived via this exercise;
- Impacts of the CoVID-19 pandemic and Brexit are not considered explicitly.

4.4 Summary of methodology and assumptions

This section outlines the methodology and assumptions made for the quantification of industrial, spillovers, environmental and safety benefits. It presents a condensed version of the methodology and the extensive version can be found in Annex 2. The industrial model is split between each stakeholder group whilst environmental and safety benefits are detailed at the industry level.

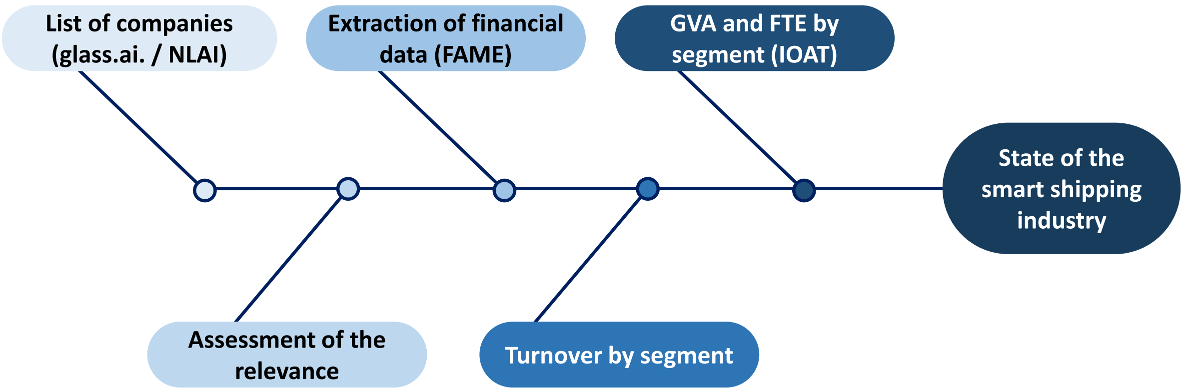
4.4.1 Industrial effects

SG1 – Technology providers

Technology providers are the core actors of the **smart shipping industry**. They include providers of smart ports, autonomous vessels, and on-board technologies. For this group, we undertake a bottom-up analysis of the commercial SSI, with particular focus on the 4 main technology segments.

This section outlines the assessment methodology at a high level. A complete version is available in the Annex 2.

Figure 17 Assessment of industrial effects



Note: GVA = Gross Value Added; FTE = Full Time Equivalent; IOAT = Input-Output Analytical Tables (from ONS).

Source: London Economics

Based on the initial **list of companies** provided by NLAI and consolidated by glass.ai (Annex 3), more than 450 companies were analysed. For each company, we manually investigate publicly available information (website, companies house, LinkedIn) to determine the relevance of the company.

We have identified **215 relevant companies** that split between the four segments of analysis. For this stakeholder group, we focus on the three relevant technology segments for which **36** companies were identified as active in the smart port segment, **38** in the autonomous vessel segment and **68** provide on-board technologies. Note that companies can be active in multiple segments.

Once the companies were assessed for relevance, we use our subscription to FAME to download the financial information of each company. FAME provides details on the **turnover**, the **employment** level, the ONS Standard Industrial Classification (**SIC**) **codes** of industry segments in which the company is active, among others.

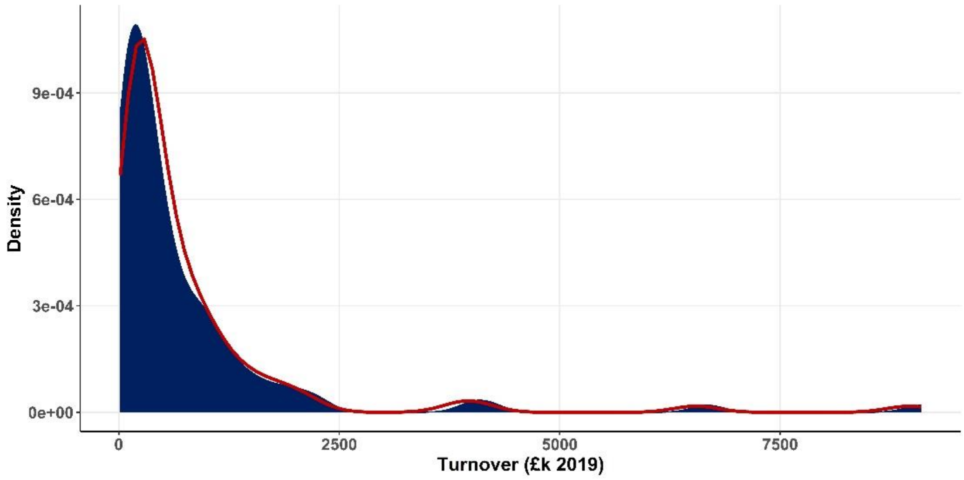
To ensure the completeness of the data, companies that are below the small firm exemption from publishing turnover data are randomly assigned an approximate value for turnover.

We use the **observed sample distribution** of company turnover we extracted from FAME, based on the list of companies assessed relevant to the study. We plot the distribution of companies by turnover bin and extrapolate a distribution function using a **Kernel approximation**. Kernel approximation is a machine learning method used to recognise patterns in the data and analysis the general distribution and relations within this data. It is similar to regression, clustering, or principal component analysis methods but more appropriate to the data used in this report.

We further transform the distribution into a **random distribution** and apply randomisation to any companies that did not provide their income in their financial report.

The detailed methodology is presented in Annex 2.

Figure 18 Observed density distribution (blue) and kernel approximation (red)



Source: London Economics analysis (FAME and glass.ai data)

At the value chain level, the direct **GVA** effect can be thought of as the value added to goods and services by the value chain's employees and the technologies themselves. We compute the direct GVA at the company level. We use the individual company SIC codes provided by FAME (based on reporting to Companies House) and match them to the GVA per output available in the Input-Output Analytical Tables (IOAT) from the ONS[115]. This approach assumes that GVA per output is uniform across the companies in each SIC code. To verify this assumption or improve it, a survey of the relevant companies would be required, but such activity was not in scope for the present project.

For the **employment** levels, we start from the FAME data and fill the gaps using the same approach as for the GVA. The IOAT provides the average number of employees supported per £1m of

[115] ONS (2020).

economic output per SIC code. For indirect and induced effects, we use industry multipliers from the Maritime UK report[116] (see table below).

Table 7 Multipliers

Sector	GVA	FTE
Maritime	1.7	5.0
Space	1.3	1.3
Aviation	4.0	4.0
Telecoms	3.2	-

Source: London Economics (Maritime UK, Oxford Economics, Aerospace Technology Institute)

Early impacts and leveraged sales from R&D

Early in the development phase, companies might receive support from grants. This investment will enable the support of engineers and researchers to increase the level of a technology. This funding also has immediate benefits for the UK economy by stimulating economic activity in the industrial supply chain. These benefits are measured in terms of Gross Value-Added (GVA) and employment supported with the methodology presented above.

Since grantees deliver complex solutions in new environments, organisations involved may provide UK suppliers with technology, commercial knowledge, and intellectual property (IP) that they can leverage to support commercial activity in other areas. These leveraged sales are in addition to any follow-on sales opportunities that come from long-term procurement of their solution to beneficiaries in the value chain. Leveraged sales are sales earned by the company, resulting from an R&D investment.

SG2 – End users

The end-users constitute the part of the MI that will benefit from the integration of new technologies. The benefits have various forms but are mostly generated by efficiency gains in operational cost reductions, emission reduction and increased safety during operations (see Annex 4).

To capture the effect of technology adoption on industrial indicators, we need to draw assumptions on the technology adoption level over time. We use the Bass diffusion model to project the adoption and the benefits.

The properties of technology diffusion have been widely studied. Diffusion (adoption) of new products (innovations) typically follows an S-shaped curve. This typical S-shaped nature of innovation diffusion was used to obtain a better understanding of how far along the adoption path each selected sector may be in a given period, as well as, when the tipping point in sales – i.e. the point when the annual increase in sales reach their peak before slowing down – is likely to occur, given current sales forecasts.

A detailed methodology about the model can be found in the Annex 2.

[116] Maritime UK (2019). State of the Maritime Nation Report 2019.

The employment level is estimated based on the GVA generated from technology adoption. We use the employee's productivity ratio to make this estimation over time, assuming it is variable over time and using the projections from the baseline scenario.

End users in this context refers to the users of the various smart shipping technologies considered in this report i.e. ports and shipping companies. However, it is clear that there is a group beyond these organisations in value chain, namely users of shipping. Benefits to the shipping industry may be transferred to manufacturers or retailers through changes in shipping costs resulting from a revised cost profile in the shipping industry. The degree to which benefits are passed on to customers depends on the competitive landscape in the shipping industry, as well as elasticities of supply and demand, both of which are beyond the scope of this report.

SG3 – Business services providers

The Business Services Providers (BSP) group constitutes the part of the MI that generates benefit from the support provided to technology developers and end users. Technically, their operational income captures a given share of the wider industry's which can be seen as a within-industry transfer. As of 2020, the BSP represented 15.1% of the maritime industry.[117] BSPs might also provide smart shipping solutions and/or be end users of smart shipping technologies, so they could be further up the value chain too. This distinction is captured in the methodology below. Additionally, UK BSP serve the international as well as domestic market.

Technology adoption may have two impacts on BSP companies. The **direct effect** from new technologies being adopted by BSP companies may **reduce operational costs** (e.g. adopting AI techniques) and consequently **increase the share of GVA** that is produced per unit of output. The **indirect effect** is linked to the growth of the maritime industry. The necessity to adopt new technologies may **increase the demand for support services** such as shipbroking, funding, among others. This may increase the income of BSP companies following the adoption rate of other companies (e.g. with an increased reliance on digital technologies, the needs for cybersecurity increases).

We have identified service companies the same way we assessed companies from SG1. However, it was more difficult to identify smart shipping focussed companies because the publicly available information was often vague. Therefore, we have decided to widen our relevance scope and the findings might overestimate the SSI.

We consider the group to be representative of the wider maritime industry instead and we have used the same methodology as for SG1 companies to determine its industrial contribution (income, GVA, FTE).

The employment level is estimated based on the GVA generated from technology adoption. We use the employee's productivity ratio to make this estimation over time, assuming it is variable over time and using the projections from the baseline scenario.

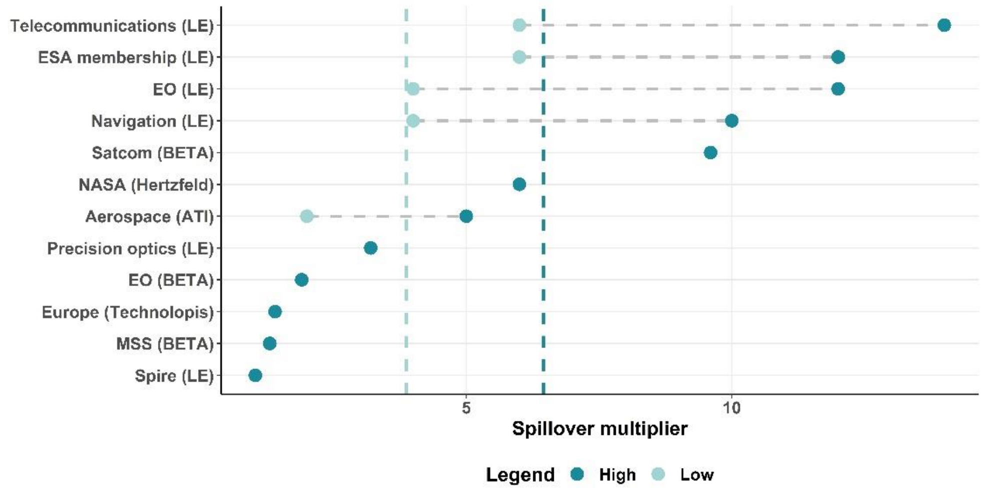
[117] Maritime UK (2019). State of the Maritime Nation Report 2019.

4.4.2 Knowledge spillovers

Knowledge/Technology spillover effects coming from the technological developments associated with the SSI value chains, which are expected to encompass several technical domains such as AI, manufacturing, autonomy, robotics, and data analytics (see Section 2.3).

London Economics carried out an analysis of the returns of public investments[118] in the space industry and extrapolated the potential benefits from spillovers as **multipliers** as well as a wider analysis on spillover returns in the space industry[119]. Spillovers multipliers range from low level of diffusion (**3.9**) to a high level of diffusion (**6.5**). The model uses the average of low and high levels.

Figure 19 Spillover multipliers – Evidence from the literature

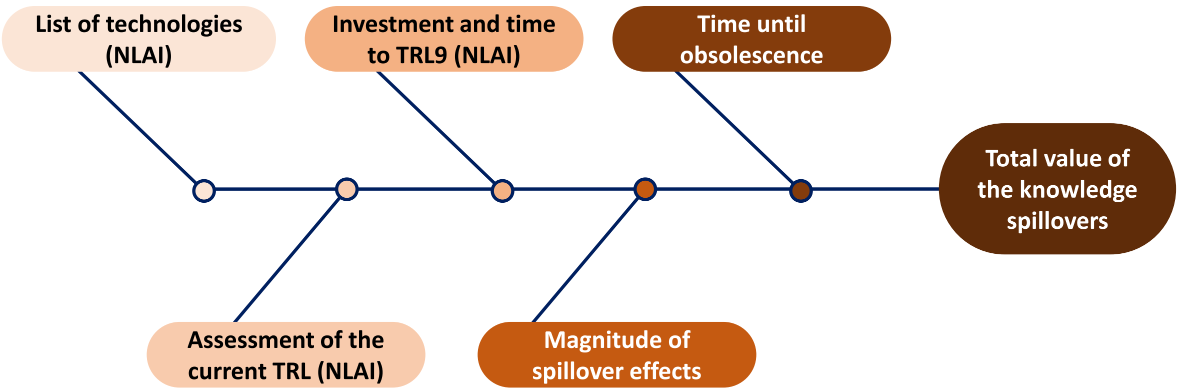


Note: BETA = Bureau d'économie théorique et appliquée. The dashed lines represent the low- and high-level averages.

Source: London Economics

As one does not expect the benefits to be linear over time, London Economics expanded the best practice by adding a probability distribution of benefits over time. We have developed a model to capture the knowledge spillovers. It uses technology development costs and time to market to estimate the magnitude of knowledge spillovers.

Figure 20 Assessment of spillover effects



Note: TRL: Technology Readiness Level
Source: London Economics

[118] London Economics (2015). Return form Public Space Investments.
[119] London Economics (2018). Spillovers in the space sector.

Current TRL levels were assessed by experts at NLAI, identifying which company (UK and/or non-UK) is established as the technology leader, reviewing reports, publications, websites and using maritime expertise.

From the current TRL, we can infer the investment and time required to bring the technology to maturity based on a study from the IMO[120] that analyses green shipping technologies development.

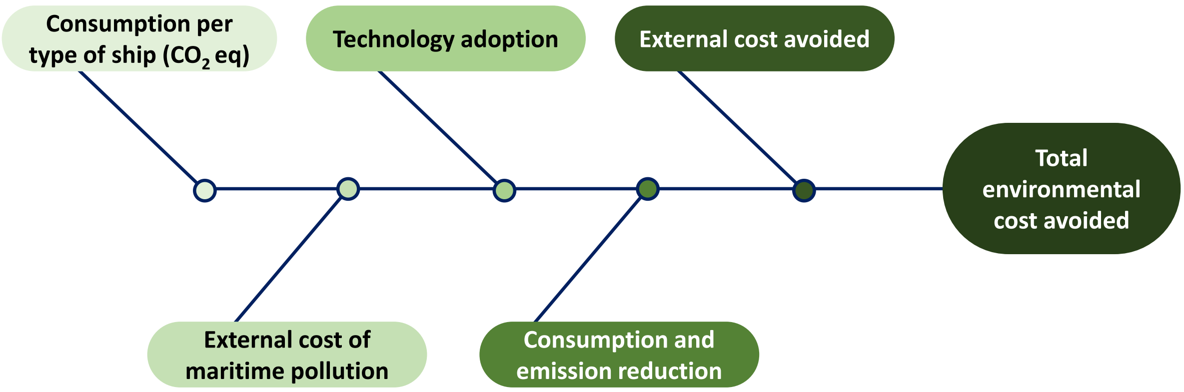
The magnitude and time to obsolescence are assumptions taken from London Economics' previous research and challenged by NLAI technology experts. These inputs are critical to the estimation of the distribution of the potential benefits.

See A2.3 for the detailed methodology.

4.4.3 Environmental impacts

To estimate the level of emission reduction and thus external costs savings both while at sea and at berth, we have modelled two separate cases.

Figure 21 Assessment of environmental benefits



Source: London Economics

At sea, emissions depend on vessel size, distance travelled, speed, fuel efficiency and the engine exhaust factor (measured in tons of CO_2 per tonne of fuel). The result yields CO_2 emissions in tonnes per trip. A more detailed explanation of the calculation can be found in A2.4. We assume a 1% efficiency gain to fuel consumption to indicate how much CO_2 can be saved. Assuming an external cost factor of £65 per tonne of CO_2 estimated by DEFRA[121], we can estimate the external cost savings for each percent increase in fuel efficiency (the efficiency can also come from exhaust cleaning technologies or others).

In the port, ships still require electricity for hotelling and loading/unloading activities. This demand can be met either through fuel consumption provided by auxiliary engines or by using **shore power**. Comparing the CO_2 emissions of generating electricity through the auxiliary engine with the CO_2 emissions from the national power grid lets us estimate how much CO_2 can be saved. This method might as well discard ports which are not supplied with clean energy.

The emission savings depend on the time spent in port, the electricity generation of auxiliary engines, engines exhaust factor, and national power grid emissions (our baseline assumption uses

[120] IMO (2019). Reduction of GHG emissions form ships.
[121] BEIS carbon values.

the weighted average emissions from the UK power grid mix) in terms of grams of CO_2 per kWh (see A2.4). Applying the same external cost factor of £65 per ton of CO_2 gives the emissions and external costs saved by shore power, given that the emissions from the national power grid per kWh are lower than from fuel.

Our calculations do not include the price of installing fuel saving technology, shore power or the cost of electricity paid in ports. The price of fuel saving technology depends on the type of technology used, the price for shore power technology on ships varies depending on whether it is a retrofit or new build. The cost for electricity is also volatile, and ports may decide to generate their own renewable energy independent from the national grid, hence cost estimates are not taken into account. Nevertheless, the results section includes a summary of our findings in terms of abatement costs.

Scenarios

To calculate emissions and external costs that can be saved through efficiency gains or alternative power, we have developed different scenarios. Since emissions during the voyage phase depend on both the type of ship as well as the distance travelled, we have included three ships of various sizes ranging from **5,000 to 19,000 TEU**. To calculate savings for various exemplary routes, our scenarios include 6 different routes. Several ports among these routes have already adopted shore power for container ships, i.e. the Ports of Los Angeles and Antwerp.

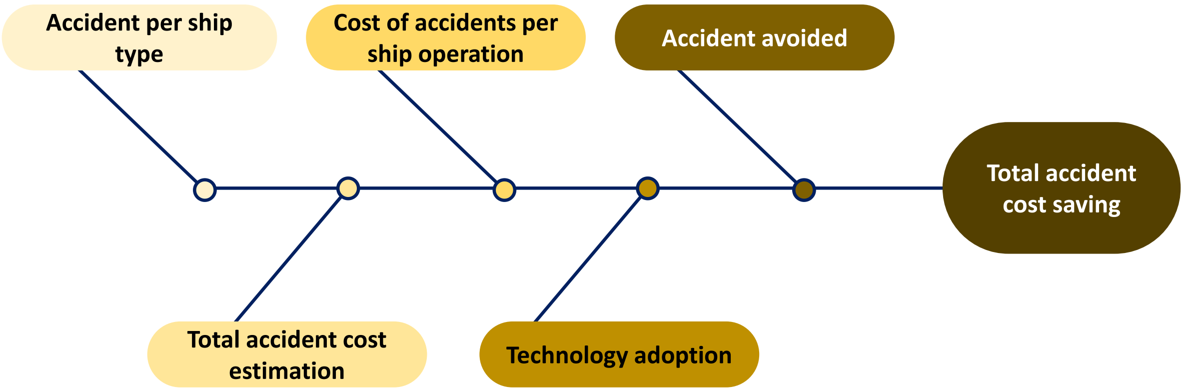
To analyse emission savings at ports, the model includes different estimates of time spent in port. Average times that ships typically spend in ports range from **25 to 65 hours**, depending on the type of vessel and port. Other conditions, such as weather, traffic or terminal capacity also play a role. Depending on the type and size of ship, the power consumption of the auxiliary engine differs. For container vessels, it ranges from 1,000kW for a small vessel of 2,000TEU to 7,000kW for a large vessel of 13,000TEU[122], up to 16,000kW for a very large container ship with 19,000 TEU (MSC Zoe[123], A2.4). The emission savings from shore power very much depend on the source of electricity from the power grid. Thus, we have included the exhaust factors of different energy of sources as well as the energy mix of the UK in 2019.

4.4.4 Safety and security impacts

The total saving through the implementation of technology is calculated using the Department for Transport's road accident and casualty cost estimations[124], estimates of the total insurable value (TIV) of vessels[125] and shipping accident data published by the European Maritime Safety Agency (EMSA). The cost estimate considers the value of lives lost, hull and machinery damage, cargo lost and pollution.

[122] De Melo, G. and Echevarrieta, I. (2014). Resizing study of main and auxiliary engines of the container vessels and their contribution to the reduction of fuel consumption and GHG. "IAMU AGA15". LAUNCESTON: 2014, p. 441-452.
[123] MSC (2015). MSC Zoe Christening in Hamburg.
[124] Department for Transport (2020). Accident and casualty cost.
[125] Heij, C. and Knapp, S. (2016). Evaluation of total risk exposure and insurance premiums in the maritime industry. Econometric Institute Report, (EI 2016-25).

Figure 22 Assessment of safety benefits



Source: London Economics

The DfT Road accident costs place economic value on casualties and fatalities and estimate the economic costs such as loss of output and medical costs, and the human cost of accidents which encompass pain, grief, and suffering. Road accident data estimating the cost of injuries and fatalities are used as a proxy for the loss of life and total cost of injuries to persons in maritime accidents. Factors included in the calculations are:

- Loss of output due to injury calculated as the present value of the expected loss of earnings, plus non-wage payments made by employers;
- Ambulance costs and the costs of hospital treatment;
- The human costs of casualties based on willingness to pay to avoid pain, grief and suffering to the casualty, relatives and friends, as well as intrinsic loss of enjoyment of life in the case of fatalities.

Heii and Knapp (2016) provide estimates of the TIV at the individual ship level and aggregate this data into five different ship types; general cargo, dry bulk, container, oil tanker, passenger, other. TIV is comprised of:

- Valuations of hull and machinery based on second-hand prices;
- Average cargo values by Deadweight Tonne (DWT using UNCTAD trade statistics;
- Oil pollution costs excluding damages to marine ecosystems based on international conventions and special drawing rights (SDRs);
- Loss of life based on international conventions and SDRs;
- Third party liabilities based on international conventions and SDRs.

The loss of life estimate within the TIV gives an overall insurable value of all lives on a vessel. To avoid assumptions surrounding the number of lives on-board vessels involved in accidents, this value is eliminated in our estimations. As our data specifies the number of lives lost per accident, we use the DfT data which quantifies the value of each life lost.

5 Socio-economic impacts

This section presents the results of a financial intervention from the government. The scenario assumes that an initial investment of **£560m** is made over four years and **shared** between the government (**£319m**) and grantees (**£241m**). The initial investment was determined by a detailed assessment of new technologies by NLAI. It corresponds to the investment required to bring the selected technologies to TRL9. Details about these technologies are available in the Annex 5.

The counterfactual scenario assumes the whole investment is borne by companies and the government is not involved in the R&D process.

The scenario presented in this section is hypothetical. The level of funding required to bring the technologies to market are based on the assessment of selected technologies. It does not reflect the current strategy of the government[126].

5.1 State of the smart shipping industry

Based on our analysis, a total of **215 companies** are active in one or more of the four smart shipping sectors:

- For the **smart ports** sector, 36 companies are relevant. The companies mostly focus on port traffic management, smart mooring systems, shore power, and automated terminals and cargo handling. Between 2015 and 2020, total turnover has increased from **£208m to £230m**. Based on the industry wide real CAGR of 2.8%, turnover in 2050 is projected to be **£527m**. Similarly, GVA has increased from **£117m** in 2015 to **£128m** in 2020, with an expected GVA of **£294m** in 2050 resulting in a cumulative GVA of **£3,600m** for the period between 2021 and 2050. Employment has slightly declined **from 1,300 to 1,200 FTE** but is projected to be at **2,800 FTE** by 2050 based on the expected CAGR of 2.8%. The companies which contribute the most to turnover of the smart port sector are: Associated British Ports and Royal Haskoning DHV;
- 38 Companies are active in the **autonomous vessels** sector. This involves development and production of remotely operated vehicles (ROVs), automated underwater and surface vehicles (AUVs and ASVs) as well as sensors. Turnover rose from **£128m** to **£157m** between 2015 and 2020, expected to reach **£359m** in 2050. GVA increased from **£59m** to **£74m**, with projected GVA of **£168m** in 2050 adding up to a cumulative GVA of **£2,100m**. Employment increased from to **700** to **800 FTE** and is projected to reach **1,800** FTE in 2050. Companies adding the most to autonomous vessel turnover are BAE Systems, Rolls Royce, Soil Machine Dynamics and since its merger in 2017, TechnipFMC;
- **On-board technology**, which 68 companies are involved in, is concerned with on-board sensors, satellite systems, Electronic Chart and Display Information Systems (ECDIS), autonomic emergency systems, passage planning, virtual logbooks, as well as energy and ballast-water management. Turnover slightly fell from **£136m** in 2015 to **£132m** in 2020 but is expected to be at **£303m** in 2050 considering the estimated 2.8% CAGR of the industry. GVA stayed almost constant **(£63m** in 2015 and **£62m** in 2020). With an estimated GVA of **£141m** in 2050, the cumulative GVA amounts to **£1,700m**. Employment rose from **1,100** to **1,200 FTE** between 2015 and 2020 (**2,800** in 2050). The companies adding the most turnover to the on-board technology sector are IBM and Rolls Royce;

[126] UK Innovation Strategy

- **Professional services** include the largest number of companies, 131 in total. Not all companies directly contribute to the provision of smart shipping technology services, but they provide essential support services such as ship brokerage, insurance of vessels, fleets or cargo, education and training for personnel, legal and financial services, consulting, and ship surveying – all necessary to leverage R&D funding. Turnover between 2015 and 2020 has slightly declined from **£673m** to **£652m** but with the CAGR of 2.8% it is estimated to be at **£1,493m** in 2050. GVA fell from **£277m** to **£271m** and is projected to be at **£620m** in 2050, which leads to a cumulative GVA of **£7,600m**. Employment fell from **3,700** to **3,300 FTE** and is forecast to reach **7,700** FTE in 2050. The main contributors to professional services turnover are: Braemar Shipping Services, Clarkson, and The North of England P&I.

5.2 Industrial impacts

5.2.1 SG1 – Technology providers

The impacts on technology providers come from multiple channels spread over time. The first stream comes from the grant itself. This funding has immediate benefits for the UK economy by stimulating economic activity in the industrial supply chain. These benefits are measured in terms of Gross Value-Added and employment supported.

Given our research and current findings, we estimate that the investment that would be required to bring every group of technology to market is **£560m** between now (2021) and 2024 (latest technology matured). This represents an investment of nearly **£140m** per year.

Table 8 Investment required to TRL-9, by technology group

Technology group	Investment	Public grant (57%)	Matched funding (43%)
Smart ports	£170m	£97m	£73m
Autonomous vessels	£340m	£194m	£146m
On-board technologies	£50m	£28m	£22m

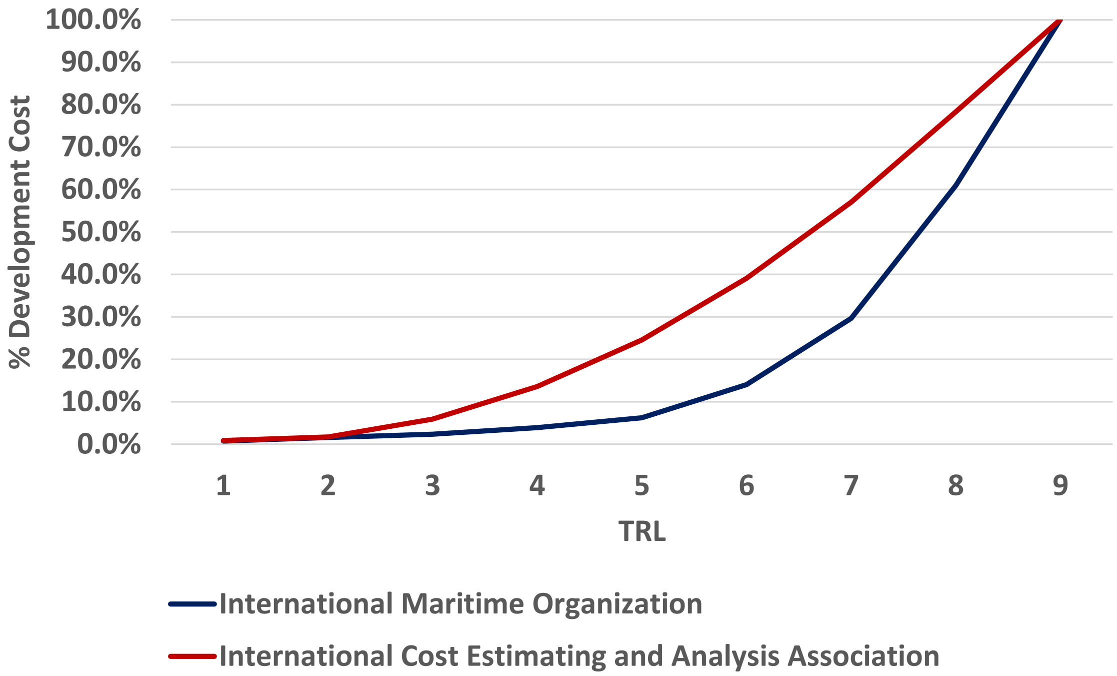
Source: London Economics analysis, data from NLAI and IMO

For each individual technology, we have assessed the current readiness level based on publicly available information. We have selected the company (UK or non-UK) we judged was the most advanced on a given technology. From this standpoint, we were able to assess the current level of the technology and use the IMO data to estimate the investment that would be required to bring the technology to TRL9, and hence the time. The full matrix is available in Annex 5.

We assume the current technology level in the UK to be at most as high as our findings. In some cases, the information about the current technology level in the UK was unavailable. Therefore, we consider that UK companies could invest in developing the current technologies further.

The model assumes that the investment is distributed evenly among companies and follow the IMO and International Cost Estimating and Analysis Association (ICEAA) distributions for TRL development. We also assume that the time between TRL levels is even due to the lack of information and research in this domain.

Figure 23 Cumulative cost proportion per TRL level increment.



Source: London Economics; IMO; IEEAA[127]

The assumed level of funding from government acts as additional income with which we can compute the additional GVA and number of employees. Hence the grant is factored in the observed income of the SSI. Based on the total assumed government investment (**£319m**), smart ports technology developers are expected to receive **£95m** over 4 years, autonomous vessel developers could receive **£194m** over 4 years while on-board technology specialist would get **£29m** within 2 years. Here it is assumed that the grantees have capacity to absorb the investment, e.g. through recruitment, as required i.e. supply can meet any given level of demand.

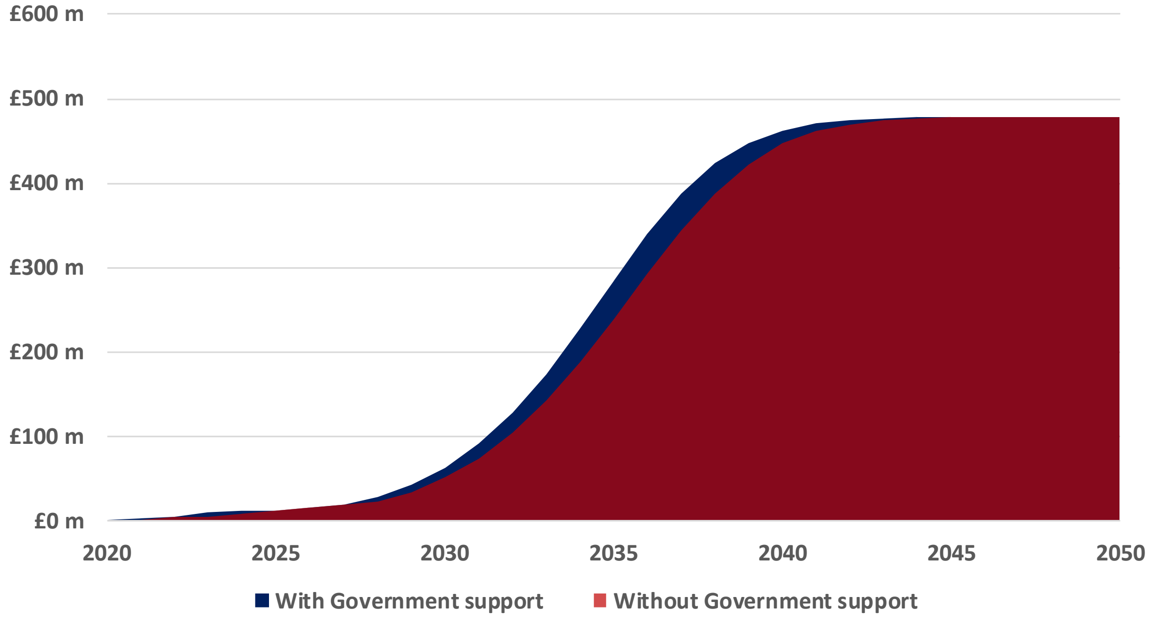
The second channel generating wider benefits comes from participating companies (grantees). Access to a grant is assumed to enable faster development of a technology and consequently a faster access to market. This benefit is captured by the additional **leveraged commercial sales**. This is a simplifying assumption that does not consider whether government-funded projects are more or less likely to succeed than self-funded industrial activities.

This effect is captured by a combination of the Bass model which assumes the rate of adoption of technology over time and a leveraged sales factor. We use a factor of **0.37**[128] meaning that for each £1 of public investment, £0.37 are added in the company's income as leveraged sales. We then project the expected leveraged income onto the adoption curve from the Bass model.

Results show that with government support, the additional sales might start as early as 2022 but substantial additional revenues are expected to start around 2030. The cumulative income in present value terms could reach **£4.1 billion** between 2020 and 2050. Without government support, these benefits are expected to start much later and therefore the cumulative present value would only reach **£3.6 billion** in 2050. This represents an additionality of **£500m**.

[127] International Cost Estimating and Analysis Association. 2017.
[128] London Economics (2019). Economic evaluation of the IPP: Economic return to the UK.

Figure 24 Distribution of leveraged sales (values in £2020)



Source: London Economics

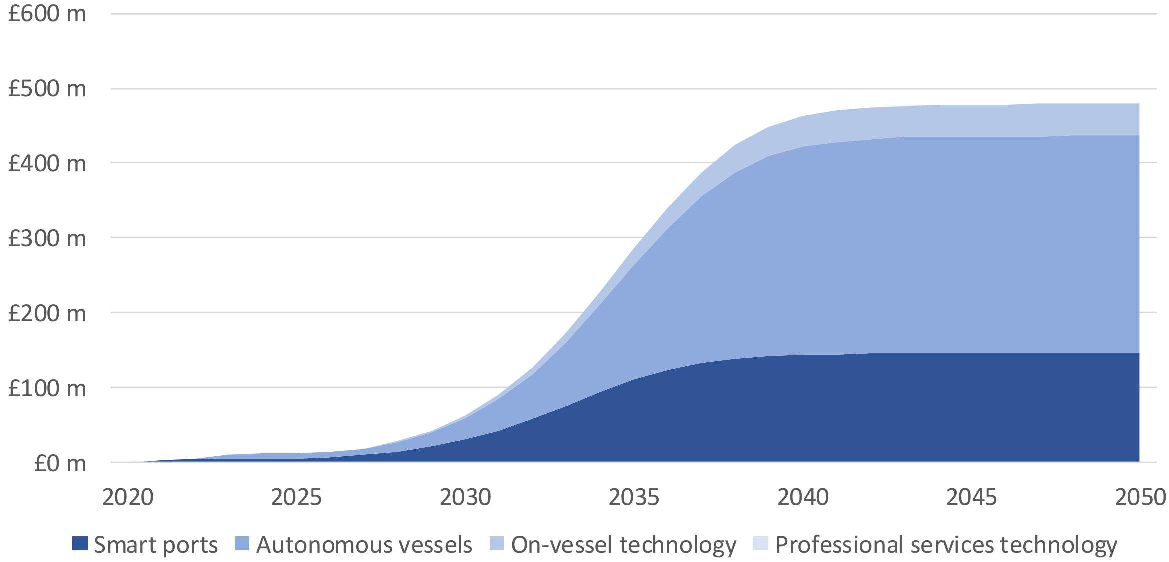
At the segment level we can see that the autonomous vessels are likely to generate a greater return since the readiness of the services is expected within a few years. A total of **£2.4 billion** are expected until 2050. Compared to the counterfactual scenario, this represents an additionality of **£364m** (blue area on Figure 24).

Smart ports and on-board technologies are forecasted to yield **£1.4 billion** and **£352m** in leveraged sales, respectively. This is equivalent to more than **£99m** and **£77m** in additionality, respectively.

We found that the selected 3 subcategories of professional services technologies were market ready and UK organisations were obvious leaders in the market. Therefore, the potential benefits from grant funding in developing these further are assumed to not factor in the model. However, this does not exclude them from providing benefits to the industry, but these benefits are not attributed to government investment.

The additionality across segments varies for multiple reasons. The timing of readiness across the group of technologies is not the same and there is expected to be some lag before taking off, offsetting the adoption curve in the Bass model. The amount of money invested in technologies differs from one technology to another, making the magnitude of investment and scale of impacts different. Finally, values are discounted at a rate of 3.5% per annum (following the Green Book), which has an impact on the cumulative values i.e. expected values in the future are worth less than values closer to today in present value terms.

Figure 25 Leveraged sales from public investment – with intervention



Source: London Economics

Combining the benefits from grant funding and leveraged sales, the cumulative additionality from financial support amounts to **£540m** in present value terms and over the whole period from 2020 to 2050. This is equivalent to an additional income of **£18m** per year.

The GVA generated by the additional activities is computed using the within segment GVA per income ratio. This yields a cumulative and additional GVA of **£276m** from 2020 to 2050, or **£9m** per year.

Similarly, using the within segment employee's productivity, we found that over **3,900** additional employments could be secured from the financial support.

All the results are summarised in the table below:

Table 9 Additional industrial effects attributed to a government grant programme, 2020-50

Industrial effects	Smart ports	AV	On-board techs	Total 2020-50
Grant effect - Income	£97 m	£187 m	£27 m	**£311 m**
Leveraged sales - Income	£2 m	£177 m	£50 m	**£229 m**
Direct GVA	£55 m	£185 m	£36 m	**£276 m**
Direct Employment	519	2,461	883	**3,863**

Source: London Economics analysis

5.2.2 SG2 – End users

The benefits generated by the MI are expected to be due to the improved efficiency of their activities. To capture the impact on the wider market, we use the Bass diffusion model. The calibration inputs are presented in the table below.

Table 10 Inputs for Bass Model Calibration

Input	Value	Source
Coefficient of innovation	0.003	Rehmatulla et al. (2015)
Coefficient of imitation	0.5	Rehmatulla et al. (2015)
Market potential	62%	Clyde & Co - Medium potential
Current users	1.6%	London Economics
Technology maturity	2024	NLAI – Technology matrix
Baseline scenario	2.8%	London Economics - BAU
Efficiency gain	[10%, 20%, 30%]	London Economics – based on literature review (see Annex 5)

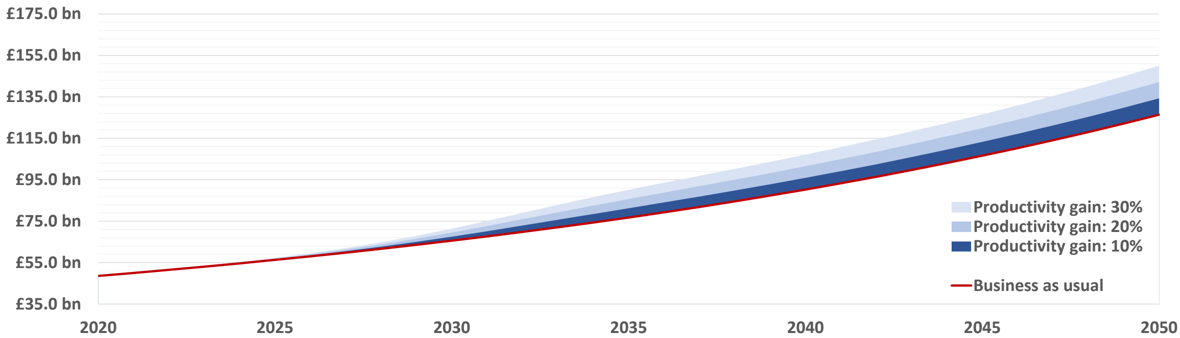
Source: London Economics analysis of the literature

The efficiency gain is assumed to vary between 10% and 30%. We report the lower scenario with 10% efficiency gain in our results.

In 2020, it was estimated that the MI generated **£48.6bn** in turnover. Using the counterfactual assumption (2.8% growth per year), this would yield a turnover of **£126bn** by 2050. By using the diffusion model, the turnover in 2050 would reach **£134bn** and up to **£150bn** in the 30% growth scenario.

The overall benefit from technology adoption is presented below. It displays the 3 different productivity gain growth paths and the no growth scenario.

Figure 26 Maritime industry productivity gains

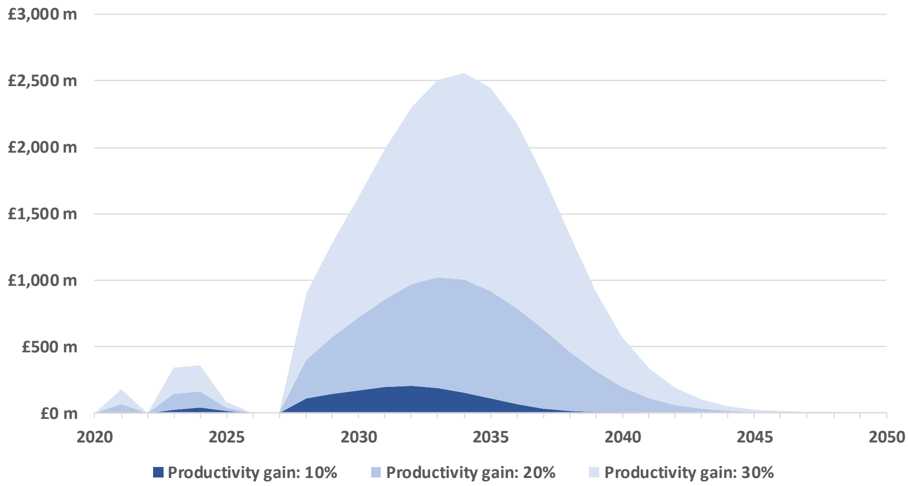


Source: London Economics

The additionality from technology adoption may come from domestic and international technology suppliers. To capture the impact of domestic additionality, we use the technology model to determine the proportion of this additionality that may come from the public financing. We determine the proportion of additional leveraged sales and grants that are generated with the intervention and multiply it to the projected turnover over time.

The additionality is distributed as illustrated below. The early 'peaks' are attributed to the early impact of the grants. The troughs are a consequence of the design of the model. Returns from technologies in scope are subject to different start dates and magnitude which means that at a given date, the returns generated by technologies in the scenario with government support are equal to the returns in the scenario without government intervention. This means returns cancel out and the additionality is equal to zero.

Figure 27 Additionality



Source: London Economics analysis

In the 10% efficiency gain scenario, the cumulative income additionality that is attributable to government financial support is **£1 billion** while in the 30% efficiency gain scenario, this additionality rises to **£2.9 billion**.

The maritime industry was estimated to directly generate around **£17bn** in GVA for the UK economy in 2020. For 2050, direct GVA of the maritime industry for the UK is estimated to reach **£56bn**. In cumulative terms, the additional GVA generated by grants support is equal to **£400m** in the 10% efficiency gain scenario and up to **£1.1 billion** in the 30% efficiency gain scenario.

We apply a GVA multiplier of **1.70**[129] to the direct effect to compute the contribution of smart shipping technologies to the wider economy. This yields a total GVA (direct + indirect + induced) of **£48bn** in 2020 and **£151bn** in 2050. This corresponds to an additionality of **£1 billion** in the 10% efficiency gain set up.

The employment level also benefits from the increased efficiency in the industry. Direct employment was estimated around 200,000 FTE in 2020 which could grow up to 600,000 FTE in 2050 with a 10% efficiency gain. Assuming that efficiency gains do not translate to lower job numbers, and given the additional impact of an intervention, **6,500 jobs** could be directly created with government support. By using the maritime employment multiplier of 5.0, we find that over **39,000** additional FTE could be supported in the wider economy due to domestic efforts.

Note that we have used the 'best guess' estimates that use multipliers used in the Maritime UK analysis. GVA and employment multipliers may vary if we look at other sectors.

Table 11 summarises the findings in terms of additionality attributable to the domestic support. Note that the additionality reduces over time. This owes to the fact that even in the counterfactual scenario, technology adoption happens regardless of the existence of support from the government. Companies will adopt new technologies anyway because they need to remain competitive and, in some cases, the regulation enforces adoption (e.g. IMO greenhouse gas regulations).

[129] Maritime UK (2019). State of the maritime nation report 2019.

Table 11 Income additionality of the maritime industry, 2020-50

Income	Additionality 2020-50
Shipping	**£459 m**
Port	**£155 m**
MES	**£219 m**
Services	**£148 m**
Total	**£981 m**

Source: London Economics

5.2.3 SG3 – Business services providers

As mentioned above, there are two main components to the benefits SG3 might generate. First, their operational income captures a given share of the wider industry's. Second, the adoption of new technologies could increase their efficiency, income and GVA.

Our model takes into account both streams. However, the technology assessment has determined that the current technologies were either ready to adopt, or already integrated by the companies. This means **the baseline simulation** does not require additional funding for the development of technologies and consequently, will **neither generate early returns from R&D nor spillovers**.

Many training colleges and courses are adapting to current circumstances (online courses are being developed). Warsash Maritime school is the world leading university in ship handling. Hence, while the need for technology development in training is marginal, there is a need to supply adequate education for the new technologies being developed in other segments of the value chain. Most training programmes will mature within a year but, depending on the requirements of legislation and complexity of the technology, this may be more protracted. Adequate training has the capacity to improve efficiency within companies by improving knowledge and skills of future workers.

In addition, insurance and brokerage services remain essential services that the wider industry must use. Therefore, when users increase their activities, part of their revenue will be transferred in these services.

The assessment of SG3 shows that in 2020, 131 companies have generated **£652m** in turnover. This represents **£288m** in GVA (43%). We estimate that the turnover in 2050 could reach **£1,500m** using a CAGR or 2.8%.

Using the assumption that the service industry captures a given share of the industry, and assuming this share is the proportion of turnover generated by service companies in the wider Maritime industry, we estimate that SG3 will capture between **15.1%** (in 2020) and 16.6% (in 2050) of the additional turnover generated by SG1 and SG2 companies.

With this approach we estimate that the total additionality attributed to a government grant support yields a cumulative turnover of **£80m** over 30 years.

For the GVA, we also assume that SG3 companies start adopting new technologies from today given the technologies are assumed ready. Hence, using the Bass adoption model and assuming technology adoption in service companies reduce operational costs, the GVA share of turnover over time increases, yielding a GVA of **£845** in 2050. The additionality remains relatively small given that in the counterfactual scenario, the adoption of technologies happens at the same time (owing to the absence of R&D needs). Therefore, the cumulative GVA additionality from an indirect government intervention (affecting SG1 companies) is **£70m**.

In terms of employment, **3,300 FTE** are assumed as of 2020. Using the growth model, this number is expected to grow to **10,000 FTE** by 2050. This represents an additional **1,000 FTE** that the UK government intervention would secure.

5.3 Technology spillovers

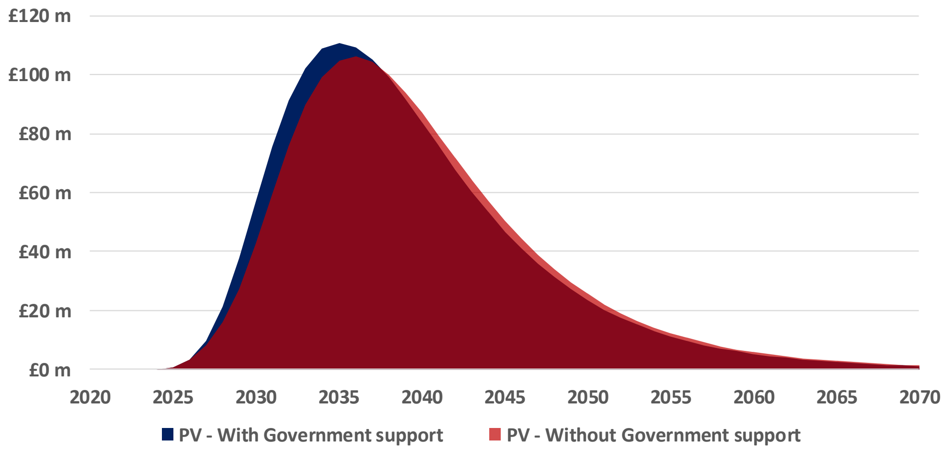
The 19 technologies identified have been reviewed by a panel of experts. External consultations have identified the minimum requirements for determining the spillovers by assuming the duration of the development (to TRL9), the investment required to bring it to maturity, magnitude of potential spillovers (ranging from very low to very high) and the time until when the technology will be ready.

Each technology is part of a wider group of and we assume group to be operational when every single technology is mature and the whole set of systems can be integrated.

The distribution of the benefits is shown in Figure 28, which shows the extent of spillover returns with and without the intervention from the government. Technologies were estimated to have a life expectancy of 50 years following London Economics' previous research into the space sector[130,131] i.e. the time it takes for the technology to become obsolete. The difference between the projections lies in the fact that without intervention, it may take longer to find the necessary investment (financial and human) which delays the development. R&D grants can also be accompanied by dissemination efforts that usually involves making research public via white papers, which increases the transfer of knowledge in the public domain (knowledge spillovers).

We assume that a proportion of companies receiving the grant chose the dissemination option (63% based on Innovate UK database) and therefore, this proportion of companies increase their spillover contributions.

Figure 28 Distribution of knowledge spillovers (values in £2020)



Source: London Economics

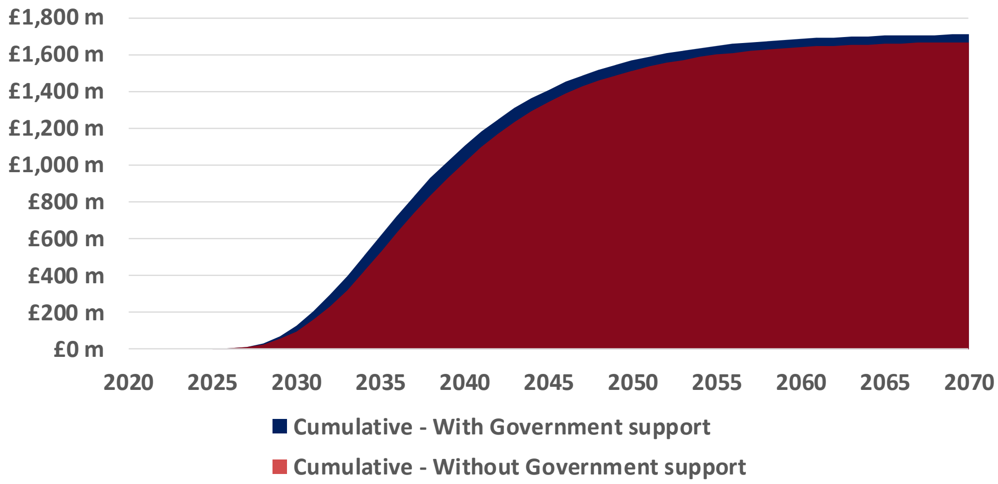
Whilst the figure presents the spillovers until technological obsolescence, we can see that in 2025, the spillovers in the scenario without intervention have not yet occurred. Autonomous vessel technologies have the highest return potential and yet are the technologies which will take the longest to reach the market. By 2050, they are expected to yield **£1.57 billion** and this might drop

[130] London Economics (2015). Return on public space investments
[131] SpaceResources.lu (2018). Opportunities for space resources utilization.

to **£1.51 billion** in the absence of intervention. This represents an additionality of **£56m** from grant funding.

The following graph illustrates the cumulative value of spillovers in both scenarios.

Figure 29 Cumulative value of knowledge spillovers (in present value terms) to 2070



Source: London Economics

5.4 Environmental impacts

The UK **maritime sector**[132] contributes **3.4%** to overall UK greenhouse gas emissions (Maritime 2050[133]), 59% of which of comes from international shipping and 41% from domestic shipping. Specifically, domestic shipping in 2016 accounted for 11% of UK domestic nitrogen oxides (NO_x) emissions, 2% of fine particulate matter ($PM_{2.5}$) and 7% sulphur dioxide (SO_2) emissions. Globally, shipping is responsible for around **2.2%** of CO_2 emissions, which, under a business-as-usual scenario, **may increase between 50-250% by 2050** (3rd IMO GHG Study[134]). Thus, to comply with the objectives of the Paris Agreement, several policy interventions have been made at the international level.

The International Maritime Organisation (IMO) has set the target to reduce global greenhouse gas (GHG) emissions from shipping by 50% until 2050 compared to the 2008 level[135]. As of January 2020, ships are obliged **to limit sulphur emissions to 0.5% m/m** (mass by mass) instead of the previous 3.5% under the new IMO regulations. Within the Emission Control Areas (ECAs), the sulphur emission cap has already been 0.1% m/m since 2015 and will stay at that level[136].

Domestically, the UK has outlined its target to reduce air pollution in the Clean Air Strategy 2019, lowering emissions of CO_2, NO_x, PM, SO_2 and other air pollutants. Following the lines of the Climate Change Act from 2008, the UK has set a "net-zero" target to 2050, with a 78% reduction step by 2035[137]. This includes the domestic shipping industry. Part of the Clean Air Strategy is the **Clean Maritime Plan**[138], which aims to reduce the environmental impacts of the maritime industry in the

[132] The maritime sector includes shipping, ports, services, engineering and leisure marine industries in Maritime 2050
[133] Department for Transport (2019). Maritime 2050. Navigating the future.
[134] IMO. (2016). Third greenhouse gas study.
[135] IMO. (2020). Cutting sulphur emissions.
[136] Zis T., Angeloudis P., Bell MGH., and Psaraftis, H.N. (2016). Payback Period for Emissions Abatement Alternatives: Role of Regulation and Fuel Prices. Transportation Research Record.
[137] HMG net zero target
[138] Department for Transport (2019). Clean Maritime Plan.

UK while maintaining its leadership in the maritime sector. The vision is to achieve **zero emission ships by 2050** as outlined by **Maritime 2050**.

Technologies to tackle emissions

Opportunities to reduce emissions within the shipping industry include:

- **Fuel alternatives** such as hydrogen or LNG;
- **Exhaust cleaning technologies**;
- **Alternative propulsion** such as electric engines and batteries for electricity storage onboard, or wind propulsion;
- **Operational changes** such as slow steaming; and
- **Increased efficiency in ports** through shore power or reduced waiting time.

The most commonly used fuel in the past has been **Heavy Fuel Oil (HFO).** Due to its sulphur content of 3.5%, it will no longer be an option under the new sulphur regulation. Hence, other fuels provide a feasible alternative. One option is **Marine Diesel Oil (MDO),** which has a sulphur content of 0.1%. It does not require any changes to the engine and is widely available but is much more expensive than HFO.

Another option is **Liquid natural gas (LNG).** LNG is generally cheaper than either type of fuel and it allows reducing sulphur dioxide and PM emissions by 99%, nitrogen dioxide by 85% and CO_2 by 20% compared to regular fuel[139]. Until recently, LNG was used mainly for smaller vessels or ferries, or ships were designed as LNG-ready, allowing an easy transition from fuel to LNG. The adoption of LNG technology largely depends on the availability of LNG infrastructure in ports. Currently, LNG is available to vessels in 93 ports globally, with an additional 54 ports in the process of implementing LNG infrastructure[140]. LNG is likely to also play a key role in container shipping, as CMA CGM, a French container transportation and shipping company, planned 9 LNG-powered 23,000TEU vessels. The first one launched its maiden voyage in September 2020.

Hydrogen may provide another fuel alternative in the future, as it has already been used for smaller boats, research vessels or ferries. To date, there is no hydrogen-powered container vessel but according to a recent study by the International Council on Clean Transportation (ICCT) it has the potential to power almost all container shipping across the Pacific Ocean[141]

To comply with the **new sulphur regulation**, ship carriers can also install exhaust cleaning systems (scrubbers) on-board. **Scrubber systems** can help making ships compliant with new sulphur regulations by cleaning the exhaust. This means ships do not have to buy the more expensive low-sulphur fuel (MDO) but can continue to burn cheaper HFO and keep their emissions below cap. Overall, scrubber systems can help reduce CO_2 emissions by **3%** (see Table 12).

Lower emissions can also be achieved through different modes of propulsion. **Alternative propulsion** through electric power is being tested and implemented on smaller vessels, such as passenger ferries. Examples are the Danish ferry Ellen or the Norwegian Ampere car-ferry. For large vessels like container ships, electric propulsion is unlikely to be feasible. Instead, larger vessels may benefit from **wind propulsion** installed in addition to the main engine. At sea, sails can be set to

[139] Link-Wills, K. (2020). Largest LNG-powered container ship making maiden voyage. American Shipper.
[140] Greenport (2020).
[141] Collins, L. (2020). Hydrogen can power virtually all container ships crossing the Pacific.

contribute to propulsion, and depending on wind conditions, this may reduce fuel consumption by **up to 80%**, according to UK-based company Windship Technology[142].

Alternatively, **air lubrication**, developed by Silverstream Technology, creates a flow of small air bubbles along the bottom of the ship which reduces water resistance. According to Silverstream, this can lead to **fuel savings of 5 to 10%**[143]. For a smaller vessel this means CO_2 emission reductions between 274 and 548 tonnes on the journey between Felixstowe and New York, saving between £18,000 to £36,000 of external cost of CO_2. A large vessel (19,200TEU) using this technology could save between 515 and 1,030 tonnes of CO_2; resulting in £33,500 and £67,000 lower external costs per journey; equivalent to 111 up to 223 fewer cars on the road for a year.

Improving on-ship operations also has the potential to reduce emissions. The highest efficiency gain can be achieved by **reducing speed,** also called slow steaming. Since fuel consumption increases exponentially with speed, lower speeds can achieve emission reductions of up to **30%.** Using smarter **navigation or autopiloting** systems can increase efficiency by **1-4%.**

Table 12 Potential Technologies for Efficiency Increase

Area	Technology	Potential for fuel/CO2 reduction
Propulsion	Wind propulsion	Up to 80%
Operational	Weather routing	1-4%
	Autopilot upgrade	1-3%
	Speed reduction	10-30%
Other	Scrubber systems	3%
	Air lubrication	5-10%

Source: U.S. Department of Energy[144], Odense Ship Steelyard[145]

Shore power is one of the main ways to reduce GHG emissions within the ports and nearby cities. While ships are at berth, they require power for unloading cargo or hotelling activities (electricity, water, kitchen) and rely on auxiliary engines. Depending on the type and size of ship, a significant amount of GHGs is emitted through the auxiliary engine in ports. Shore power allows ships to connect to the local electricity grid so they can switch off the auxiliary engine. If shoreside electricity is generated with less emissions than the auxiliary engine emits, GHG emissions can be reduced. Studies found shore power could reduce emissions of ships at berth in the UK by 25% for CO_2, 46% for SO_2, and 92% for NO_x[146].

Shore power is particularly interesting for cruise ships, since their hotelling activities at berth require a significant amount of energy. But it may also be relevant for oil tankers and container ships, since they require the second and third largest share (respectively) of electricity among vessel types while at berth[147]. Shore power has already been implemented in several ports around the world. Among others, the Ports of San Diego, Los Angeles, San Francisco, Vancouver, Hamburg or Oslo offer shore power for cruise vessels, while container ships can access shore power at the Port of Antwerp, Oakland or Los Angeles.

Another option to reduce carbon emissions in ports is by reducing the time ships spend in ports. Making operations in the port or terminal more efficient will lower emissions and external costs.

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142 Windship Technology website
143 Silverstream Tech website
144 Eia. (2015). Marine fuel choices for ocean-going vessels within emissions control area.
145 Odense Steel Shipyard Ltd (2016).
146 Hall (2010). Assessment of CO2 and priority pollutant reduction by installation of shoreside power.
147 Winkel et al. (2016). Shore Side Electricity in Europe: Potential and environmental benefits.

Smarter port management, e.g. with software such as PortXChange in the Port of Rotterdam, may also contribute to better time management and lower emissions.

Abatement Costs

To use **shore power**, the required infrastructure needs to be installed both on ship and in the port. The cost of installing in ports is estimated at around £1.2m to £2.7m per port[148 149]. If the local power grid does not support the additional electricity demand, further infrastructure adjustments outside of the port may be required. In the case of the Port of San Diego, this amounted to £25m[150]. For ships, the cost of retrofitting the necessary equipment can range from £232,000 to £1.5m[151]. For new builds the costs would be slightly lower since installation costs are less.

Switching fuels to comply with the new sulphur regulations does not require any additional installation, but on average the price differential in 2019 was above US$200 or £155 per tonne of fuel, with **average prices of HFO and MDO at £325 and £500 respectively**. LNG is available at lower cost than both MDO and HFO but the required infrastructure at ports is not yet available. Powering ships with LNG also requires higher on-board installation costs.

For **scrubber systems**, the cost of equipment required on ship is estimated between £0.8m and £4.7m, with installation costs for retrofits amounting up to £1.6m. Thus, total costs can range from **£1.6 to £6.2m**. However, ships with scrubber systems installed require **1.5-2% more fuel**.

Depending on fuel type and ship size, it can still be beneficial to install scrubber systems rather than switching fuel. Additional costs from **switching to MGO** fuel assuming a £155 price differential per tonne are **£2.6m annually**, while additional costs for **scrubber system** amount to **£1.4m per year** for a vessel of 8,500TEU and a vessel speed of 17-18 knots.

In terms of additional annual cost per TEU capacity of a medium-sized ship (around 8,500TEU), additional fuel costs are £51/TEU while installing scrubber systems costs £20/TEU. For smaller vessels (4,500TEU), annual costs of a fuel change are £47/TEU compared to £56/TEU for scrubber systems; for large vessels (13,100TEU) £38/TEU for a change in fuel and £24/TEU for installation of scrubber systems.

5.4.1 Results – at sea

The amount of CO_2 emissions, and hence the external cost that can be saved at sea through an efficiency gain, depends on the size of the ship, the speed, and the voyage length. On a shorter journey, e.g. from **Barcelona to Antwerp** (2,146 NM), CO_2 emissions can be reduced by **31 tonnes** for a smaller vessel (5,500TEU) and **58 tonnes** for a large vessel (19,200TEU) for each 1% efficiency gain (see Figure 30). On longer journeys, such as the **Europe-East Asia** Trade Route (Rotterdam-Singapore, 9,343 NM), emission reductions range from **134 tonnes** for a smaller vessel to **252 tonnes** of CO_2 for a large vessel (see Figure 30). This is equivalent to 30 to 55 fewer cars on the road for one year for each 1% fuel saved per trip.

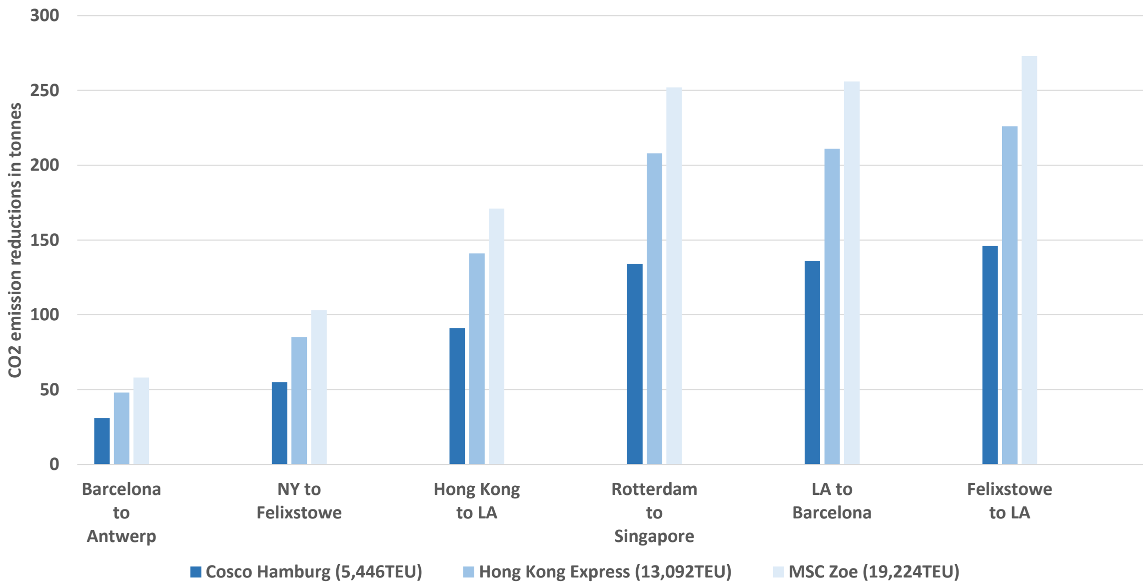
[148] Johnson and Styhre (2015). Increased energy efficiency in short sea shipping through decreased time in port.
[149] All abatement costs are based on an 0.77£/US$ exchange rate (15.10.2020)
[150] Wang, H, Mao, X and Rutherford, D (2015). Costs and benefits of shore power at the port of Shenzhen.
[151] All abatement costs

Table 13 CO₂ and external cost avoided per trip with 1% efficiency gain at 20 knots

	Cosco Hamburg	Cosco Hamburg	Hong Kong Express	Hong Kong Express	MSC Zoe	MSC Zoe
Trip	tCO2	£	CO2	£	CO2	£
Barcelona to Antwerp (2,146 NM)	31	£1,999	48	£3,100	58	£3,757
NY to Felixstowe (3,826 NM)	55	£3,565	85	£5,527	103	£6,698
Hong Kong to LA (6,363 NM)	91	£5,929	141	£9,192	171	£11,139
Rotterdam to Singapore (9,343 NM)	134	£8,705	208	£13,497	252	£16,355
LA to Barcelona (9,508 NM)	136	£8,859	211	£13,735	256	£16,644
Felixstowe to LA (10,153 NM)	146	£9,460	226	£14,667	273	£17,773

Source: London Economics

Figure 30 CO2 emission reduction for 1% efficiency gain at 20 knots

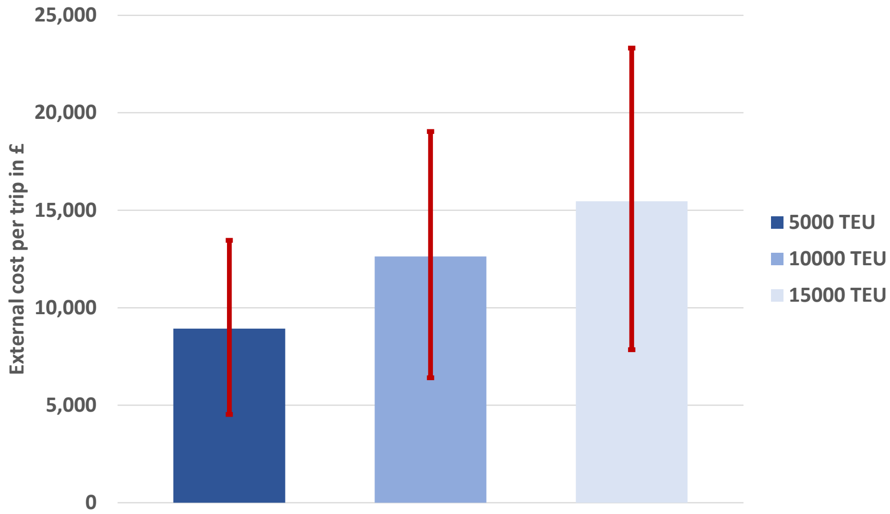


Source: London Economics

Depending on which external cost estimation for a tonne of CO_2 is used, the results per trip may differ. Figure 31 displays the range for external costs that can be saved for low, central, and high external cost estimates per tonne of CO_2 (£33, £65, £98 respectively)[152]. For a small vessel (5,000 TEU), external cost savings range from £4,500 to £13,500; for a large vessel (15,000 TEU) they range from £7,900 to £23,300 per trip.

[152] BEIS. Valuation of carbon emissions.

Figure 31 External cost savings for low, medium, and high external cost



Note: 10,000NM trip at 20 knots, 1% efficiency gain. The red bars show the lower and upper estimates based on DEFRA values.
Source: London Economics

5.4.2 Results – in port

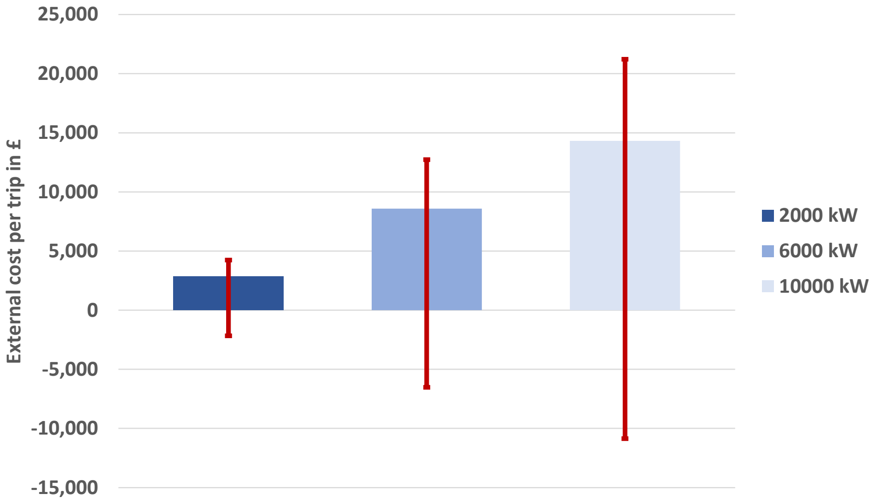
Table 14 CO_2 and external cost avoided by using shore power, UK Energy Mix 2019

	Cosco Hamburg (5,446TEU – 4,000kW)	Cosco Hamburg (5,446TEU – 4,000kW)	Hong Kong Express (13,092TEU – 7,000 kW)	Hong Kong Express (13,092TEU – 7,000 kW)	MSC Zoe (19,224TEU, 16,000kW)	MSC Zoe (19,224TEU, 16,000kW)
Trip	**tCO2**	**£**	**CO2**	**£**	**CO2**	**£**
25 hours	46 t CO2	£2,984	80 t CO2	£5,222	184 t CO2	£11,936
48 hours	88 t CO2	£5,729	154 t CO2	£10,026	353 t CO2	£22,917
65 hours	119 t CO2	£7,758	209 t CO2	£13,557	477 t CO2	£31,033

Source: London Economics

The potential CO_2 emissions that can be saved by switching to shore power range from **46 to 119 tonnes for a smaller vessel to 184 to 477 tonnes of CO_2 saved for a very large vessel** (see Table 14) based on the duration spent at the port. Depending on the source of electricity used for shore power, the savings may be even larger. If ports use renewable energy, e.g. by generating solar or wind energy, the carbon emissions per kWh will be even lower than those from the national grid (247g_{CO2}/kWh for national grid in 2019; 85g_{CO2}/kWh for solar; and 26g_{CO2}/kWh for wind), as seen by the upper bounds in Figure 32. Depending on the source of electricity used for shore power, the external cost savings may be negative as seen by the lower bounds in Figure 32 when lignite is used to produce shoreside electricity.

Figure 32 External cost savings for different shore power energy sources



Note: Upper bound wind; lower bound lignite; £65 external cost per tonne of CO_2 and 48h spent at port. The red bars show the lower and upper estimates based on DEFRA values.
Source: London Economics

5.4.3 Ecosystem

Next to air pollution, shipping and the maritime industry contribute to further environmental problems. These include:

- Pollution by **oil** or **bilge water;**
- Noxious substances (e.g. from anti-fouling paint);
- **Sewage** from ships;
- **Garbage** from ships; and
- **Ballast water.**

Oil spills harm marine animals such as birds, mammals, fish and shellfish either by impairing their physiological functions or through chemical toxicity, which can have lethal effects. Highly viscous oils (HFO) affect the marine environment mainly through smothering, while lighter oils have more toxic effects. Key organisms may be lost, leading to ecological changes and potential takeover of habitats by opportunistic species. Commercially important species may suffer from population declines or become too contaminated for consumption. For the Exxon Valdez Oil Spill in Alaska in 1989, the social costs have been estimated to be around £485 per gallon of oil spilled[153]. The social costs include clean-up costs, criminal fines, economic damages, civil settlement costs, but not environmental costs. In the case of the Prestige oil spill off the Spanish coast in 2002, the overall costs are assumed to be £2,040m in the short run and £7,700m[154] in the long run[155].

Recent advances in **oil spill clean-up technologies** include clay sponges to draw out oil, high speed skimming vessels, magnetic soap, or oil filtration machines[156]. Earth observation can also contribute

[153] Cohen (2010). A taxonomy of oil spill costs.
[154] At an exchange rate of 0.91£/€ (18.10.2020)
[155] Liu and Wirtw (2006).
[156] Butler (2020). 6 of the latest advances in oil spill cleanup.

to mapping oil spills and providing real-time data required for clean-ups or monitor illegal discharges from ship traffic or offshore operations.

Fouling on the hull of the ship through marine organisms can significantly enhance hull drag, thereby increasing fuel consumption. To avoid this, **anti-fouling paint** is used to hinder marine growth. However, the release of biocides from anti-fouling paint into the water can result in environmental harm.

Ballast water is problematic for marine ecosystems because it transports aquatic organisms from one region to another, where non-indigenous organisms can cause harm to the local environment. To mitigate environmental damage, the **IMO Ballast Water Management Convention** requires all international sea going ships to implement a ballast water management plan as of 2017[157]. Several UK companies have developed advanced ballast water treatment systems to help ships comply with the regulations and reduce damage to marine ecosystems[158].

To mitigate the dangers to the marine ecosystem from shipping, the **International Convention for the Prevention of Pollution from Ships (MARPOL)** was established by the IMO in 1973[159]. It requires ships to have waste, ballast water, or garbage management systems for ships above a threshold of 12m or 400 gross tonnes.

Despite regulations, all forms of pollution can happen still by accident, or deliberately to save costs. Thus, regulations needs to be strictly monitored, e.g. by aerial surveillance and satellite imagery by the EU Joint Research Centre[160].

5.5 Safety impacts

Accident data from January 2012 to September 2019 is published by the **European Maritime Safety Agency** (**EMSA**). The data includes accidents which took place in **EU28 countries**[161]. Additionally, statistics identifying accident causes from the European Marine Casualty Information Platform (EMCIP) are used to identify the proportion of accidents caused by different ship operations.

Heii and Knapp (2016) estimate global annual insurable value of the maritime industry as US$30.6 trillion (£23.9 trillion[162]). General cargo ships and passenger ships have estimated insurable values of US$69 million (£53.8 million) and US$10 million (£7.8 million) respectively, excluding the value of lives. Vessels categorised as ‘other’ are valued at US$17 million (£13.3 million).

According to EMSA, general cargo ships were the main category involved in a marine casualty or incident (43.8%), followed by passenger ships (23.7%) during the 2011-2018 period. These estimates are used to calculate the cost of accidents. All ships which fall outside cargo and passenger ships are categorised as other.

The total cost of accidents depends on the number of injuries, lives lost, seriousness of the accident and the type of vessel involved. The total cost of maritime accidents between January 2012 and September 2019 is estimated to be **£7.2 billion**. This figure represents the cost of 634 very serious casualties, 7,790 people injured, 655 lives lost, damages to 26,584 ships, and the total insurable

157 More about ballast water management
158 Cathelco, Chelsea Technology, Cleanship, Cold Harbour Marine
159 UK Government. Prevent pollution and reduce harmful emissions at sea.
160 EU JRC publication repository
161 JRC (2009). Long Term Monitoring of Oil Spills in the European Seas.
162 An exchange rate of US$1/£0.78 is used based on the exchange rate on 15/10/2020

value of the 215 ships sunk[163]. Ship damage is estimated as **0.2% of the total insurable value** of the ship[164] excluding the value of statistical life of persons on-board[165], totalling **£1.7billion** between January 2012 and September 2019.

Estimates of the total value of maritime casualties which could have been prevented by automated mooring systems, autonomous vessels, on-board technology and automated cargo handling is estimated to be worth **£5.1 billion** in the EU 28 since 2012, equivalent to **72%** of the total cost of maritime accidents over the same period.

Implementing real time alerts by using advanced technologies could help reduce the number and severity of accidents.

Table 15 Value of accidents to ships by ship operation and technology solution.

Ship operations	% of accidents	Value of accidents	Technology solution
In passage – displacement/non-displacement/Transitional model	35%	£2.4bn	Fully autonomous vessels / ships with automated processes and decision support
Fishing[166]	13%	£0.9bn	N/A
Manoeuvring / Turning	13%	£0.9bn	Autonomous vessels
In passage – other[167]	12%	£ 0.8bn	Autonomous vessels
Unknown	5%	£ 0.3bn	N/A
Berthing/Unberthing/Shifting berth	5%	£ 0.3bn	Automated mooring systems
Special service[168]	4%	£ 0.3bn	N/A
Loading / Unloading	4%	£ 0.3bn	Terminal automation and cargo handling
Anchoring	3%	£ 0.4bn	Autonomous vessels
Other	2%	£ 0.3bn	N/A
Repairing/Maintenance	2%	£ 0.2bn	N/A
Sailing	1%	£ 0.1bn	N/A
Emergency[169]	0%	£ 0.01bn	N/A

Source: London Economics

5.5.1 Automated mooring systems

Mooring operation is an essential task performed by seafarers and dockworkers. It can be a dangerous operation and is prone to human error. The estimated cost of accidents caused by mooring activities is **£327m.**

[163] The value of lives lost and injuries are estimated using DfT data. TIV data is used to estimated damages to ships involved in accidents. Where a ship sunk, the full TIV excluding lives is used to estimate damages.
[164] GIRO Conference and Exhibition (2012). Juggling Uncertainty, the actuary's part to play.
[165] The value of persons on-board the ship is excluded from the calculation as the cost of injuries and lives lost are quantified separately using DfT data.
[166] Fishing accidents include gutting fish, handling fish, stowing fish, towing fishing gear, shooting fishing gear, hauling fishing gear, preparing fishing gear, and stowing fishing gear.
[167] In – passage other includes alongside, at anchor, ballasting, cleaning/washing, embarking/disembarking people, moored, open/close door, hatches, etc., starting/stopping engine and under pilotage.
[168] Special service activities include Disposal of residues, dredging, drifting, fuel change-over, hove-t/dodging, idle, off-hire, in icebreaker assistance, inerting, on watch, ship-to-ship gas freeing, stripping, transfer of cargo drilling, ice breaking, guard ship operations, windfarm operations, fish farm operations, replenishment at sea operations, towing/pushing, trials/drills/tests, purging.
[169] There is not a clear definition of this category available

Automated mooring systems can reduce risks associated with mooring by removing the human element form the operation completely. This new technology can move the vessel out of the dock or into the harbour, only needing the ships officer to select a destination[170].

The Port of Turku in Finland is implementing an automated mooring system provided by Cavotec. The system will be able to service a 218-metre long berth. A similar system was installed in the Port of Helsinki in 2016 and is said to have performed 5,000 moorings since its introduction[171]. These systems provide several benefits including improved safety, reduced mooring times and a reduction in the amount of vessel motion, fuel consumption and ship emissions.

AutoMoor have developed technologies that enable a faster berthing process by using vacuum technology to attach and secure a vessel at berth eliminating the need for mooring lines, saving money and time in faster product transfer. This technology improves safety within the port environment as it reduces personnel involvement, reducing human error and exposure. The technology also limits the vessels motions during the berthing process and monitors the mooring loads on the berthing vessel[172].

A similar smart docking solution has been developed by Wärtsilä, a smart technology provider for the maritime sector. The system improves safety and efficiency by reducing the potential for human errors resulting from ship officers having to manoeuvre the vessel. The system requires the ship's captain to select the destination, after which the system takes over and either moves the vessel out of the dock or into the harbour without the need for human intervention[173]. Open ports are also addressing challenges associated with mooring, innovative technology is being deployed which can keep vessels in place in rougher conditions. The system secures and responds to the movements of the vessel to ensure safer loading and unloading of goods[174].

Safety innovation is not only occurring in the automation of systems, but also in essential equipment like ropes. When a mooring line holding a docked vessel snaps, the abrupt energy release can cause the rope to whip across the dock and ship at a speed of almost 500 MPH which can cause serious accidents resulting in fatalities or cause damage to port facilities. Maersk and TIMM Ropes have developed Snap Back Arrestor (SBA) ropes which features a special core that elongates more than the surrounding rope, acting to absorb and dampen the energy released when mooring ropes break while under strain. Instead of the rope snapping back, the SBA rope will drop to the ground when broken.[175]

Mooring ropes can break because crewmembers do not take appropriate measures to prevent rope damage from adverse weather and sea conditions. Visual inspections cannot always identify damage or deterioration to ropes. Mitsui O.S.K. Lines (MOL), Teijin Limited, and Tesac Corporation have developed smart ropes which feature in-built sensors that monitors the status of ropes enabling crew members to determine the tension and strength of ropes more accurately. MOL plans to leverage its knowledge and adopt technology utilising the Internet of Things (IoT) to develop a more advanced mooring system, further boosting the effectiveness and safety of its operations, and reducing vessels' environmental impact[176].

[170] One such example is the Wärtsilä's SmartDock solution.
[171171] Olujide. (2019). Cavotec to Deliver Automated Mooring to Finnish Port.
[172] Olujide. (2019). Trelleborg's Smart Mooring Tech to Boost Finland Port.
[173] Olujide. (2019). Wärtsilä Reveals Automated Docking Technology.
[174] Deltares. (2019). Validation tests for innovative mooring technology in ports of the future.
[175] Port Technology Innovation. (2020). Maersk implements mooring innovation.
[176] Olujide (2019). MOL to Demonstrate Smart Mooring System.

5.5.2 Automated vessels

According to an Allianz study, human error is responsible for between **75% and 96%** of marine casualties. Similarly, EMSA found that human action (such as inappropriate manoeuvring or fatigue) represented **65.8%** of accidents[177]. Autonomous vessels have the potential to increase the operational safety of ships by minimizing accidents due to human error[178] and reduce shipping costs associated with accidents. The estimated cost of accidents between January 2012 and September 2019 which could have been avoided by deploying autonomous vessels is **£4.3 billion**[179]**.**

Countries like Japan and the Republic of Korea are investing heavily in developing autonomous navigation systems to reduce workloads of seafarers to reduce the risks of accidents. Japan is focusing on autonomous navigation/collision avoidance, remote control navigation, and automated berthing while the Republic of Korea is investing approximately US$130 million between 2020 and 2025 in autonomous navigation systems.

Ocean research non-profit ProMare and IBM developed the Mayflower Autonomous Ship (MAS), a fully autonomous AI and solar powered marine research vessel. The vessel is designed to traverse oceans gathering vital environmental data to enhance the understanding of critical issues such as global warming, micro-plastic pollution and marine mammal conservation. The vessel features an "AI Captain" able to sense, think and make decisions at sea with no human captain or onboard crew. The onboard technology is able to scan the horizon for possible hazards, make informed decisions and change its course based on live data. A portal was also developed by IBM to provide real-time updates about the ship's location, environmental conditions and data from its various research projects to the public. Live weather data will be streamed from The Weather Company, as MAS is receiving forecast data[180].

Safety is being improved in the surveillance of offshore structures using Autonomous Guard Vessels (AGV). AGVs can continuously monitor nearby marine traffic visually and by using radar and AIS data. Any intruding vessels can be given information on how to safely navigate the area as well as being physically escorted away from the site by the AGV[181].

Autonomous vessels rely on connectivity and companies such as Roll-Royce Marine and Iridium are working together to increase the reliability of connectivity with the introduction of an L-band satellite broadband service. This satellite technology aims to enable connectivity between vessel and shore or vessel-to-vessel in a remote and autonomous system which increases system reliability and mitigates the risk of power outage or other network infrastructure related incidents. The technology is able to work in all types of weather and works globally, including ships traveling along northern sea routes[182]

Remotely controlled vessels without seafarers on-board

Crew on-board vessels are exposed by a number of risks due to their working environment. Crew often face injuries and fatalities from normal shipping operations due to slipping and falling, loss of control of machinery and materials on-board becoming loose or falling. The estimated value of injuries and fatalities between January 2012 and September 2019 is **£1.4 billion**.

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[177] EU EMSA
[178] Research and markets (2020). Global Autonomous Ships Market: Growth, Trends and Forecast to 2025.
[179] This estimate is derived using figures from the table above.
[180] IBM. (2020). Mayflower Autonomous Ship Launches.
[181] Port technology innovation (2020). Sea Machines unveils new concept Autonomous Guard Vessel design.
[182] Werner (2018). Satellite operators offer communications for autonomous ships.

Technology which enables ships to be controlled remotely is being deployed by multiple manufactures. These innovations illuminate the need for crew on-board, minimising the risk of human error and eliminating risks of crew sustaining injuries on-board.

The Remotely Operated Service at Sea (ROSS) project is an initiative developed by offshore services operator SeaOwl to further remote-control vessel technology. The technology, which is already deployed within military ships, enables the vessels crew pilot the ship from land this results in cost savings and eliminates the risks which crew would be exposed to on-board the vessel. SeaOwl is partnering with Marlink who can provide a special purpose highly resilient satellite network solution for the ROSS project[183].

Hydrography, marine geophysics and oceanography are high-risk activities generally consisting of crew working aboard small survey vessels in changing marine environments. An autonomous survey vessel owned by Netherlands-based survey company Deep BV will soon be operating in the Wadden Sea. The vessel, supplied by Sea Machines Robotics Inc., can be remotely controlled and monitored from a shipboard or shore-based centre located anywhere with network connectivity. The Sea Machines SM300 autonomous control system will enable remote command of the vessel, including navigation and positioning, the control of on-board auxiliaries and sensors, and ship-to-shore data flow. The system reduces several inefficiencies by enabling personnel to focus less on recurring and repetitive tasks, and more on value adding tasks; eliminating the need for a conventional 1:1 relationship between a survey crew and vessel and improving vessel tracking precision. This technology can be installed in existing vessels reducing the need for investment in terms of cost and time.[184]

Ships with automated processes and decision support

Collisions represented 16% of accident caused between 2012 and 2019, this would equate to **£626m** using our total value of avoiding incidents between January 2012 and September 2019 above.

An AR navigation system developed by Mitsui O.S.K. Lines (MOL) is being used to reduce the number of collisions. The system alerts mariners to nearby vessels that could pose a risk, as well as shallow sea areas and other potential hazards. Seafarers can ensure they are on course using the real-time video course information derived from nautical instruments[185]. IBM's vision recognition systems will help identify other ships, debris, whales, and icebergs, while an AI-enabled “captain” will command the vessel reducing the number of collisions[186].

Identification of obstacles in the ships path can reduce the number of collisions and improve safety in passage. The SPx Server is a radar tracker which combines multiple echoes from large ship reflections into single plots. Additional information is provided by the tracker including target track identification, heading and speed. The software supports multi-hypothesis and multi-model tracking to improve tracking efficiency and reduce nuisance alarms. In order to integrate the technology into existing infrastructure, developers designed it to operate with many different radar types from multiple manufacturers[187].

Decision support is also being introduced on vessels to make the maritime industry safer for everyone. Start-ups, such as Shone, are using the power of AI to facilitate crew decision-making on-

[183] The digital ship
[184] Blenkey (2020). Sea Machines autonomy selected for unmanned Wadden Sea surveys.
[185] Port Technology. MOL to Lead the World in AR Navigation.
[186] International shipping news (2020). Autonomous ships are about to set sail — into choppy waters.
[187] Cambridge pixel (2019). Cambridge Pixel Supplies Radar Tracking & Display Technology to Marico Marine for Port of Dover Contract.

board vessels through decision support, maritime safety and piloting assistance[188]. Voyager Worldwide, a leading maritime navigation solutions provider, announced a major upgrade to its Voyager planning station. The new system will include automation of route and passage planning, information sharing between ship and shore and new interactive guided workflow processes to reduce operational risk and streamline navigation processes resulting in increased safety and more effective vessel management. The new system also automatically delivers digital and paper Notices to Mariners on-board as soon as they available[189].

Credit: Lakeview Images/Shutterstock.com

Autonomous ships introduce challenges for current legislation, infrastructure, and established operations. Maritime Autonomous Surface Ships (MASS) involves the automation of vessel and onboard processes which could alter how ports and ships interface with each other. Port authorities from China, Denmark, Finland, Japan, the Netherlands, Norway, Republic of Korea, and Singapore have established a network called MASSPorts to address the challenges of making ports ready for autonomous shipping. The network believes that vessels and ports must be equipped with infrastructure that has common terminology, forms, and standards of communication, ship reporting and data exchange to enhance inter-operability of systems across different ports and for seamless operation. The network outlined goals that are designed to address the challenges of implementing autonomous technologies and achieve alignment of standards for the operation of MASS in ports. They will seek to develop detailed guidelines and conditions for MASS trials in ports, including agreeing on the conditions for MASS trials and working within the IMO's interim guidelines for MASS trials. Representatives from the IMO, International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) and the International Association of Ports and Harbours (IAPH) are also involved in the network[190].

Autonomous ships may introduce complications in maritime regulations, but AI can help ensure vessels are incompliance of regulations by detecting irregularities in the vessels operation such as ship to ship transfers, course deviations, transmission gaps, flag hopping, enabling the maritime sector to make better and faster decisions, enhancing operations and increasing efficiency. Windward, a maritime intelligence company, released a Maritime Predictive Intelligence solution powered by Maritime Artificial Intelligence Analytics (MAIA™). The technology consists of 10 billion

[188] International shipping news (2020). Autonomous Shipping: Trends And Innovators In A Growing Industry.
[189] The digital ship
[190] The maritime executive (2020). New Network Supports Port Readiness for Autonomous Shipping.

datapoints and 300 behavioural analysis models. The system helps stakeholders manage risk associated with shipping by screening, searching and analysing maritime data to identify potential treats and high-risk business partners. This technology increases transparency in the shipping sector and has use for a number of stakeholders, including authorities, banks, insurers and shipping companies[191].

Autonomous systems present challenges for underwriting risks, these challenges are exacerbated by the uncertainty surrounding interaction between humans and these new technologies. into international conventions such as the International Convention for the Safety of Life at Sea (SOLAS), the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), and the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs)[192]. The insurance sector is trying to break down barriers associated with introducing autonomous vessels. Lloyd's Register (LR) and the UK's National Physical Laboratory (NPL) are collaborating to establish and enhance the current body of knowledge on maritime autonomy. The aim is to clarify the requirements for the assurance of autonomy and assist stakeholders in realising the potential of these systems in the market. This will enable risk management practices and autonomous vessel certification to be consistently applied[193].

Insights from incident data using AI technology can assist in helping insurers establish products for autonomous vessels and help health and safety bodies address risks in the shipping sector. Lloyd's register had partnered with STC global to combine Natural Language Processing AI and root cause analysis technologies to help the Health and Safety Executive (HSE) to better understand and identify the underlying causes of accidents, enabling the HSE to address issues efficiently and in an efficient manner. The tool will identify past, present and potential future incidents to establish trends, patterns, systemic problems, and latent dangers. Combining Natural Language Processing AI and root cause analysis technologies will allow the system to identify recurring causes and map out hazards and trends, enabling the industry to focus on strategies to prevent incidents and create a safer work environment[194].

Autonomous ships have the potential to increase safety but also introduce risks within the maritime sector, as the technology has yet to prove its ability to increase safety, work consistently and integrate with established working practices. There is uncertainty surrounding the interactions between manned and unmanned ships. Individuals may employ different behaviour when sailing near unmanned vessels which might lead to the need for specific routes for autonomous ships. Similarly, operators of leisure crafts may need to be educated and legislation may need to be introduced to reduce the risk of accidents which could potentially be caused by these vessels.

Maritime industry players such as Maersk, COSCO and Austal and the ports of Barcelona and San Diego have been subject to cyber-attacks. Increasing reliance technology systems never seen before means that malware could have a huge negative impact on business and put lives at risk, especially in the case of automated technology. CEOs contributing to the Global Maritime Issues Monitor 2019 listed cyber threats as one of the issues they felt least prepared to tackle.

As the risks of cyber-attacks are so high[195], companies and governments are seeking to build solutions to this issue. Recently, the Korean Register presented Hyundai Heavy Industries (HHI) with

[191] Windward (2020). Windward Launches AI-Powered Predictive Maritime Intelligence Solution to Optimize Business and Mitigate Risk at Sea.
[192] Olano (2019). Marine insurance rides the technology wave.
[193] (2020). LR and the National Physical Laboratory partner on marine autonomy assurance.
[194] Safety4sea (2020). Partners to use AI to unlock insight from vast amounts of incident data.
[195] David McCandless. Ransomware attacks infographic

the world's first Cybersecurity (CS Ready) class notation for a very large liquefied petroleum gas (LPG) carrier. The notation is issued to new ships that successfully pass 49 inspection items in a total of 12 categories, including risk and asset management, cyber incident response and recovery[196].

5.5.3 Terminal automation and cargo handling

According to the EMSA database, accidents involving the loading and unloading of cargo represented 4% of accidents since 2011. The total value of avoiding these accidents is estimated to be worth **£251m**.

Risks associated with cargo handling are increased due to the presence of hazardous materials. Misdeclaration of hazardous cargo has been at the root of major marine incidents, causing loss of life and severe damages. In 2019, several carriers announced the imposition of additional fees as a partial solution for this recurring problem. ZIM, a shipping services company has developed screening software in China, the US and Israel to detect incidents of mis-declared hazardous. The AI based software uses Natural Language Processing (NLP) and machine learning to analyse documentation and alert operations personnel of occurrences of omission, concealment or erroneous declaration of hazardous cargo in real time[197].

Credit: Pxfuel

5.5.4 Safety on-board vessels

According to EMSA statistics, 4% of accidents are due to flooding/floundering, costing the sector **£377m** between January 2012 and September 2019. On-board technology is introducing further safety measures in the maritime sector. The NAPA Loading Computer Type Four[198] enhances safety in flooding emergencies and provides a vessel's master with more information to ensure a safe return to port. It also now calculates damage stability associated with an actual loading condition and/or actual flooding cases by using the direct application of user or sensor defined damage to enable safe return to port. This computer technology has gained approval of damage stability functions and is IACS Type Four compliant[199].

Enhanced communication capabilities onboard vessels can improve accident awareness and reporting, making vessels a safer work environment. Rohde & Schwarz, an electronics company, partnered with NTT Communications Co. Ltd. to provide a secure interference communications system for the Philippine Coast Guard. The system will be integrated into new response vessels built by Mitsubishi Shipbuilding Co. Ltd. and financed by the Japanese government as part of their

[196] Digital ship (2020). KR issues first cybersecurity class notation to HHI for very large LPG carriers.
[197]Port technology (2020). ZIM launches AI-based system to detect cargo misdeclarations.
[198] NAPA computer type 4
[199] Siltanen (2020)., Evolving ship stability for passenger safety.

Maritime Safety Capability Improvement Project. The new IP-based technology will control all shipboard communication and connect on-board voice terminals as well as all other subsystems for internal and external communications via a uniform IP network, allowing secure communication between voice terminals, smartphones and on-board/off-board telephony services, as well as close integration with the broadcast and alarm system. Equipment will provide high-speed data transmission, enabling the crew to securely exchange data with the rest of the fleet, shore stations and governmental authorities[200].

Search and rescue technology is also becoming more sophisticated, researchers at MIT have developed a search-and-rescue algorithm which identifies hidden "traps" in ocean waters, where objects and missing people may have converged. This technology developed alongside the Swiss Federal Institute of Technology (ETH), the Woods Hole Oceanographic Institution (WHOI) and Virginia Tech may help first responders quickly zero in on regions of the sea where missing objects or people are likely to be. The algorithm analyses ocean conditions such as the strength and direction of ocean currents, surface winds, and waves, and identifies in real-time the most attracting regions of the ocean where floating objects are likely to converge[201].

Sensing Feeling of London and Scorpio Group shipping company are working together to develop a risk index which maps seafarers' emotional state. The risk index will be developed through video analytics to identify how seafarers are feeling and the risk of giving them control over a vessel.

5.6 Other policy intervention mechanisms

The model only considers the impacts of grant funding and does not consider the other mechanisms we have presented in section 3.6. However, we understand that these interventions could still have an impact on businesses and consumers. This section provides a qualitative assessment of the potential impacts of additional interventions and discuss which assumptions they could affect.

R&D funding and de-risking investment

Our analysis provides the quantitative results of a government funding in smart shipping technologies. It uses the assumption that if companies are given an R&D grant, the returns will be higher than without support. This can be explained by a few mechanisms.

The funding feeding into companies R&D capacities can result in additional physical resources, such as material and test beds for fundamental research, but also in increased human capital e.g. engineers and other workers. We have also seen before that the funding may reduce the project duration, because it can create a shortcut in the research for funding, which in a counterfactual scenario may not even exist.

Government could help in **de-risking** the investment by acting as a guarantor on loans the smart shipping companies may seek to increase their capital investment in R&D. The guarantor scheme could increase the trust given to companies seeking R&D funding and increase their chances to access funding or projects with high capital expenditures. The guarantee, supporting the access to fund, may in turn increase the success rate of projects via a selection of eligible and trusted companies.

[200] Navy recognition
[201] Chu (2020). New MIT Search-and-Rescue Algorithm Identifies Hidden "Traps" in Ocean Waters.

Tariffs and tax reliefs may also influence the diffusion of technology. The support to companies could represent an incentive to include new technologies in their business. This might influence the Bass model specification, potentially seeing a greater imitation rate and resulting in the adoption curve shifting forward in time (the market cap would be attained quicker, and the total additionality would increase).

Facilitating collaborations and partnerships

The openness of **collaboration** (trust, collaboration, and knowledge sharing between stakeholders) can have a strong influence on the transfer of knowledge and the creation of spillovers. Formal and informal relationships between organisations can increase spillover likelihood and magnitude.[202]

The existence of **local clusters** and the participation to wider international programmes also increase the level of collaboration and all type of companies could benefit from such set up. Local enterprise zones bring companies spatially closer together, which could increase the success rate of R&D projects and the diffusion of knowledge. The IPP study has shown that more than 80% of the participants in the programmes have increased their business relationships with their customers, partners, and suppliers. The programme is said to have facilitated the development of collaborative solutions between stakeholders and allowed them to build trust.

The creation of local clusters (like Harwell for the space industry) yields agglomeration effects that are the principal economic benefit of centralisation. These benefits can take the form of spillovers resulting from knowledge sharing, access to specialised labour, development of sector-specific infrastructure or access to customers within supply-chains.[203]

5.7 Summary of results

We have defined 3 **stakeholder groups**:

- SG1: The **technology providers** who invest in R&D to bring new technologies to the market;
- SG2: The **end users** (ports and shipping companies) which may adopt the technologies and improve efficiency; and
- SG3: The **business services providers** who capture a share of the market by supplying support services such as insurances and shipbroking.

And for each group, we assessed the impact of a **£560m R&D investment** over four years from 2021 to 2024 in smart shipping technologies on the following outputs:

- **Industrial outputs**: turnover, GVA and employment;
- **Knowledge spillovers**; and
- **Externalities**: environmental and safety impacts.

[202] London Economics. (2018). Spillover in the space sector.
[203] IPPR. (2019). Decentralising Britain: The 'big push' towards inclusive prosperity.

Table 16 Summary of the results (additionality)

Investment = £560m	Indicator	SG1	SG2	SG3
Industrial effects	**Turnover**	£540m	£983m	£80m
Industrial effects	**Direct GVA**	£275m	£383m	£70m
Industrial effects	**Direct Employment**	3,986 FTE	6,535 FTE	1,017 FTE
Spillovers	**Knowledge**	£56m	None	£0m
Externalities	**Environment**	Not quantified	Not quantified	Not quantified
Externalities	**Safety**	72% of total costs	72% of total costs	72% of total costs

Source: London Economics analysis

6 Strategic choice

6.1 General considerations

The markets for civilian smart shipping technology are for the most part international markets with strong competition along quality and price dimensions, a mix of small and large suppliers, and long-established firms and start-ups. The smart shipping industry has shown capacity for innovation under competitive conditions and progress can be observed along different technology pathways and across all the segments in scope of this study.

However, barriers to entry exist. While economies of scale are generally not an issue (large scale commercial shipbuilding is not considered to be viable within the UK smart shipping sector), there are barriers to access international markets, notably in the form of protectionist measures, state aid, technology barriers, local content requirements and forced technology transfer.

While government action to level the global playing field is desirable, the strategic choice for the UK regarding the pursuit of technology leadership should be governed principally by commercial considerations, i.e. the ability to provide better products and services more cheaply than the competition. This includes the recognition that foreign competitors may enjoy absolute cost advantages in certain segments of the shipping sector (notably in shipbuilding, outside some specialist segments), but also that UK competitive advantage in smart shipping may come from suppliers outside the narrow maritime sector and include areas of strength in the broader professional services market, for example.

6.2 Strategic priorities

The areas in which UK capabilities can be leveraged to achieve substantial and long-lasting benefits from technology and business leadership are:

- The manufacturing and deployment of smaller autonomous vessels;
- Smart shipping sensor development and sensor integration services;
- Smart shipping command and control systems and expertise;
- Smart shipping data and intelligence services;
- Smart shipping cyber security and risk management;
- Training in the adoption and utilisation of smart shipping technologies.

This section explores to what extent there is a first-mover advantage, which may help the government to prioritise its support for the smart shipping sector.

6.3 First-mover advantage

First-mover advantage refers to the benefit, relative to competitors, of being first to market with a new product or service. First-mover advantage can take different forms, but is most commonly thought of in terms of being first:

- to **introduce a new technology** and **acquire new technical know-how**;
- to **acquire a scare resource** without which later entrants cannot compete effectively; or

- to acquire a **customer base** which faces switching costs later on (this is especially relevant in technologies that exhibit **network effects**).

Rigorous identification of first-mover advantage is complex and requires the analysis of the structure of costs and pay-offs as well as the nature of strategic interactions between competitors in a given market environment. Given the uncertainty surrounding these variables in real-world markets, it can typically be determined only in hindsight.

However, the management literature provides useful heuristics regarding the broad market conditions under which first-mover advantage may be more likely to occur. Suarez and Lanzolla (2005)[204] provide a framework for assessing first-mover advantage that takes the pace of market growth and technological development as the key variables. As such it is useful in the analysis of smart shipping technologies, where a global market meets a diverse and dynamic technology landscape.

The key consideration in this framework is that **moving first is expensive** and maintaining a technological edge when the technology is developing quickly even more so. A fast pace of technological innovation moreover provides potential entrants with recurring opportunities to **leapfrog the incumbent**, which means any advantages for first movers are unlikely to persist. This interacts with market dynamics: a fast-growing market is likely to attract investment, which may enable the technology leader to expand more quickly and capture a large market share. On the other hand, a market that is growing slowly allows the first mover to build up production capacity over time with less threat of entry, thereby cementing its position.

The key implications of the framework for the smart shipping sector are:

- Smart shipping in general is **not very conducive to durable first-mover advantage** as the sector is characterised by growth, global reach and technological innovation, which makes it an **arena for dynamic competition**. However, while long-term benefit for early technology leaders may be unlikely, there are worthwhile short-term gains to be had for UK firms;
- To enjoy longer term benefits from moving first in a technology-driven market requires not just being first to market with a new technology, but an **ongoing edge in R&D** to keep ahead of the competition;
- Growing markets favour firms with access to resources that enable them to scale up quickly to meet demand. This includes access to markets, distribution networks, skills, and production capacity. Access to these resources is not necessarily correlated with technology leadership.

The table below summarises the general predictions of the framework. The assessment of six smart shipping segments which are likely to be served by UK suppliers is provided in the following sections.

[204] Suarez, F. F. and Lanzolla, G. (2005). The Half-Truth of First-Mover Advantage. Harvard Business Review.

Table 17 Assessment of first-mover advantage based on market conditions

Market characteristics	Short lived first-mover advantage	Durable first-mover advantage	Smart shipping segments
Technological development: slow Market evolution: slow	Unlikely	Very likely	-
Technological development: slow Market evolution: fast	Very likely	Likely	Training; cyber security & risk management
Technological development: fast Market evolution: slow	Very unlikely	Unlikely	Command & control systems & expertise*.
Technological development: fast Market evolution: fast	Likely	Very unlikely	Small autonomous vessels; sensors & sensor integration services; data & intelligence services

Note: * Scale economies and network effects could create more durable advantage.

Source: Adapted from Suarez and Lanzolla (2005).

6.4 Additional strategic considerations

Additional strategic considerations relate to social objectives in terms of regional employment and value creation in the UK, and sovereign connectivity for the UK within the international trading system:

- Coastal communities in the UK are among the poorest in Europe. The UK's regional disparities are extreme compared to other European countries. The difference in economic output per capita between London and the poorest regions in the UK was multiple times higher compared to its EU neighbours, making the UK the most regionally unequal country in the EU (IPPR, 2019). Relative poverty in coastal areas is especially pronounced in England[205]. Coastal towns in the UK also show a concentration of more broad-based measures of deprivation[206]. The decline of British seaside towns since the 1970s owes more to the decline of domestic tourism than changes in maritime industries.[207] Investment in maritime industries that create employment and increase the value added by coastal economies, is likely to yield disproportionate economic and social benefits for the country.
- The UK's reliance on seaborne imports - around 95% of all import and export tonnage in the UK is transported by sea[208] - means that a high-throughput and reliable port infrastructure is a vital part of the national infrastructure. Investment in the technologies that ensure that this infrastructure functions efficiently and reliably is a valid strategic objective and likely implies a need for the UK to be at least on par with the most advanced international competitors.

6.5 Smart shipping technologies likely to be delivered by the UK

Our research suggests that there are **six** smart shipping technologies that are most likely to be delivered by the UK:

[205] ODI Leeds (2020). Is the UK coast poor?
[206] The English Indices of Deprivation 2019.
[207] House Of Lords Select Committee on Regenerating Seaside Towns and Communities- Report of Session 2017–19. The future of seaside towns.
[208] Department for Transport Statistical Release: UK Port Freight Statistics: 2019.

6.5.1 The manufacturing and deployment of smaller autonomous vessels

Large manufacturing projects outside of naval and specialist vessels are not considered to be viable within the UK smart shipping sector, but there are far more addressable opportunities for the rapid development and deployment of **smaller autonomous platforms (surface and underwater).** The global markets opening for these platforms include scientific research, marine survey, maritime surveillance, and defence. Project Armada's fleet of state-of-the-art Unmanned Surface Vessels – controlled from a base in Southampton – is a truly world-leading initiative and highlights the commercial potential made possible by the breadth of the UK's smart shipping sector. Many consider that the UK's key strength lies in the smaller autonomous companies that were ground-breaking when MASS evolved, as they have the experts within them. These smaller companies **can move faster in niche markets** and tackle those jobs seen to be **'dull, dirty or dangerous'.**

Based on the framework for assessing first-mover advantage, this is a smart shipping segment characterised by fast market growth and fast technological development, in which **short-term advantages could be gained by UK suppliers**. However, future entry by competitors is likely, which will erode profitability. The adequate policy response might be to invest in R&D to maintain broad-based technology leadership, while also supporting scalability to allow suppliers to take advantage of the growing market.

6.5.2 Smart shipping sensor development and sensor integration services

The UK is also very well placed to lead on the development of **sensors designed specifically for smart shipping products and services**. The emergence of marine autonomous systems is creating significant new demand in this area. For example, demand for smaller ruggedised sensors that require less power and for highly skilled sensor integrators who can ensure reliable operation for many months of unmanned or remote operation. Within the broader smart shipping sector, advanced condition-based monitoring systems (whose real commercial benefits lie in AI-driven alerts) require new (and ideally non-invasive) sensors to meet the growing demand for data.

The knowledge and expertise on offer at sites such as the National Oceanography Centre's Marine Robotics Innovation Centre provides a good platform to launch new products and services related to sensors, and there are still considered to be many untapped opportunities within sensor development initiatives not currently focusing on the maritime domain.

The market conditions here are similar to the smaller autonomous vessels segment (fast pace of innovation and fast-growing market) and suggest that a **strategy of investment in R&D** and in capacity to serve a growing market is appropriate, but that this **may not result in a lasting advantage** for first movers.

6.5.3 Smart shipping command and control systems and expertise

One of the key advantages of the NewSpace revolution is the promise of more readily available – and more affordable – satellite communications and data transfer opportunities. Within smart shipping this has benefits for the potential **of remote command and control** – both for the remote piloting of autonomous systems and to support a much broader range of remote advice services on manned ships. Lloyd's register has identified the need to develop classification rules governing shore-based command and control centres, and **this should be considered a priority** to provide the UK with competitive advantage in this area.

The UK is seen to lead on the command and communication aspects of smart shipping technologies, and this should be exploited to cement UK's position as world leading. There was a strong sense that the UK could lead the world on the development of shoreside control centres. A collaborative effort could be made to build control and technology innovation centres in some of UK's key strategic ports, insisting more on those that focus on a particular maritime trade activity. For example:

- Felixstowe port could have a remote centre that revolves around container shipping;
- The Port of London could have a remote centre based around marine insurance, maritime regulation, and maritime law;
- Aberdeen could have a remote centre focussing on the Oil and Gas sectors;
- Plymouth could have a remote defence-orientated centre.

While the technology building blocks in this segment are largely mature, there is a lot of innovation in wider systems design, including human-machine interfaces and new business models for the delivery of seaborne services. However, this segment may turn out to be more of an enabler of other services (a platform), rather than a commercial market in itself. While the market conditions at the moment do not suggest much potential for a commercial first-mover advantage, the potential for UK-developed control infrastructure as a platform business model, with the potential for network effects (e.g. bringing together and coordinating different parts of the transport system), leaves the **possibility that sustainable competitive advantage can be generated**.

6.5.4 Smart shipping data and intelligence services

Within the maritime sector, more sensors will likely collect more data in new ways, and often autonomously. Many sectors are now entering the Fourth Industrial Revolution, which is defined in the UK's Industrial Strategy[209] as being "characterised by a fusion of technologies – such as artificial intelligence, gene editing and advanced robotics – that is blurring the lines between the physical, digital and biological worlds".

New layers of data may lead to the growing potential of **data and intelligence services**. Within the smart shipping sector, data analytics services cut right across the innovation sphere – from condition-based monitoring alerts to autonomous navigation systems to the delivery of smart grid technology as demonstrated in Portsmouth in the Port Energy Systems Optimisation (PESO) project (co-funded by Innovate UK).

Within this sector, several industry respondents identified **blockchain** specifically as a major, cross-cutting area of potential growth within smart shipping data services. In 2019, the U.S.-based Blockchain Council reported that **the UK houses the second-highest number of blockchain start-ups in the world**[210], which provides a good base on which to build.

As with other smart shipping sectors, these areas of capability are not specific to smart shipping. For example, smart structures with embedded optical sensors are widely used, and could be used in smart ships more, if new cross-sector relationships can be brokered.

Data-enabled smart services are a growth area across many sectors and can disrupt traditional sectors in unforeseen ways. Innovation in this area is less based on fundamental research and more on **applied commercial research**, in which the private sector traditionally has a stronger role.

[209] HMG (2019). Regulation for the Fourth Industrial Revolution.
[210] Sharma. Top 10 countries leading blockchain technology in the world.

Moreover, **first-mover advantage is unlikely to persist** as competition from within the maritime sector, but also from general analytics specialists is strong. There is no indication at this stage that there are strong network effects in relation to maritime analytics, so **overall first-mover advantages are unlikely**.

6.5.5 Smart shipping cyber security and risk management

CEOs contributing to the Global Maritime Issues Monitor 2019 listed **cyber threats as one of the issues they felt least prepared to tackle.** The potential for cyber-attacks was also highlighted as being likely **to have great impact on their businesses**. The marine and maritime sector has been pushing ahead with rapid digitalisation in recent years, so is increasingly reliant on cyber systems. Malware is more sophisticated than ever, and the increased use of automation and advanced analytical technologies will increase exposure points at a time when the threat continues to rise. In recent years, the industry has been shaken by **cyber-attacks against shipping giants Maersk, COSCO and Austal, as well as major ports such as San Diego and Barcelona.**

The UK is well placed to address the cyber security needs of a maritime sector waking up to these threats. **The UK Cyber Security Forum has over 500 core members** (SMEs) and companies such as Abatis Marine are developing bespoke solutions for the marine and maritime sector.

While there is a significant technology dimension that is evolving, cybersecurity is a mature market. However, market growth is strong as smart technology spreads across the maritime domain. As such, **first mover advantages exist** and businesses can establish lasting leadership positions by focussing on marketing, accessing customers and delivery capacity.

6.5.6 Training in the adoption and utilisation of smart shipping technologies

With so many new technologies and applications coming to market – in many cases aligned to new regulations and ways of working – the need for **more training** also comes into play. The introduction of ECDIS (Electronic Chart Display and Information System) is a helpful example of where training was mandated alongside the installation of the technology. Shipping's transient workforce means it is not always appropriate for classroom-based training and education. Companies are beginning to offer online training tools to better suit the needs of students, enabled by better, more pervasive communications. The UK is well placed to build on its global service reputation to deliver up-to-date training services fit for the 21st century. Moreover, this would help to protect the UK's own workforce. There is great knowledge being developed in industry and universities, but the UK needs to hold on to it.

The market for training is growing fast in line with the adoption of new smart shipping technologies. There is **likely to be first mover advantage** as this is a market with **potentially significant economies of scale**. Barriers to entry (access to the latest technology) are likely to benefit equipment manufacturers and systems integrators (rather than independent providers). The ability to access and serve growing markets internationally is key for unlocking this potential. Traditional forms of business support and export promotion are likely to be the adequate policy response.

6.6 SWOT analysis

We have conducted a SWOT analysis identifying positive and negative aspects of investment in the smart shipping sector to deduce the viability of investment. The sector is broken down into four sub-sectors, *smart ports, autonomous vessels, on-board technology* and *professional services technology*

(PST). Overall, there are weaknesses within the UK shipping sector in terms of market structure, but also significant growth opportunities, especially in the area of PST.

Figure 33 UK SWOT Analysis

Strengths

- Naval vessel building
- Manufacturing and deployment of smaller autonomous vessels
- Large number of companies active in the on-board technologies segment
- London is the world's leading centre for marine insurance
- Lloyds register is in the global top four biggest classification societies
- World leader in shipbroking
- Training and maritime colleges

Weaknesses

- Top-down approach to port development
- SME access to funding
- Fragmentation of funding
- Lack of large commercial shipbuilding industry
- Lack of major cargo shipping operators
- Lack of export incentive
- Small player in the integrated bridge system and marine propulsion system sectors

Opportunities

- Decarbonisation
- British Ports Association & Associated British Ports investment lobbying
- Sub-24m autonomous vessel market
- Fitting and servicing ships
- Development of shipbroking technology sector
- Utilise PST to develop other smart shipping sectors

Threats

- Anti-competitive barriers
- Cyber-attacks
- Short-lived first mover advantage; leapfrogging

Source: London Economics, NLAI

6.6.1 Strengths

Credit: tcly/Shutterstock.com

Currently, technological strengths in the UK smart shipping market are derived from naval technology and the sub-24m autonomous vessel market. Other well-established sectors such as the (re)insurance, broking and classification industries give strength to the UK smart shipping sector.

The UK is particularly strong in the naval vessel building sector. In 2018, the UK alongside 13 other NATO members, made a commitment to develop maritime unmanned systems aimed at combating the threat of mines, terrorist activities, smuggling and piracy[211]. In addition to naval technology, the UK has a strong sub-24m autonomous vessel market. Sub-24m vessels include watercrafts such as crew transfer vehicles for offshore wind/energy transfers and autonomous guard vessels for observation, surveillance, and reconnaissance.

Aspects of the PST sector, specifically, broking, insurance and classification remain strengths within the UK smart shipping sector. Brokers, such as Clarksons and the London Maritime Arbitrators Association, have extensive experience and expertise in the area, **maintaining the UK as a world leader in shipbroking**. London is the world's largest global (re)insurance hub[212] and according to Maritime London, **London is also the world's leading centre for marine insurance**. There are three forms of marine insurance: cargo insurance; hull insurance; and protection and indemnity insurance (P&I). The UK is a leader in the insurance area especially with regards to risk assessments. Lloyds Register, the first classification society in the world, is in **the global top four biggest classification societies**.

[211] NATO (2019).
[212] LMG (2020). London Matters.

6.6.2 Weaknesses

There are weaknesses in the UK smart shipping sector, including a fragmented market, lack of funding and limited export support.

The UK is **not considered a world leader** in smart ports and continues to trail global competitors due to a **lack of funding** directly into ports, surrounding ports and marine innovation. Contrary to their European counterparts, UK ports operate a top-down funding approach i.e. they rely on their operators/clients to request and demand new *smart port* initiatives. European ports and their city authorities innovate and develop their ports, funding new port initiatives, developing the surrounding harbours and investing in marine innovation.

The UK does not have a large commercial shipbuilding industry nor is it populated with major cargo shipping operators such as Maersk and COSCO. At least in the near future (5-10 years), this is not a likely area of significant growth for the UK. As established, the UK does not have a large commercial shipbuilding industry. Larger vessels (>24m) or SOLAS-size vessels tend to be sourced from the Far East and equipped with on-board technology (OBT) for its respective purpose.

Currently, corporations from Finland, Germany, Norway, US, and Japan dominate the integrated bridge system and marine propulsion system sectors [213]. While the UK remains a small player in these sectors, the Royal Navy does source integrated bridge systems from various UK defence companies such as QinetiQ and BAE System. Rolls-Royce (relevant division recently acquired by Kongsberg) is the only major manufacturer of marine propulsion systems in the UK.

Funding and investment

Within the UK smart shipping industry there it is difficult to obtain funds and coordinate research and investment activities. This fragmented market inhibits the coordination of programs which complement each other, reducing synergies and scope for further innovation.

Lack of coordination presents difficulties finding the volume of investment needed within the UK's **autonomous vessels sector** to allow it to compete with other maritime nations.

Fragmentation of funding is potentially hindering the development of all aspects of the smart shipping sector. InnovateUK funds projects individually and independently, even if a select number are cross-disciplinary projects with potential for collaboration. Even within the shipping sector, InnovateUK may invest into three or four *smart shipping* projects, perhaps from SMEs, start-ups or university funded initiatives. These separate projects will not be governed with an overarching board to ensure coherence, relatability, and cost efficiency. This means relevant projects could remain unaware of each other or without the connectivity to merge research, pool resources, labour, data findings and development methods that would otherwise produce results which could be well utilised in a growing *smart shipping* industry. DfT could introduce a properly integrated programme with an overarching board community to innovate multiple projects, get better value for money and create a coherent vision.

[213] Key players in the integrated bridge systems sector include: Kongsberg (Norway), Wärtsilä (Finland), Northrop Grumman Corporation (US), Raytheon Company (US), Furuno Electric Co. Ltd (Japan) and Japan Radio Co. Ltd (Japan). In the marine propulsion system sector, Wärtsilä (Finland), MAN Energy Solutions (Germany), Mitsubishi Heavy Industries (Japan), Caterpillar (USA), Daihatsu (Japan), Yanmar (Japan), Cummins (USA) are the main corporations.

Interviewees identified fragmentation as a major barrier to the UK's smart shipping sector development. Start-ups and SMEs are strong proponents of the UK's smart shipping sector yet may find it hard to access the funding required to enter the market. A more effective use of the small business research initiative (SBRI) and alternative forms of procurement models could present a more diverse and accessible market for small innovative companies. Government-led focus on SBRI may benefit areas such as OBT and PST because of knowledge spillovers, cross-disciplinary development, and academic practise.

Lack of exporting support

Unlike other industries, there is no UK Export Finance scheme available for manufacturers to gain access to working capital finance for their exports. This lack of support acts as a barrier for producing and developing technologies for UK maritime industries as manufactures are not incentivised to expand from export activities.

6.6.3 Opportunities

Credit: AlexKol Photography/Shutterstock.com

The British Ports Association (BPA) represent operators and clients who are interested in port development. The Associated British Ports (ABP) is the UK's leading port operator with a network of 21 ports across the UK. Coordinating investment lobbying activities between these associations could put pressure on the government to invest in smart port technology such as port digitisation, automation and short sea shipping[214].

Smart ports could help the UK to reduce its greenhouse gas emissions and help achieve its goal of net zero. Smart ports engage in route and traffic optimisation and develop port community systems reducing the amount of time ships spend waiting to berth and subsequently the level of greenhouse gas emission. Additionally, this investment in innovative technology could create spillovers across disciplines meaning that shore-power/smart energy solutions, such as wind-assist, can be used due to the development of route optimisation.

The UK has a strong hold on sub-24m 'specialist' vessels (naval, unmanned surface vessels, guard vessels) which could create significant growth for the UK's *smart shipping* sector. Crew transfer vehicles (CTVs) for transferring staff to and from offshore wind/energy farms could be an opportunity for significant growth. The standard for CTVs are sub-24m and complement the UK's strong offshore wind/energy sector. Companies such as SureWind and L3Harris are looking into the development and usage of CTVs.

Autonomous guard vessels also present opportunities for the UKs sub-24m *autonomous vessel* sector. Autonomous guard vessels are used for observation, surveillance and patrolling capabilities. The UK is in a strong position to drive growth in this sub-sector of the smart shipping industry.

[214] Short sea shipping is a potential answer to avoiding a cargo-vehicle build up in Kent and Dover. CoVID-19 put pressure on supermarkets and retailers. Short-sea shipping could have alleviated the pressure on ports from large cargo-vehicle usage by spreading the access of goods and trade to other UK ports such as Felixstowe and Southampton.

Finally, the Marine and Coastguard Agency (MCA) are researching autonomous vessels of sub-24m size to test autonomous vessel data-sharing platforms for marine autonomous surface ships (MASS) projects. MCA is part of the MARLab group, which includes Solis Marine Consultants and Maritrade. Working with this group could present the smart shipping industry with significant growth potential.

Whilst the UK does not have a large commercial shipbuilding industry of SOLAS-size vessels, the UK could equip commercial cargo vessels with British OBT systems, creating growth in the smart shipping sector. Most commercial cargo ship hulls used by Western operators are constructed in the Far East and populated/fitted with electronic, propulsion, safety, navigation, communication, and other OBT by Western manufacturers. The UK has a number of OBT companies and subsidiaries which it could utilise to grow the OBT industry. Further investment in the OBT sector could also grow the PST sector by incentivising UK companies specialising in OBT to service their products under UK insurance firm policies.

As smart shipping becomes more integrated into the global maritime industry, the need for professional services in the area of insurance, classification and ship brokering will grow. The UK has substantial knowledge and infrastructure relevant to PST which could offer significant growth opportunities for the smart shipping sector and the wider UK economy. Partnerships could be established between the PST sector and other sectors of the smart shipping industry, such as the OBT and autonomous vessel sectors, to help develop the smart shipping industry as a whole.

One of our interviewees stressed that the UK "could and should be world leaders in the service industry aspect of smart ship technology and MASS, such as classification societies, insurance, legal services, training, and training accreditation".

The UK has a long history of shipbroking but discussions on the status of the industry and the development of new technologies are emerging. AI and algorithm software are now being utilised by shipbrokers to innovate the industry and present opportunities for the UK to lead on industry innovation. Softcom Solutions, a London based maritime software company, and Shipamax, a UK-based shipping-supply chain and shipbroking software company, could aid the UK's attempt at modernising the shipbroking industry.

6.6.4 Threats

As mentioned before, overseas competitors may have unfair advantages and prevent UK firms from exploiting technology leadership. These anti-competitive behaviours include:

- anticompetitive state aid;
- anticompetitive pricing practices;
- forced technology transfer;
- discriminatory government procurement practise and local content requirement.

Increasing the reliance on digital technologies increases the vulnerability to cyber-attacks. Jamming and spoofing activities have been rising in the last years and this digital threat jeopardise the safety of operations and cargo. The loss of GNSS signal for instance can have adverse effects throughout the whole value chain, though with different impacts for the efficiency of operations. But in some places where cargo handling is fully automated, a loss of signal would completely freeze the transfer of cargo. The economic impact of a 5-day outage was estimated at £5.2bn for the UK (in 2018), of which the maritime industry accounts for £1.1bn. If an alternative solution to GNSS is provided to mariners, some of the economic loss is likely to be alleviated[215].

Despite the opportunities to be the first mover, we have seen earlier that the advantage it may give to UK companies is short-lived. This owes to the dynamics of the smart shipping industry and the fast evolution of smart technologies and digital technologies in general. The threat comes from overseas competitors, which might take advantage of this and leapfrog the UK leadership. This however can turn into an opportunity if the first mover is a non-UK company.

[215] MarRINav. 2020. Maritime Resilience and Integrity in Navigation - Work Package 5 Cost Benefit Analysis.

7 Conclusion and recommendations

This report presents extensive evidence of the state of the smart shipping industry in the UK as well as its possible directions and needs for intervention. The report includes findings from a wide variety of sources including a literature review, stakeholder consultations, news surveys, and data analysis and modelling.

7.1 Smart shipping technology trends

The research has focused on four groups of technologies which define the smart shipping industry:

- **Smart ports** – terminal automation, shore power, traffic management and information systems;
- **Autonomous vessels** – automated processes, remotely controlled vessels and fully autonomous ships;
- **On-board technologies** – navigation, communication, safety, vessel optimisation and alternative propulsion or fuels; and
- **Professional services technologies** – consulting, shipbroking and insurance.

Smart port technologies rely on automation, big data, AI software systems, and alternative energy. Many technologies have already been implemented in other ports around the world, e.g. the Port of Rotterdam. In order for UK ports to handle growing cargo turnover and fulfil environmental requirements, smart port technologies will play a key role and a domestic capability is necessary.

IMO level 3/4 **autonomous ships** are expected in 5 or more years from now. This owes to the challenges of technology development, as well as the administrative and safety requirements for testing. Many stakeholders consider the UK's strength to be in smaller companies focused on autonomous vessels, who were ground-breaking when MASS evolved, and they have the experts within them. These smaller companies can move faster in niche markets (e.g. ASV or sensors).

The key trends in **on-board technologies** are machine learning, AI and vessel optimisation systems. They assist in safe navigation, ship performance, maintenance, connectivity, and alternative propulsion. There are pockets of innovations, generally from smaller companies and universities but there is no real trend in the direction of technology development. The need for accurate and assured positioning, navigation, and timing (PNT) on-board a vessel is an enabler for many other aspects of the Smart Shipping industry.

For **professional business** services, the UK offers great opportunity in the field of consulting. Leading universities, maritime colleges, and regulatory experts provide much weight to the UK maritime 'brain trust' which is showing value on many projects. UK shipbrokers continue to dominate the international shipbroking sector. With the emergence of new technologies and applications, the demand for qualified operators and personnel increases, which amplifies the need for training.

Our research suggests that there are **six smart shipping technologies that are most likely to be delivered by the UK**:

- Manufacturing and deployment of **smaller autonomous vessels**;
- Smart shipping **sensor** development and sensor integration services;
- Smart shipping **command and control systems** and expertise;

- Smart shipping **data and intelligence** services;
- Smart shipping **cyber security and risk management**; and
- **Training** in the adoption and utilisation of smart shipping technologies.

The **key drivers of smart shipping technology** advances are improving environmental sustainability and energy efficiency, optimising workflows to increase capacity and efficiency, digitising transaction documentation, and accompanying the effects of Brexit.

7.2 Economic rationale for intervention and theory of change

The **logic model** captures the various needs for intervention to address potential market failures. It focuses on the long-term goals set by Maritime 2050 and determines the rationale for government intervention in order to support the achievement of these specific goals. Our findings are summarised in the table below.

Table 18 Logic model summary of findings

UK's Maritime 2050 10 core strategic ambitions	Long-term goals
Strategic ambition 1	Enhancing UK competitive advantage.
Strategic ambition 2	Leading the way on clean maritime growth.
Strategic ambition 3	Maximising benefits from maritime technology.
Strategic ambition 4	Retaining global leadership in maritime safety and security.
Strategic ambition 5	Growing the maritime workforce and transform their diversity.
Strategic ambition 6	Promoting a liberalised trading regime.
Strategic ambition 7	Supporting continued investment in maritime infrastructure.
Strategic ambition 8	Strengthening and enhancing the UK's reputation as a leading maritime Country.
Strategic ambition 9	Promoting the UK's UK-wide leading maritime cluster offer.
Strategic ambition 10	Showcasing the UK's maritime offer to the world.
Rationale for intervention	**Definition**
Efficiency	Technology enables ports to optimise workflow and efficiently use limited space.
Employment	Investment in technology could create direct, indirect and induced employment.
Environment	Streamlining logistics, e-noses and appointment systems to reduce port traffic could reduce greenhouse gasses.
Safety and social capital	Technology could improve safety conditions, enable better informed decisions and allow seafarers to speak to their family and friends increasing their quality of life.
Security	Linking port security systems, surveillance cameras, sensors, drones and tracking tools could heighten security in ports.
Supporting SMEs	SMEs could foster innovation, generate employment and increase productivity.
Spillover effects	Knowledge spillovers could benefit other sectors of the economy.
Political	Maintaining the UK's presence as a leading maritime nation.
Growth	Economic growth itself also forms a key driver under which many of the other rationales for intervention fall.
Market failures	**Definition**
Coordination failure	Many small parties contribute to a large supply chain, resulting in split incentives.
Imperfect information	There is imperfect information and uncertainty surrounding the benefits of investing in developing shipping technologies.
Externalities	Externalities, impacts on uninvolved third parties, are not reflected in the price of the products and services.
Barriers to entry	Barriers include capital requirements, transition costs and minimum efficient scale.

Source: London Economics

To avoid these market failures and achieve the long-term goals, the following interventions have been identified:

- Funding - Providing R&D funding and re-risking innovation investments

  - Provision of R&D funding
  - Tariffs and tax relief
  - De-risking investments
  - Supporting companies seeking to scale-up
- Collaboration – Facilitating collaborations and partnerships
  - Connecting and supporting future partners
  - Utilising local enterprise zones / local growth hubs
  - Facilitate collaborations outside the maritime sector
- Education and skills – supporting education and skill development
  - Education and skill development
- Policy and regulation – policy and regulatory frameworks that foster innovation
  - Continue to be a leader in the development of regulatory standards
  - Addressing a lack of joined up initiatives

7.3 The socio-economic returns from investment in smart shipping technologies

Our model estimates that, with an assumed public grant support of **£300m** injected in smart shipping companies, the wider maritime industry could boost its activities and yield nearly **£1bn** additional economic output in the long run from 2020 to 2050. The model captures the expected UK government induced additionality, assuming investments would happen regardless in the counterfactual scenario but be delayed compared to government intervention i.e. entirely borne by companies. This translates into **£1.3bn** GVA and more than **39,000** jobs secured from 2020 to 2050.

Within the smart shipping industry, the public grant support is expected to generate more than **£600m** additional income split between a direct grant effect supporting R&D effort and leveraged sales, and nearly **£350m direct GVA** (£950m total GVA) from 2020 to 2050. The majority of additional income, GVA and employment stems from developments in the field of autonomous vessels. The additionality of spillovers from technology development are expected to be rather small, with a **total of £56m** over the period of analysis.

Table 19 Summary of the results (additionality)

Investment = £560m	Indicator	SG1	SG2	SG3
Industrial effects	**Turnover**	£540m	£983m	£80m
Industrial effects	**Direct GVA**	£275m	£383m	£70m
Industrial effects	**Direct Employment**	3,986 FTE	6,535 FTE	1,017 FTE
Spillovers	**Knowledge**	£56m	None	£0m
Externalities	**Environment**	Not quantified	Not quantified	Not quantified
Externalities	**Safety**	72% of total costs	72% of total costs	72% of total costs

Source: London Economics analysis

The model shows that with an assumed public grant of £300m invested in smart shipping companies over the next 4/5 years, the overall additionality remains low and the potential for technology spillover minimal. A larger fund would have net positive impacts on domestically generated additionality. It would not only increase the returns but also increase the number of participating companies in R&D, increase cooperation and secure employment in key segments.

The **environmental benefits** from smart shipping technology for a sea journey varies highly based on the type of ship, its size, speed, length of the voyage and time spent at port. A 5,000 NM trip at an average speed of 20 knots produces nearly 12,000 tonnes of CO_2 for a 15,000 TEU container ship. Adopting green technology would help save 1,200 tonnes of CO_2 per 10 percent of efficiency gain. The table below simulates the CO_2 savings for the same route but with varying ship size and efficiency gains.

Table 20 Tonnes of CO_2 saved as a function of the efficiency gain and the size of the ship.

	Ship size (1,000 TEU)	Ship size (3,000 TEU)	Ship size (5,000 TEU)	Ship size (7,000 TEU)	Ship size (9,000 TEU)	Ship size (11,000 TEU)	Ship size (13,000 TEU)	Ship size (15,000 TEU)
Efficiency gain 5%	154	266	343	406	461	509	554	595
Efficiency gain 6%	184	319	412	488	553	611	664	714
Efficiency gain 7%	215	372	481	569	645	713	775	833
Efficiency gain 8%	246	426	549	650	737	815	886	952
Efficiency gain 9%	276	479	618	731	829	917	997	1,071
Efficiency gain 10%	307	532	687	813	921	1,019	1,107	1,189

Note: For 5,000NM trip at 20 knots

Source: London Economics

The logic is similar for ships at ports. During cargo handling operations, ships rely on auxiliary engines and fuel. Providing cleaner energy like shore power generated from less polluting energy sources could save a substantial amount of greenhouse gas emissions (as shown in the figure below). CO_2 savings are highest for low-emitting energy sources such as wind (26 g_{CO2}/kWh).

Figure 34 Tonnes of CO_2 saved as a function of the energy mix exhaust and time spend in port.

	Time at port: 20 hours	Time at port: 25 hours	Time at port: 30 hours	Time at port: 35 hours	Time at port: 40 hours	Time at port: 45 hours	Time at port: 50 hours	Time at port: 55 hours
25g CO2/ kwh	96	120	144	168	192	216	240	264
50g CO2/ kwh	92	116	139	162	185	208	231	254
100g CO2/ kwh	85	107	128	149	171	192	214	235
150g CO2/ kwh	78	98	118	137	157	176	196	216
200g CO2/ kwh	71	89	107	125	143	161	179	196
400g CO2/ kwh	43	54	65	76	87	98	109	119

Note: Shore power based on (top to bottom) wind, biomass, solar, UK energy mix 2019, natural gas and coal.
Source: London Economics

Environmental technologies can have strong impacts on the reduction of emissions at sea and in ports. To meet the 2050 environmental targets defined by the IMO and the **Clean Maritime Plan** the UK needs to invest in these technologies via a green fund:

- **Fuel alternatives** such as hydrogen or LNG;
- **Exhaust cleaning technologies**;
- **Alternative propulsion** such as electric engines and batteries for electricity storage onboard, or wind propulsion;
- **Operational changes** such as slow steaming; and
- I**ncreased efficiency in ports** through shore power or reduced waiting time;
- **Ballast technologies**.

Some of these technologies are already considered and over £30m was attributed to R&D in the Clean maritime demonstration competition[216].

Regarding **safety** onboard and in ports, automation will be a key enabler of safety improvements. Estimates of the total value of maritime casualties which could have been prevented by automated mooring systems, autonomous vessels, on-board technology and automated cargo handling is estimated to be worth **£4.9 billion** in the EU 28 since 2012, equivalent to **71%** of the total cost of maritime accidents over the same period.

[216] Clean maritime demonstration competition (2021)

7.4 Strategic decisions and benefits

Analysis suggests that smart shipping is **generally not very conductive to durable first-mover advantage** as the sector is characterised by growth, global reach and technological innovation, which makes it an arena for dynamic competition. However, there may be first-mover advantages in certain fields of smart shipping as well as worthwhile short-term gains from first-mover advantage of UK firms. In other fields, being a follower can be the superior strategy for UK businesses as moving first is expensive.

The fields in which there is likely to be a first-mover advantage are:

- **Training** in the adoption and utilisation of smart shipping technologies; and
- Smart shipping **cyber security and risk management**.

The appropriate policy response is to **maintain a strong research base** and an ongoing edge in R&D to maintain technology leadership where possible. Growing markets favour firms with access to resources that enable them to scale up quickly to meet demand.

There is no strong evidence that UK companies could reap additional benefits from first-mover advantages due to additional government support. But another key role for government is to work (through organisations such as the WTO and OECD) to **reduce anti-competitive barriers** in the shipping sector that give overseas competitors an unfair advantage and prevent UK firms from exploiting technology leadership. Such actions should target[217]:

- anticompetitive state aid;
- anticompetitive pricing practices in shipbuilding;
- forced technology transfer;
- discriminatory government procurement practice and local content requirement.

Importantly, benefits from smart shipping for the UK might accrue primarily in **adjacent industries**, such as the broader logistics industry, and industries that rely on seaborne transport or require access to the sea, notably the offshore energy industry. It is likely that these – not narrowly defined smart shipping – are also the industries where the impact on regional employment would be greatest.

An **international level playing field** is also important for transparency and security. Promoting common standards (including for data) is an import task for multilateral bodies that the government should support. Making the UK a first user of smart shipping technology, not just a first mover in certain technologies, is likely to enable more broad-based benefits. Measures such as innovation-friendly regulation and technology demonstration through **testbeds and public procurement** in line with the DfT's Maritime 2050 strategy are key to achieving this.

[217] Braat. (2020). A true global industry.

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ANNEXES

Annex 1 List of acronyms

Table 21 Table of acronyms

Acronym	Definition
ABP	Associated British Ports
AI	Artificial intelligence
AIS	Automatic Identification System
AV	Autonomous Vessel
BAU	Business-as-usual
BCG	Boston Consulting Group
BPA	British Port Association
BSP	Business services provider
CAGR	Compound annual growth rate
CAPEX	Capital Expense
COLREGS	Convention on the International Regulations for Preventing Collisions at Sea (1972)
DEFRA	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
DWT	Deadweight tonnage
ECA	Emission Control Area
ECDIS	Electronic Chart Display and Information System
EMSA	European Maritime Safety Agency
EO	Earth Observation
ESA	European Space Agency
FTE	Full-time employment
GHG	Greenhouse Gas
gt	gross tonnes
GVA	Gross value-added
HFO	Heavy Fuel Oil
HMRC	Her Majesty's Revenue and Customs
IAPH	International Association of Ports and Habours
ICCT	International Conference on Communication Technology
ICEAA	International Cost Estimating and Analysis Association
IET	Institute of Engineering and Technology
ILO	International Labour Organisation
IMO	International Maritime Organisation
IOAT	Input-Output Analytical Tables
IoT	Internet of Things
IP	Intellectual Property
kWh	Kilowatt Hour
LE	London Economics
LNG	Liquid Natural Gas
LPG	Liquified petroleum gas
LR	Lloyd's Register
MARPOL	International Convention for the Prevention of Pollution from Ships

MASS	Maritime autonomous surface ships
MBS	Maritime business services
MDO	Marine Diesel Oil
MES	Marine engineering and scientific industry
MI	Maritime Industry
ML	Machine learning
MoD	Ministry of Defence
MSC	Mediterranean Shipping Company
NM	Nautical mile
NOx	Nitrogen Oxide
OECD	Organisation for Economic Cooperation and Development
OLS	Ordinary Least Squares
ONS	Office of National Statistics
PCS	Port Community System
PM	Particulate Matter
R&D	Research and development
ROV	Remotely Operating Vehicles
SG	Stakeholder Group
SIC Code	standard industrial classification code
SME	Small and medium enterprises
SO2	Sulphur Dioxide
SOLAS	International Convention for the Safety of Life at Sea
SSI	Smart shipping industry
STCW	Certification and Watchkeeping for Seafarers
STEM	Science, technology, engineering and math
STM	Sea traffic management
TEU	Twenty-foot Equivalent Unit
TIV	Total insurable value
ToC	Theory of Change
TRL	Technology readiness level
UKRI	UK Research and Innovation
UNCTAD	United Nations Conference on Trade and Development
UUV	Unmanned underwater vessels

Source: London Economics

Annex 2 Technical methodology annex

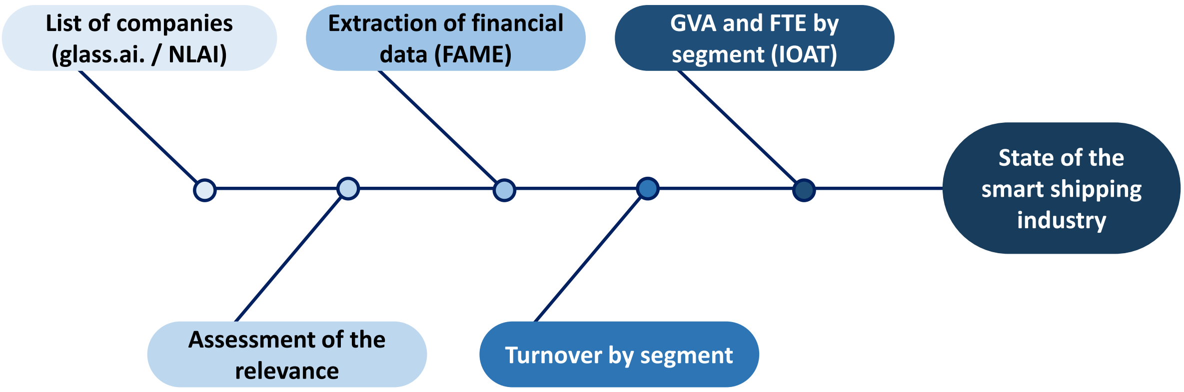
The economic model tries to capture the essential metrics to evaluate the impact of government intervention. We divide these indicators into 3 main categories:

- **Industrial impacts** which include turnover, GVA and employment (full-time equivalent)
- **Knowledge spillovers**
- **Externalities** which consider environmental impacts (e.g. GHG reduction, ecological impacts), and safety and security impacts.

A2.1 Assessment of SG1 and SG3

The starting point of the assessment of SG1 and SG3 is a list of companies generated by our partner, glass.ai., which uses an AI that scrapes web content and delivers datasets of rich textual data from the open web. The system also matches the web results to the official Companies House register.

Figure 35 Assessment of industrial effects



Note: IOAT: Input-Output Analytical Tables (from ONS).
Source: London Economics

Relevance and smart shipping activity share

For each company, we manually investigate publicly available information (website, companies house, LinkedIn) and determine if the company is relevant.

Relevant activity will be determined by evidence of an organisation's engagement in advanced technology development. Depending on data availability, one of several methods can be employed to estimate the share of an organisation's activities that are relevant to the SSI market segment. We term this parameter the 'SSI share' of an organisation, expressed in percentage terms.

Note the wider SSI term is used here but in practice, we apply the following methods for each segment of the SSI value chain. These methods include the following:

Method 1: SSI share directly available: Whilst unlikely, some of the larger or more SSI intensive organisations may provide figures that resemble a direct estimate of their total income that is SSI relevant in the financial accounts.

Method 2: Divisional share: Some organisations that do not provide an SSI specific share directly may provide a detailed breakdown of their business activities by division, which could in turn be broken-down further into product groups. Estimation of the SSI share of total income is calculated by using annual report and website information to identify the relevant division(s) and then estimating the proportion of that division that is accounted for by SSI-specific activities.

Method 3: Product share: Some of the smaller organisations may not provide enough information to either of the methods described above. For these organisations, a cruder estimation may be necessary. This involves reviewing product lists and catalogues and assuming that SSI share is equivalent to the proportion of these products that could be identified as being SSIrelevant.

For smaller organisations, it may not be possible to estimate SSI share to the degree of precision that is possible for larger organisations with more publicly available material. In such cases, it may instead be necessary to assign organisations to different ranges of SSI share (e.g.0-33%, 33-66%, 66-99%, 100%) and to use simulation of specific SSI shares between these ranges afterwards.

Based on the initial **list of companies** provided by NLAI and consolidated by glass.ai (Annex 3), more than 450 companies were analysed. For each company, we manually investigate publicly available information (website, companies house, LinkedIn) to determine the relevance of the company.

We have identified **215 relevant companies** that split between the four segments of analysis. **36** companies were identified as active in the smart port segment, **38** in the autonomous vessel segment, **68** provide on-board technologies and **131** supply professional and business services. Note that companies can be active in multiple segments.

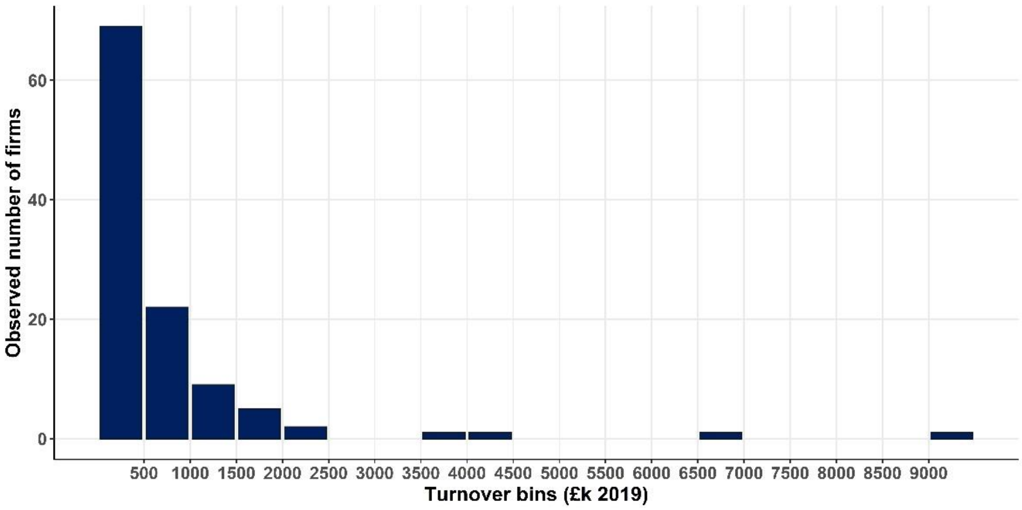
Turnover

Once we have assessed the companies for their relevance, we use our subscription to FAME to download the financial information of each company. FAME provides details on the turnover, the employment level, the Standard Industrial Classification (SIC) codes of industry segments in which the company is active, and flags on the status of the company (active, dormant, etc.).

In some cases, FAME does not provide sufficient information to assess the turnover or the employment level. This owes to the exemption rule of the UK government which states that companies with turnover below £10.2m or with less than 50 employees are not obliged to report their complete annual results.

To ensure the completeness of the data, we use an alternative method to generate a turnover for a company that have no reported turnover. Based on the existing data, we generate a distribution of turnover and infer a probability distribution based on the observed data. This approximates a bar chart by a smoothed line using kernel inference (used in the approximation of normal distributions). Kernel approximation is a machine learning method used to recognise patterns in the data and analysis the general distribution and relations within this data. It is similar to regression, clustering, or principal component analysis methods but more appropriate to the data used in this report.

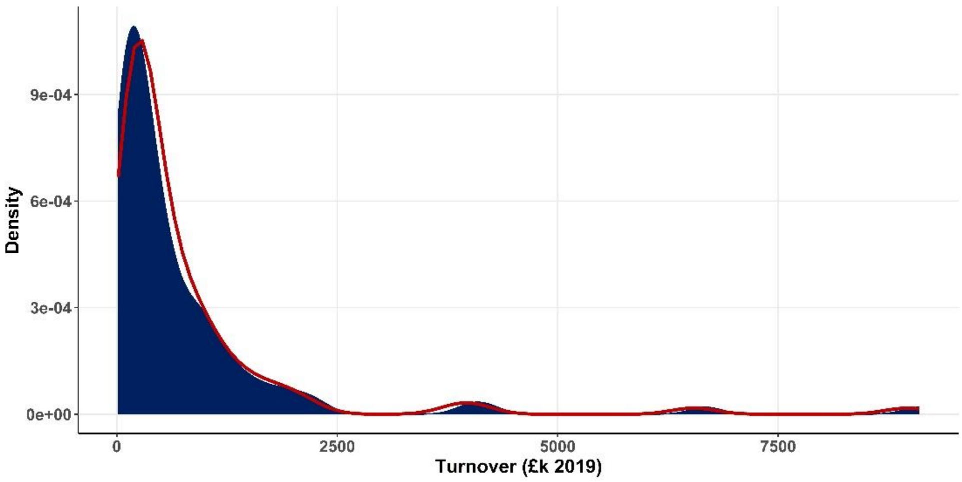
Figure 36 Observed distribution of companies with 2 to 10 employees by turnover bins



Source: London Economics (FAME and glass.ai data)

We control for the number of employees since the glass.ai data provides an estimate of the number of employees (LinkedIn data). We can generate a distribution for each group of companies and randomise the missing data using the kernel distribution function.

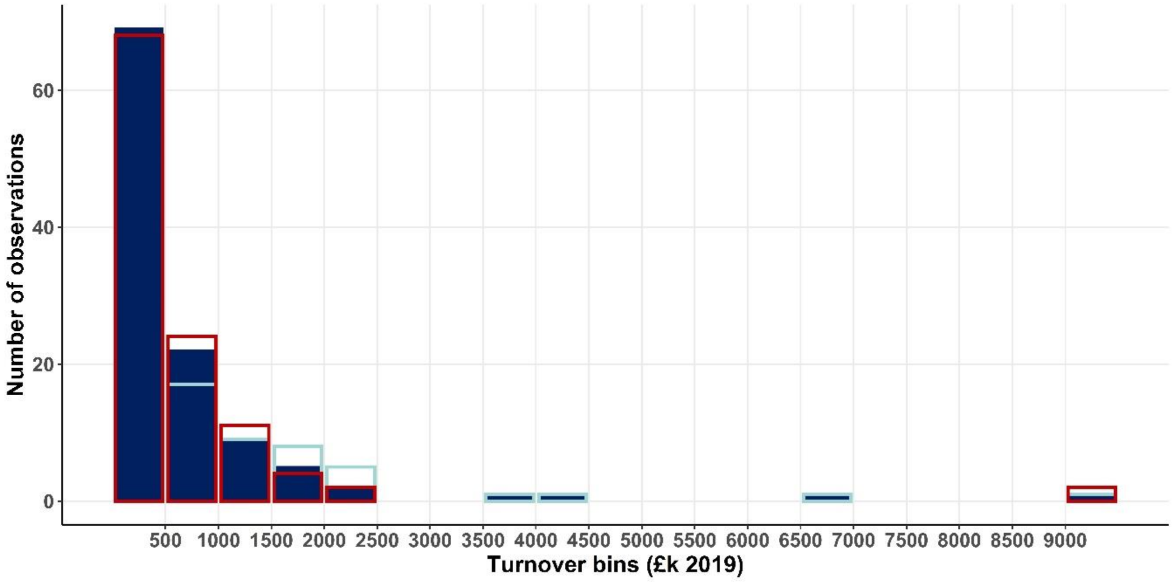
Figure 37 Observed density distribution (blue) and kernel approximation (red)



Source: London Economics (FAME and glass.ai data)

Finally, we randomly assign turnover to companies with missing information using the probability distributions above. The following chart illustrates two separate runs of the randomisation. It shows that the model outlined above adequately estimates the distribution of companies. The dark blue bins represent the observed distribution while the red and light blue boxes represent the randomised samples.

Figure 38 Observed (dark blue) and randomised distribution of companies by turnover bins



Source: London Economics (FAME and glass.ai data)

GVA and employment

To calculate the full impact of Gross Value-Added (GVA), it is necessary to consider three different layers of impact:

- The first channel is the **direct effect**. At the value chain level, the direct effect can be thought of as the value added to goods and services by the value chain's employees and the technology itself. We compute the direct GVA at the company level. We use the individual company SIC codes provided by FAME and match them to the GVA per output available in the Input Output Analytical Tables (IOAT) from the ONS.
- The **indirect effect** is linked to the employment supported and value added within UK firms that are suppliers to the companies in the value chain. Indirect GVA is generated by suppliers to the value chain, which provide the manufacturers with raw materials, components, subsystems, utilities, and consumables (the effect caused by the changes in intermediate demand).
- The **induced effect** is defined as the economic activity supported by the spending of the employees in the organisations of the value chain and supplying companies. Employees spend part or all their income on goods and services within the UK economy, which generates income for organisations within other industries meeting their demand, and, in turn, drives value creation and supports employment.

For the employment levels, we start from the FAME data and fill the gaps using the same approach as for the GVA. The IOAT provides the average number of employees supported per £1m of economic output per SIC codes. For indirect and induced effects, we use industry multipliers from the Maritime UK report[218].

[218] Maritime UK. (2019). State of the maritime nation report 2019.

SG3 companies also generate additional GVA by developing and adopting new technologies that **reduce operational costs** (e.g. adopting AI techniques) and consequently **increase the share of GVA** that is produced per unit of output.

Early impacts and leveraged sales from R&D

The funding is set by the analysis of the technology's readiness levels assessed by NLAI. In this configuration, only SG1 companies receive a grant from the government. Hence the early impacts on sales and R&D investment only apply to SG1.

Early in the development phase, companies receive support from grants. This investment will enable the support of engineers and researchers to increase the level of a technology. This funding also has immediate benefits for the UK economy by stimulating economic activity in the industrial supply chain. These benefits are measured in terms of Gross Value-Added (GVA) and employment supported with the methodology presented above.

Since grantees deliver complex solutions in new environments, organisations involved may provide UK suppliers with technology, commercial knowledge, and intellectual property (IP) that they can leverage to support commercial activity in other areas. These leveraged sales are in addition to any follow-on sales opportunities that come from long-term procurement of their solution to beneficiary actors of the value chain. Leveraged sales are sales earned by the company, resulting from an R&D investment.

A2.2 Assessment of SG2

The end users constitute the part of the MI that will benefit from the integration of new technologies. The benefits have various forms but are mostly generated by efficiency gains in operations costs reductions, emission reduction and increased safety during operations.

To capture the effect of technology adoption on industrial indicators, we need to draw assumptions on the technology adoption level over time. We use the **Bass diffusion model** to project the adoption and the benefits.

The properties of technology diffusion have been widely studied. Diffusion (adoption) of new products (innovations) typically follows an S-shaped curve. This typical S-shaped nature of innovation diffusion was used to obtain a better understanding of how far along the adoption path each selected sector may be in a given period, as well as, when the tipping point in sales – i.e. the point when the annual increase in sales reach their peak before slowing down – is likely to occur, given current sales forecasts.

The employment level is estimated based on the GVA generated from technology adoption. We use the employee's productivity ratio (output per hour worked) to make this estimation over time, assuming it is variable over time and using the projections from the baseline scenario.

A2.2.1 Reasons for model choice

The reasons for choosing the Bass Diffusion Model were as follows:

- It is the most widely used mixed influence model and is backed up by a wide range of research and management applications[219] – see Table 22 for a small number of examples of recent applications.
- To illustrate the previous point: Bass's original paper was named, by the Institute for Operations Research and Management Sciences, as one of the top ten most influential papers in management science[220] and, in 2006, was the most widely cited model for diffusion of innovation growth[221]- as of November 2018 the paper had 8,502 citations on Google Scholar.
- The model is also simple and easy to understand, yet sophisticated enough to yield a realistic adoption process that "provides a good fit to the S-shaped curve"[222]
- It considers both external (factors influencing the adoption choice coming from external sources) and internal (factors influencing the adoption choice coming from internal sources).
- This consideration of external and internal sources also gives the model an intuitive interpretation in terms of innovators, who first adopt the technology, and imitators, who imitate first adopters (see Section A2.2.2).
- Explanatory power – the Bass model fits almost as well as much more complex models[223]

[219] Boyle (2010). *Some forecasts of the diffusion of e-assessment using a model*. Innovation Journal. Vol. 15:1-30
[220] Hopp, W. J. (2004). *Ten most influential papers of management science's first fifty years*. Management Sci., Vol. 50
[221] Meade N., Islam T. (2006). *Modelling and forecasting the diffusion of innovation—a 25-year review*. *Int Forecasting.* Vol. 22
[222] Chandrasekaran and Tellis (2007). *A Critical Review of Marketing Research on Diffusion of New Products*
[223] Golder, P. N., Mitra, G., D., (2018). *Handbook of Research on New Product Development*: Edward Elgar Publishing

Table 22 Recent applications of the Bass Diffusion Model, selection of examples

Source	Application
London Economics. (2019). Industry 4.0 and the Future of UK Space Manufacturing	Used the bass model to estimate the impact of **technology adoption in the space industry**.
Grimm et. al. (2018). *Estimating Future Health Technology Diffusion Using Expert Beliefs Calibrated to an Established Diffusion Model*. Value in Health	Used the bass model to estimate **future health technology diffusion**, calibrated using expert beliefs
Hernandez and Zhang (2017). *Comparing Adoption of Breakthrough and "Me-too" Drugs Among Medicare Beneficiaries: a Case Study of Dipeptidyl Peptidase-4 Inhibitors.* Journal of Pharmaceutical Innovation. Vol. 12(2):105-109	Used a Bass model to compare adoption of **breakthrough drugs** and new pharmaceuticals ("Me-too" drugs), which provide the same mechanism of action as existing drugs
Ntwoku, Negash, and Meso (2017). *ICT adoption in Cameroon SME: application of Bass diffusion model*. Information Technology for Development. Vol. 23(2):296-317	Used a Bass diffusion model to study SME adoption of **information and communications technology** (ICT) in low-income countries using the example of Cameroon
Yoon and Yoon (2017). *An estimation of offset supply for the Korean emissions trading scheme using the Bass diffusion model.* International Journal of Global Warming. Vol. 12(1):99-115	Applied the Bass model to estimate the possible **carbon offset supply** in the Korean emissions trading scheme
Lai (2017). *Modelling the Technology Diffusion by Using Bass Model.* Proceedings of AC 2017. Academic Conferences Association. pp. 169-195	Use the Bass model to explore technology diffusion in **precision machinery industry**
Wang et. al. (2017). *Managing component reuse in remanufacturing under product diffusion dynamics*. International Journal of Production Economics. Vol. 183(B):551-560	Use a use the Bass model to model the product diffusion process of **component reuse and remanufacturing**
Zhu et al. (2014). *Forecasting Mobile Internet Diffusion Trend Based on Optimized Bass Model.* International Journal of Multimedia and Ubiquitous Engineering. Vol. 9(9):351-356	Used a modified Bass model to forecast **mobile Internet diffusion**
Wong et al. (2011). *Predicting the Diffusion Pattern of Internet-Based Communication Applications Using Bass Model Parameter Estimates for Email*. Journal of Internet Business. Vol. 9(2):1-25	Used a Bass model to predict the diffusion pattern of internet-based communication applications based on **email.**
Turk and Trkman (2011). *Bass Model Estimates for Broadband Diffusion in European Countries.* Technological Forecasting and Social Change. Vol. 79(1):85-96	Used a bass model to estimate **broadband** diffusion for European OECD member countries
Chuang and Hsu (2010). *Applying Bass model and KK model to forecast multinational diffusion in LCD TV industry: empirical evidence from Asian and North America*. Scientific Research and Essays, 5 (18) (2010), pp. 2608-2614	Applied Bass model to forecast multinational diffusion in **LCD TV** industry (data from Asia and North America).
Boyle (2010). *Some forecasts of the diffusion of e-assessment using a model. Innovation Journal. Vol. 15:1-30*	Used a Bass model to forecast diffusion of e-assessment in **GCSE qualifications** in England

Note: This list provides a non-comprehensive selection of a small number of recent examples of the Bass Diffusion Model.

Source: London Economics

A2.2.2 The Bass Diffusion Model

The fundamental assumption of the Bass Model is that "the probability of adopting by those who have not yet adopted is a linear function of those who had previously adopted"[224]:

$$P(Adoption\ in\ t\ |\ not\ adopted\ yet) = \frac{f(t)}{1 - F(t)} = p + \frac{q}{M}F(t)$$

Where:

f(t) = portion of the market that adopts at t
F(t) = the portion of the market that has already adopted at t
p = the coefficient of innovation representing influences from external sources
q = the coefficient of imitation representing influences from internal sources
M = the ultimate market potential representing the maximum possible adoption rate

The model is driven by two types of adopters:

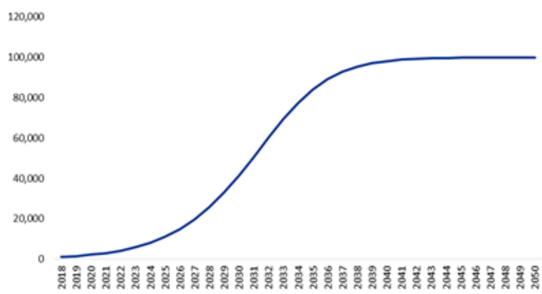
- Innovators who are the first to seek out and adopt a new innovation;
- Imitators who are more cautious and wait to see the experiences of others until choosing whether to adopt or not.

In each year there are a fixed number of potential innovators (p), and several further potential adopters influenced by internal sources, i.e. imitating the innovators, (q/M) x number of previous adopters. Each year a certain number of these potential adopters decide to actually adopt.[225]

As more and more organisations adopt the new technology, more and more organisations are tempted to follow suit, and more of those tempted do actually adopt. Therefore, the number of imitators increases over time while the number of innovators decreases.

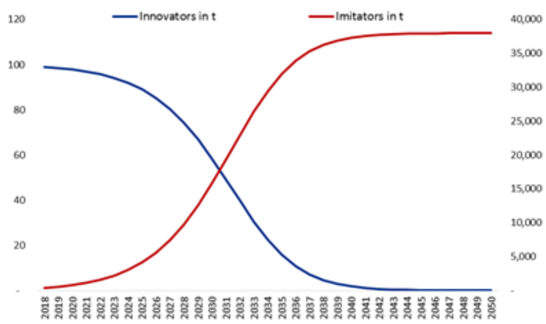
The ultimate market potential (M) imposes an upper limit on the potential number of adopters (adoption rate).

Figure 39 Total number of adopters by t



Notes: Graph based on an example process to illustrate the Bass diffusion model. ***Source: London Economics***

Figure 40 Number of innovators (blue) and imitators (red) adopting in t



Notes: Graph based on an example process to illustrate the Bass diffusion model. ***Source: London Economics***

[224] Bass, F. M. (1969*). A New Product Growth Model for Consumer Durables*. Management Science 15: pp. 215-227
[225] Adopters in t = p(M - all previous adopters) + q · (1-1/M) · all previous adopters = Innovators in t + Imitators in t.

A2.3 Knowledge spillovers

Technology transfers occur either **actively** (e.g. formal knowledge sharing through articles, new releases, colloquia, patents and licences), or **passively** because the knowledge created by a firm or government agency can typically not be contained within that entity (e.g. imitation, employee changes, reverse engineering). While intellectual property laws enable firms to protect the results of their R&D investments to a certain extent, the economic exploitation of new technologies through incorporation into novel products or production processes is likely to reveal some aspects of the new knowledge to other agents.

Spillover beneficiaries can use this leaked knowledge to imitate the products or processes by 'reverse engineering' of technology, or they might use the knowledge as an input into own research processes. Conversely, the termination of a particular R&D stream by one company can signal to other firms that the research is unproductive. Employee mobility and companie mergers and acquisitions are further vehicles for the transmission of technical knowledge (Jaffe, 1998)[226].

Technological spillovers occur more often as technology **transfers**. The process of development (TRL improvement) sometimes allows **adaptation of the technology to a non-maritime sector**. Transfers occur between a generator (usually a contracting firm involved in the development of the technology with the space agency) and a recipient firm, which has seen an opportunity to absorb a technology to improve its activities. An effective transfer to the industry is generally determined by a set of **properties** about the technology and people/organisations involved in the transfer.

The technology itself must be **flexible** and **adaptable** to the other sectors. It should not be too mature (i.e. it should be a low TRL) because once the technology has reached **TRL 6-7**; it is on the verge of being fully integrated in maritime systems. Fully integrated technologies may not allow for spinoffs because the architecture is entirely reliant on the system it was designed for. In addition, a technology evolving from an **incremental** innovation has more chances to end up spinning-out than a **radical** (breakthrough) innovation.

London Economics carried out an analysis of the returns of public investments[227] in the space industry and extrapolated the potential benefits from spillovers as **multipliers** as well as a wider analysis on spillover returns in the space industry[228]. Spillovers multipliers range from low level of diffusion (**3.9**) to a high level of diffusion (**6.5**). We use the average of low and high estimates in our model.

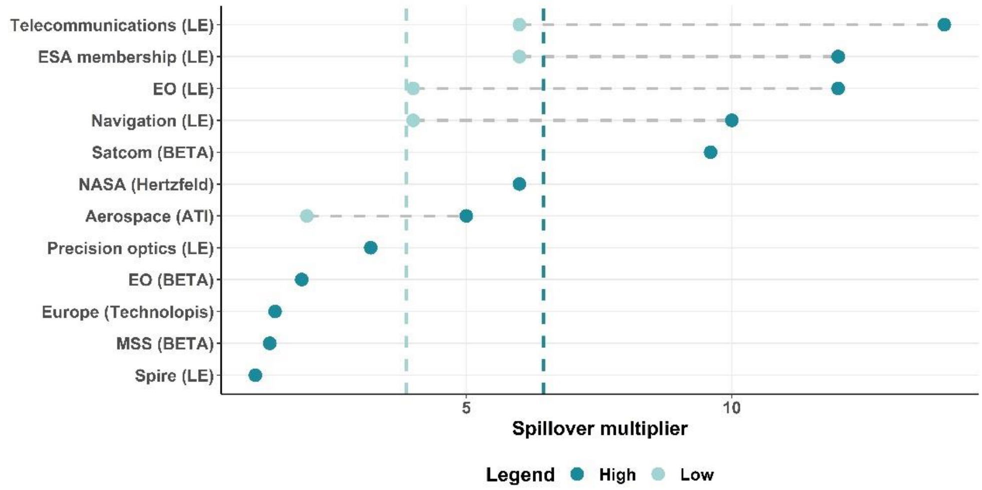
[226] Jaffe, A.B., Trajtenberg, M. (1998). *International Knowledge Flows: Evidence from Patent Citations.* NBER Working Paper No. 6507.
[227] London Economics. (2015). Return form Public Space Investments.
[228] London Economics. (2018). Spillovers in the space sector.

Table 23 Spillovers multiplier table

Project/Report	Low	High
Spire	1.03	1.03
Precision optics	3.2	3.2
ESA membership	6	12
Earth Observation	4	12
Telecommunications	6	14
Navigation	4	10
Earth Observation (Canada)	1.9	1.9
MSS (Canada)	1.3	1.3
Satcom (Canada)	9.6	9.6
NASA technologies	6	6
European space technologies	1.4	1.4
Aerospace technologies	2	5
Average	**3.9**	**6.5**

Source: London Economics

Figure 41 Spillover multipliers – Evidence from the literature



Note: BETA = Bureau d'économie théorique et appliquée. The dashed lines represent the low- and high-level averages.
Source: London Economics

The adoption of the new product is expected to start relatively quickly up to a maximum where the 'critical mass' of adopters is reached. At this point, the spillover benefits are at maximum, and start to decrease smoothly as the technology becomes obsolete and is replaced by more advanced ones.

We have developed a model to capture the knowledge spillovers. It uses technology development costs and time to market to estimate the magnitude of knowledge spillovers. This model combines findings from our previous research[229,230] and additional inputs from the technology adoption literature.

[229] Luxembourg Space Agency. (2018). Opportunities for Space Resources Utilisation.
[230] London Economics. (2018). Spillovers in the space sector.

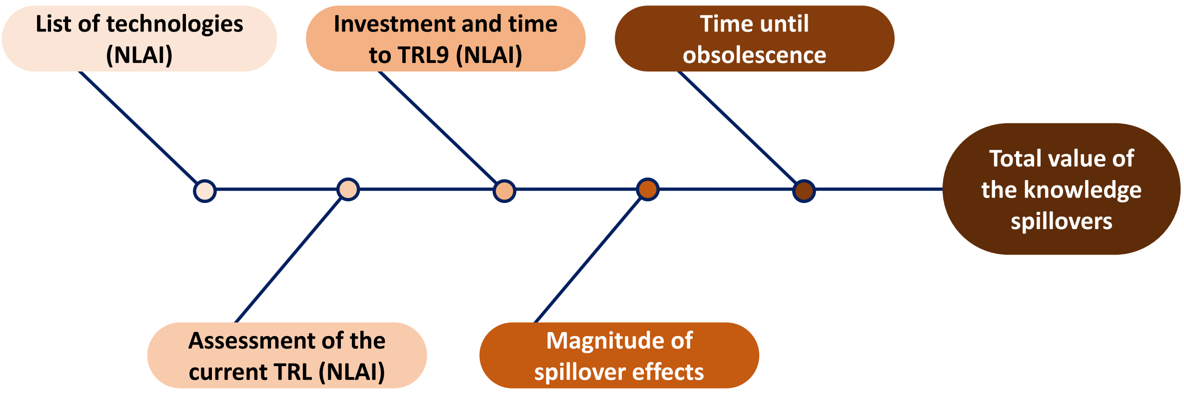
For each technology identified, we browse the literature and use the interviews to assess their current technology readiness level (TRL)[231], the investment required to bring the technology to TRL9 and the time it will take to reach the market.

The following methodology has been designed to reflect this best practice and incorporate currently available evidence on magnitude:

- **Line-up** our previously categorised evidence on the nature and magnitude (i.e. R&D multipliers) of knowledge/technology spillovers from investments in space-related R&D and technologies,
- **Characterise** the shortlisted technologies that are to be advanced in the selected SSI value chains and key parameters (e.g. lag, duration, potential for spillovers, potential for efficiency gain, potential for GHG reduction, etc.),
- **Incorporate** estimates (£) of the public and commercial R&D investment required to raise the TRL level of the shortlisted technologies to the necessary level,
- **Match** each of the characterised technologies (with their parameter values, and R&D investment) with the most appropriate R&D multipliers,
- **Estimate** R&D spillovers per characterised technology within scope, and
- **Aggregate** estimation results.

As we do not expect the benefits to be linear over time, London Economics expanded the best practice by adding a probability distribution of benefits over time. We have developed a model to capture the knowledge spillovers. It uses technology development costs and time to market to estimate the magnitude of knowledge spillovers.

Figure 42 Assessment of spillover effects



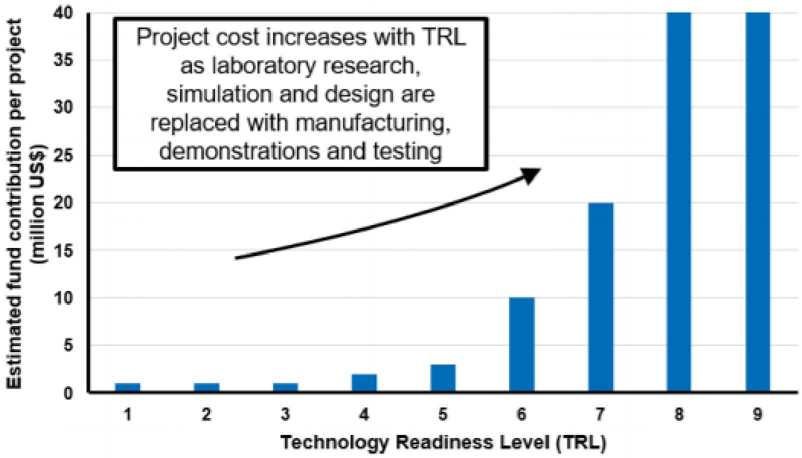
Note: TRL: Technology Readiness Level
Source: London Economics

Current TRL levels are assessed by NLAI which identifies which company (UK and/or non-UK) is established as the technology leader. By looking at reports, publications, websites and using their expertise in the maritime industry, they can estimate the current TRL level of each technology.

[231] UK government guidance on Technology Readiness Levels. Available at: https://www.gov.uk/government/news/guidance-on-technology-readiness-levels.. [Accessed 06/11/2020].

From the current TRL level, we can infer the investment required to develop a technology TRL9. This is done using a study from the IMO that analysed green shipping technologies development. IMO estimate that the total costs required to increase by one TRL level increase with the maturity of the technology.

Figure 43 Cost per TRL



Note: We have adjusted the last TRL level to £50m to reflect the additional effort required between TRL8 and 9.
Source: IMO

By analysing the company level information about the technology, we also try to capture an estimation of the time (in years) it will take to bring the technology to maturity and commercialise it. If this information is not available, we use the assumption that the overall investment is proportional to the time it takes to achieve a project. We use the Innovate UK database[232] to infer such relationship.

The data provides information on the total cost, the grant received, the length of the project with start and end date and other various information about the company and the project funded.

We run a simple OLS regression on the project duration to look for that evidence. The econometric specification is the following:

$$Time_i = \alpha + \beta_1 \log(Cost_i) + \beta_2 MI_i + \beta_3 Year_i + \beta_4 Size_i + \epsilon_i$$

Where:

i = project index
Cost = Total cost of the project (< £10m)
MI = Matched investment ([0,1])
Year = Project start year (value between 2010 and 2019)
Size = Company size (Includes: large, medium, and micro)

The regression is carried out on nearly 15,000 observations and shows a significant positive correlation between project duration and proportion of matched funding.

[232] Innovate UK funded projects since 2004. (2020).

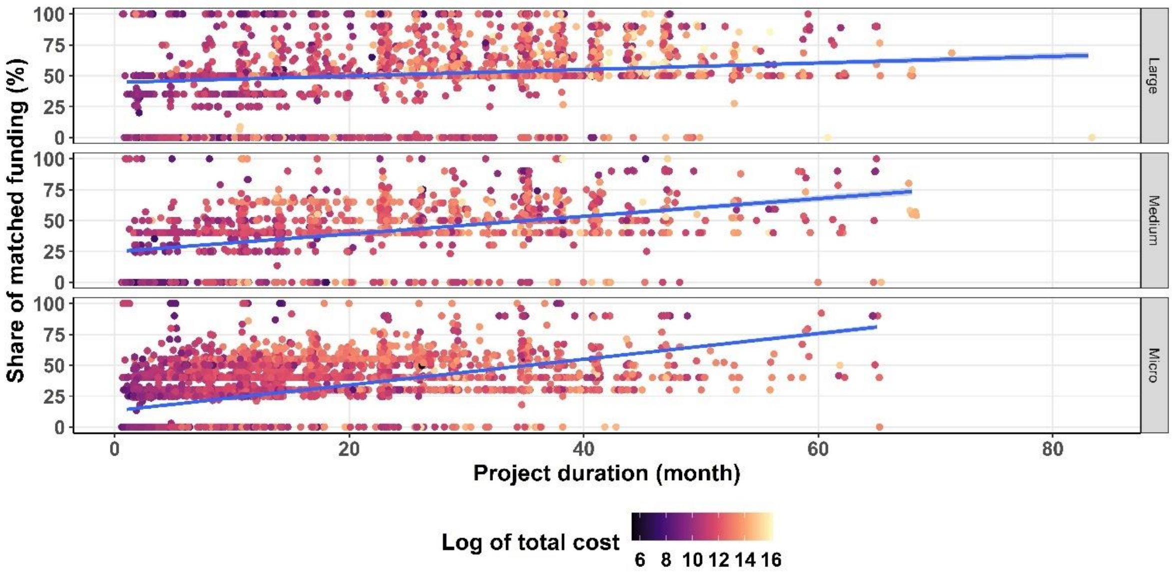
Table 24 Linear regression results

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-19.74325	0.66341	-29.76	< 2e-16	***
Log (Total Costs)	3.46431	0.05465	63.388	< 2e-16	***
% Matched Investment	8.64862	0.42154	20.517	< 2e-16	***
Year = 2011	-0.32204	0.42126	-0.764	0.444596	
Year = 2012	0.05304	0.39006	0.136	0.891831	
Year = 2013	0.58516	0.37666	1.554	0.12031	
Year = 2014	1.95068	0.36811	5.299	1.18E-07	***
Year = 2015	0.87765	0.37806	2.321	0.020276	*
Year = 2016	-0.89406	0.41249	-2.167	0.030216	*
Year = 2017	-1.48491	0.40668	-3.651	0.000262	***
Year = 2018	-1.67664	0.42793	-3.918	8.97E-05	***
Year = 2019	-7.51042	0.50196	-14.962	< 2e-16	***
Enterprise Size = Medium	-2.58676	0.25507	-10.141	< 2e-16	***
Enterprise Size = Micro	-7.83707	0.20268	-38.666	< 2e-16	***
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1					
Residual standard error: 9.377 on 14,962 degrees of freedom					
Multiple R-squared: 0.486, Adjusted R-squared: 0.4856					
F-statistic: 1,088 on 13 and 14,962 DF, p-value: < 2.2e-16					

Source: London Economics (data from Innovate UK).

We can also visualise this effect by type of company.

Figure 44 Linear correlation between project duration and matched funding



Source: London Economics

A2.4 Environmental impacts

Based on Dai, Hu and Wang (2020), our methodology is as follows:

Fuel consumption in tonnes per day while at sea is modelled by Equation (1):

$$FC = \delta * \sqrt{W} * V^3, \tag{1}$$

where δ is an indicator of fuel efficiency, W measures weight of the vessel in tonnes approximated by TEU*10, and V measures the vessel speed in knots. The estimate of fuel efficiency for a ship of medium size (8000 TEU), based on Notteboom and Vernimmen (2009)[233], is $\delta_{8000TEU} = 5.813 * 10^{-5}\sqrt{W}/(V^3)$.

CO_2 emission in tonnes per trip is given by Equation (2):

$$CO_2 = \gamma * D * FC, \tag{2}$$

where D is the voyage length in days, and γ represents the exhaust factor of tonnes of CO_2 per tonne of fuel. It is given by the fuel's carbon fraction (typically 86.4%) multiplied by a factor that converts carbon to CO_2 (44/12).

$$\gamma = (0.8645) * \left(\frac{44}{12}\right) = 3.17 \tag{3}$$

To calculate how much CO_2 can be saved, the efficiency gains in percent are multiplied with initial emissions, modelled by Equation (3). In order to attain an estimate of external cost that can be avoided due to the efficiency gain, the avoided emissions are multiplied with an external cost factor for CO_2, which is given as £65 per tonne of CO_2[234].

The emissions produced by ships in ports depend on the time spent in port in hours, the power consumption of the auxiliary engine, and the exhaust factor. The power consumption correlates with ship size, as displayed in Table 25:

Table 25 Auxiliary engine power consumption

1,000-2,000 TEU	2,000-3,000 TEU	>3,000 TEU	>4,000 TEU	> 10,000 TEU	>15,000 TEU	>19,000 TEU
500-2,000 kW	1,000-2,500 kW	1,000-4,500 kW	2,000-7,000 kW	2,200-6,000 kW	4,000-10,000kW	Up to 16,000 kW[235]

Source: De Melo and Echevarrieta (2014)[236], MSC

The CO_2 emissions in tonnes per port stay are given by equation (4):

$$CO_2 = \varepsilon * T * PC \tag{4}$$

where ε represents the exhaust factor in grams of CO_2 per kWh, T represents the time spent at port in hours, and PC gives the power consumption of the auxiliary engine in kW. The exhaust factor of using the auxiliary engine depends on the type of fuel used. It is 690 g_{CO2}/kWh for MDO and 722 g_{CO2}/kWh for HFO[237]. We used the average of 706 g_{CO2}/kWh in our calculations.

[233] Notteboom and Vernimmen (2009). The effect of high fuel costs on liner service configuration in container shipping. Journal of Transport Geography. Volume 17, Issue 5. Pages 325-337.
[234] Schneider Electric (2018). Study of ship emissions whilst at berth in the UK. Available at :. [Accessed 06/11/2020].
[235] MSC (2015). MSC ZOE Christening in Hamburg.
[236] De Melo and Echevarrieta (2014). Resizing study of main and auxiliary engines of the container vessels and their contribution to the reduction of fuel consumption and GHG.
[237] International Transport Forum. (2014). Shipping emissions in ports.

The exhaust factors of various electricity sources are given in Table 26:

Table 26 Exhaust factors energy source

Energy source	Exhaust factor in gCO2/kWh	UK Energy mix 2019
Lignite	1,054	-
Coal	888	2.1%
Oil	733	-
Natural Gas	499	40.9%
Solar PV	85	2.7%
Biomass	45	-
Nuclear	29	17.4%
Hydroelectric	26	-
Wind	26	-
RES Mix	46	36.9%
Other (waste, imports...)	45	-
UK Average	**247**	**100%**

Note: The UK average is a weighted average of the relevant sources.

Source: UK Energy Statistics[238], World Nuclear Association[239]

Comparing the CO_2 emissions from using the auxiliary engine with the CO_2 emissions from shore power gives an estimate of the CO_2 emissions that can be saved. Applying the external cost factor of £65 per tonne of CO_2 to the emissions saved indicates the external cost that can be avoided through using shore power.

Table 27 Scenario options Summary

Voyage phase	3 Ships - Cosco Hamburg (4,446 TEU) - Hong Kong Express (13,092 TEU) - MSC Zoe (19,224 TEU)	6 Journeys - Barcelona to Antwerp (2,146 NM) - NY to Felixstowe (3,826 NM) - Hong Kong to LA (6,363 NM) - Rotterdam to Singapore (9,343 NM) - LA to Barcelona (9,508 NM) - Felixstowe to LA (10,153 NM)	
Port Phase	Time spent at port between 25 and 65 hours	Energy Sources - Lignite - Coal - Oil - Natural Gas - Solar PV - Biomass - Nuclear - Hydroelectric - Wind - RES Mix - Other (waste, imports…) - UK energy mix 2019	Power Consumption ranges between 1,000 and 16,000 kW

Note: The table presents all different options identified and used in the model (i.e. the voyage phase explored 18 different scenarios – 3 ships over 6 journeys).

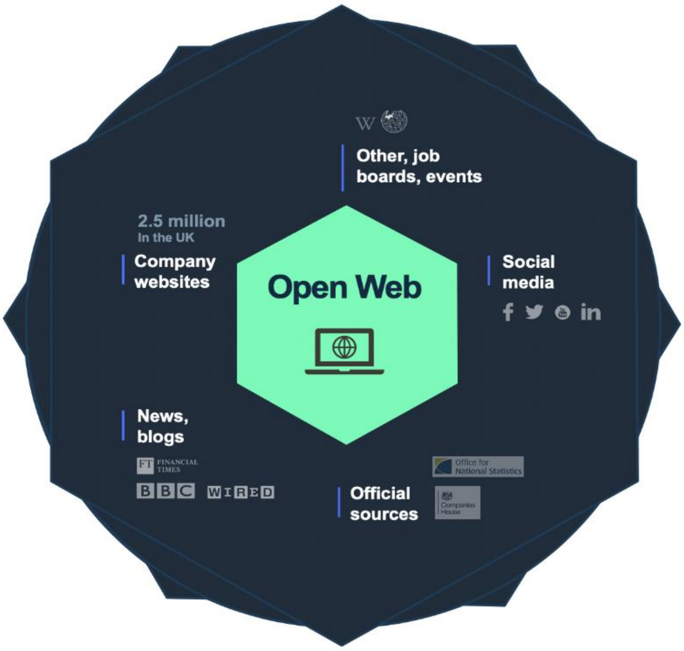
Source: London Economics

[238] BEIS (2020). UK energy statistics 2019.
[239] World Nuclear Association (2011). Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources.

Annex 3 Glass.ai. methodological note

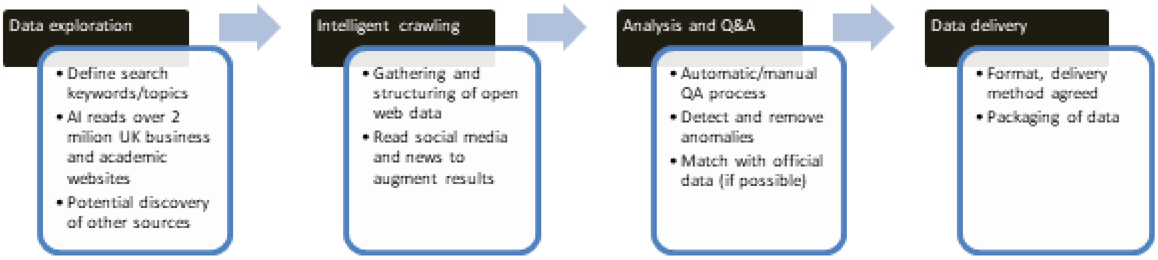
Process and sources

To help the London Economics team to identify and measure selected emerging sectors of the UK economy (e.g. marine tech) we apply AI, which understands web content and delivers datasets of rich textual data from the open web. The system also matches the web results to official Companies House register data. For reference, below are the main open web sources our AI system reads in the UK:



At the initial stage of the project, glass.ai put forward and agreed with the London Economics team a list of keywords for the selected sectors. To help with this task, glass.ai developed a taxonomy of 300k+ topics across sectors and themes. The crawler automatically classifies companies by sector (see **section 2** for details).

Taking 'marine tech' as a sector example, once the taxonomy has been confirmed, we use our proprietary algorithms to augment the glass.ai results and identify any text that may suggest the companies are involved in marine tech-related activities. We provide the provenance of the results for validation. To ensure more complete coverage, we also augment the results with additional data from sources including new sources, social media, and Companies House data. It's an iterative process, working collaboratively with the project team throughout. Below is the high-level process:



Output

The main output for the project is a dataset provided in comma-separated variables (CSV) or a similarly accessible format. The data fields we propose for each sector are the following (assuming the companies have active sites with relevant text):

- Company/entity name - name of the business/entity as it appears on the website;
- Website - URL for the business/entity;
- Description - textual data pertaining to the type of economic activity conducted by the business extracted from the website (usually from the company/entity description). This textual data will contain only human-readable text from the website;
- Sector - predicted sector for the companies/entities by the glass.ai engine;
- Sector-related topics – e.g. 'marine tech' topics from the website, usually found within the company description;
- Location, postcode – details of the main trading address, and we can also aggregate numbers for companies/entities with many locations on the website;
- Official data matching – company registration number, if available. The company incorporation date, registered name, SIC code and registered address can also be provided;
- Social media matching - links to social media accounts (Twitter, LinkedIn) whenever available from the websites;
- Number of employees - number of staff, whether available from the website, press releases or LinkedIn (proxy for employees);

The deliverables will be exclusive to London Economics.

We cannot predict exactly how many relevant businesses will have rich web data. Currently our crawler reads and interprets the data from the websites of 2M+ UK businesses. Of these, the engine has identified descriptions for 73% of them. We will not know if there is a similar percentage for the selected sectors until we run the crawl. Below is a sample of the data we can deliver showing a selection of fields:

key	organization_name	organization_website	organization_descr	sector_group	sector	ch_incorpo	sys_phrases	location	sys_address_pos	organization_cou	sys_ch_crn	sys_ch_name	sys_ch_postcod	ch_sic_text_1	sys_link_linkedin	twitter_link	employees
626976	1 Virtual World	1virtualworld.com	Supplying IT Strategic Advisory Services for various organisations delivering IT strategy, digital transformation and technology innovation.	Professional Services	Consulting	23/04/2015	artificial intelligence;machine	BANCHORY	AB31 4BW	United Kingdom	SC504096	1 VIRTUAL WOR	AB31 4BW	59112 - Video production	https://uk.linkedin.com/com	https://twitter.co	
11496800	10x Psychology	http://10xpsychology.com	10x Psychology provides modern assessment tools, predictive analytics and innovative solutions, spanning the entire employee lifecycle from hiring	Professional Services	Staffing and Recruiting	16/09/2015	predictive analytics	GUILDFORD	GU2 7AE	United Kingdom	9780665	10X PSYCHOLO	SW6 4QP	72200 - Research and ex	https://www.linkedin.com/cc	https://twitter.co	11-50 employees
627142	1859 Cloud	1859cloud.com	1859 Cloud is developing a new & unique investment ecosystem seeking financial growth and positive change. 1859 Cloud connects some of the	Financial Services	Investment Management	09/07/2015	swarm intelligence;artificial	LONDON	W1J 8LA	United Kingdom	09678874	1859 CLOUD LIM	W1J 8LA	62090 - Other informatior	https://www.linkedin.com/cc		1-10 employees
2683563	2M Automation	http://2m-automation.co.uk	Motion is magic, it is mysterious, and it is behind everything we do. At 2M we harness this to make wondrous things happen through automation. 2M have	Professional Services	Design	01/05/2003	robot	OLDHAM	OL8 4QQ	United Kingdom	04750866	2M AUTOMATIO	SK9 4LY	74100 - specialised desig	https://uk.linkedin.com/com	https://twitter.co	1-10 employees
11496803	3co	http://3co.ai	3co provides the world's simplest solution for selling beautiful products through augmented reality. We develop 3D scanning robotics & augmented	Technology	Information Technology and Services		robotics	LONDON	EC2A 4AR	United Kingdom					https://uk.linkedin.com/com		1-10 employees
11496804	3Cubed Search	http://3cubed.tech	Female founded and run, 3Cubed was established in answer to the gap in the market for emerging and immersive tech-specialist recruitment. Built on	Technology	Computer Software	19/08/2016	ai;robotics	LONDON	EC2A 4UY	United Kingdom	10338210	3CUBED SEARC	CM17 0ET	82990 - Other business s	https://www.linkedin.com/cc	https://twitter.co	1-10 employees
4443624	4 Kings Security	http://www.4ks.co.uk	Whatever the scale, 4ks has the right solution for you, we work with you at every step to ensure that your needs are met and every aspect is	Professional Services	Security and Investigations	29/10/2001	facial recognition	CATERHAM	CR3 5EG	United Kingdom	04312710	4 KINGS SECUR	CR3 5EG	43210 - Electrical installa			
628042	4Sight Imaging	www.4sightimaging.com	Founded in 2004, 4Sight Imaging develops and applies patented imaging technology to deliver automated visual solutions that solve many challenges	Technology	Computer Software	25/08/2004		BOLTON	BL1 2AX	United Kingdom	05214775	4SIGHT IMAGIN	BB1 5QB	82990 - Other business s	https://uk.linkedin.com/com		11-50 employees
11496807	50 Creative Solutions	http://50creativesolutions.con	A highly approachable and creative technology entrepreneur & digital marketing agency, specializing in all forms of mobile responsive websites	Professional Services	Marketing and Advertising	29/04/2019	artificial intelligence	LUTON	LU1 4DG	United Kingdom	11969258	50 CREATIVE SC	AL3 7LE	63990 - Other informatior		https://twitter.co	
628163	67 Bricks	67bricks.com	67 Bricks is a software development consultancy. We specialise in helping publishers ingest, enrich and manage content and we use enriched content	Technology	Computer Software	09/05/2007		OXFORD	OX1 1BN	United Kingdom	06242204	67 BRICKS LTD	PE27 5BH	62020 - Information techr	https://www.linkedin.com/cc	https://twitter.co	11-50 employees
628178	6point6	6point6.co.uk	Integrating digital technology into your business can result in fundamental changes to how you operate and deliver value to your customers. To go	Technology	Information Technology and Services	09/03/2017	artificial intelligence;ai	LONDON	SW1Y 4JH	United Kingdom	10660712	CLOUD GATEW	WC1V 6LJ	62012 - Business and do	https://uk.linkedin.com/com	https://twitter.co	51-200 employee
11482414	74Ds	http://74ds.co.uk	Today, we're the founders of a successful startup, and our life can now be summarized in doing all that we can do to grow our, as fast as possible.	Professional Services	Security and Investigations	15/08/2017	artificial intelligence	BRISTOL	BS9 3BY	United Kingdom	10917200	74DS LTD	BS9 3BY	62020 - Information techr			
11496808	9fin	http://9fin.com	9fin uses artificial intelligence to automatically extract key information from bond & loan documentation. By making data easy to search, filter and	Financial Services	General Financial Services	28/10/2016	artificial intelligence;predictive	LONDON	N1 7GU	United Kingdom	10451957	9FIN LIMITED	EC2V 6DN	63990 - Other informatior	https://www.linkedin.com/cc		11-50 employees
11496809	A-dapt	http://a-dapt.com	Adaptive-media is an original AI-based video and facial analysis format that uses deep neural network technology to adapt digital content naturally to the	Professional Services	Marketing and Advertising		ai;deep neural network	LONDON	EC2A 4UY	United Kingdom					https://uk.linkedin.com/com		1-10 employees
631340	A3L	http://a3l.uk.com	Digital technologies to help you carry out your operations more effectively. A3L understand that new technology can be 'high risk' and so we offer full	Industrial and Agriculture	Aviation, Aerospace and Defense	20/12/2012	robot	SHEFFIELD	S2 3EN	United Kingdom	8338546	ADVANCED AER	S11 9JL	30300 - Manufacture of a	https://www.linkedin.com/cc		1-10 employees
2100	AA Robotics	www.aarobotics.co.uk	AA Robotics specialises in the supply of small assembly robots for flexible factory automation. Uk & Ireland Distributors for DENSO robots.	Industrial and Agriculture	Industrial Automation	26/09/2007	robotics;robot;industrial robot	AYLESBURY	HP20 1DQ	United Kingdom	06382573	AA ROBOTICS L	HP20 1DQ	28220 - Manufacture of li	https://www.linkedin.com/cc	https://twitter.co	1-10 employees
11496810	AB Dynamics	http://abdynamics.com	Founded in 1982 as a vehicle engineering consultancy, AB Dynamics has grown steadily to become one of the world's most trusted suppliers of	Supply Chain and Transp	Automotive	07/02/2013	autonomous driving;robot	BRADFORD-ON-	BA15 1GB	United Kingdom	8393914	AB DYNAMICS P	BA15 1GB	82990 - Other business s	https://uk.linkedin.com/com	https://twitter.co	51-200 employee
740306	ABAKA	www.abaka.me	ABAKA is a SaaS Cognitive Financial Advice Platform. We provide financial institutions, of any size, anywhere in the world, the software to thrive in the	Financial Services	General Financial Services	11/01/2016	ai	LONDON	SW1W 0SR	United Kingdom	9943429	ABAKA HOLDIN(	SW1W 0SR	62090 - Other informatior		https://twitter.co	
11477656	AbleAI	http://ableai.co.uk	We have designed and developed, through practical experience and using Artificial Intelligence (AI), the Able AI platform to enable our disabled and	Technology	Computer Software	24/08/2018	artificial intelligence;ai	LIVERPOOL	L3 9DG	United Kingdom	11536028	ABLE AI LTD	L3 9DG	62020 - Information techr		https://twitter.co	
3392444	Above Surveying	http://www.abovesurveying.c	Above Surveying brings together an unparalleled blend of UAV, IT and Solar PV experience to the market. Solely focused on the solar sector, Above	Real Estate and Construc	Civil Engineering	26/11/2013	ai;machine learning;robotics	COLCHESTER	CO4 3ZL	United Kingdom	08790960	ABOVE SURVEY	CO4 3ZL	47990 - Other retail sale	https://www.linkedin.com/cc	https://twitter.co	11-50 employees
11496812	Absolute Derivs	http://absolutederivs.com	Working with Global Clients on their OTC Derivatives Solution in line with current and future regulation: - From Natural Language Processing (NLP)	Financial Services	General Financial Services	23/08/2017	natural language processing	LONDON	N1 7GU	United Kingdom	10930060	ABSOLUTE DER	SW1P 2PN	70229 - Management cor	https://uk.linkedin.com/com	https://twitter.co	1-10 employees
11476708	Absolute Robotics	http://absoluterobotics.co.uk	Absolute Robotics supplies, designs and implements fit-for-purpose solutions for customers using the cutting-edge features and technology of	Industrial and Agriculture	Industrial Automation	08/08/2018	robotics;machine vision	BRISTOL	BS34 8RB	United Kingdom	11506074	ABSOLUTE ROB	B60 3EU	71122 - Engineering relat	https://www.linkedin.com/cc		1-10 employees
11496813	Abstract Leap	http://abstractleap.com	Abstract Leap is a passionate and talented team of software engineers that design and build unique software solutions for small and large enterprises.	Technology	Computer Software		artificial intelligence	OXFORD	OX4 4GP	United Kingdom							
11496814	Abtrace	http://abtrace.co	Data Science informed by Clinical Experience. Delivered by a next generation decision support tool. Our first product is focused on tackling	Healthcare and Scientific	Hospitals and Medical Practices	24/08/2018	natural language processing	LONDON	W2 1BE	United Kingdom	11535661	ABTRACE LIMITI	WC2B 4AS	62090 - Other informatior	https://uk.linkedin.com/com	https://twitter.co	1-10 employees
3402885	Academy Of Robotics	http://academyofrobotics.co.u	We are a technology company with an extraordinary technical team of engineers, scientists, and researchers. We specialise in creating technology	Supply Chain and Transp	Automotive	09/09/2014	machine learning;artificial	CARDIFF	CF11 9HB	United Kingdom	09209349	ACADEMY OF R	CF14 8LH	62012 - Business and do	https://uk.linkedin.com/com	https://twitter.co	1-10 employees

Matching with official data and social media sources

We understand that it is very important that the web data on companies is matched with official data sources. Over the past few months, the team at glass.ai have developed models to match the web results with Companies House (CH) in line with interest from our customers. Currently we've matched almost a third of all UK companies between detailed web data and the corresponding CH record. As far as we know, no other company has attempted or achieved this level of matching. We have recently completed a project with the ONS with a match rate of 60% of the results using internal data from a list of 30k UK companies.

We have also developed techniques to match the web data to social media (LinkedIn, Twitter). The level of matching depends on the sector and size of the company, as well as whether the social media handles are provided on their websites.

Innovation and approach

Glass.ai has an ongoing discovery process that reads websites and classifies the site as a company website if it detects certain criteria around content (e.g. active, in English, business content) and if possible, will predict the sector and geography of the business if enough content is available on the site (e.g. a UK address). Currently glass.ai reads over 2m UK-based business websites. We believe this represents a significant proportion of UK businesses with a web presence. Where possible we also match the websites with UK businesses from the official data. As well as discovering new content, this ongoing process keeps the existing view of the businesses that it knows about up to date.

To make this possible, glass.ai has invented AI technology that applies techniques at the frontiers of machine language understanding to create an automatic semantic layer for the web. It combines language understanding through semantic analysis with resource crawling at scale and the maintenance of a deep topic ontology.

Semantic Analysis: First, our crawler classifies the content of text on web sources (e.g. company descriptions, topics, news, etc.) with state-of-the art precision. When our crawler then goes to a website, it makes its own decisions and it can understand what the description for the company is, the news, products mentioned, people, and jobs advertised, and extracts linked entity models from the unstructured web content. Our current entity-detection accuracy is 95%, and we believe the work conducted to date on this is world leading. To achieve this semantic entity recognition, we train models offline using machine learning techniques against small volumes of data that can be efficiently applied against web-scale volumes of data. Using this infrastructure, new language models can be built to detect new types of content.

Business descriptions, for example, are identified with language models that consider multiple features such as location on the web page, use of specific keywords and phrases, or sentence structure, for example. Also, based on descriptions and other attributes, each business is classified into one or more sectors and assigned a weight showing its proximity to the sector. Specialised businesses tend to have a single sector with high weight, while those with a diversified activity have multiple sector predictions with lower weight values. The automatic sector classification has been trained using a sample of company classifications based on an industrial taxonomy created by LinkedIn. Current accuracy of the descriptions and sector predictions is 95%.

Resource Crawling: in a second step, we have industrialised the extraction process by developing an intelligent crawling service that targets the crawl to read content and follow links that are most likely to find the entities that it has been created to detect. By directing the crawl to find known entities and concepts 'within' the crawl instead of retrospectively filtering data returned, we are able to get large scale information-extraction efficiently running on very modest hardware, and the system as designed scales linearly. This means we can read millions of sources without the need of massive computation resources.

Topic Ontology: in a third step, we have derived a 'topic map' for the data. This taxonomy includes business activities, products and services, and is key to understanding what a company does and the activities it is involved in. This allows us to query the data by subject classification. For example, a 'geospatial' search would suggest semantically related simple topics such as 'geomatics', 'drones', and others. The system currently contains around 300k topics. We continue to improve this topics map to drive simple and complex entity detection and add other entity types to the ontology. The topic ontology has been built and continues to evolve from reading the web content that is crawled and consuming crowd sourced content, such as Wikipedia. It can also be augmented by subject specific lists in cases where they are not sufficiently covered by the current core topic ontology.

Limitations

The public web provides a rich context around the activities of businesses. However, not all UK businesses have a website, so our approach is limited to those that have an independent web presence. This may impact the representation of smaller organisations as they are less likely to have a website than larger organisations. Further, the absence of web presence can be sector dependent. That is, certain sectors may be more likely to have a web presence than others.

We estimate there are circa 2.5m UK organisations with an active website. At present our crawler has not discovered all the websites of these organisations and is currently reading 85%+ of them. To mitigate this risk for specific research, the core glass.ai dataset can be augmented with external lists of known businesses and their websites, and core online resources.

As the web is constantly changing and new sites are appearing and disappearing, sites may be missing because they have not yet been discovered by our onboarding schedule or may have been in a format or structure that our processes were not able to read or do not match the models that are being detected. In particular because our approach is language based - relying on reading static text content - it may struggle to read image, flash or Javascript-heavy sites where content is displayed dynamically or embedded in other objects.

When performing targeted research, a challenge using specific keywords to identify activities is that if a relevant business doesn't list those words on their website or is on a page that has not been read by our directed crawl then the business may not be included in the results. This can be mitigated by supplying a broad range of topics associated with the types of companies that need to be discovered and using the topic ontology to discover topics related to the supplied list.

Quality assurance

To quality-assure the data, we do both manual and automatic quality assurance processes across the data fields. The glass.ai team checks samples of the data to identify errors and isolate classes of issues. In addition, automated aggregate and statistical checks are run across all data to ensure confidence in the delivered set and to detect and remove any anomalies that are discovered. All these checks and balances will be used to provide assurance that the data outputs are robust and reliable. We believe the results of our semantic entity detection technology are world class. The latest quality (accuracy) numbers for some of the main fields are 95%+.

Annex 4 Estimates of the economic impact of robotics, automation, and digitalisation

Source	Regional coverage	Sectoral coverage	Technological coverage	Estimated impact
Accenture (2017). *Industrial Digitalisation Review Benefits Analysis* (Made Smarter Review (2017))	UK	Manufacturing	Industry 4.0	Value at stake estimated to be approximately £455 billion over the next decade
		Construction		Value at stake estimated to be approximately £89 billion over the next decade
		Food and drink		Value at stake estimated to be approximately £56 billion over the next decade
		Pharmaceuticals		Value at stake estimated to be approximately £22 billion over the next decade
		Aerospace		Value at stake estimated to be approximately £18 billion over the next decade
Made Smarter Review (2017). *Working group report on jobs and the economy*	UK	Total economy	Industry 4.0	Net gain of 175,000 jobs.
Made Smarter Review (2017). *Sustainability working group report*	UK	Total economy	Industry 4.0	Reduction in CO2 emissions by 4.5 percent.
Made Smarter Review: Industrial Digitalisation 2017	UK	Total economy	Industry 4.0	Improve industrial productivity by more than 25% by 2025.
BCG (2017). *Is UK Industry ready for the Fourth Industrial Revolution*	UK	Manufacturing	Industry 4.0	Industrial efficiency gains of 25% and increased manufacturing sector growth rates of 1.5-3 percent, delivering growth of around 0.5% of GDP annually.
BCG (n.d.). *The Benefits of Industry 4.0.*	UK	Automotive	Industry 4.0	10-20% productivity increase, measured by conversion costs
		Food and beverage		10-20% productivity increase, measured by conversion costs
		Components		20-30% productivity increase, measured by conversion costs
		Machinery		10-20% productivity increase, measured by conversion costs
		Other manufacturing		20-30% productivity increase, measured by conversion costs
Accenture (2015). *The Growth Game-Changer: How the Industrial Internet of Things can drive progress and prosperity*	World	Total economy	Industrial Internet of Things	Add US$10.6 trillion to the world economy by 2030, given current investment levels. The estimate could rise to up to US$14.2 trillion with greater investment and the enactment of key measures to absorb IIoT technologies.
KPMG (2016). *The Digitalisation of the UK Automotive Industry*	UK	Automotive	Industry 4.0	Fully embracing digitalisation could yield gains of £6.9 billion every year by 2035 for the automotive sector, and a benefit to the total economy of around £74 billion cumulatively by 2035.
Barclays (n.d.). *Future-proofing UK manufacturing*	UK	Manufacturing	Automation / robotic equipment	Estimated the value added to the UK by the manufacturing sector of a moderate increase in investment in automation of £1.24 billion to be £60.5 billion over the next decade (direct effects), and a further £2.5 billion a year by 2020 and £3.9 billion a year by 2025 (indirect effects).

Annex 4 | Estimates of the economic impact of robotics, automation, and digitalisation

Source	Regional coverage	Sectoral coverage	Technological coverage	Estimated impact
McKinsey (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy*	World	Total economy	Internet of Things	Potential direct economic impact of US$2.7 to US$6.2 trillion per annum in 2025.
			Advanced Robotics	Potential direct economic impact of US$1.7 to US$4.5 trillion per annum in 2025.
			3D Printing	Potential direct economic impact of US$0.2 to US$0.6 trillion per annum in 2025.
McKinsey (2018). *Disruptive force in the industrial sectors*	Global	Total economy	Artificial Intelligence	Market size for AI estimated to grow at an annual rate of 50% - 60% from US$2 billion in 2016 to US$130 billion in 2025.
			Connected devices	Connected devices estimated to growth at an annual rate of 15% - 20% from 18 billion units in 2016 to 75 billion units in 2025.
			Cybersecurity	Market size for cybersecurity estimated to grow at an annual rate of 5% - 10% from US$96 billion in 2016 to US$210 billion in 2025.
Special Interest Group Robotics and Autonomous Systems (2014). *RAS 2020 Robotics and Autonomous Systems.*	UK	Non-military	Robotics and Autonomous Systems	Estimated market for non-military Robotics and Autonomous Systems (RAS) products and technologies of £70 billion by 2020-2025, impacting 15% of GVA (£218 billion) on the UK economy, and a potential to raise manufacturing sector productivity by up to 22%, generating a long-term employment increase of up to 7%, if current RAS technology was optimised.
Lockheed Martin (n.d.). *3D Printing 101*.	Firm level	Satellite production	3D Printing	Utilising 3D titanium printing in satellite production can reduce cycle time by 43% and yield a cost reduction of 48% compared to traditional satellite production.
PWC (2017). *Sizing the prize – What's the real value of AI for your business and how can you capitalise?*	World	Total economy	Artificial intelligence	Contribution of up to £15.7 trillion in 2030 (US$6.6 trillion from increased productivity and US$9.1 trillion from consumption side-effects).
Brynjolfsson, Hitt and Kim (2011). *Strength in Numbers: How Does Data-Driven Decisionmaking Affect Firm Performance?*	United States	Firm level	Data-driven decision making	Firms that adopt data-driven decision making have 5% - 6% higher output and productivity than expected, given their investments in other information and communication technology.
Barua, Mani and Mukherjee (2013). *Measuring the Business Impacts of Effective Data*	Fortune 1000 firms	Firm level	Data-driven decision making	A 10% increase in the usability of data - presenting data more concisely and consistently across company platforms (e.g. laptops) - is associated with a 14% increase in labour productivity on average.
Citigroup-Oxford (2015). *TECHNOLOGY AT WORK: The Future of Innovation and Employment*	Firm level	Mining	Autonomous drill rigs	Shifting to autonomous drill rigs can increase productivity by 30% - 60%.

Source	Regional coverage	Sectoral coverage	Technological coverage	Estimated impact
Meech, J. (2012). *Simulation of Autonomous Mine Haulage Trucks*	Firm level	Mining	Autonomous mine haulage trucks	Shifting to autonomous mine haulage trucks is associated with a 15-20% increase in output, a 10-15% decrease in fuel consumption, and an 8% reduction in maintenance costs.
Dave Clark, Senior Vice President of Worldwide Operations and Customer Service at Amazon. Cited by: Citigroup-Oxford (2017). *TECHNOLOGY AT WORK v3.0: Automating e-Commerce from Click to Pick to Door*	Firm level	e-Commerce	Autonomous warehouse robots	Automated picking and packing processes, utilising Kiva robots, reduce operating expenses of Amazon's fulfilment centres by ~20%.
Evans and Anninziata (2012). *Industrial Internet: Pushing the Boundaries of Minds and Machines*	US	Total economy	Industrial Internet	If the industrial internet could achieve a productivity growth differential similar to the internet revolution (3.1%), it could generate average income gains of US$20,000 by 2030, approximately 40% of current US GDP per capita. A more conservative productivity growth of 2.6% would still deliver average income gains equivalent to 25% of US GDP per capita.
	Global	Health care		Deployment of the industrial internet can drive health-care costs down by roughly 25% - equivalent to approximately US$100 billion in savings per year.
		Commercial aviation		Cost reductions of 1% from better flight planning and operational changes, brought about by the industrial internet, could save the global commercial airline business nearly US$2 billion in fuel costs per year. A 1% reduction in capital expenditures, brought about by the industrial internet, could result in cost savings of US$1.3 billion per year, or approximately US$29 billion over 15 years. A 1% improvement in maintenance efficiency due to the industrial internet could reduce commercial jet engine maintenance costs by US$250 million.
		Rail transportation		A 1% reduction in rail operations systems inefficiencies, brought about by the industrial internet, would save about US$1.8 billion per or, or approximately US$27 billion over 15 years.
		Power production		Improvements in country-level average gas generation efficiency of 1%, due to the industrial internet, would reduce fuel spending by more than US$3 billion in 2015 and US$4.4 billion in 2020, or approximately US$66 billion over a 15 year period.
		Oil & Gas Development and Delivery		An additional 1% reduction in capital expenditure, due to the industrial internet, would translate into savings of US$6 billion per year or US$90 billion over 15 years.
Vodafone (2017). *IoT Barometer 2017/18*	World	Firm level	Internet of Things	Among industrial adopters, the Internet of Things increased revenue by 19% on average and cut costs by 16% on average.

Source: London Economics

Annex 5 Technology assessment matrix

Group of technologies	Example of leading company	Current TRL level	Investment to develop to TRL 9	Time to TRL9 (years)	Efficiency gain	Cost reduction	Environmental benefits	Accidents avoided
Smart ports		**5**	**£170m**	**0.63**				
Terminal automation and cargo handling	Navis	9	-	0.00	5	4	2	3
Port community systems	IPCSA	5	£120m	0.21	4	3	1	1
Traffic management system	SAAB (sea traffic)	9	-	0.00	5	4	2	5
Automated information systems	Antwerp Gateway Terminal	9	-	0.00	4	4	3	4
Real-time location systems (RTLS)	N/A	9	-	0.00	5	2	1	1
Automated mooring systems	Trelleborg	9	-	0.00	4	2	1	4
Gate automation	CAMCO Technologies	9	-	0.00	5	1	1	1
Shore power	ABB	9	-	0.00	4	3	5	1
Smart energy and environmental solutions	Exxon, Shell DP World	8	£50m	0.63	4	3	5	1
Autonomous vessels		**6**	**£340m**	**3.13**				
Ships with automated processes and decision support	Kongsberg	8	£50m	2.34	1	2	1	3
Remotely controlled ships with seafarers on-board	Kongsberg	7	£90m	3.13	1	2	1	3
Remotely controlled ships without seafarers on-board	Kongsberg	7	£90m	3.13	2	3	1	3
Fully autonomous ships	Kongsberg	6	£110m	1.88	3	4	1	3
On-board technology		**8**	**£50m**	**3.91**				
Condition-Based Monitoring	Wartsila (propulsion)	9	-	0.00	5	3	2	4
Artificial Intelligence / predictive modelling	GreenSteam (performance optimisation) (UK)	8	£50m	3.91	5	4	5	1
Energy management	Seimens	9	-	0.00	4	3	2	1
Professional services technology		**9**		**0.00**				
Training	Solent university Southampton (UK)	9	-	0.00	3	1	1	5
Insurance	Lloyds (UK)	9	-	0.00	1	1	1	1
Shipbroking	Clarksons (UK)	9	-	0.00	4	1	4	1

Note: Assessment of gain, cost reduction, environmental benefits and accidents avoided are qualitative and subject to bias. It ranges from 1 = very low to 5 = very high.
Source: London Economics and NLAI

Somerset House, New Wing, Strand,
London, WC2R 1LA, United Kingdom
info@londoneconomics.co.uk
londoneconomics.co.uk
@LondonEconomics
+44 (0)20 3701 7700