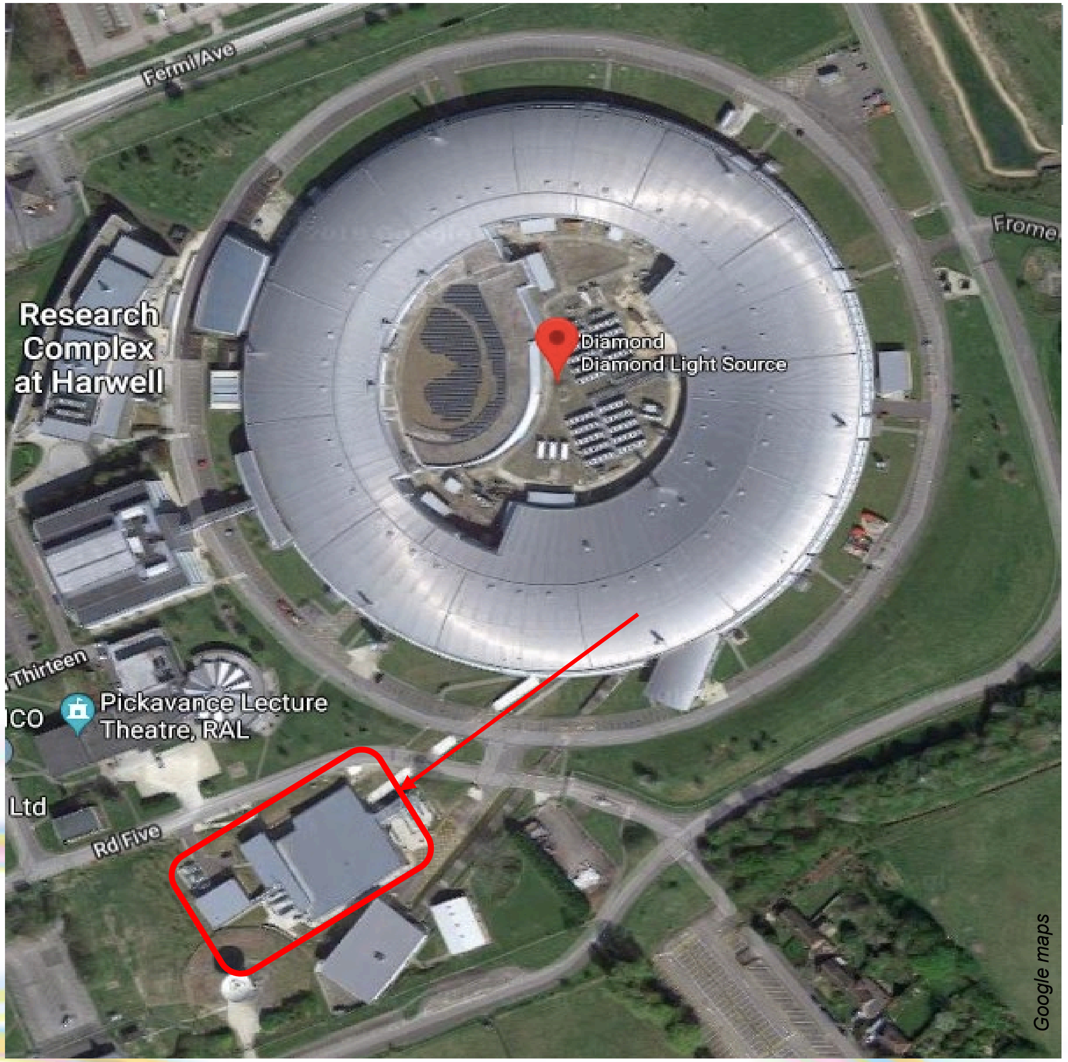
Impact of large central facilities for science and engineering – known and unknown quantities

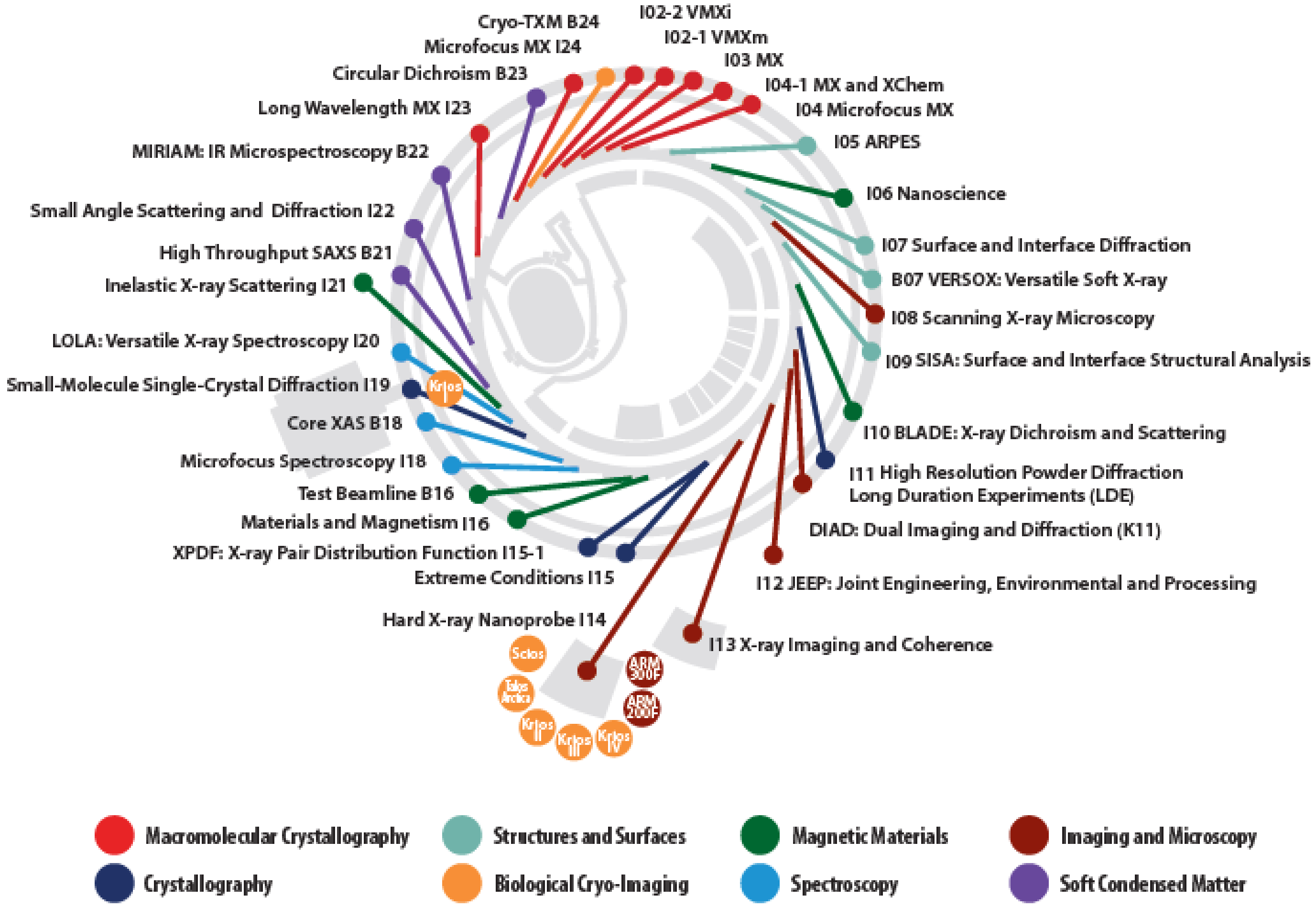
Andrew Harrison, Diamond Light Source, UK

Impact of Research Infrastructures 2.0

September 16th-17th 2021

Construction started 2003, operational 2007, 33 beamlines completed 2020





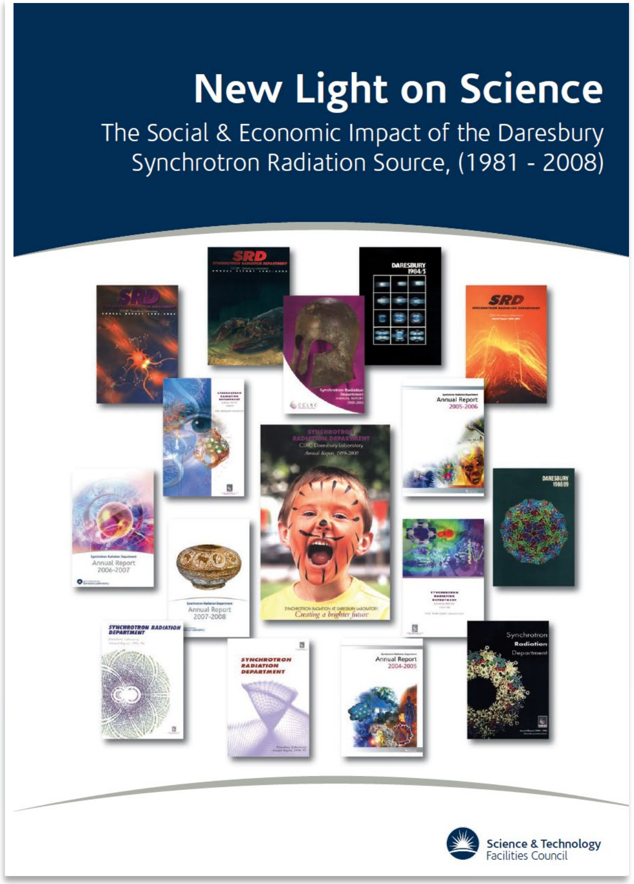
Motivation and methodology

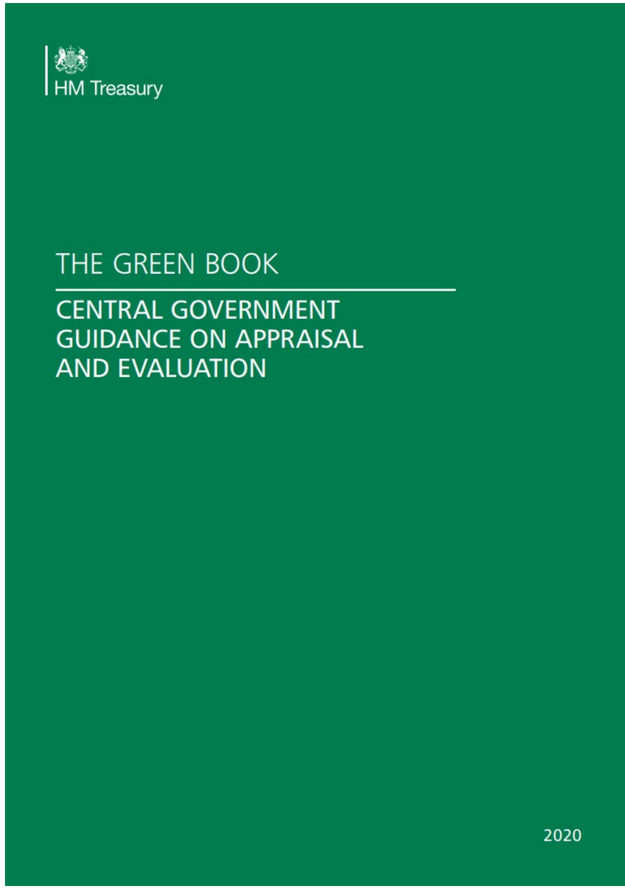
- Justify continued funding for Diamond
- Making the case for an upgrade – Diamond-II

Diamond's predecessor – the Synchrotron Radiation Source (SRS) at Daresbury ran from 1981 – 2008

Socio-economic study that could refer to direct impact from historic perspective as well as applying sector-relevant macro-economic multipliers and also citing case studies – yielding a financial economic benefit of almost twice the lifetime budget

https://stfc.ukri.org/files/impact-publications/new-light-on-science/





Diamond's Socio-economic Impact

Developed and delivered with Technopolis in collaboration with shareholders STFC/UKRI and Wellcome

Very wide survey of users in academia and industry, gathering facts, opinions and advice and case studies, combined with Diamond statistics, including bibliometrics

Aim to be acceptable to UK Government (Treasury), aligned with their methodology for assessment – macro-economic multipliers no longer hold weight and need to build more bottom-up models (very valuable interaction with CSIL)

https://www.technopolis-group.com/new/impact-of-diamond-synchrotron/

Model and Scope

Developed logic model based on OECD approach, starting with Diamond objectives and then worked through inputs to impacts – monetizable and not – across areas of scientific, technological, societal and economic

Inputs	Key indicators	Sources of evidence
Investment	• Value of investments made by BEIS/STFC, the Wellcome Trust and Others for a total amount of £1.2 billion • **762 FTE staff**	Diamond finance Diamond HR database

	Activities	Key indicators	Sources of evidence
Scientific	Development of facilities	• **32 Beamlines** • **11 electron microscopes**	Diamond KPIs
	Use of facilities by users	• **14,274 experimental shifts** delivered in 2019/20 for academic users which illustrates the current level of activity; this is almost a 9-fold increase since 2007 • **5,851 remote user visits** and 6,454 onside remote visits in 2019/20. Overall user visits have increased by a factor 17 since 2007	Diamond KPIs
		• **700 user visits** via the proprietary access route **180 companies** using Diamond for their research since 2007	Diamond contractual information
	Collaborative activities and ventures	• Diamond has **68 active formal scientific collaborations**; **22 new collaborations** are being progressed as we issue this report • In addition, Diamond has **54 active grants**, **25 new grants** having been awarded in 2019/20	Diamond

	Output	Key indicators	Sources of evidence
Scientific	Knowledge creation	• **9,600 articles** published in peer reviewed journal as of September 2020 • **Almost 77% of the articles in the Diamond publications database are open access (according to data from SciVal 2010-2019, all types of open access included). 9,960 structures** deposited in the PDB • In 2018, **34% of all structures solved by synchrotrons in Europe** and around **13% of all worldwide** synchrotron structures were solved at Diamond	Diamond KPIs

	Outcomes	Key indicators	Sources of evidence
Scientific	Knowledge creation	• Important scientific advances reported by the majority of academic users surveyed	Technopolis survey of academic users
	Outcomes for facility users	• 94% of 321 academic users surveyed claimed that their use of Diamond had been **beneficial for their national or international reputation** • Evidence from the user survey that Diamond is playing a role in **academic recognition** (see Appendix F) • 54% of 318 academic users surveyed reported that their use of Diamond had been **very important or critical** to their subsequent ability to **access grant funding** • Evidence from the user survey that using Diamond had led to improvements in the users own **knowledge, skills and capabilities**	Technopolis survey of academic users
	Outcome for Industry users	• Evidence from the industry user survey that using Diamond had led to improvements in the **skills and capabilities of staff** • 73% of 22 industry users surveyed stated that Diamond was **very important or critical** to their part of their business	Technopolis survey of industry users

	Impact	Key indicators	Sources of evidence
Scientific	Knowledge creation	• Based on study done in 2017, Diamond's contribution to the PDB (4,666 structures deposited) can be valued at £352 million. Please note that only 45% of the structures deposited by Diamond have been monetised. • Since the beginning of operation in 2007, Diamond has been involved in the publication of over 9,600 articles which have a total estimated value of £677 million • The **impact of journals** in which Diamond publications appear is high (**65% above average**) • The **impact** of the publications themselves is **59% above the world average** • In fact, **19%** of Diamond publications belonged to the **top 10% most highly cited in their field** • Patents citing Diamond publications are collectively valued at £10.2 billion (in 2018 prices). A conservative estimate of this proportion is around 1%,which would mean that **the contribution from Diamond could be worth at least £103 million.**	PDB Diamond publications database CTWS and Scival Bibliometric repor
	Industry income	• Diamond's annual proprietary income has grown, from £300 thousand (2008/9) to over £3 million (2019/20). Since 2008, the cumulative **income from industrial users** has reached over £15 million	Diamond Industri Liaison Office
	Benefits to users	• Estimated direct benefits to users by providing free access to the instruments of £551.5 million (this is the average between lower and higher estimates)	Desk research

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Monetising impact

- Anticipated need to develop model for ‘Value for Money’ for future upgrades – so tried to monetise outputs
  - Direct impact through operational expenditure
  - Research output based on resource directed at producing papers
  - Beamtime for users in academia and industry based on willingness to pay
  - Structures deposited in Protein Data Bank (9,960)
  - Value of patents (percentage of Diamond contribution to world value)
  - Software and Apps
  - Training (through comparison with commercial rates)

- Huge void in assessment: value to industry in terms of new products and services – no-one prepared to share commercially sensitive figures

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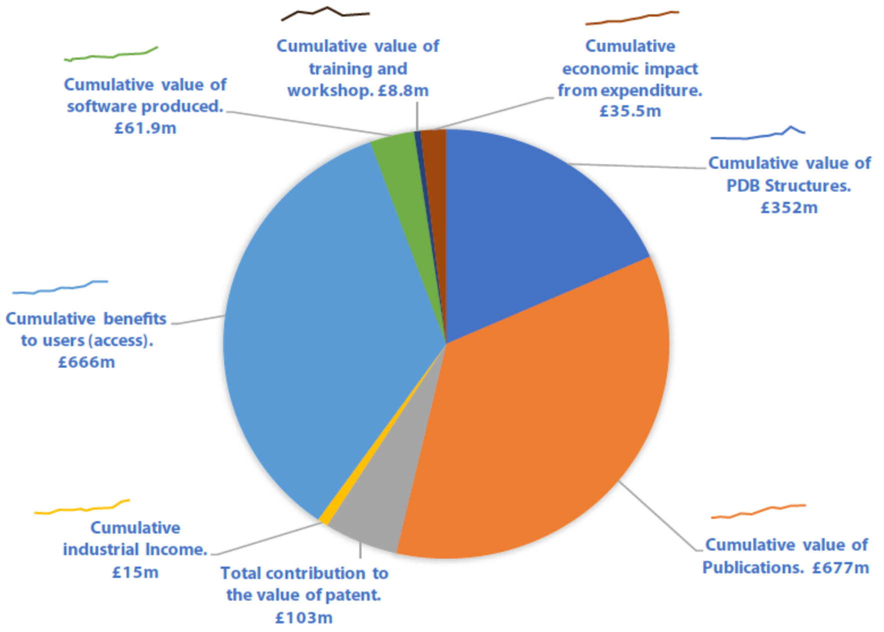
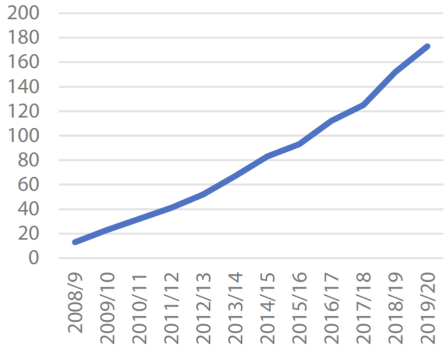
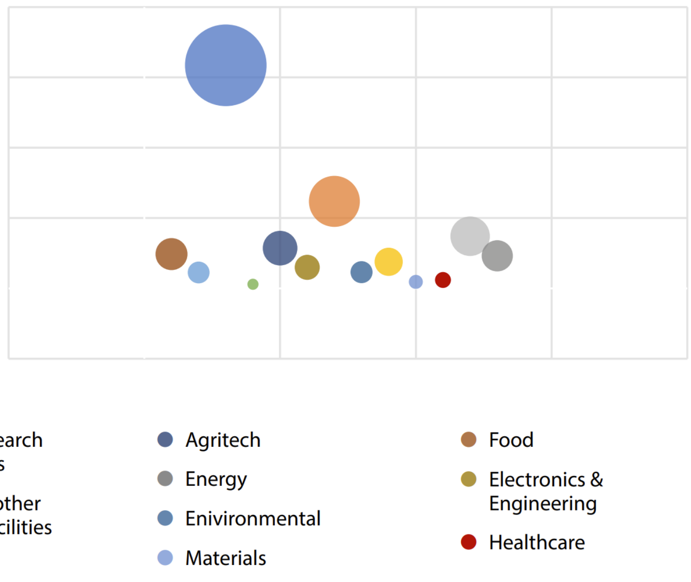
Wider impact

- Cumulative impact of at least £1.8 bn to date based on total expenditure of £1.2 bn – but **we are failing to capture most of the value to industry**







- Social impact of research – drugs for depression, cleaner water, COVID-19 research – all expressed through many case studies
- Value of outreach and education for the public

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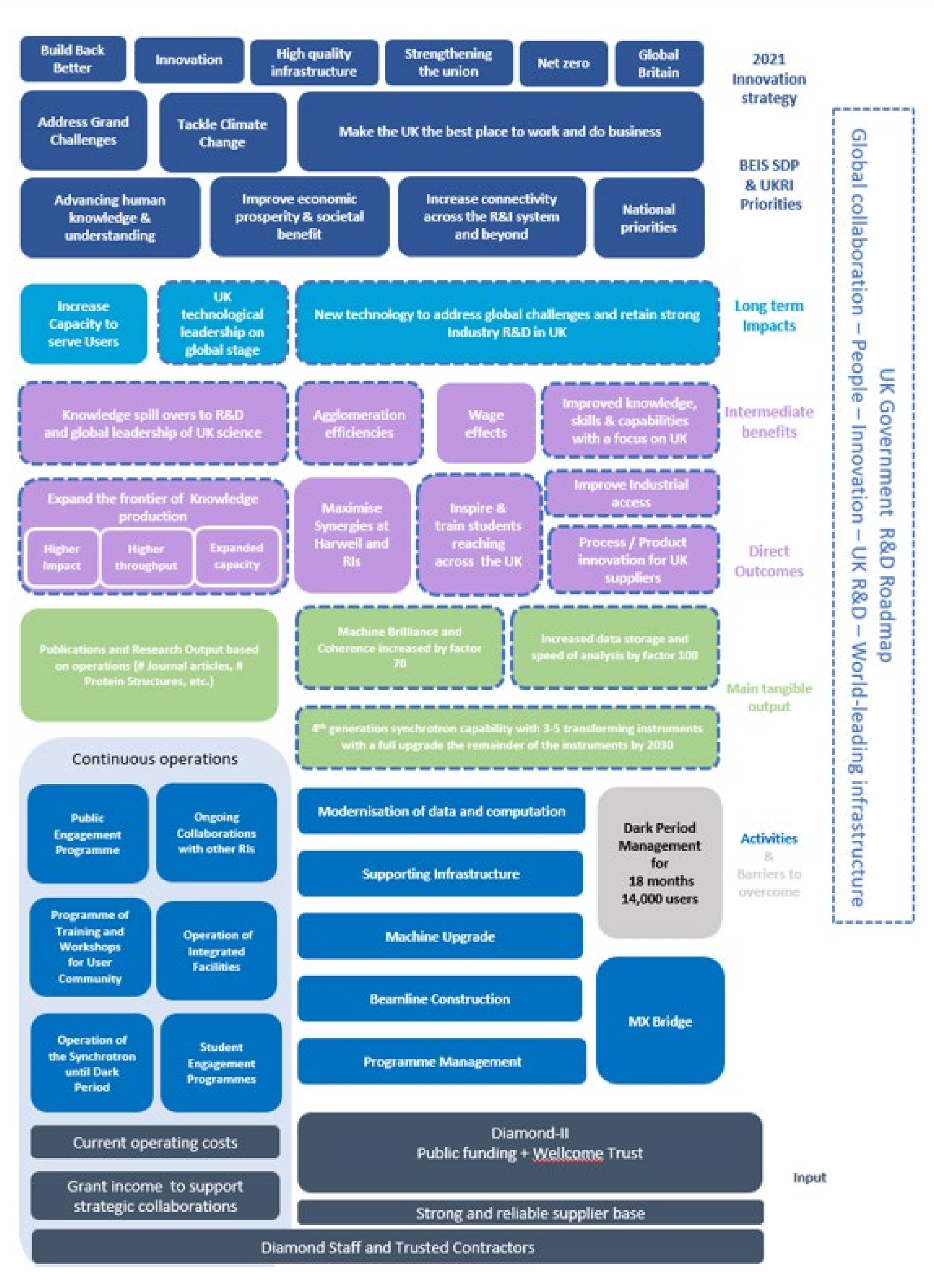
Upgrade case

- Case rests on strategic need (aligned with Government priorities) and ‘Value for Money’ (VfM)
- Assess various options according to their ability to deliver to strategic objectives, VfM and risks

- Options put forward:
  - ‘Do nothing’ (counterfactual)
  - Minimal option: buy time at another facility
  - Core upgrade (machine only)
  - Upgrade machine, beamlines and IT support
  - Upgrade machine, beamlines and IT support + more beamlines
  - Build a wholly new synchrotron

Benefits model

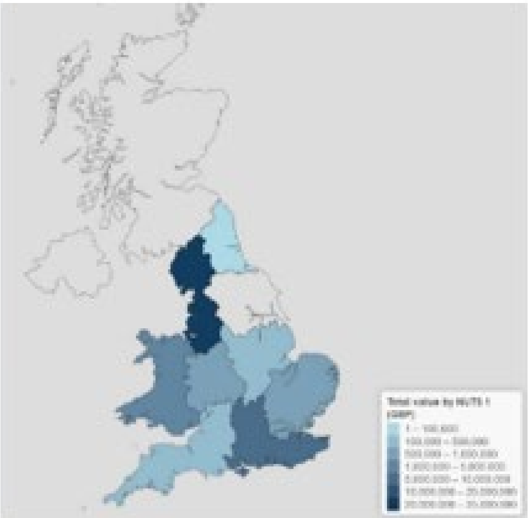


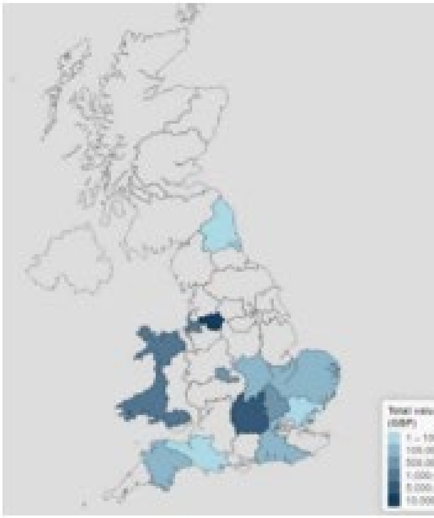
- Fit with national strategy – 'build back better'

Option	Do nothing	Buy time	Diamond-II core	Diamond-II Programme	Diamond-II full	New synchrotron
Strategic objectives						
Deliver a world leading research facility	1	1	6	8	9	10
Generate and disseminate knowledge	1	5	6	8	9	10
Increase the capacity for the science community	1	6	3	7	9	9
Increase efficiency and productivity of industrial partners	1	1	5	8	9	10
Maximise benefits for Harwell institutes working together	6	3	6	8	9	6
Inspire the next generation of STEM professionals	1	4	6	8	9	10
Total score	1.5	3.5	5.25	7.8	9	9.4
Critical Success Factors						
Strategic fit/timeliness	1	6	6	8	8	2
Value for money	4	8	4	9	10	4
Supplier capacity and capability	5	1	6	8	8	10
Potential affordability	10	7	8	7	3	1
Potential achievability	10	5	10	8	8	8
Facility dark period	10	10	6	6	6	10
Environmental sustainability	10	7	8	8	8	1
Total score	7.1	6.3	6.9	7.7	7.3	6.6

Benefits model

- Particular sensitivity in the UK to the ‘levelling up’ agenda and regional impact outside affluent South East of England – users – industry and academic - suppliers, jobs, trained people (more mobile)





University users

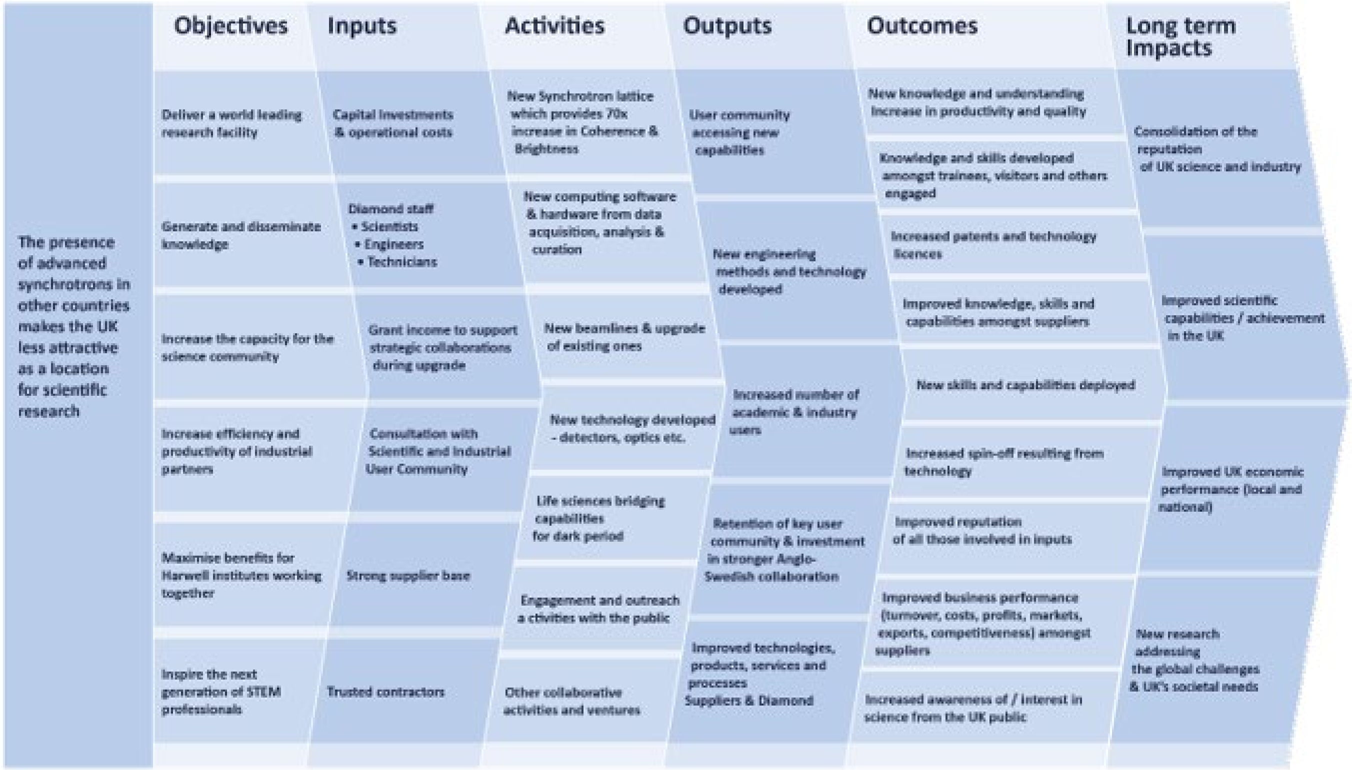
Industry and suppliers

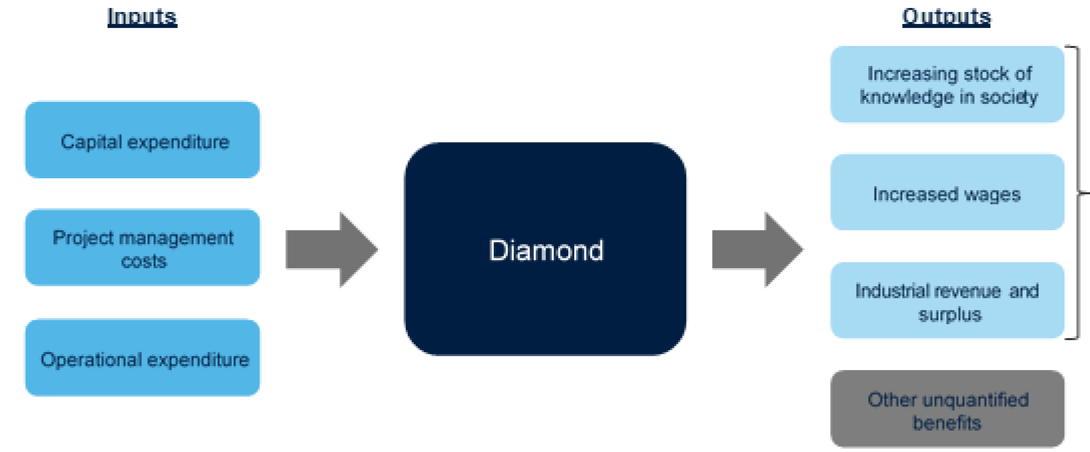
STEM jobs

Value to suppliers in different regions

Value for money appraisal

- Establish impact model based on OECD methodology linking inputs through activities outputs, outcomes and ultimately high-level impacts





Source: Oxera.

- For VfM inputs includes 'BAU' OpEx and outputs are bottom-up and monetisable and non-monetizable. Note the appraisal period is 2021 – 2050 – estimated lifetime of D-II

Monetisable and non-monetisable benefits

- Quantified
  - Increased stock of knowledge in society via scientific research
  - Increased wages from PhD training
  - Commercial revenue and consumer surplus
- Not quantified
  - Patents
  - Supplier benefits (developing new technology)
  - Research grants from outside UK
  - Employee training for personnel other than PhDs
  - Agglomeration benefits (particularly Harwell Campus)
  - Spin-off companies

Modelling the counterfactual

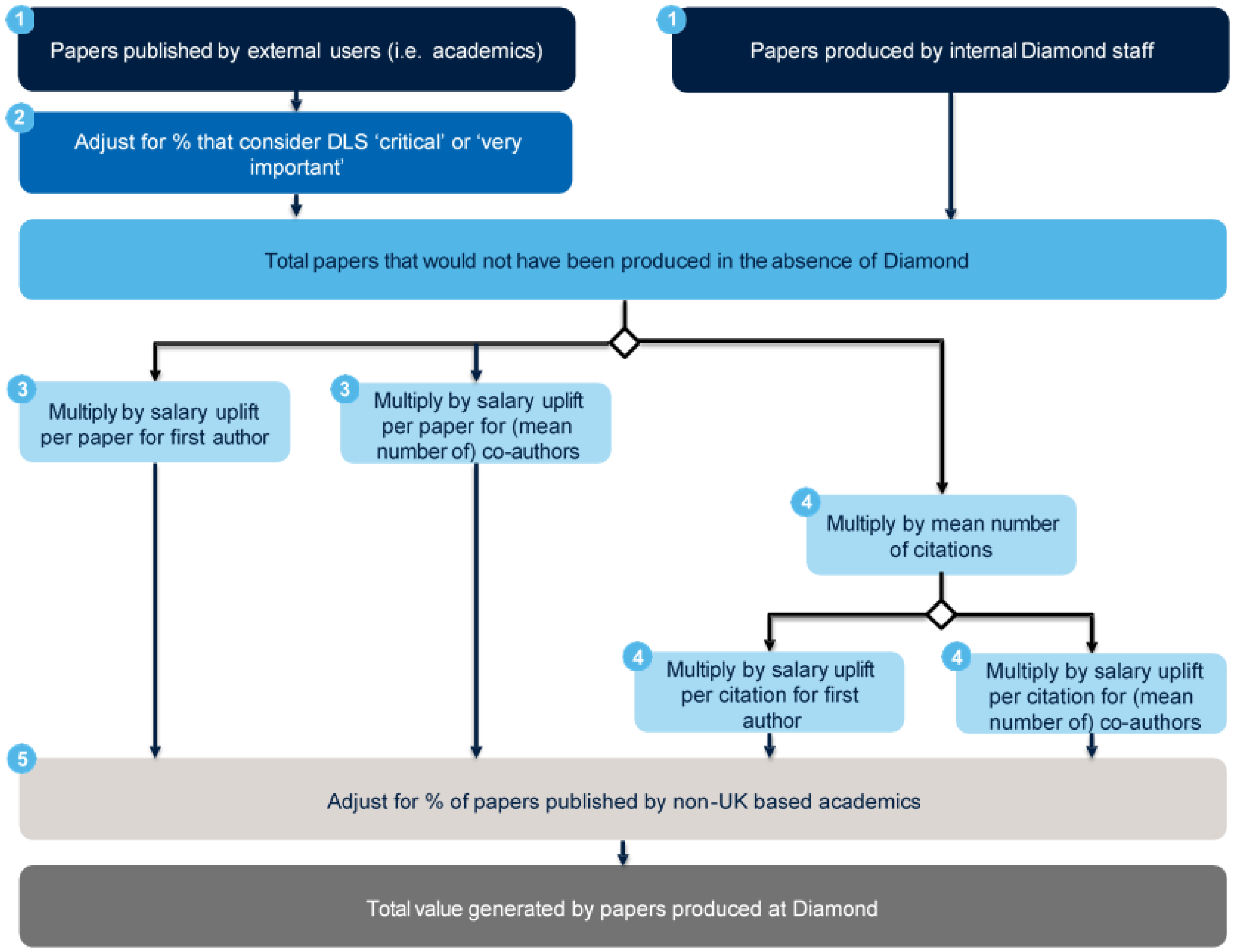
- Consequences of the ‘do nothing’ option

- Diamond would continue to run and conduct lower-level rolling upgrades but become increasingly uncompetitive, with university researchers, industry, PhD training gradually transferring elsewhere, including abroad (lost national benefits)

- Specific improvements that would not be realised
  - No uplift in capacity (16% increase in possible beamlines around upgraded machine)
  - No uplift in paper productivity based on uplift from SRS to Diamond (134%)
  - No uplift in quality based on citation uplift from SRS to Diamond (27%)

Increased stock of knowledge

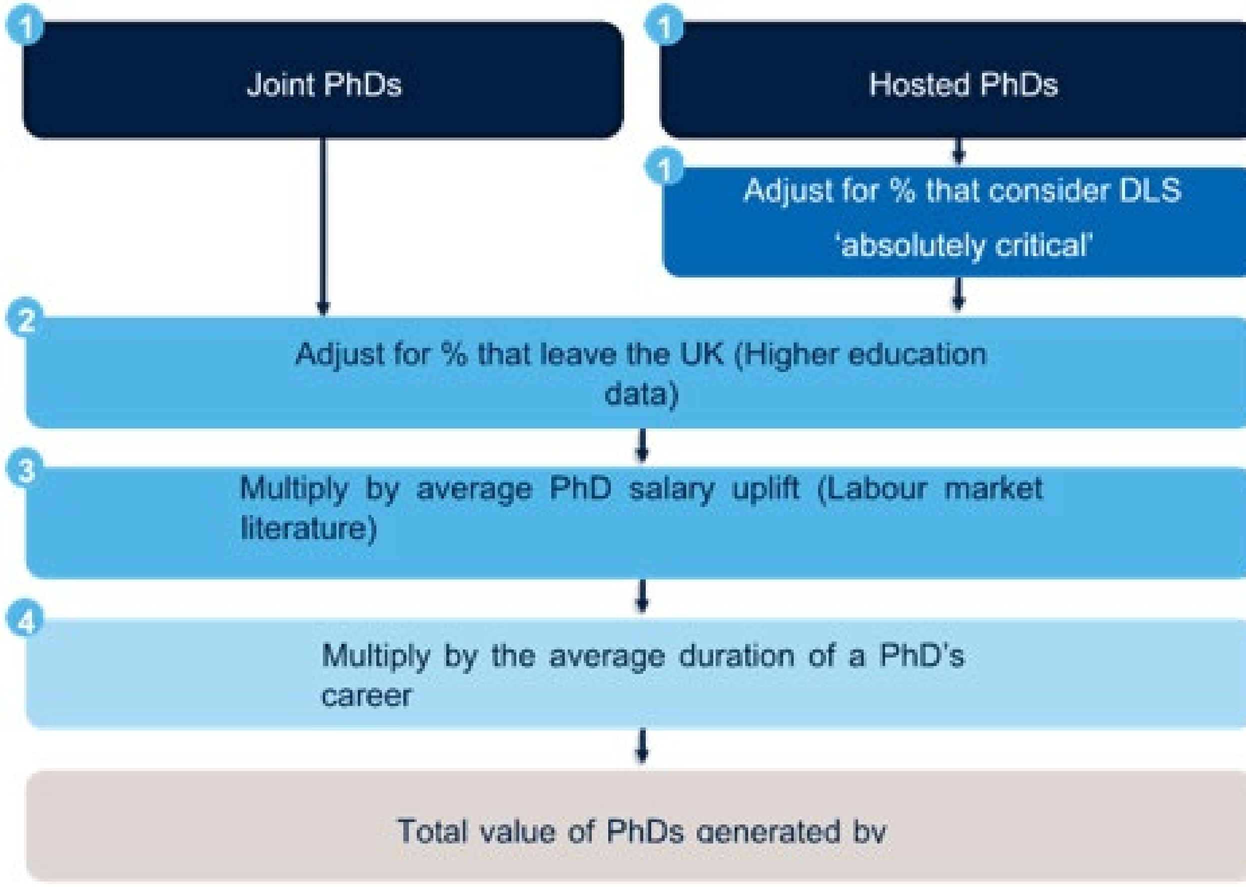
- Proxy provided by 'value' of publications with lower-limit estimate based on extent to which number or quality of publication increased academic salaries
- Steps in calculation for each option
  - ***Estimate number of papers*** *(uplift due to upgrade modelled on uplift from SRS to Diamond)*
  - *Adjust to reflect* ***quantity that would not have been produced in absence of Diamond*** *(productivity compared to average research groups)*
  - ***Estimate value of paper to salary*** *(Strathman study), multiplied by number of papers (corrected for co-authors)*
  - ***Estimate impact of improved quality of papers*** *expressed as citations, with citation uplift modelled on uplift from SRS to Diamond*
  - ***Adjust for proportion outside the UK***



Increased wages through training PhD students

- Currently trains *per annum* about 75 PhD students in-house year and ~1000 pa through visits to do experiments – both of which will increase through upgrade making more time available. Positions and beamtime very selective – tends to involve higher-level students – and are supply-side limited
- Steps in calculation for each option

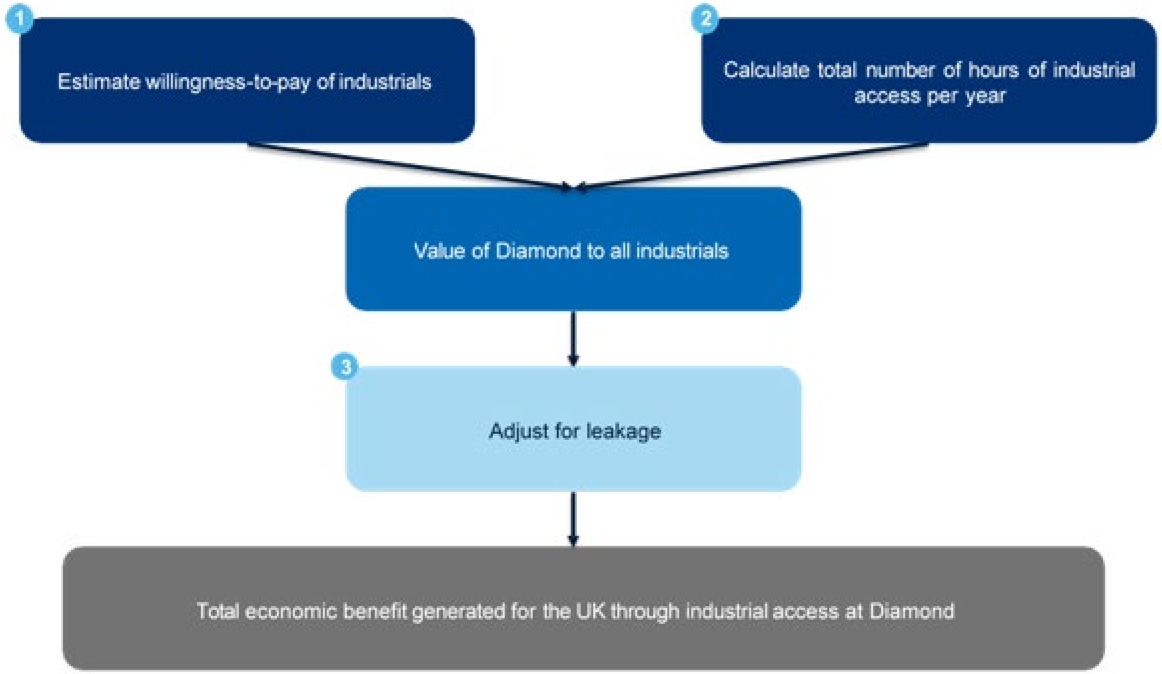
  - ***Estimate number of PhD students*** *– can increase with the number of beamlines according to options*
  - ***Adjust for % that leave the UK*** *(approx. 25%)*
  - *Multiply by the* ***salary uplift for a PhD student*** *over average career span post-PhD (39 years)*



Commercial revenue and consumer surplus

- Industry does not reveal commercially sensitive information e.g. enhanced profits for such analysis so proxy must be used for developments of new products and services
- Very rare for industry to build dedicated beamlines let alone a new facility – interest expressed in willingness to pay for access

- ***Estimate the willingness of industrial users to pay for proprietary access*** *(known at Diamond and informally across other synchrotrons)*
- ***Estimate the hours of industrial access at Diamond*** *(known at Diamond and informally across other synchrotrons)*
- ***Adjust for percentage industrial users from outside the UK***



Top-down check

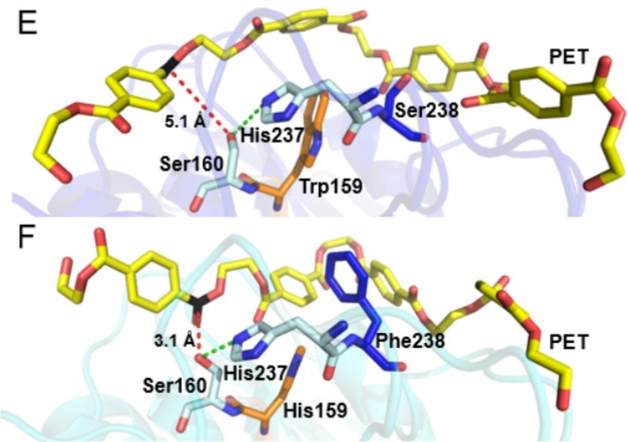
- Check against 'top-down' calculation of BCR based on sector averages derived from meta-studies
- Returns from R&D investment estimated to have mean total rate of return of 85%, yielding BCR multiplier of 1.85
- Likely to be significant under-estimate – particular aspects of this sector (e.g. pharma) very dependent on academic work and Diamond is well above sector average based on average impact of publications

Source	Sample/Industries	Period	Private R&D RoR	Social R&D RoR
Englander *et al*. (1988)	Machines, instrument and equipment	1985	25%	30%
Bernstein & Nadiri (1988)	Chemical products Electrical products Scientific instruments	1981	13% 22% 16%	29% 30% 128%
Mohnen & Lepine (1991)	Aircraft and parts Metal fabricating Scientific and Professional equipment.	1983	8% 275% 49%	11% 319% 76%
Verspagen (1995)	4 hi-tech industries 9 OECD countries	1973-88	21% to 24%	NA
Bernstein (1998)	Metal fabricating Electrical products Chemical products	1962-1989	17% 13% 16%	157% 96% 98%

Putting it all together: preferred option

- Ready to pitch for the Diamond-II Programme with *almost* all options included as best compromise between VfM, delivery on strategic objectives, and risk
- Arguably more inspiring are the case studies and projected impact on society – health, the environment, improved transport and communications – and I would hope that this will inspire decision makers

Results	Option 1: Do nothing (All costs)	Option 2: Do minimum (All costs)	Option 3: Diamond-II core (All costs)	Option 4: D-II programme (All costs)	Option 5: D-II full programme (All costs)	Option 6: New synchrotron (All costs)
VfM appraisal:						
Benefits (discounted, £m)						
Costs (discounted, £m)						
NPV (discounted, £m)						
BCR (discounted)	1.88	1.91	2.86	3.81	3.89	1.91
Qualitative benefits Appraisal (strategic objectives):	1.5	3.5	4.85	7.8	9.0	9.4
Qualitative benefits appraisal (critical success factors):	7.1	6.3	6.9	7.7	7.3	6.6
Risk appraisal: (Score 0-XX)	438	382	285	275	290	430
Overall ranking	6	5	3	1	2	4



Challenges

- Standardising the principles of calculation of economic impact
- Finding a balance between societal and economic impact

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