PERFORMANCE IN USE PORTFOLIO FOR IoT

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CONTENTS

3 INTRODUCTION TO PERFORMANCE IN USE FOR IOT
4 Rationale for IoT Future Cities Interventions
   How should the insights generated from the Impact Frameworks be used?
5 Guidance on how to approach the Impact Frameworks

7 ECONOMIC IMPACT FRAMEWORK
7 Section A What is the Project?
   Assessment 1 Type of Project
   Assessment 2 Scope, Scale & Reach
   Assessment 3 Implementation Costs
14 Section B What Will the Intervention Achieve?
   Assessment 4 Direct Efficiency Improvements

19 SOCIAL IMPACT FRAMEWORK
19 Introduction
21 How to use this Framework
22 Scope of the framework

26 ENVIRONMENTAL IMPACT ASSESSMENT
26 Introduction
27 Stage 1 Scoping the project
28 Stage 2 Mapping impact
34 Stage 3 Impact calculation

36 TECHNOLOGY OPTIMISATION
36 Summary
37 An Introduction to Optimisation
37 Application of Optimisation to IoT in Future Cities
38 Taxonomy of IoT Applications for Urban Environments
39 Urban IoT Markets
45 Application of Optimisation to Urban IoT Applications

46 SUMMARY REMARKS
INTRODUCTION TO PERFORMANCE IN USE FOR IOT

Performance in Use comprises a portfolio of four cross-cutting impact frameworks engineered to help cities, companies and citizens to make better decisions about how to implement future cities applications on the basis that the level of understanding required to deliver this insight is critical to effective market development. This document is structured to provide an overview of how Internet of Things (IoT) technologies are applicable in cities from a technical perspective across Economic, Social, Environmental and Technical based approaches.

The placement of IoT solutions in the city requires careful consideration which largely extends from the application space. There are numerous functional and non-functional requirements that must be considered. Issues relating to scale and coverage requirements determined by the application space, practical deployment considerations, the management and maintenance of devices and networks in the field, criticality considerations, the management of resultant data, cost benefit determinants, societal implications and the environmental footprint are considered at length.

Performance in Use comprises four integral impact guides that span Economic, Social, Environmental and Technology Optimisation. These impact frameworks have been designed to both capture value and quantify the performance IoT deployments. In addition, for maximum value capture, an integral standalone fifth tool, Standards-in-Use has been developed to enable Cities to assess their maturity against PAS181 and PAS182 standards, which relate to a Smart City framework and a Smart Cities data concept model. The portfolio has been engineered in a fashion that is sufficiently broad in order to capture an array of potential IoT deployments within the Urban Environment, in addition to allowing the user to scale the extent of desired analysis up and down depending on the intervention timeframe and budget constraints. Therefore, the frameworks can be applied flexibly in isolation, ex-post or ex-ante. However, it is advisable to deploy the frameworks in parallel to one another to fully capture the resultant lifecycle interdependencies of an intervention.

The Performance in Use portfolio a) facilitates market creation b) captures the broad value proposition, and c) provides business justification for Future Cities IoT initiatives across a range of vital areas for Private Enterprise, Local Authorities and Society broadly, these include:

- **Drive for efficiency/cost savings**: budgetary pressure on public and private organisations delivering services to residents, visitors and business in cities means there is a real premium on initiatives which can deliver the same service for less or reach more people with the same level of investment.

- **Competition for talent & quality of life**: cities increasingly compete among themselves to retain and attract people, and this can be done in part by offering higher quality city services. In particular, the higher value skills needed to help the knowledge economy grow and implement Future City schemes are in particularly high demand and are likely to gravitate towards places with a reputation for digital innovation in an urban setting.

- **Responding to changing context & aspirations**: the rapid flows of people and ideas means cities require increasingly responsiveness services which can quickly adapt to changing patterns of need among residents, businesses and visitors. People’s expectations are also changing rapidly and they increasingly expect to engage with services that are tailored to their needs and which they can make informed choices about.

- **Attracting investment**: migration and technology trends suggest that the market for Future City goods and services is set to grow globally over the coming decades. Ambitious
and foresighted cities are trying to secure investment for their businesses in order to secure a toe-hold in these markets in the hope that they will grow and help the city in turn prosper.

Rationale for IoT Future Cities Interventions

- **Strong City Component**: although many of the initiatives could operate outside city environments they are best able to demonstrate their value when they capitalise on the scale and density of city-life. They should be trying solve some of the tensions that arise from the concentration of people living and working in close proximity and also at the same time try to take advantage of the density and proximity which comes with city-life. The schemes should be designed to benefit the city in its widest sense and have impacts that go beyond just the people and businesses that are using the service.

- **Innovative**: IoT interventions should be endeavouring to solve existing challenges with new solutions. There will inevitably be a degree of experimentation and trialling involved in the projects. The framework has been designed to accommodate the longer term potential which flows from wider spread adoption, while still concentrating on the core and more tangible aspects of the current scheme under review. The innovation need not be new to the world, it could simply be deploying new solutions from other policy areas.

- **Openness**: there is a central drive in the UK to promote greater levels of transparency, especially in the public sector and to unlock the potential of data held by agencies while also boosting levels of engagement with city issues. Open and engaged cities which are proactively pursuing this agenda may consequently be more competitive and resilient as a result.

How should the insights generated from the Impact Frameworks be used?

The insights generated by the frameworks can help in three potential ways:

- **Better position for wider adoption & exploitation**: the evidence assembled when populating the framework can help articulate the benefits to investors and service users in order to generate the interest needed to scale up and realise the initiative’s fuller potential.

- **Tighten scope & specification**: working through the framework should help refine the nature of the initiative to ensure everyone is clear on what it is trying to achieve and firm up the detail of how it needs to be delivered in order to best achieve its objectives.

- **Improve value**: once the full comparison of costs and benefits has been undertaken, the framework can be a useful guide to highlight alternative approaches or refinements which offer greater return on investment or deliver services at lower cost.
Guidance on how to approach the Impact Frameworks

The Standards-in-Use tool is best used as a preparatory exercise to identify challenges and opportunities at the onset of an IoT deployment, and then again at the end of the deployment to assess the results obtained, whether the standard has been met and identify further room for improvement. The Economic, Social and Environmental impact frameworks that comprise the Performance in Use portfolio will yield maximum value to Cities when used in conjunction with the Standards in Use tool.

The Economic, Social and Environmental Impact Frameworks contain a degree of replicability at the onset of the assessments; this is due to the flexibility in which these impact frameworks can be performed i.e. in isolation or alongside one another. The ‘Evaluator’ who is completing the Impact Assessment only need to define the intervention type, aims, scope, scale and reach of the IoT intervention once in a rigorous fashion. The Performance in Use Impact Frameworks are comprehensive in that they consider a number of factors throughout the duration of a project, for example the efficiency (cost saving) and effectiveness (behaviour changing) outcomes, pragmatic top-down and bottom-up approaches that address the scale, potential inter-linkages between systems and benefits spread among them, actualized (ex post) versus potential future (ex ante) impacts.

For all Impact Frameworks, it is advisable to construct a baseline pre-IoT intervention, this will be a data collection activity in order to establish the state of the world. For instance, in order to make an initial assessment regarding the degree of measureable economic impact that a given project will achieve, it is necessary to conduct a high-level assessment in order to accurately assess impact.

For instance:

- **Socioeconomic benefits**: employment, gross value added or welfare benefits
- **City**: costs saved through delivery of public service, reduced traffic congestion leading to time savings (efficiencies), and a reduction in diseconomies of agglomeration; increased visitor expenditure

<table>
<thead>
<tr>
<th>Economic impact</th>
<th>Social impact</th>
<th>Environmental impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type (Descriptor)</td>
<td>Type (Descriptor)</td>
<td>Type (Descriptor)</td>
</tr>
<tr>
<td>Aims, Scope, Scale &amp; Reach Implementation Costs</td>
<td>Aims, Scope, Scale &amp; Reach Pathways to impact (Theory of Change)</td>
<td>Aims, Scope, Scale &amp; Reach Mapping Impact</td>
</tr>
<tr>
<td>Efficiency Improvements</td>
<td>Tier of Impact</td>
<td>Impact Calculation</td>
</tr>
<tr>
<td></td>
<td>Design and Implement Assessment</td>
<td></td>
</tr>
</tbody>
</table>

IoTUK
PERFORMANCE IN USE

Performance in use portfolio for IoT
Introduction to performance in use for IoT

FRAMEWORK FEEDBACK OPTIMISATION

ECONOMIC IMPACT FRAMEWORK

SOCIAL IMPACT FRAMEWORK

ENVIRONMENTAL IMPACT FRAMEWORK

TECHNOLOGY OPTIMISATION

CITY STANDARDS

CITY STANDARDS

TECHNOLOGY OPTIMISATION

CITY STANDARDS

PERFORMANCE IN USE
SECTION A WHAT IS THE PROJECT?

Purpose: to understand the nature, scope, focus and scale of the project and to identify the core and indirect aspects of the impact assessment.

Before setting out to assess the scale of benefits it is expected to generate, it will be helpful to set out the nature of the service under review. This will help provide some structure to the assessment of impacts in Section B but will also allow for comparison and contrast with similar schemes deployed elsewhere.

There are three assessments involved in this first section:

• Assessment 1: Type & Aims of Project
• Assessment 2: Scale, Scope & Reach
• Assessment 3: Implementation Costs

ASSESSMENT 1 TYPE OF PROJECT

Purpose: to understand the nature of the project and help compare impacts between different initiatives.

1A General Description

Given that IoT deployments cover a wide span of different types of initiatives and are constantly evolving as new technologies are deployed, it is helpful to firstly set out a short jargon-free description of the project. The description should endeavour to explain as best it can:

• the nature of the opportunity the service is exploiting, or the problem it is seeking to solve
• its overall objectives i.e. what it is setting out to achieve, both now and in the longer term if proven and scalable
• how the service will be delivered, including the technology to be deployed
• how the service will be accessed and applied
• what is innovative about the initiative?
**18 Target Outcomes**

In order to clearly understand how the long term impact of the project might be gauged, it will be helpful to set out the policy area in which the initiative is operating. This will help identify the sorts of indicators of change against which its achievements could be measured. Although one of the central features of Future City schemes are their ability to operate across traditional policy/service domains, it is important to identify the most important areas where each initiative’s effects might be identified.

There are three broad categories of beneficiary where impacts of schemes might be captured and which provide the underlying rationale for developing the new services:

1. **City**: more widely some schemes are focused on lifting up the overall health and attractiveness of the city for the benefit of all.
2. **People**: improving the circumstances of individual service clients or users i.e. residents of and visitors to the city.
3. **Businesses**: trying to grow the economic base of businesses already trading in the city as well as boosting inward investment, and encouraging local entrepreneurs looking to start up, particularly a Future City supply chain business.

These three categories can be further broken out to identify particular policy/service objectives. The objectives set out below are not intended to be restrictive or exhaustive and instead are provided to help stimulate thinking and provide some structure to the description of the initiative under review. Some services will aim at achieving a range of different target outcomes and across each of the three categories:

1. **People**
   - **Mobility**: enabling quicker journey times
   - **Health**: allowing people to live healthier/longer lives
   - **Assisted Living**: enabling vulnerable people to live higher quality and more independent lives
   - **Energy**: ensuring better management and consumption of scarce energy and/or shifting to more sustainable sources of energy
   - **Education**: assisting pupils to learn more effectively and improve the quality of teaching
   - **Safety**: supporting more rapid and effective emergency responses
   - **Retail**: enhancing the quality and attractiveness of the city’s retail offer

2. **Businesses**
   - **Enterprise**: establishing a growing base of competitive businesses supplying Future City services and technologies in the growing global market for goods and services
   - **Test Bed**: securing early-mover advantage for the city by attracting innovators, investment & critical mass to develop and test new solutions in the city, and also encouraging closer collaboration between businesses

3. **City**
   - **Public Realm**: offering more attractive and better managed public spaces for the benefit of residents and visitors
   - **Environmental Quality**: reducing the city’s pollution and carbon contribution
   - **Democratic**: better engaging communities/citizens in city life and decision making and supporting more cohesive communities
   - **Adaptive Services**: delivering more responsiveness services which better adapt to changing patterns of need
   - **Fairness**: tackling inequality by improving circumstances for priority target groups in particular need.

This list is extensive on account of the range of areas in which IoT interventions operate, but it is not intended to be exhaustive or restrictive. There may be additional policy areas in which IoT interventions operate and which should be added. It is important however to be sure that
the project will affect underlying conditions in the service areas in which it operates. This aspect of the framework will be revisited later in Assessment 7 to understand potential impacts. There may be a temptation to emphasise the breadth and wider potential of the initiative, but it is better to be realistic about where the project will actually have most effect. No more than two or three of the categories above should be selected.

1C Intervention Goals
In order to begin developing a typology of IoT deployments and to develop a clear understanding of the nature of the scheme under review, it will be helpful to spell out two key aspects of what the service is delivering:

1C1 Delivery Objectives
Broadly speaking we expect IoT deployments to focus on two delivery objectives:

- **Reduce Costs**: helping delivery bodies make efficiency saving in the costs of the planning & delivering services.
- **and/or Increase Use of Service**: focussing on driving up use of the service, either overall or among target user groups.

1C2 Focus of Intervention
IoT deployments aim to achieve one, or both of the following:

- **Better Informed Delivery & Planning**: helping delivery bodies better implement services in the city.
- **or Better Informed Service Users**: providing customers with better information to help them make more informed choices about when and how much service to use.

Some projects will involve aspects of all four dimensions of the Intervention Goal assessment, whereas other might be narrowly confined to just one or two.

1D Data Processes
Data will sit at the heart of any IoT deployment involving technology and it will be helpful to set out in simple terms how the project proposes to add value to data. There appears to be three general processes which projects focus on:

- **1D1**: Data Collection: generating new data through sensors and surveys
- **1D2**: Data Integration: bringing previously disparate data sets together for analysis
- **1D3**: Data Sharing: making previously closed data open and available to others for analysis.

As with other elements of this Assessment many projects will involve a combination of all three types of process.
ASSESSMENT 2 SCOPE, SCALE & REACH

Purpose: to specify the specific nature and structure of the project in order to provide a clear structure for the assessment of impacts. This Assessment aims to quantify the initiative and to clearly set out the distinction between the three crucial dimensions of the project.

- 2A: Core Project & Direct effects
- 2B: Wider Project & Indirect effects
- 2C: Follow-On Potential

2A Direct Core
This is the essential heart of the project where funds are being invested to improve a service for the benefit of a clear client group. In essence the Direct Core Impacts describe what the investment makes happen and should be the most tangible, immediate and measurable parts of the scheme. The Core Direct aspect of the project may actually be modest in relation to the wider indirect and follow-on potential, especially in the case of pilot projects and test beds.

2B Wider Indirect
This element captures the spin-off, complementary, incidental aspects of any initiative. It includes the things that might happen, but which are not an essential part of the investment case and organisations/service users which inadvertently gain some benefits. The Wider Indirect aspects should reflect those supplementary initiatives which are permitted or facilitated by the Core Direct investment/initiative. These impacts are generally measurable and quantifiable but the causal link to the project is weaker.

2C Follow-On Potential
This element captures what might follow-on from the immediate investment/initiative and should reflect the full long term potential of the technology/service if it were widely adopted and fully integrated into the city, or if roll-out were significantly scaled up to other locations. These aspects of the service should not yet be actively implemented and could rely on pipeline technology developments which have yet to be realised. Nevertheless, there should be a reasonable likelihood that they could happen, if the Core Direct aspect of the project is a success.

Making the distinction between Core and Wider Indirect is not always easy and will to some extent involve a degree of arbitrary decision-making. The questions to ask in deciding where the line lies between direct and indirect are:

- **Who is meeting the investment costs?**
The organisations delivering the initiative and paying for it to be put in place point us towards the Core, whereas other organisations with an interest in it but having a more detached role are more likely to point us towards the indirect elements of the scheme.

- **What is the primary objective of the initiative?**
All initiatives have a core set of primary objectives (or problems they want to solve) and against which their success will be measured. There may be another complementary/ancillary and potential benefits which might accrue and be used to promote the scheme, but these are not what success and failure will be determined by.

- **Who is the primary target client/user group?**
Likewise, any scheme should have a clear sense of who its target client group is and for whom it is committed to improving the lot of. In the case of paid for services the core client group is those who are paying for the services. Other people and organisations may also benefit but these are unintended, secondary beneficiaries who may not even be using the service and are not financially contributing directly to it.
Once these questions are answered it should be easier to identify the core of the project and distinguish it from the wider indirect aspects.

**Example: City Parking Schemes**: these might be paid for by the car park operators and designed to reduce vacant spaces in car parking for the benefit of commuters. In addition to the core scheme, however other road users might benefit from reduced traffic in the vicinity of the car park and businesses might report reduction in lateness as people get to meetings and work more promptly.

**Example: Pupil Mapping & School Place Planning**: a scheme to map demographic data alongside school places and cross border flows of students would directly benefit local authorities (and other organisations) responsible for planning school places. The costs would relate solely to developing and sharing the intelligence and the direct benefits would focus on the costs savings of reducing over/under supply of school places. The indirect benefits would accrue to parents and pupils who in due course might get more ready access to the schools of their choice closer to home, and more widely to local commuters who benefit from reduced school time traffic.

For each project, it would be helpful to set out the following across the three elements above:

- **2A Description**: a short statement explaining which aspects of the project sit in the Direct Core and Wider Indirect elements, and which sit in the Longer Term Potential.

- **2B Users/ Beneficiaries**: explain who the primary clients for the Core Direct Service are, and who is expected to indirectly benefit from the service. Other groups of people who may benefit in the longer term should be listed in the Longer Term Potential element.

- **2C Geographical Area**: it may also be helpful to set out the target geography over which the scheme is operating in each category. This can be useful for schemes which are geographically concentrated (e.g. on city centre retail core) but which might have an indirect benefit for neighbouring areas (e.g. wider city centre). Do not feel compelled to make a distinction: in some cases, the core geography alone may be enough to capture spatial aspects of the project and in other the Longer Term Potential may simply be global.

- **2D Timescale**: The Core project will have a delivery start and completion date (i.e. when the money is fully invested). The Indirect aspects of the project may operate over a slightly longer timescale, especially if they rely upon behaviour change or developments in complementary initiatives. The Outcomes that they generate will take longer again to emerge, and end date is requested to set the time frame over which these benefits could be captured.
ASSESSMENT 3 IMPLEMENTATION COSTS

Purpose: to clarify the resources involved in setting up and delivering the service in order to allow a value for money estimate.

In order to put the benefits generated by an IoT deployment in context, it is important to understand their costs. Often the focus of the sole on the positive benefits that initiatives can generate but what ultimately matters is the benefit/cost ratio. This can be simply done using a single headline figure, however in order to better understand the composition of different projects and to help compare initiatives on a like for like basis, it would be helpful to break the costs down into different categories. This could be simply done by distinguishing between one-off/capital/set-up costs and on-going/recurring revenue type costs. To allow a more effective understanding of the project it would be most helpful to identify costs under the following categories:

- 3A Core Direct Project Costs
- 3B Wider Indirect Costs
- 3C Potential Follow-on Costs

3A Core Direct Project Costs
The core costs associated with setting up and operating the service should ideally be grouped under five different budget lines and calculated using the timeframes set out in Assessment of Core Direct costs at 2D:

3A1 Partnership
Although IoT deployments are technology dependent, a significant amount of the actual cost involved in bringing them forward is tied up in building and maintaining relationships among organisations and staff, often but not exclusively, at the set up phase. This can be involving time spent getting agreement to share data, permissions to implement new facilities and time involved in management change to the new service delivery mode. These costs are often hidden and so hard to estimate fully, but are an important part of making schemes succeed and so should be identified as best they can.

3A2 Infrastructure
Costs associated with building new physical capacity, mainly focussed on extending digital networks, but could also include the capital costs of new facilities such as parking and transport facilities (if included in the Core definition of the project). This could also include additional data storage and handling capacity if it is a capitalised cost. The costs of maintaining the underlying infrastructure should also be included here. As a rough guide any physical items expected to have a life-span over 5 years should be included here.

3A3 Data
Future City projects often incur costs for cleaning, analysing and presenting data and information. This could be one off costs generating code to automate analysis or ongoing costs to undertake additional analyses. It could be in the form of staff time and purchasing software and hardware to handle the data processes.

3A4 Devices
Costs associated with sensors, handsets, wearable's, vehicles, tags etc. which sit on the network to gather and share data should be separately captured. This should include items with a clear specific purposes (as opposed to general purpose infrastructure at 3A2). As a
Performance in use portfolio for IoT
Economic Impact Framework

3A5 Realisation
Further costs may be incurred generating user-friendly interfaces and applications to allow service users to access the data/intelligence the project has generated. The wider costs of realisation should also include marketing and promotion to drive up adoption of the service and on-going support needed to maintain the end-user interface. Future City projects with a strong technological base, can often fail to generate the critical mass of users needed and so it is important to understand how much resource is devoted to making a success of getting users on board with the new service.

3B Wider Indirect Costs
Additional costs associated with any of the wider indirect aspects of the project (set out at Assessment 2) should be separately identified from the Core costs. These are expected to be by their very nature, quite limited as the indirect benefits are those which are induced or facilitated by the Core Direct aspect of the project. Nevertheless, there may be occasions where complementary services incur additional costs as a direct knock-on consequence of the initiative. There is no need to break out these costs into separate categories, but a note should be made as to what they relate to for future reference. The timescale over which these costs are captured should tally with the timescale for the Wider Indirect aspect of the scheme set out in Assessment 2D.

3C Potential Follow-on Costs
Where Assessment 2 includes a description of the Follow-on Potential of the scheme (i.e. from wider spread roll out/adoption or adaptions) it would be helpful to identify, as best you can, the likely costs involved in realising that potential. This could be hard to do, especially where the scale of wider roll-out is hard to predict or the future costs of technology are likely to dramatically change. It is acknowledged that any costs set out here would almost certainly be highly speculative and distant into the future. Nevertheless, it would help set the context for the future and provide an insight into the scale of investment needed to fully realise the potential of the scheme.
SECTION B WHAT WILL THE INTERVENTION ACHIEVE?

Purpose: this section of the framework provides a structured series of assessments to identify the expected benefits from the project.

The assessments in this section look separately at the direct effects which are grouped into:

- Direct Efficiency Enhancements (4) which would accrue to the company or organisation delivering the service in terms of reduced costs or improved revenue generation

To properly undertake the Assessments in this section, the distinction between core and indirect elements of the service, and the time frame over which it is expected to yield benefits (in Assessment 2) is critical. Given the experimental nature of many IoT interventions, the balance between direct and costs and benefits might be quite fine, and it is only when the indirect and longer term potential are factored in can the full value of the scheme be recognised.

It may not always be clear which category (is) of benefit to use. The framework is intended to help guide and not to be a rigid straight-jacket. It is intended to help explore the wide range of potential benefits and at the same time help highlight where there is a risk of double-counting. Ultimately, it is not important where exactly the benefits are captured as many of them could fit against multiple categories. If the project’s benefits cannot be mapped neatly onto the framework, please select a best fit category. It is better to get the benefits listed than to ensure they neatly sit in the framework and boxes set out here.

Bear in mind that small percentage changes in efficiency terms or service improvements can have quite profound impacts on the overall scale of benefits. A sound project will be one where the marginal benefits are greater than the marginal costs of implementing it. Often IoT interventions are working at the margins to effect modest changes. Their real value comes in the fact that they can often be relatively cheap to introduce and can generate wider indirect benefits or have potential for much wider exploitation and adoption downstream.

Although IoT deployments are often very novel, they largely tackle existing challenges and deliver services in new ways. The enhancements addressed in the section are designed to capture the benefits over and above the established service or way of working.
ASSESSMENT 4 DIRECT EFFICIENCY IMPROVEMENTS

Purpose: to capture the scale of the direct efficiency improvements which the project has or can be realistically expected to generate.

Many IoT deployments offer the prospect of delivering established services in new and more efficient ways which will generate financial savings to the service provider(s).

This assessment should be applied only to the Direct Core activities in the project (as defined in Assessment 2).

The Assessment needs to explore three ways in which efficiency improvements might manifest themselves:

- **4A: Reduced Fixed Costs**
- **4B: Reduced Operating Costs**
- **4C: Improved Revenue Generation.**

Capturing the benefits from reduced or better deployment of fixed costs is not straightforward and is likely to require some complex analysis. It is important however to keep the assessment proportionate and be realistic about the speculative nature of the claims being put forward. In many cases rough estimates and imprecise projections based on experiences elsewhere or previously will be the best way forward. The important point to bear in mind is the need for a degree of transparency in the assumptions that underpin the Assessment.

The simplest approach to this Assessment is to estimate current capital costs and simply attach a percentage change figure to the headline or component parts.

The range of potential benefits is reasonably broad but there may be others effects which need to be considered. The framework is flexible enough to accommodate alternative perspectives, however the emphasis needs to be on measurable benefits based on sensible assumptions and reliable evidence.

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4A Reduced Fixed Costs

IoT interventions often focus on services where there are substantial capital investments required (e.g. transport, energy, construction etc.). The use of technology can help reduce the fixed costs in a number of different ways.

How to: to estimate the scale of savings made an estimate of current or past fixed costs is required. Unless there are specific budget line savings that can be removed from the fixed element, then a simple percentage reduction figure with an accompanying explanation should be provided.

Below we have set out as series of prompts to help you think about the different ways that the fixed cost involved in delivering an initiative can be reduced. Remember, not all of these will apply to your scheme.

**4A1 Lower Planning Costs**

Organisations and departments can use Future Cities technologies to collaborate more effectively and plan together for the future by better integrating data from disparate sources. This collaboration can happen across organisations, delivery departments and service areas.

- **Example: Transport and Education Planners** combine traffic, demographic and school place data to jointly plan future school provision across administrative boundaries.

- **Example: Infrastructure Maps** allow a combination of infrastructure data (public/private owned spaces, broadband and utilities access, planned traffic works etc.) to be combined in a consistent format to facilitate smart planning for developments in the city.

**4A2 Better Intelligence on Demand**

Technology can provide agencies with more precise intelligence on the need and demand for the services they are offering. Data can be used to ensure capital costs are optimally deployed and aligned with expected patterns of usage.

- **Example: Intelligence on Travel Patterns** can help transport planners locate bus/tram stops and parking provision to reflect the peak capacity requirements and other modes of travel and use.
• **Example: Cycle Planning** based on the actual patterns of cycling throughout the city at different times of the day can be used to enhance cycling infrastructure capacity and safety at the most important pinch points on the network.

4A3 New Technology Costing Less
In some cases, (although not always) introducing technological solutions can also reduce costs. ICT costs have reduced significantly over time. These benefits could emerge at the planning stage where sensor technology is used to replace traditional and more expensive methods of gathering information or in terms of lower cost capital items replacing more expensive ones. Where technology is being replaced, care needs to be taken in the assessment to compare benefits and costs with the Alternative and Do Nothing scenarios (see Assessment 8 & 9).

• **Example: Sensor Mapping of Real-Time Pedestrian Flows** can be used instead of expensive street surveys which involve deploying people to manually count people movement.

• **Example: Electronic Voting** could be delivered more cheaply (and potentially more frequently) than traditional paper ballots involving polling stations and associated staff.

4A4 Fewer Assets Doing More
Many Future City projects are developing multi-purpose technologies which extend the range of data that can be collected and the services/ functions that they can support. Also new technologies continue to emerge that extend the range over which data can be collected meaning fewer assets are needed to cover the same geographic area. As a by-product of more collaborative planning and cost reductions, additional benefits may also be realised in the form of better sharing of multi-purpose assets.

• **Example: Multi-Purpose Sensors** are now available which can collect data on environmental conditions (air quality, noise etc.), movement flows (pedestrian and traffic flows) and also support CCTV capabilities. As the communication range grows, fewer of them are required to provide coverage and as collaboration between agencies extends, more services can make use of the same network of devices for their own planning/delivery purposes.

• **Example: GPS monitoring of city assets** can allow them to be repurposed to meet excess demand from other services such as disaster response (e.g. waste collection vehicles could be used to transport supplies or remove rubble)

4A5 Better Use of Existing Infrastructure
Many projects try to make better use of the fixed infrastructure assets in cities (such as roads, cycle lanes, car parking space, retail, public space etc.) Schemes which allow more users to make better use of these existing assets without having to invest heavily in extra physical capacity, can lay claim to efficiency benefits.

• **Example: City-Wide Smart Parking Schemes** can help reduce under-utilisation of parking spaces and smart transport schemes can help make better use road and transport infrastructure, for example by better managing peak flow congestion.

• **Example: Cycle Map Apps** e.g. RateMyRoute can be used to help cyclists find quicker and safer cycle routes nearby and give them user reviews on the routes and their potential danger and difficulty levels.
4B Reduced Operating Costs
In addition to the one off, capital and planning costs involved in service delivery there is clear scope to secure further efficiency savings in the form of reduced on-going operating costs which will accrue to the organisation delivering the service.

**How To:** firstly you should generate an estimate of the normal operating costs prior to, or in the absence of the scheme and an estimate of the number of customers or units involved in that level of delivery. There are several broad channels through which Future City projects appear to target efficiency benefits for which there are prompts below and which each need to be considered in turn. For each of the relevant channels, estimate the percentage saving per unit of delivery based on the expected scale of operation in order to arrive at an overall estimate of the reduction in operating costs. If there are other identified channels these should be stated.

4B1 Lower Per Unit Delivery
Some schemes can ensure services are simply cheaper to deliver on a per-unit or per-user basis. This could be a further reflection of the 4A5 Better Use Of Existing Infrastructure and care needs to be applied to avoid double-counting.

- **Example:** Electronic Information Boards can supply the same volume of (if not more) information for a much lower per reader/user cost than conventional methods such as printed material.

- **Example:** Intelligent Street Lighting: can adjust depending on the presence of people to reduce energy consumption and this providing lighting to the same area for lower cost.

4B2 More Users Per Period
Similarly, there are projects which simply extend their reach by intelligent use of new technologies and in effect serve more users in a fixed period of time.

- **Example:** Intelligent Routing Systems for collection services can guide drivers round the optimum routes thus reducing journey time and allow more drop/collection per hour/day.

4B3 Less Waste
Better use of intelligent systems can help service delivery organisations cut the amount of resource spent unnecessarily by reducing delivery times, maximising essential journey times and rationing supply to align closely with demand.

- **Example:** Remote Care Services can maximise the time that carers have with patients by cutting out travel time between locations.

- **Example:** On Demand Bus Routing can serve more people on a round by only visiting stops where passengers are waiting.

- **Example:** Electronic Booking Systems particularly those with a reminder function and ability to re-arrange can reduce missed appointments and maximise contact time between carer and patient.
**4C Better Revenue Collection**

Many public services are provided free at the point of delivery because the cost involved in charging users in line with the value of the service outweighs the benefits. In other circumstances simple charging structures for services do not always reflect the marginal costs of delivery and value to every user.

This Assessment endeavours to capture the benefit of initiatives where revenues to the service provider become better aligned to the cost of delivering the service. The heart of the assessment is whether the service delivery organisation is better able to collect revenues that reflect actual use, the marginal costs of delivery and the additional value supplied to the user.

In any system where the pricing mechanism is altered there will be some people who see themselves as winners and other who see themselves as losers. These benefits accrue to the individual service user.

**How To:** Future City projects offer the prospect of more optimised approach to collecting revenues from customers via two mechanisms. To estimate the scale of benefits, simply estimate the uplift in revenues to the service operator following the introduction of the new revenue collection mechanism based on the same level of service use among customers.

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**4C Variable Pricing**

Data on supply and demand can be used to vary charges levied for using services to reflect the limited supply of fixed assets. Users of the service can adapt their demand and use patterns in response to rises and falls in the prices set against the value they derive from the service.

- **Example:** Uber, the taxi service imposes a Surge premium in local areas when demand for its taxis outstrips supply, allowing users can decide to pay the extra or wait.

- **Example:** Variable Road Pricing (and car parking) could use a variable pricing system which goes up to reflect peak demand and to help better manage/avoid congestion.

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**4C2 Tackling Free Riders**

Technology can be used to better charge users in line with their actual use of the service. Where services are free at the point of access or charge a flat fee, technology could be used to better measure actual use/consumption and charge customers accordingly. Technology could also be used to tackle the challenge in some service of non-payers and fare-dodgers

- **Example:** RFID Ticketing: sensor based ticketing could be used in open access tram systems to identify non-payers.

- **Example:** Carbon Impact Metering: a range of devices to capture waste, water and energy consumption could be deployed to charge business and households more precisely in line with their carbon impact.

- **Example:** Digital Parking: enforcement costs can be dramatically reduced by using number plate recognition to replace more traditional systems of ensuring parked cars have the correct ticketing.
INTRODUCTION

What is Social Impact?
For the purposes of this Framework, social impact can be defined as the net direct and indirect effects of a project on the well-being of individuals, families, and communities. The social impact of an IoT project includes its unintended as well as its intended consequences, both positive and negative. Usually, the social impact of an IoT intervention will relate to members of the public, or subgroups of the public in the area the activity is undertaken, though sometimes the radius of impact may be wider or narrower than the defined area of the project. A small, local IoT intervention may only affect public well-being in a very specific geographical area, but a national intervention could in principle affect the whole UK population.

Social impacts relate to changes to attitudes, values, beliefs, and behaviour which have either positive or negative effects on individual and collective well-being. In this sense, social impacts are not altogether separate from economic and environmental impacts, indeed economic and environmental impacts are likely to manifest in various kinds of social impact. For this reason, it is essential that social impact assessment is undertaken alongside, and as a complement to, other forms of impact assessment and not as a compartmentalized or ‘silo’ activity. The goal of social impact assessment should not, however, be viewed as a surrogate strategy for assessing economic effects; the assessment of social impacts can and should be considered in their own right.

Insofar as they are articulated at the inception stage, the social impacts of Future Cities projects should be intended to make a positive contribution to the wellbeing and quality of life of potentially affected individuals and communities. However, negative social impacts may also occur, usually as unexpected or unintended consequences of an activity. This is likely to be the case when an IoT intervention rationale and objectives foreground its technological rather than its likely social effects.

An intervention or activity may not impact on all members of the community or group of interest in the same way, or to the same extent. For example, moving a service online may result in an increase in users and more positive feedback from those users. However, there may be a group of people who lack online access or skills for whom this change has negatively affected their ability to use the service. Both groups have been affected, but in different ways.

When undertaking Social Impact Assessment, it is preferable where possible to gather evidence of impact directly from potentially affected citizens. That is, the particular group(s) who are expected to be impacted should also be directly involved in the assessment. Due to the range of potential IoT project types, many projects may not, in the development stages, directly impact on the public, or the public may not be aware that there has been a change. The Framework addresses this issue by allocating projects to ‘tiers’, which determine the type of assessment to which they should be allocated.

The Framework guides the user through a series of practical steps in identifying social impact aims, mapping preconditions to achieving those goals, and deciding whether and how best to assess these preconditions and whether objectives and goals have been met.

Key Concepts and Indicators
Key to any assessment of social impact is the identification of indicators of social outcomes which might be affected (positively or negatively) by the project, policy, or programme. The following are indicative rather than exhaustive examples of dimensions of social impact which have been identified from the SIA literature. The concepts of wellbeing and quality of life are outlined in greater detail as these are considered central to the overall aims of IoT interventions as well as relating to many other social impact concepts.
Social Capital refers to “the stock of ‘social networks together with shared norms, values and understandings that facilitate cooperation within or among groups’ (Cote and Healy, OECD, 2001). The presence of social capital helps individuals to achieve things in collaboration with others in society because communities function with a greater degree of understanding and trust, among other things.” (Defra, 2011, pp8). Social Capital is itself a complex concept and is further described in an ONS (2011) review as: Bonding social capital (closer connections between people such as family members or those from the same ethnic group); Bridging social capital (more distant connections between people which are weaker but more cross-cutting such as with business associates, acquaintances); Linking social capital (connections with people in positions of power, characterized by relations between those within a hierarchy where people are not on an equal footing).

Social Cohesion: the social bonds that help neighbours work together to achieve shared goals, particularly the social ties which enable neighbours to achieve a stable and predictable public environment (Sampson and Groves 1989). Human Capital is “the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being’ (Cote and Healy OECD, 2001:18). It is owned by individuals and also consists of personal attributes, for example, strength and intelligence that contribute to earning potential (Halpern, 2005) (Defra, pp8). Indicators of human capital are primarily related to educational and skill attainment (cf. formal and informal qualifications) and labour market outcomes (cf. employment, occupational status, earnings).

Digital Capital has grown from the concept of digital inclusion and relates to both access to more efficient, faster technology and also user technical competence and skills in using those technologies. Training and information may increase digital capital, as well as considering issues of access. Digital capital also considers how technology if these uses could increase wellbeing and life chances.

Wellbeing and Quality of Life: Wellbeing and quality of life (QoL) are commonly used terms, often used interchangeably or as overlapping constructs. There are key debates relating to these constructs and their relationship to each other, but for the purposes of Future Cities, it is helpful to think of them as highly overlapping and to consider both sets of literature of equal relevance. It is of note that there is a separate literature on health-related quality of life and this is unlikely to be as relevant for Future Cities. QoL and wellbeing encompass both. There is one key dimension which relates to both and is important when considering objective and subjective indicators, and these are important to consider when planning assessment. Objective indicators are those variables that can be considered or measured independently of individual evaluations. In contrast, subjective indicators require an individual to give an appraisal of evaluation of a particular condition.

It may be possible to gather some objective indicators of a local area, such as number of uses of a sporting facility, but not individual subjective indicators, such as increased self-reported health and social activity. In contrast, some objective measures, such as health records may not be accessible, in which case self-reported health could be used.

There does not exist a single definition of either wellbeing or quality of life. However, quality of life consists of a number of domains (these vary in the literature) which, taken together, encapsulate the

<table>
<thead>
<tr>
<th>Common objective social indicators</th>
<th>Common subjective social indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life expectancy</td>
<td>Relationships with family</td>
</tr>
<tr>
<td>Crime rate</td>
<td>Sense of safety</td>
</tr>
<tr>
<td>Unemployment rate</td>
<td>Material possessions</td>
</tr>
<tr>
<td>School attendance</td>
<td>Happiness</td>
</tr>
<tr>
<td>Working hours per week</td>
<td>Job satisfaction</td>
</tr>
</tbody>
</table>
concept of QoL as a whole. Some of these domains are commonly described using wellbeing terms. These domains are, by their nature, social and so vary between cultures and political persuasions. QoL domains from the literature include:

- Physical wellbeing / health
- Material wellbeing / environment
- Social wellbeing / social inclusion / feeling part of the community
- Work and productive activity / personal development
- Emotional or psychological wellbeing
- Rights or civic wellbeing / political voice
- Relationships with family and friends
- Independence / self-determination / sense of freedom
- Personal safety / sense of security

These domain areas cover a wide range of social impacts, including some that overlap with environmental and economic impacts. There are also overlaps with some of the indicators already discussed, such as social capital. Each domain is in itself broad and can include within it several indicators, with each indicator being described by a number of descriptors. An assessment starts with consideration of the relevant higher level domains and works down to identify those descriptors which could be assessed.

Where it is viable to assess indicators of QoL to determine social impact, it is also possible that changes to QoL and wellbeing could be considered to be an outcome of social impact, with social impact having a causal relationship with wellbeing rather than being a social impact in of itself.

Quality of life and wellbeing measures require consideration of the project aims and also the population of interest. A project aimed at the older population would share dimensions with one aimed at working aged adults, but may have different emphasis (i.e. more on social connections and less on education). QoL domains can also be used as a way to describe identified areas of need; for example, a project focused on reducing crime may identify a high crime area and investigate methods of crime reduction. In doing so, it is already situated within a QoL domain, but it may not have been described as such before considering the impact assessment.

HOW TO USE THIS FRAMEWORK

The four stages of assessment

The Social Impact Framework can be used in isolation, however it is most robust when it is used alongside the Economic Impact Assessment and to a lesser extent the Environmental Impact Assessment. If you are carrying out a social impact assessment, you should therefore ensure that you are familiar at the outset with any other assessments that have been carried out, or are planned. Depending on the type of IoT intervention, there is likely to be some overlap, which will provide an opportunity to share learning across the assessments.

The social impact assessment framework comprises 4 stages:

- **Stage 1** involves producing a project description and setting out the explicit or planned outcomes and impacts, technical, economic, environmental, and social as codified in the project description.

- **Stage 2** requires identification of project stakeholders, both internal and external, who will determine the likely level and nature of social impact the project will produce. They will collaboratively develop a ‘theory of change’ based on the project’s goals; an explicit statement of the mechanisms through which social impact might occur.

- **Stage 3** uses the outputs from stages 1 and 2 to determine the appropriate next steps of assessment. This is done by allocating projects to one of three ‘tiers’:
  - The first tier defines IoT interventions which (at the point the assessment is made) have no identifiable direct or indirect social impacts on members of the public. Interventions allocated to tier 1 do not proceed to stage 4 of the framework.
  - The second tier is for projects that are identified as being likely to have an indirect social impact but where it is unlikely that the affected citizens will be aware of an impact or the members of the public that are impacted are not likely to be accessible.
• The third tier is for projects with clear potential social impacts and where data (qualitative or quantitative) could feasibly be collected from those (or a sample of those) members of the public affected.

• **Stage 4** is for interventions allocated to tiers 2 and 3 which require data collection and analysis to assess social impacts. Stage 4 sets out the steps to be taken in order to carry out a suitable empirical study of the social impacts of the Intervention.

### SCOPE OF THE FRAMEWORK

**Stage 1 Define project purpose and scope**

Before considering how to assess social impact, it is necessary to set out in simple terms, what the IoT intervention involves. This involves addressing a number of key questions regarding the project, so that a non-specialist would be able to understand it. By doing so, it may also help to start seeing the project from the perspective of an interested outsider or member of the public, so as to consider potential unforeseen impacts.

**General Overview:** Set out a short description of the project, avoiding jargon and using terms and concepts that a non-specialist, or someone with no prior knowledge of the intervention would understand. Some helpful questions are:

- What is the problem the intervention is seeking to solve?
- What is the overall aim or objective?
- How will technology be used in the project; how will it be designed, delivered and deployed?

**General Aims:** Write a set of objectives for the IoT intervention. These can cover all areas: economic, social, environmental, technical or aims that are not easily labelled.

**Determine stakeholders:** Consider all the groups of people who are involved in the intervention and who will be effected by its implementation. Write a list including:

- Who is involved in conception, development and implementation? This may include institutions and Local Authorities for example.
- Who will be effected? Pay particular consideration to any groups of the public who will be effected and be clear about which members will be effected. For example is it all the people in a particular geographical area, only road users, only those who use a particular service.

**Social Impact Aims:** Consider which of the intervention aims relate to having an impact on the public or a subgroup of the public. These could be within your general aims or a subset of these aims. To ensure a wide range of impacts are considered:

- Use checklist to determine whether any of the more common impacts suggested are relevant to the aims of the intervention. These may also help to specify aims more clearly.
- Review both the economic and environmental impacts assessment for the intervention and identify any aims that could also be relevant to social impact.

### Stage 1 Report Template

<table>
<thead>
<tr>
<th>General overview</th>
<th>Short description of project written so that it will be understood by a non-specialist audience</th>
</tr>
</thead>
<tbody>
<tr>
<td>General aims</td>
<td>All key aims, not only social</td>
</tr>
<tr>
<td>Project Stakeholders</td>
<td>Who is involved in conception, development and implementation? Who will be impacted?</td>
</tr>
<tr>
<td>Project aims that relate to social impact</td>
<td>What are the projects aims that relate to having an impact on the public or a subgroup of the public?</td>
</tr>
<tr>
<td>Identify relevant economic and/or environmental impacts</td>
<td>Identify economic and/or environmental impacts (from relevant frameworks) that could have a social impact</td>
</tr>
</tbody>
</table>
Stage 2 Map pathways to impact

Determine social impact stakeholders: Having identified both the IoT intervention stakeholders and also the social impact aims, identify the stakeholders who are specifically involved in or affected by the social impact aims. This may be all of the previously described stakeholders or a subsection of them.

Mind map: Where possible involve project stakeholders to mind map/brainstorm the main social aims of the intervention. Having identified each long term social impact some key questions are:

- How will you define success in meeting this intervention aim? – This should be specific and observable.

- What are the necessary and sufficient preconditions for each aim?
  - Who or what will change?
  - Over what time period?
  - By how much?

- Use backwards mapping to start ordering the preconditions, starting with the ultimate/long term outcome and working back. These should include at least 3 stages (early, intermediate and long-term) but can include more as shown in figure X below.
  - For each aim these may be multiple penultimate outcomes and for each of those several intermediate aims etc. For now, note them down as part of brainstorming – these will not all become part of the assessment.

---

Stage 2 Map Pathways To Social Impact

Determine social impact stakeholders

Mind Map

Specify Theory of Change

Identify direct and indirect pathways to social impact

Consider potential unknown and unexpected outcomes

Digital inclusion

Ethics of intervention

Outcomes which are not the aim of the project but may impact on the public

Consider any groups who may be excluded from benefits

Consider whether the project involves any ethical issues which may concern the public
**Stage 3 Determine tier of assessment**

Different IoT interventions will require different approaches to social impact assessment. Stage 3 of the Framework assists the user in coming to a judgment about the appropriate level of assessment to conduct for each specific intervention at different time points.

It is likely that some interventions will have no discernible social impacts outside the project team and associated personnel. For example, a project might – in its early stages at least – focus on establishing the feasibility of a future implementation of a technological innovation rather than on the implementation itself. While the results of a project of this nature might ultimately be expected to have a social impact on citizens, this will be some way down stream. Therefore, little of value will be gained at this stage by implementing assessments which seek to map and assess wider social impacts.

The Framework defines 3 tiers of social impact assessment:

- **Tier 1**: interventions in tier 1 are assessed as being unlikely to have discernible direct or indirect social impacts on citizens, including on personnel and associated staff working on service delivery. Projects allocated to tier 1 would not proceed to stage 4 of the assessment framework.

- **Tier 2**: interventions in tier 2 are assessed as being unlikely to have discernible direct social impacts on citizens but could have indirect impacts via their direct effect on personnel and associated staff working on service delivery. Projects allocated to tier 2 would proceed to stage 4 of the assessment framework but would be subject to a more limited assessment.

- **Tier 3**: interventions in tier 3 are assessed as being likely to have either direct and/or indirect social impact on citizens, in addition to any indirect effects via impacts on personnel and associated staff working on service delivery. Allocating an intervention to a particular tier of assessment should not be considered as a final judgment, it can and should be updated throughout a project’s life-cycle as the potential impacts evolve and change.

The flow chart below can be used to assist in determining which assessment tier an intervention should be allocated to.

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**Figure X: Flowchart for determining IoT Tier of assessment**

Orange = No  
Blue = Yes

---

IoTUK
Stage 4 Design and implement assessment

In Stage 4, the Evaluator will compile learnings throughout Stages 1-3, they will need to establish the specified timeline of the IoT intervention and assess the Tier pathway of the assessment. It will then be essential to identify the indicators for the outcome pathway, bearing in mind that the methods of data collection will be critical to this step. In the next instance, ensure to incorporate the relevant ethical considerations to be examined throughout the assessment.
ENVIRONMENTAL IMPACT ASSESSMENT

INTRODUCTION

This framework has been designed to assess the measurable environmental benefits of IoT projects and initiatives and to generate quantitative estimates of environmental impacts where possible, with a specific focus on interventions focusing on (IoT) Internet of Things, to make a city process or service more effective and efficient.

Two separate measurements form the basis of the Environmental Impact Assessment. Firstly, it covers the negative environmental and energy impacts, - or “footprint” - of IoT hardware needed for the implementation of a project. Secondly, it takes into account the positive effects - or “handprint” [1] - of project solutions. If a project's handprint exceeds its footprint, the project results in a Net Positive impact. The aim is to identify and quantify all impacts in as much detail as possible from available data, or in the absence of data, apply proxies or best estimates.

As with all measurements frameworks, it needs to be applied several times during a project's lifetime in order to be effective:

1. Prior to project implementation in order to effectively baseline the project and to provide an overview of potential environmental impacts of the project. Importantly, this stage also outlines which data the project needs to collect in order to provide robust, scientifically accurate measures. A preliminary assessment based on estimates or proxies prior to the project's implementation can also help inform and refine the project's scope with the aim of improving its value.

2. During the first three months of the project running when solution optimisation is being implemented, initial data should be gathered, assessed and if any changes are required the solution can be tweaked in an iterative fashion.

3. Once the solution is fully implemented, a complete assessment can be run in order to understand the full benefits of the solution.

The framework outlined here is designed to work in all three scenarios.
STAGE 1 SCOPING THE PROJECT

Scope of the project
This guide assumes that an assessment of the overall scope, benefits and value of the initiative has been performed for the project/solution in question, including answering the following questions:

- What is the project?
- What will the project achieve?
- What are the alternatives?

Prior to commencing on an Environmental Impact Assessment, it is important to understand the scope of the project as it affects how measurement will be performed and more crucially what will need to actually be measured. Moreover, it is important to understand that an Environmental Impact Assessment framework focuses on those aspects of the initiative that have an environmental benefit. Although in some cases the main outcomes of the project may lie elsewhere - e.g. providing an economic or social impact, in most cases the project will also have an environmental benefit. In other cases, however, such as initiatives aimed at improving citizen’s health using the Internet of Things (IoT), the environmental benefits might be very minor or very challenging to quantify.

Paradoxically, some projects that are environmental in scope may not have a direct environmental benefit at all if they are not accompanied by additional solutions. For example, the installation of air quality sensors in a city area, does not have a direct environmental benefit associated if there are no other initiatives aimed at impacting the air quality as part of the project. Of course, measuring and communicating the air quality to citizens and local authorities can motivate the implementation of solutions that will ultimately impact air quality but these are so wide and varied they are impossible to assess a priori.

The scope or primary objective of the project needs to be suitably described prior to assessing what are the associated environmental impacts or efficiencies. For example, in the case of a Smart Parking Scheme the scope of the project is the installation of sensors in parking spaces to provide real time information to drivers via a mobile application or other means on parking availability. While the motivation behind this initiative may be to help reduce the under-utilisation of parking spaces and thus mainly economic in nature, there are environmental impacts associated with such solutions that can be mapped - these are covered in the next stage of the framework.

Scale and reach
In order to provide a clear structure and all the necessary information for the assessment of the environmental impacts, not only the scope needs to be defined, but also the scale and reach of the project. Identifying the following elements may also assist in the process of mapping the environmental impacts:

- **Beneficiaries** of the initiative, which may include several groups.
- **Geographical area** in which the project is being implemented.
- **Timescale** for the rollout of the project - this will determine whether it is possible to perform a preliminary assessment of the impacts and thus influence the data that will be collected.
STAGE 2 MAPPING IMPACT

Project Footprint
The environmental footprint of a city project is the sum of all the negative environmental impacts provided by all the pollution generated and resources consumed over the entire supply chain to produce, use, and maintain the equipment necessary to roll out such project. The environmental load caused by the implementation and roll out of the project is mainly provided by:

- The embodied environmental impact of the pieces of equipment installed
- The impact caused by the use and maintenance of such equipment

The footprint of the production of any piece of equipment is estimated by the manufacturer, and is usually done through a life cycle assessment (LCA). LCA enables the estimation of the cumulative environmental impacts resulting from all stages in a product's life cycle, including the activities that go into producing the necessary resources, manufacturing, transporting, using and disposing of that product. The typical stages of a life cycle run from extraction of raw materials, through design and formulation, processing, manufacturing, packaging, distribution, use, re-use, recycling and, ultimately, waste disposal. Figure 1 illustrates all stages considered in a LCA.

The International Organization for Standardization (ISO) establishes the protocols for performing life cycle assessments. The standards are contained within two main documents:

- ISO 14040 “Environmental management — Life cycle assessment — Principles and framework”
- ISO 14044 “Environmental management — Life cycle assessment — Requirements and guidelines”

The main categories of environmental impacts that are assessed in an LCA are listed in Table 1. The manufacturer should make available the results of the LCA if it has performed one. Otherwise, the user can only quantify the effects of use and maintenance by using the technical specifications of the equipment. Unfortunately, in many cases, the manufacturer will not have performed an LCA on its equipment, as we have found in the few use cases we have studied in detail. It is still recommended, however, to list the equipment under scope and document the equipment's specifications with as much information as is available, as this will provide an idea of the extent of the project's footprint, and in case the environmental impact of the equipment becomes available in the future.

Fig. 1. Stages included in a life cycle assessment.
The scope of the project’s footprint should be clearly defined, that is, what pieces of equipment are included in the analysis. In the case of city IoT projects the equipment under scope will mostly include:

- End-use devices
- Sensors
- Hardware for telecommunication networks
- Data centres
- Other city infrastructure

To avoid unnecessarily complicating the analysis, we would advise that devices that already existed for other purposes prior to the roll-out of the project (for example, users’ mobile phones if these are used in the project) are kept out of the scope of the environmental impact assessment. As an example the table below shows the Project Footprint of the Islington Council smart waste programme (see Use cases).

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>DESCRIPTION</th>
<th>QUANTIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Warming</td>
<td>Global warming potential of greenhouse gases released to the environment</td>
<td>CO2 equivalents</td>
</tr>
<tr>
<td>Water Intake</td>
<td>Freshwater taken from the environment</td>
<td>Volume of water</td>
</tr>
<tr>
<td>Water Consumption</td>
<td>Net freshwater taken from the environment minus water returned to the same watershed at the same quality or better</td>
<td>Volume of water</td>
</tr>
<tr>
<td>Acidification</td>
<td>Acidification of water and soil</td>
<td>H+ equivalents</td>
</tr>
<tr>
<td>Eutrophication</td>
<td>Oxygen depletion as a result of nitrogen and phosphorous deposit into freshwater or marine environments</td>
<td>PO4 equivalents</td>
</tr>
<tr>
<td>Land Occupation</td>
<td>Total land occupied to support the product system assessed</td>
<td>Area</td>
</tr>
<tr>
<td>Abiotic Depletion</td>
<td>A measure of the depletion of non-renewable resources that includes fossil energy, metals and minerals</td>
<td>Qty resource used</td>
</tr>
<tr>
<td>Biotic Depletion</td>
<td>A measure of the depletion of forests and vegetable fuels</td>
<td>Qty resource used</td>
</tr>
<tr>
<td>Waste</td>
<td>Waste generated</td>
<td>Weight</td>
</tr>
</tbody>
</table>

Table 1.- Typical environmental impact categories included in an LCA.
## Environment Impact Assessment

### Type of equipment | Equipment | LIFE CYCLE ASSESSMENT | Impact from use & maintenance
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>End-use devices</td>
<td>N/A</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Sensors</td>
<td>Enevo WE-008 sensor (wireless container fill-level monitoring)</td>
<td>Manufacturer did not perform LCA</td>
<td>400 -- Zero maintenance: 3.6V High performance Lithium Battery - Life: 10+ years</td>
</tr>
<tr>
<td>Telecoms networks</td>
<td>Enevo One server</td>
<td>Manufacturer did not perform LCA</td>
<td>1? -- ??</td>
</tr>
<tr>
<td>Data centre</td>
<td>Enevo's data centre</td>
<td>OUT OF SCOPE</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>N/A</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Project footprint analysis of the smart waste programme in Islington Council (see Use cases).
Project Handprint

A project’s “handprint” is defined here as the environmental load reduction or the environmental positive impact enabled by the specific solution that is the scope of the project. Environmental load reduction is achieved through the efficiencies the project generates which, for example, in the case of IoT solutions will mainly be provided by the collection, analysis and communication of data and the use of this data for better or more efficient decision making or for automatically optimizing a process. Other types of efficiencies generated by city projects can be classified under the categories specified in Table 3, which have been adapted from Ref. 2. For each of these categories we have identified sub-categories in which ICT city projects can be classified and we have provided a few examples of solutions for each of them. Please note that this list is not intended to be exhaustive or restrictive.

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>SUB-CATEGORIES</th>
<th>SOLUTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>(E1) Process and functional optimization</td>
<td>Power efficiency gain (decrease in power rate consumption of an asset)</td>
<td>Smart Lighting (LED), eco-driving, real-time traffic alerts, ...</td>
</tr>
<tr>
<td>(E2) Data collection, analysis and communication</td>
<td>Optimization of power consumption (decrease in time of running an asset, change in timing of power consumption)</td>
<td>Smart Lighting, power demand management, occupancy sensors, ...</td>
</tr>
<tr>
<td>(E2-A) For better decision-making</td>
<td>Route optimization (decrease in travel distance or time spent in travel)</td>
<td>Smart Parking, Smart Bin Collection, Car sharing, Real-time traffic alerts, ...</td>
</tr>
<tr>
<td>(E2-B) For automated process optimization</td>
<td>Optimization of water use (decrease in water consumption)</td>
<td>Soil monitoring, weather forecasting, ...</td>
</tr>
<tr>
<td>(E2) Data collection, analysis and communication</td>
<td>Influence citizens’ behaviour for a positive environmental impact</td>
<td>Behavioural campaign to influence recycling rates, use of public transport, ...</td>
</tr>
<tr>
<td>(E3) Digitalization and dematerialization</td>
<td>Elimination of travel</td>
<td>Videoconferencing, remote work, apps for intermodal travel/public transportation, ...</td>
</tr>
<tr>
<td>(E3) Digitalization and dematerialization</td>
<td>Elimination of materials</td>
<td>E-commerce, E-paper, Online media, optimization of existing assets instead of building new ones, ...</td>
</tr>
<tr>
<td>(E4) System integration</td>
<td>Clean electricity generation, integration of energy storage</td>
<td>Integration of renewables in the grid or locally in buildings, ...</td>
</tr>
</tbody>
</table>

Table 3. - Categories, sub-categories, and examples of efficiencies generated by an ICT city project.
Project environmental impacts associated with generated efficiencies
Once the scope of the project is defined, the first step to perform an environmental impact assessment is to identify the environmental efficiencies enabled by the project’s solutions, as well as possible inefficiencies. The list of efficiency categories provided in Table 3 can help identify the impacts associated with a particular project. As well as the primary efficiencies enabled by the project, indirect efficiencies, both positive and negative, should also be identified. For example, Table 4 shows the primary and indirect efficiencies of a Smart Parking solution.

Baseline scenario and type of environmental impact
For each of the identified environmental efficiencies, the impact can only be estimated by comparing the new scenario enabled by the project with the corresponding baseline scenario, which represents the conditions most likely to occur in the absence of the proposed project. Determining the baseline scenario is thus critical to be able to accurately estimate the environmental impacts.

We then need to identify the type of environmental impact that is most appropriate to estimate for each identified efficiency, whether it is saved emissions, saved energy, saved waste, etc. Table 5 shows a list of the main types or categories of environmental impacts to consider. It is likely that each project will have one main type of environmental impact associated. However, it is important to identify other secondary types of environmental impacts generated by the project efficiency under consideration, even if they cannot be estimated in detail. For example, the construction of less parking spaces due to the more efficient use of existing ones, will not only save emissions associated with the construction process but, if the parking spaces were to be constructed on current green areas, due to the impervious surface that characterize parking spaces, their construction would also contribute to heat island effect and could impact storm water runoff.

<table>
<thead>
<tr>
<th>SCOPE</th>
<th>ENVIRONMENTAL EFFICIENCIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation of sensors in parking spaces to provide real time</td>
<td>Primary</td>
</tr>
<tr>
<td>information to driver via an application on parking availability</td>
<td>Enhanced mobility: Reduction in travel distance</td>
</tr>
<tr>
<td></td>
<td>find parking space</td>
</tr>
<tr>
<td>Primary</td>
<td>Indirect positive</td>
</tr>
<tr>
<td>Enhanced mobility: Reduction in travel distance to find parking</td>
<td>Less parking spaces being constructed</td>
</tr>
<tr>
<td>space</td>
<td></td>
</tr>
<tr>
<td>Indirect positive</td>
<td>Indirect negative</td>
</tr>
<tr>
<td>Less parking spaces being constructed</td>
<td>More car trips as a result of the improved</td>
</tr>
<tr>
<td></td>
<td>service</td>
</tr>
</tbody>
</table>

Table 4. Scope and environmental project efficiencies of a Smart Parking project.
The ISO standard ISO 14064-2 focuses on GHG projects or project-based activities specifically designed to reduce GHG emissions or increase GHG removals. “It includes principles and requirements for determining project baseline scenarios and for monitoring, quantifying and reporting project performance relative to the baseline scenario. It provides the basis for GHG projects to be validated and verified.”

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>DESCRIPTION</th>
<th>QUANTIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG emissions</td>
<td>Global warming potential of greenhouse gases released to the environment</td>
<td>CO2 equivalents</td>
</tr>
<tr>
<td>Energy demand</td>
<td>Consumption of energy</td>
<td>kWh</td>
</tr>
<tr>
<td>Water consumption</td>
<td>Net freshwater taken from the environment minus water returned to the same watershed at the same quality or better</td>
<td>Volume of water</td>
</tr>
<tr>
<td>Land Occupation</td>
<td>Total land occupied by constructed infrastructure</td>
<td>Area</td>
</tr>
<tr>
<td>Green space</td>
<td>Total land occupied by green space</td>
<td>Area</td>
</tr>
<tr>
<td>Waste</td>
<td>Waste generated</td>
<td>Weight</td>
</tr>
</tbody>
</table>

Table 5: Main categories of environmental impacts to be assessed as part of a project's handprint.
STAGE 3 IMPACT CALCULATION

For each of the project environmental efficiencies identified, once the baseline scenario and the type of impact have been defined, we choose an indicator and an associated metrics. We then devise a method and identify the parameters needed to quantify the indicator. Indirect efficiencies may be harder or impossible to quantify, if so as much qualitative information on the impact as possible should be provided.

Indicator and metrics

In Stage 2 we identified the type of environmental impact we wanted to estimate, we now need to choose the associated indicator that will be used, e.g., saved emissions per year, as well as the metrics, e.g., tonnes of CO2 equivalent (1) per year (tCO2-e/yr). The specific indicator we choose may depend on the data available for a particular project, for example we may choose the indicator to cover the length of time most appropriate for the data that there is available.

Methodology and parameters

Once the environmental impact and the indicator to be estimated have been identified, a methodology to estimate the impact has to be designed and the parameters needed to quantify the impact need to be defined and either measured or estimated. The method and parameters needed are particular to every project, and depend on the aim of the project and the environmental impact being estimated, and therefore we cannot provide guidelines here. However, we provide several use cases below to illustrate the principles that are required.

For each parameter, we will specify the units, the value, the source of the data, and a confidence level. The confidence of every parameter is scored (‘+++’ high reliability to ‘+’ = very low reliability), based on whether the parameter value used is from measured data, or perhaps only a proxy or best guess, and depending on the stage at which the project implementation is at (see below).

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1 CO2 equivalent (CO2-e) is the universal unit of measurement to indicate the global warming potential (GWP) of each of the six greenhouse gases, expressed in terms of the GWP of one unit of carbon dioxide.

IoTUK
Establishing impact
An initial estimate can be calculated prior to the rollout of the project, with a more accurate estimate possible once the project is in its final stages. In addition, performing this assessment when the project is at its initial stages allows to clearly identify the parameters needed and thus ensure that they are being measured while the project is being implemented.

The availability of data will depend on the stage at which the project is at. It is therefore important to document the source of the parameter values used, as well as a measure of the confidence in the data to be able to assess the reliability of the final impact value estimated. When the impact is estimated after the roll-out of the project and measured data has been used, it is recommended that an uncertainty is estimated for each of the parameters, as well as for the final impact value. When an estimate of the impact is given prior to the project implementation, it is likely that the values used for the parameters are proxies from a similar project, databases or literature, or best guesses based on experience. In this case, where a confidence of the data will be low, it is important to provide the source of the information and to indicate that the impact estimate obtained with this data is also of low reliability.

In many cases city projects are demonstrators of a certain solution at a small scale. Therefore, as well as measuring the necessary parameters to estimate the environmental impact of the demonstrator, it might be useful to have the data to be able to scale the impact results to the full implementation over the entire borough or city.
TECHNOLOGY OPTIMISATION

SUMMARY

The guidance around Technology Optimisation is a radically new field of analysis, it is essential to note, that this work is a reflection of an evolving understanding around the complexities of Technology Optimisation. Therefore, this piece of work is the first iteration of many to come.

This guidance provides insight that will be useful for cities, in order to gain greater understanding of how to approach optimisation of IoT solutions. The report explores the application of optimisation theory and methods to Urban IoT Applications. Having already demonstrated the complexities at design time for the applications considered, an overview of optimisation, the identification of relevant objective functions and associated constraints, and their possible combination into tractable and solvable problems are discussed. Optimisation procedures are considered before discussing some of the more technical elements of IoT application design relevant and essential to the formulation of applicable and relevant optimisation procedures. A brief treatment of multi-disciplinary design optimization.

This guidance document summarises the following:

- Internet of Things is an intractably large problem and solution space. It is unlikely that there will be ‘one size fits all’ solutions. This applies equally to optimisation approaches.

- Optimisation methods can be applied to numerous IoT problems, including device design, network design, deployment, energy balancing, maintenance, and so on, and is probably more useful in its application at design time as opposed to impact assessment. Nevertheless, the two are interconnected.

- Optimisation concerns making the best decisions possible subject to known constraints. However, optimisation is a highly technical area that requires a significant understanding and application of mathematics tailored to the problem at hand in concert with familiarity with computer science in terms of algorithm design, implementation and interpretation.
AN INTRODUCTION TO OPTIMISATION

“Optimisation is central to any problem involving decision making, whether in engineering or in economics. The task of decision making entails choosing among various alternatives. The choice is governed by our desire to make the “best” decision. The measure of goodness of the alternatives is described by an objective function or performance index. Optimisation theory and methods deal with selecting the best alternative in the sense of the given objective function [13].”

Optimisation practically refers to a branch of applied mathematics that seeks to minimize or maximize certain functions, often under constraints. Essentially, contemporary optimisation methods involve the study and application of algorithms to solve mathematical problems on computers, where many disciplines, ranging from statistics, dynamical systems and control, complexity theory, algorithms are involved. Its application is relevant to a widening array of contexts, including machine learning, search, engineering design, economics, finance, and management. In this work, we describe how and where optimisation can be applied to Internet of Things technologies in Future Cities.

APPLICATION OF OPTIMISATION TO IOT INFUTURE CITIES

Optimisation methods can be applied to any IoT application conceived for deployment in the “Smart” or “Future” City context. There are an intractable number of potential applications, each of which is most likely optimised by a different objective function (or set of functions) relevant and bespoke to/per application and market segment(s). The complicated nature of the stakeholder groups involved make this a particularly challenging problem to address from a holistic perspective.

The application of optimisation theory and methods may encompass numerous aspects of the design, including devices, networks, deployments, may consider economic factors (e.g. economic feasibility and expected returns), and may extend to maintenance and other related recurring expenditure. This is particularly important to consider where an “IoT” technology may be highly lucrative in one application/market, but the exact same technology may be economically infeasible in another.
TAXONOMY OF IOT APPLICATIONS FOR URBAN ENVIRONMENTS

This section provides a brief taxonomy of the state-of-art Internet of Things (IoT) applications proposed for, and finding uptake in urban centres globally. It provides an overview of the technologies already deployed in major Smart City initiatives, e.g., [56], in addition to those which are foreseeable in the near to medium term [19, 30]. This taxonomy includes a cross section of the vertical application spaces for IoT technologies (often referred to as silos) [34], such as environmental monitoring (e.g., air quality monitoring [25]), public services (e.g., transport, waste management, etc. [10]) and utilities (e.g., energy [37], water [4, 22], etc.).

Figure 1 [30] provides a visual indication of the potential reach of the technology as it is currently conceived. The development of an exhaustive taxonomy is beyond the scope of this work. However, a suitable subset of examples taken from existing and emerging urban IoT application scenarios is sufficiently representative to articulate how optimisation approaches to IoT technologies may be developed and exploited.

A subset of scenarios will be discussed from a technical and economic perspective in the following sections with the ultimate objective of applying effective optimisation techniques to their realisation in cities. Specifically, Air Quality monitoring, Water Quality and Distribution Network monitoring and control, and ‘Smart’ buildings, wherein data from heterogeneous sensors is used to optimise lighting, heating ventilation and cooling systems (HVAC), are studied. It is explained that, irrespective of the specific application scenario, a similar design space exists across market segments. Nevertheless, requirements that extend from the application, market (i.e., standards), regulatory, and other domains will have a significant role in determining the degree to which optimisation can be applied.

Figure 1: A Vision of the Internet of Things, from [30].
**URBAN IOT MARKETS**

We briefly review the Urban IoT Markets identified by the Future Cities Catapult (FCC), and use them to guide the development of a relevant taxonomy of IoT applications. Specifically, the FCC has identified the following markets as being relevant to the IoT paradigm in context of ‘Future Cities’:

- Transport & Mobility
- Security & Crime
- Energy & Water
- Environment & Climate
- Building Management
- Governance

From a holistic perspective, this is an extremely challenging categorisation to attempt, as each of these markets is intrinsically linked in time and space in the urban environment, spanning public and private enterprises. From the markets listed, we elect to focus on ‘Energy & Water’, ‘Environment & Climate’ and ‘Building Management’. In each case, we discuss the state-of-the-art in terms of commercial systems and recent academic/research contributions. It is important to highlight the relevant differences of a number of component technologies, their design and relationship to application level requirements, to fully appreciate how each market, and application of IoT technology within that market, can benefit from optimisation across a multitude of scales.

From the markets listed, we elect to focus on ‘Energy & Water’, ‘Environment & Climate’ and ‘Building Management’. In each case, we discuss the state-of-the-art in terms of commercial systems and recent academic/research contributions (2). It is important to highlight the relevant differences of a number of component technologies, their design and relationship to application level requirements, to fully appreciate how each market, and application of IoT technology within that market, can benefit from optimisation across a multitude of scales.

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2 It is worth bearing in mind the time taken for new technologies to achieve widespread market adoption, typically thought to be counted in decades
Energy & Water
In this sub-section, emphasis is placed on Water, rather than Energy, which is discussed in the Built Environment section below, owing to the impact of the built environment on modern energy supply and demand. High level estimates of the size of the Water market run to tens of billions of pounds annually. Investment in new water infrastructure and maintenance of existing water infrastructure will continue to facilitate significant opportunities for IoT applications. Initially, Smart Meters were the major motivator of the debate, however, as noted in [52], the Smart Meter is just the beginning:

“The IoT will deliver practical, real-time asset management, providing the ability to optimise use of abstraction licences, boreholes, pumps, reservoirs, pipe networks, sewers, treatment plant and discharge licences to ensure lowest cost and most effective service to customers. It will allow systems and plant to be run closer to their limits of capacity, condition and energy efficiency. Far too often, the smart water debate focuses on the customer meter, but in a world of IoT, this is only the tip of the iceberg. The real value will come from truly sweating the connected assets within a measured and dynamically managed risk profile [52].”

The wide-ranging potential applicability of IoT technologies in the Water market alone is illustrated in Figure 2, where the scope and multiple scales of the technologies required to satisfy each sub-process is evident. Within this market, it is worth exploring additional emergent scenarios such as:

- Water Quality Monitoring and Control
- Waste Water Management
- Leak Detection & Control
- Structural Integrity Monitoring

Water Quality Monitoring and Control
The notion of next generation (4th) SCADA systems based on emergent IoT technologies has attracted interest in academic and industrial settings. With application to Water Quality Monitoring & Control, it is worth highlighting the recent EC FP7 ‘Autonomous Control of Large-scale Water Treatment Plants based on Self-Organised Wireless BioMEM Sensor and Actuator Networks’ (Hydrobionets, [http://www.hydrobionets.eu](http://www.hydrobionets.eu)) project, which focused on optimised approaches to the design of systems to enable real large-scale water quality monitoring and control; specifically detecting and reacting to instances of bio-fouling (see Figure 3). This example is reused later in terms of the optimisation techniques involved at multiple levels of the system and its design.

![Figure 3: Hydrobionets System](http://www.hydrobionets.eu)
Leak Detection
Leak detection based on advanced sensor signal processing has long been proposed and documented in the literature, e.g. PIPENET in 2007 [61]. Recently, a number of companies seeking to exploit the need for tighter monitoring and maintenance of water infrastructure have emerged, e.g. Inflowmatix (http://inflowmatix.com). Autonomous systems that react to detected leaks have been proposed, but are in their infancy. It is quite rare to find any electro-mechanical valves in contemporary water networks. However, during the next wave of infrastructure investment, it is possible that these will be designed into the system to facilitate remote operation [63].

Structural Integrity Monitoring
Structural integrity monitoring of pipelines, particularly in water distribution networks, is a major challenge in the industry. It is synonymous with leak detection, but has the capacity to provide early warning that a leak is about to occur, i.e. it has not already occurred and an actual leak is detected as before, thus enabling preventative maintenance [63].

More generally, there are significant projects under way to address the future of water systems from an ICT perspective. This is exemplified by the EU ICT4Water initiative (http://www.ic4water.eu), which oversees a range of projects ranging from those designed to educate and engage users, e.g. i-Widget (http://www.i-widget.eu), to those considering the long-term integration of supply and demand using advanced autonomous monitoring and control systems coupled with advances in analytics, e.g. WISDOM (http://www.wisdom-project.eu), and everything in between.

Summary
The objective of the previous subsections has been to highlight a cross section of the numerous propositions of IoT component technologies within the water vertical alone, and to briefly illustrate the technical differences between prospective solutions.

Given the various geographic scales and heterogeneous criticality evident per application, ranging from short range plant-based applications in [4] to leak detection in water distribution networks in [61], to metering in general, there are a significant number of choices that must be made when designing the appropriate technology. These include communications (concerning range, reliability, security), sensing (i.e. what sensors are appropriate), energy (i.e. how is the device going to be energy-provisioned to achieve the target lifetime), among others. It is thus evident that in each IoT application instance for the water market, there exists a multi-objective optimisation problem that extends from the design of the device.

Environment & Climate
Air quality monitoring in urban environments is an increasingly ‘hot topic’, with numerous efforts under way in public and private settings. The OECD estimates that particulate matter (i.e. air pollution) will be the most significant contributor to mortality by 2050 [3]. In the following subsections, we highlight a number of initiatives that seek to use IoT technologies to assist in the estimation, measurement and management of air pollution. These range from large collaborative projects designed to directly challenge this societal problem to commercial efforts to sell air quality monitoring devices in the consumer and city markets.

EPSRC Managing Air for Green Inner Cities (Magic)
The Magic project [25] was selected by the Research Council as a Grand Challenge winner in the Future Cities category. It has at its core the objective of answering the question as to whether or not it is possible to achieve cities with zero air pollution or heat island effects by 2050. To put this challenge in context, the project consortium is led by the University of Cambridge, and includes 28 academic investigators from across the leading Universities in the UK, in addition to numerous industrial supporters, and will run over the next five years. The scope of the investigation ranges from developing a fully resolved air quality model that interacts with sensor data and provides detailed calculations of the air flow, pollutant and temperature distributions in complex city geometries (whilst being fully coupled to naturally ventilated buildings, and green and blue spaces), to developing reduced order models that allow rapid calculations for real time analysis and emergency response, and finally to attempting to create a cost-benefit model to assess the economic, social and environmental viability of options and decisions.

This neatly evidences the complexity involved in developing a city-scale approach to air pollution detection and management, where it is clear and obvious that there exists neither the necessary models (which will be developed using wind tunnel and salt bath experiments using complex physical models of urban geometries in the Magic project) nor the sensor infrastructure to sufficiently address this problem. Finally, given the lack of complex (or reduced order) models, and understanding of their interaction with physical sensing infrastructure (including cloud infrastructure linking the models to the sensors), it is impossible to reason about the accuracy and relevance of a cost-benefit model until this knowledge emerges. However, given the aforementioned OECD prediction, the importance of pursuing this is also evident, and is likely to be of such societal importance that it will likely be necessary to incorporate public support to ease economic return requirements.

London Air Quality Network
The London Air Quality Network (LAQN, http://www.londonair.org.uk) is a mature network of sensors distributed across the London urban area run by King’s College. It consists of more than 100 active stations, and the system can detect various compounds and particulates [10]. The varied spatial characteristics of device deployment require modelling to ensure and improve the accuracy of the air quality estimation. Generally, London’s air quality is found to be well within acceptable bounds, although certain concentrations of pollutants are evident in dense traffic areas, e.g. shown in Fig. 4. Observation stations report using cellular connectivity at regular intervals. The system presents data via Web and mobile applications; where the user manually requests specific interest points, and the system makes the datasets available for manual download in CSV format. Alternatively, users can get near real-time snapshots of the overall air quality map through ‘Nowcast’.

It is arguable that the monitoring stations are representative Internet of Things devices, albeit that they do not use the latest communications technologies, and given their numbers, are arguably insufficiently distributed to provide the necessary granularity of data in time and space. For this reason, the use of additional modelling is necessary and exploited. This limitation has been observed by the Change London non-profit organisation, described in more detail below, who seek to improve upon the status quo.

Elastic Information Management for Air Pollution Monitoring – Imperial College
Considering the challenge described in the Magic project and the increasing likelihood of vastly greater numbers of data generating IoT devices proposed by Change London (below), applications like urban air quality monitoring require information management over widely distributed sensors under restricted power, processing, storage, and communication resources. Continual increases in size, data generating rates, and connectivity of sensor networks present significant scale and complexity challenges. Traditional methods of information management are no longer applicable in such a scenario, and as a result, new schemes have been proposed, such as elastic resource allocation strategy, introduced in [45], which is a novel management technique based on elastic computing.

Elastic computing has been proposed as a method to overcome limitations for real-time and high-performance information management for large scale sensor network applications such as air
quality monitoring at urban scales. This is worth highlighting, as it will be an essential component technology to link real-time information flows of sensor data to models (full or reduced order) to facilitate timely decision making in the future.

A deeper elaboration of the underlying cloud computing technology proposed in [45] is beyond the scope of this report. However, it is one of an increasing number of approaches proposed in the literature and commercially to handle the data resulting from IoT hardware deployments at scale. The elastic scheme proposed by the Imperial College researchers is shown to achieve high performance in terms of resource provision and scalability in simulation, and uses tracking of the dispersion of a pollutant cloud as a useful and relevant case study, shown in Fig. 5, [45]. Of particular relevance to this report with regard to the elastic cloud resource provision is the fact that the performance gains are achieved by a core technique which is a representative optimisation problem, formulated as a 0-1 Integer Linear Programming (ILP) problem. Specifically, the elastic scheduler models the constraint satisfaction problem by minimising the use of resources for collecting information for a defined quality threshold. This leveraged the assumption that the scheduler can directly request data from the sensing devices in a way such as to minimise the energy consumption of the nodes, whilst satisfying certain constraints, such as the measuring accuracy requirement, pollutant diffusion model and sensory data attributes.

**Perkin Elmer – Elm**

Perkin Elmer has developed an air quality monitoring ‘IoT’ product targeted at individuals and communities alike. Their air quality monitoring unit is called the Elm ([https://elm.perkinelmer.com](https://elm.perkinelmer.com)) (Fig. 6b), and Elm units’ data are visible via the web (Fig. 6a) or mobile ‘App’.

Elm claims their “cloud-based system powers the only web-enabled monitoring network to deliver clear and informative visualizations of reliable, relevant environmental-quality information.” Whether or not this is entirely true is debatable, but the Elm is one of the first fully connected IoT products in this space. It is known to be expensive on a per unit device cost, and is largely unproven in widespread deployment. This is hardly surprising, however, given the novelty of the majority of IoT applications in these types of market.

Figure 5: Air Quality Monitoring in London, from [45].
CleanSpace™ Tag

The CleanSpace™ tag from Drayson Technologies is a new product for personal air quality monitoring that exploits the use of Freevolt technology (http://www.getfreevolt.com/) to ensure that the tag requires not to be charged based on harvesting radio frequency (RF) energy from the environment. The product is illustrated in Fig. 7, and is one of the first standalone personal air quality monitoring devices on the market.

It is too soon to determine whether or not the product will be successful or how accurate the sensor data produced will be. However, the inclusion of new RF energy harvesting capabilities to trickle charge the device is interesting, and it has typical connectivity, making it a de facto IoT device.

Building Management

According to the United Nations, residential and commercial buildings account for 60% of the world’s energy use and are responsible for one third of global greenhouse gas emissions [5]. Therefore, given the concentration of buildings in urban environments, more efficient design and operation of the built environment is crucial to achieving sustainable future cities. Internet of Things technologies can play a significant role in the retrofit and fit-out of legacy and new building stock, respectively. There is increasing interest in industry in more practical integration of monitoring and control systems in buildings, where it should be possible to more tightly manage buildings in terms of their lighting, heating ventilation and air conditioning (i.e. the primary energy consumers) in addition to retrofitting (or install efficient) appliances with better energy ratings.

Industrial Building Automation Systems

There are numerous large commercial vendors in this space, and itself is a reasonably complex market. A typical scenario would be for a building manager to procure a building (energy) management system (B(E)MS) from a commercial vendor, possibly via some consultant’s recommendation (e.g. Arup). One contemporary example is the Trend (owned by Honeywell) system. It is typically used to control the heating ventilation and air conditioning (HVAC) systems installed in the building. These systems have centralised control over various regions (i.e. meeting rooms, offices, etc.) and tend to be operated based on particular policies (e.g. the temperature should be within certain thresholds at certain times, otherwise the space is heated or cooled). At present these systems use distributed sensors to collect temperature, humidity and air quality readings, upon which decisions are made automatically or with a presence of a human in the loop. For large organisations, take Imperial College for example, the operation of the BMS is outsourced to a specialist subcontractor once procured and installed.

It is arguable that these BMS constitute Internet of Things instances, where sensor data is collected via a closed network (typically sensors are connected using Ethernet cables), data is visualised via an ad hoc graphical user interface (GUI),

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Figure 7: CleanSpace™ Tag [4]

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4 http://www.getfreevolt.com/
5 http://www.unep.org/sbci/AboutSBCI/Background.asp

IoTUK
which enables simplified central monitoring and control, and a high degree of automation (where controllers, or actuators) are also connected to manage the building controls.

From a commercial point of view, other major players in the space include ABB, Siemens, Schneider, Acciona, Laing O’Rourke, GE, Emerson and Rockwell Automation. Indeed, the majority of these companies are regarded as world leaders in process automation technologies, not just building automation systems vendors or suppliers. Given that there are numerous industrial players vying for market share, there have been a number of emergent protocols, standards and specifications proposed. Popular building automation standards include BACnet, KNX and ModBus, but there are numerous additional possibilities based on the technologies proposed for interconnecting sensors and actuators, for example, such as ZigBee and EnOcean. A comprehensive treatise of these standards is beyond the scope of this report.

Whilst there are many vendors of integrated BMS solutions based on federated control of distributed sensors and actuators in terms of energy management, it is only recently that additional efforts have been proposed to better integrate all of the complementary monitoring and control systems that exist in buildings today. For example, security control systems which monitor premises using access control systems (such as biometrics and/or access cards e.g. RFID) and closed circuit television (CCTV) cameras are ubiquitous in modern built environments. However, it is rare that these systems are fully integrated with traditional BMS. The reasons for doing so include implementing more efficient energy policies by determining decision criteria such as typical occupancy patterns, and so forth. This can extend to user or occupant comfort under some conditions (i.e. where it is possible to control an environment with sufficient precision, and is not always the case).

APPLICATION OF OPTIMISATION TO URBAN IOT APPLICATIONS

This section provides an overview of the optimisation pipeline, from identification of relevant target metrics to solution, together with an outline of how these optimisation techniques may be applied into the Urban IoT space via techniques such as design optimisation and deployment optimisation.

Identification of Relevant Objective Functions and Constraints

The first step in any optimisation effort is to identify and quantify the target objective functions, also referred to by terms such as criteria, target metrics and goal functions. These will be functions of a number of decision variables and may be user-centric or system-centric in nature. User-centric objective functions measure some aspect of the quality of service perceived by (classes of) individual users or devices – such as the 90th percentile of request response time – and are increasingly being adopted as key performance indicators in Service Level Agreements [18]. System-centric objective functions express global measures relevant to the operation of the entire system such as system utilisation, mean throughput or daily CO2 emissions. Note that it can be difficult to find a way to express certain metrics quantitatively – either because the metric in question is inherently qualitative in nature (e.g. societal benefit) or because a precise definition for the metric may be hard to pin down in a particular use case (e.g. notions of “fairness” or “robustness”). Also objectives are frequently naturally conflicting such that improvements in one may lead to a deterioration in another e.g. availability and energy use.

In a world of limited budgets, constrained energy supply and finite resources, there are invariably restrictions which solutions must satisfy – formally these are known as constraints, of which there are two varieties. So-called hard constraints cannot be violated and are expressed as standalone inequalities or equalities. Soft constraints are incorporated into an existing objective function as a penalty term whose magnitude depends on the degree to which the constraint is violated.
SUMMARY REMARKS

Performance in Use has been engineered to empower Cities with the necessary tools to effectively measure impact and weigh the cost and benefit scenarios across an array of IoT interventions, therefore proving value for money.

It’s important to note that IoT is a developing technology intervention and that as such Performance in Use will also evolve, change and adapt as IoT matures in all its forms.

However, by applying the Impact Frameworks, Cities will benefit from gaining greater insight into the complexity of IoT deployments, enabling cities to take an informed position on IoT investment decisions and better monitor any transformative outputs from any programme of activity.