# Measuring Carbon

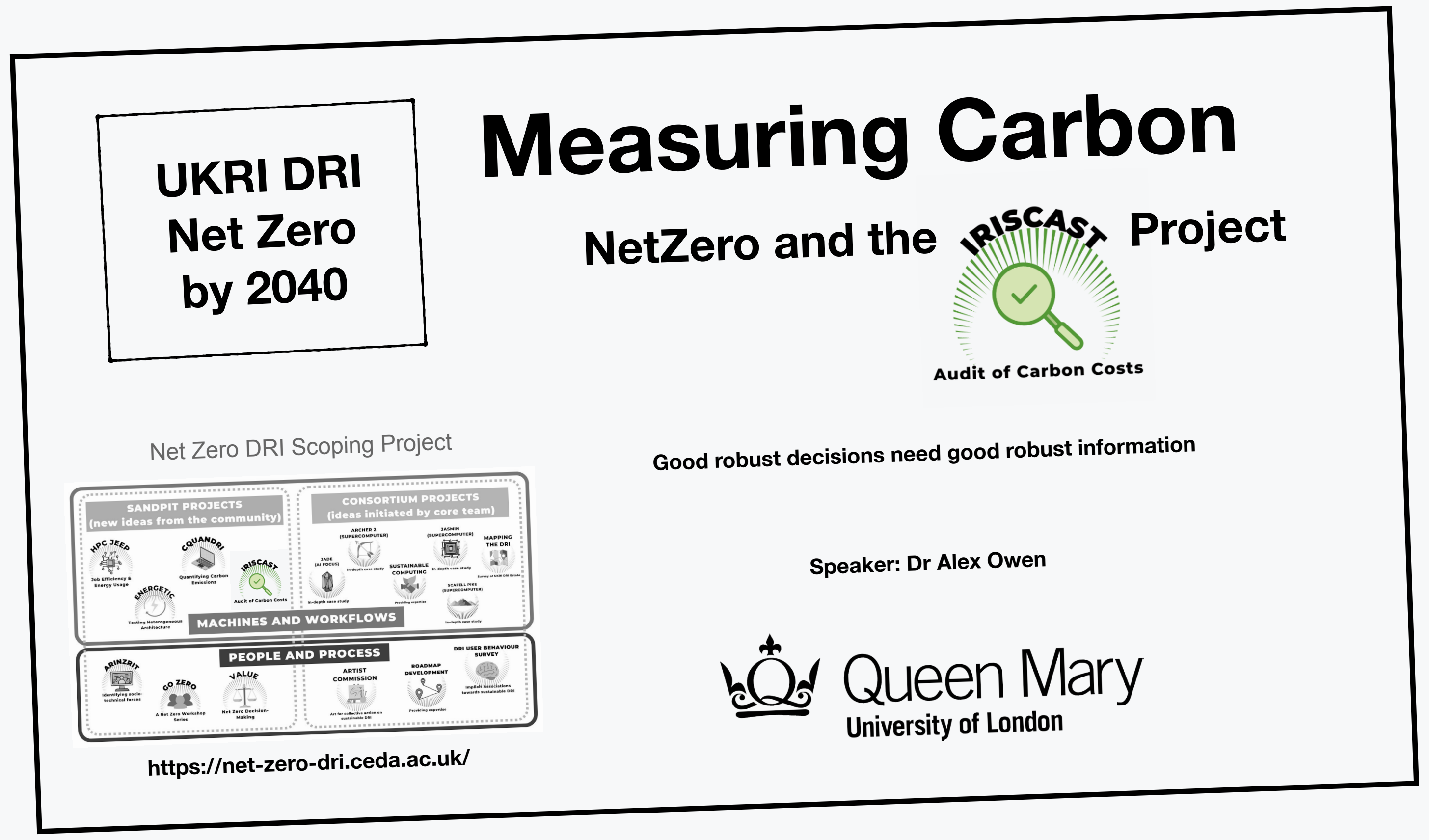
Speaker: Dr Alex Owen

r.a.owen@qmul.ac.uk

IRISCAST Audit of Carbon Costs

## & UKRI NetZero DRI

Queen Mary University of London

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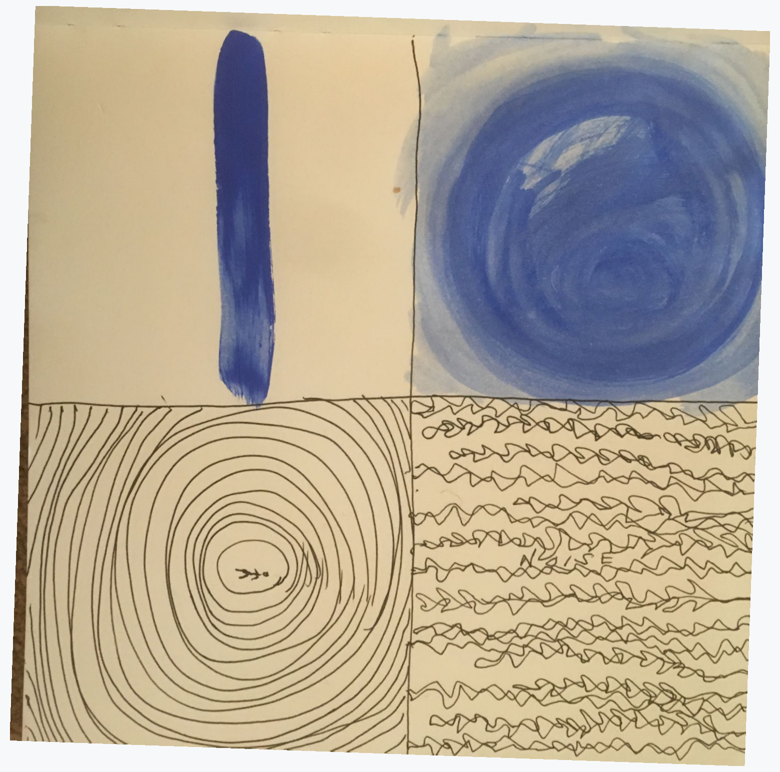

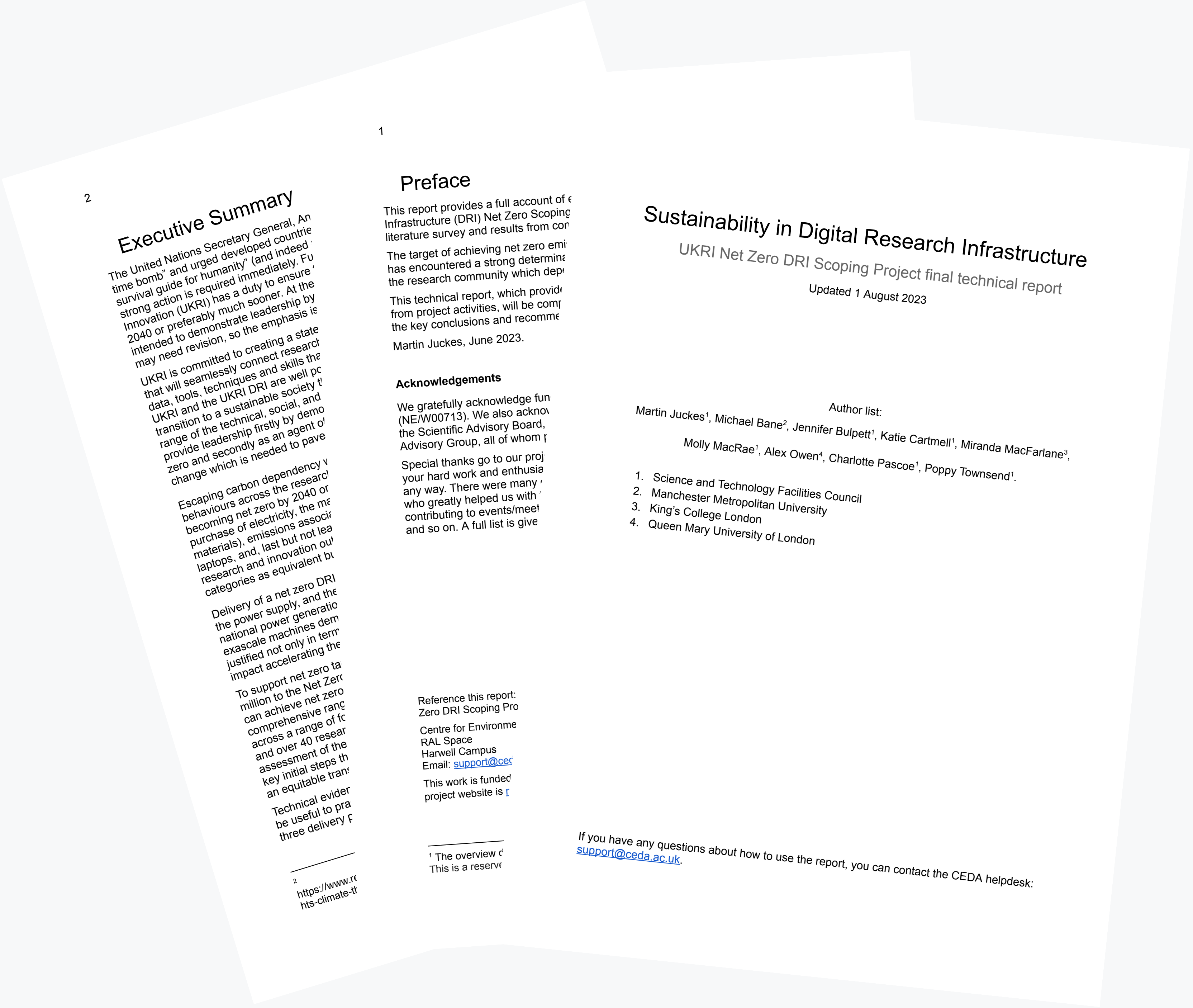


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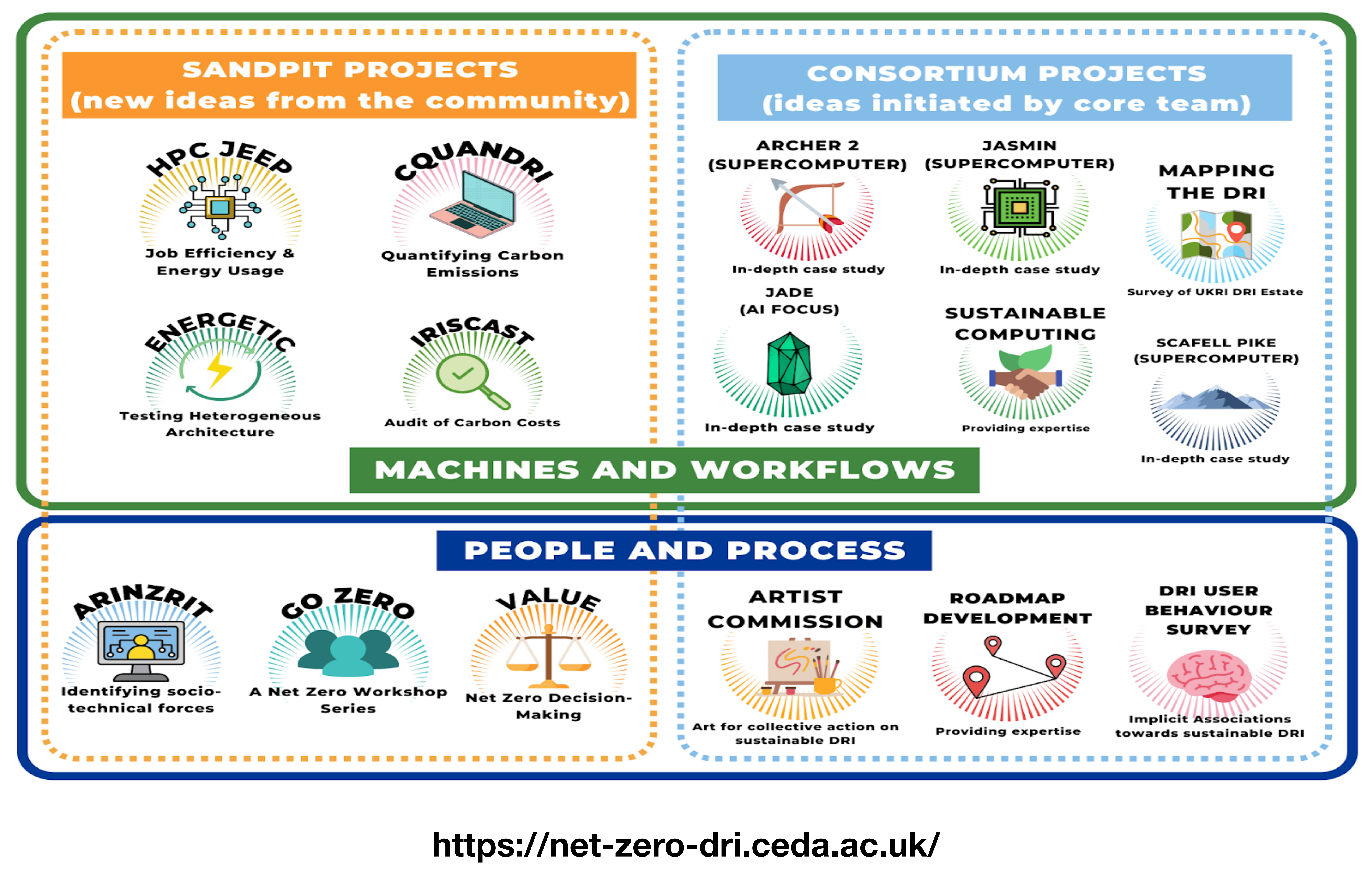
UKNOF52

# UKRI DRI Net Zero by 2040

## UKRI Net Zero DRI Scoping Project

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# Measuring Carbon

## NetZero and the IRISCAST Project

Audit of Carbon Costs


iris
DiRAC
GridPP
Queen Mary University of London
University of Cambridge
epcc
UKRI Science and Technology Facilities Council | Scientific Computing

Jon Hays (QMUL)
Nic Walton (Cambridge)
Adrian Jackson (Edinburgh)
Alison Packer (STFC)

Alex Owen (QMUL)
Alex Ogden (Cambridge)
Anish Mudaraddi (STFC)

Dan Traynor (QMUL)
Derek Ross (STFC)
Alexander Dibbo (STFC)
Jon Roddom (STFC)
Martin Summers (STFC)
Jacob Ward (STFC)
Dan Whitehouse (Imperial)
Alastair Basden (Durham)


6 Month Project Funded within UKRI Net Zero Scoping Project

# eInfrastructure for Research and Innovation for STFC

IRIS is a cooperative community brining together (mainly) STFC computing interests

Formed bottom up by science communities and compute providers

Works closely with STFC but run by the community

IRIS Science Director is Prof J Hays who is also IRISCAST Project PI

https://www.iris.ac.uk/

# What is IRISCAST?

IRISCAST is the IRIS Carbon Audit SnapshoT

24 Hour snapshot across multiple 'IRIS Facilities'

## The Challenge

Estimate carbon costs for scientific computing across a broad heterogeneous landscape

Identifying the key drivers for carbon costs

Identifying the hurdles and barriers

Communicating the carbon costs to drive change

Working coherently across different communities

## The Project

Work together coherently across different facilities with different remits, tooling, and capabilities.

Learn by doing!

Document the gaps, the barriers and the issues, drive requirements for future work and decision making

Communicate across our communities and build a foundation for future action

# Carbon Model

IRISCAST
Audit of Carbon Costs

$$C_t^p = C_a^p + C_e^p$$

**Carbon Cost (C) for a period (p) is sum of active carbon (a) and embedded carbon (e)**

$$C_a^p = CM_e^p \left( E^p_{nodes} + E^p_{network} + E^p_{cooling} + E^p_{power} + E^p_{facility} \right)$$

**Carbon Intensity of Power (Grid)**

**Measure Energy Usage (E)**
**Obtain Carbon Grid Intensity (CM)**

$$C_e^p = \sum_{1}^{\text{nodes}} \sum_{\text{t=0}}^{\text{p}} \frac{C_{\text{enode}}}{L_{\text{node}}} + \sum_{1}^{\text{networks}} \sum_{\text{t=0}}^{\text{p}} \frac{C_{\text{enetwork}}}{L_{\text{network}}} + \sum_{1}^{\text{facility items}} \sum_{\text{t=0}}^{\text{p}} \frac{C_{\text{efacility}}}{L_{\text{facility}}}$$

**Inventory of Equipment**
**Obtain Embedded Carbon**
**Estimate Lifetime (L)**

# Learning By Doing

# 24 Hour Snapshot at Six Facilities

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Audit of Carbon Costs

## Summary Inventories

| Node Model | Quantity |
|---|---|
| Dell PowerEdge R640 | 118 |
| Mellanox SN2410 | 4 |
| APC APDU9953 | 12 |

*Facility Inventory at QMUL*

| | Specification | | |
|---|---|---|---|
| Model | CPU | RAM | Quantity |
| Dell PowerEdge C6320 | x2 Intel Xeon CPU E5-2690 v4 @ 2.60GHz | 256 GB DDR4-2400MHz ECC | 60 |

*Facility Inventory at Cambridge*

| Node Model | Quantity |
|---|---|
| PowerEdge R410 | 68 |
| PowerEdge R430 | 60 |
| PowerEdge R440 | 15 |
| PowerEdge R6525 | 30 |
| ProLiant SL2x170z G6 | 24 |
| SYS-6028TP-HTR | 12 |
| X9DRT | 24 |
| Unknown (Generic Server) | 8 |

*Facility Inventory at Imperial*

| | Node Specification | | |
|---|---|---|---|
| Model | CPU | RAM | Quantity |
| Dell PowerEdge C6420 | x2 Intel Xeon Gold 5120 CPUs | 512 GB | 452 |
| Dell PowerEdge C6525 | x2 AMD EPYC 7H12 | 1024 GB | 360 |

*Facility Inventory at Durham*

## Facilities

Cambridge IRIS HPC/Cloud
STFC SCD Cloud
STFC SCARF
QMUL GridPP Tier 2
Imperial GridPP Tier 2
DiRAC (Durham)

| Node Specification | | |
|---|---|---|
| CPU | RAM | Quantity |
| AMD Epyc 7502 | 256GB | 246 |
| Intel Gold 6126 | 192GB | 164 |
| Intel E5-2650v4 | 128GB | 201 |
| Intel E5-2650v3 | 128GB | 88 |
| Network Switches | | - |

*Facility Inventory at STFC SCARF*

| | Node Specification | | |
|---|---|---|---|
| Model | CPU | RAM | Quantity |
| Dell C6420 | Intel Xeon 4108 | 96GB | 96 |
| Dell C6525 | AMD Epyc7452 | 512 | 138 |
| Supermicro | AMD Epyc7452 | 512 | 238 |
| Supermicro | Intel 6130 | 384GB | 74 |
| Dell | Various | Various | 10 |
| GPU Nodes | Various | Various | 94 |
| FPGA Node | Intel 6148 | 192GB | 1 |
| Control Plane | Various | Various | 12 |
| Storage Nodes | Various | Various | 105 |
| Network Switches | Various | Various | - |

*Facility Inventory at STFC CLOUD*

# Build a Community

# Tools at each Level

Facility Level: Cooling energy usage/PUE generally poorly known

| Facility | Enclosure Level | | | Node Level | | |
|---|---|---|---|---|---|---|
| Name | Device | Protocol | Tool | Device | Protocol | Tool |
| QMUL | PDU | SNMP | Net-SNMP | BMC | IPMI | free-ipmi |
| Cambridge | - | - | - | BMC | Redfish | Prometheus |
| Durham DiRAC | PDU | SSH | SSH | BMC | IPMI | unknown |
| STFC Cloud | PDU | SNMP | LibreNMS | BMC | IPMI | ipmitool |
| STFC SCARF | PDU | SNMP | LibreNMS | BMC | IPMI | ipmitool |
| Imperial | - | - | - | BMC | IPMI | ipmitool |

*Comparison of predominant data collection methods at IRISCAST sites. Notably using intelligent Power Distribution Units (PDUs) and Baseboard Management Controllers (BMCs).*

Precision of ipmitool output identified as a problem by Durham. They may have a patch!

Job Level: SLURM queues can report Job Energy usage

Turbostat and other RAPL tools?

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# Energy Vs Power

**For active carbon we need to know about ENERGY usage**

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Audit of Carbon Costs

**Time Stamped Energy usage is more robust than instantaneous power**

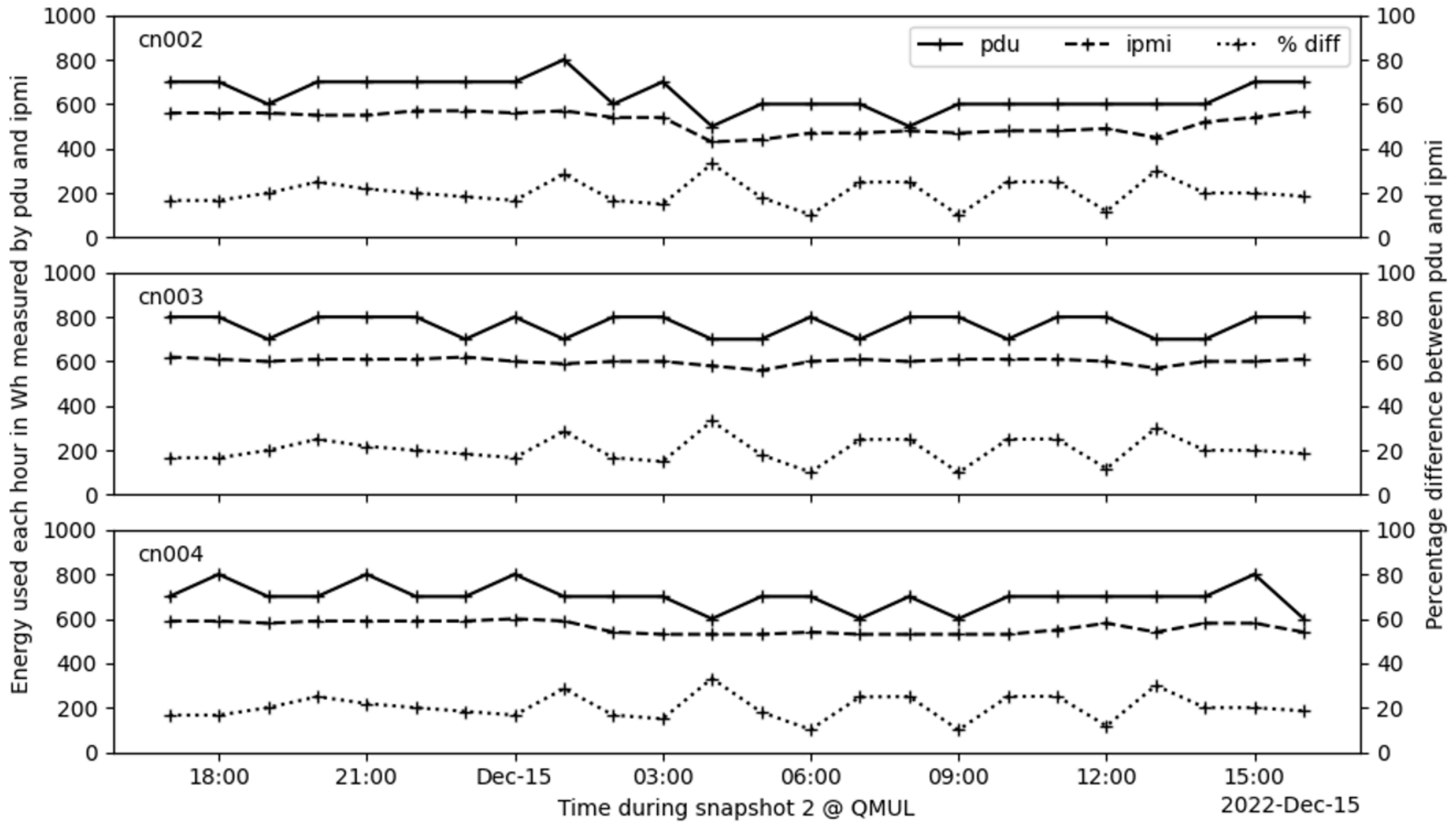
| | | | |
|---|---|---|---|
| **APC PDU's SNMP query** | ✓ | `PowerNet-MIB::rPDU2DeviceStatusEnergy.1` | **Hoctowatthour (100 wh) units** |
| **APC port n SNMP query** | ✓ | `PowerNet-MIB::rPDU2OutletMeteredStatusEnergy.n` | |
| **IPMI query (freeipmi)** | ✓ | `ipmi-oem dell get-power-consumption-data` | |
| **IPMI query (ipmitool)** | ? | `ipmitool sensor list` | **Probably Power Measurements Energy is better!** |

# PDU Vs IPMI

IPMI approx 20% low cf PDU
Except at QMUL where 1.5%
(APDU9953)

More questions than answers:
Check your calibrations!

| System | Facility (kWh) | PDU (kWh) | IPMI (kWh) | TurboStat (kWh) | No. of Nodes |
|---|---|---|---|---|---|
| QMUL | 1299 | 1299 | 1279 | 1214 | 118 |
| CAM | 261 | - | 261 | - | 59 |
| DUR | 8154 | 8154 | 6267 | - | 876 |
| STFC CLOUD | 3831 | - | 3831 | - | 721 |
| STFC SCARF | 4271 | 4271 | 3292 | - | 571 |
| IMP | 944 | - | 944 | - | 117 |
| **Total** | 18760 | | | | |




*20% difference between APC AP8459WW port measurements and IPMI measurements*

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Re test at QMUL
with AP8459WW
per port PDU
20% difference!

# Carbon Model

## Model a range of scenarios

**Measuring computer energy usage is the easy bit.**

**Cooling energy usage/PUE less well known.**

**Computer embedded carbon figures hard to find.**

**Other equipment embedded carbon figures even more hard to find.**

| Factor | Scenario Low | Scenario Medium | Scenario High |
|---|---|---|---|
| Carbon Intensity ($gCO_2/kWh$) | 50 | 175 | 300 |
| PUE | 1.1 | 1.3 | 1.6 |
| Server Embodied Carbon ($KgCO_2$) | 400 | - | 1100 |
| Server Lifespan (years) | 3 | 5 | 7 |

| | | Total carbon footprint estimate ($kgCO_2$) (Percentage active carbon) | | |
|---|---|---|---|---|
| **Server embodied carbon** | **Server lifespan** | **PUE Low Carbon Intensity Low** | **PUE Medium Carbon Intensity Medium** | **PUE High Carbon Intensity High** |
| **Low** | **3** | 1950 (55%) | 5293 (83%) | 10186 (91%) |
| | **5** | 1600 (67%) | 4943 (89%) | 9836 (95%) |
| | **7** | **1449** (74%) | 4792 (92%) | 9685 **(96%)** |
| **High** | **3** | 3483 **(31%)** | 6826 (65%) | **11719** (79%) |
| | **5** | 2519 (42%) | 5862 (75%) | 10755 (86%) |
| | **7** | 2106 (51%) | 5449 (81%) | 10342 (90%) |

**IRISCAST 24 hour snapshot roughly 1-4 people on 12 hour return Jet**

**Potential to reduce carbon emissions by an order of magnitude!**

# IRISCAST Proposes

## High Level Feedback

Carbon Equivalent per month

## Low Level Feedback

Figure of merit per Job → Carbon Equivalent per Job

1. Future DRI procurement to include a score based on embedded carbon costs and equipment energy usage.
2. New computer hardware to include energy measurement capability such as IPMI (or per port PDUs) and require the supplier to provide best estimates of embedded carbon costs.
3. Measure energy used by cooling infrastructure and the computing infrastructure.
4. Facilities to keep an inventory of equipment including embedded carbon cost and idle power draw.
5. Monthly (or other periodic) reporting of carbon usage by facilities based on 3 and 4 above. Roll into standard grant reporting regime.
6. Collect per job (or VM) energy usage by using tools like Slurm (correctly configured). Combined this with embedded carbon from inventory and electricity carbon intensity to feedback job carbon cost to the end user to drive improvements in user code and workflow.
7. Identify user communities and the authors of community codebases so that useful feedback can be given to them to drive the development of more efficient code and workflows.

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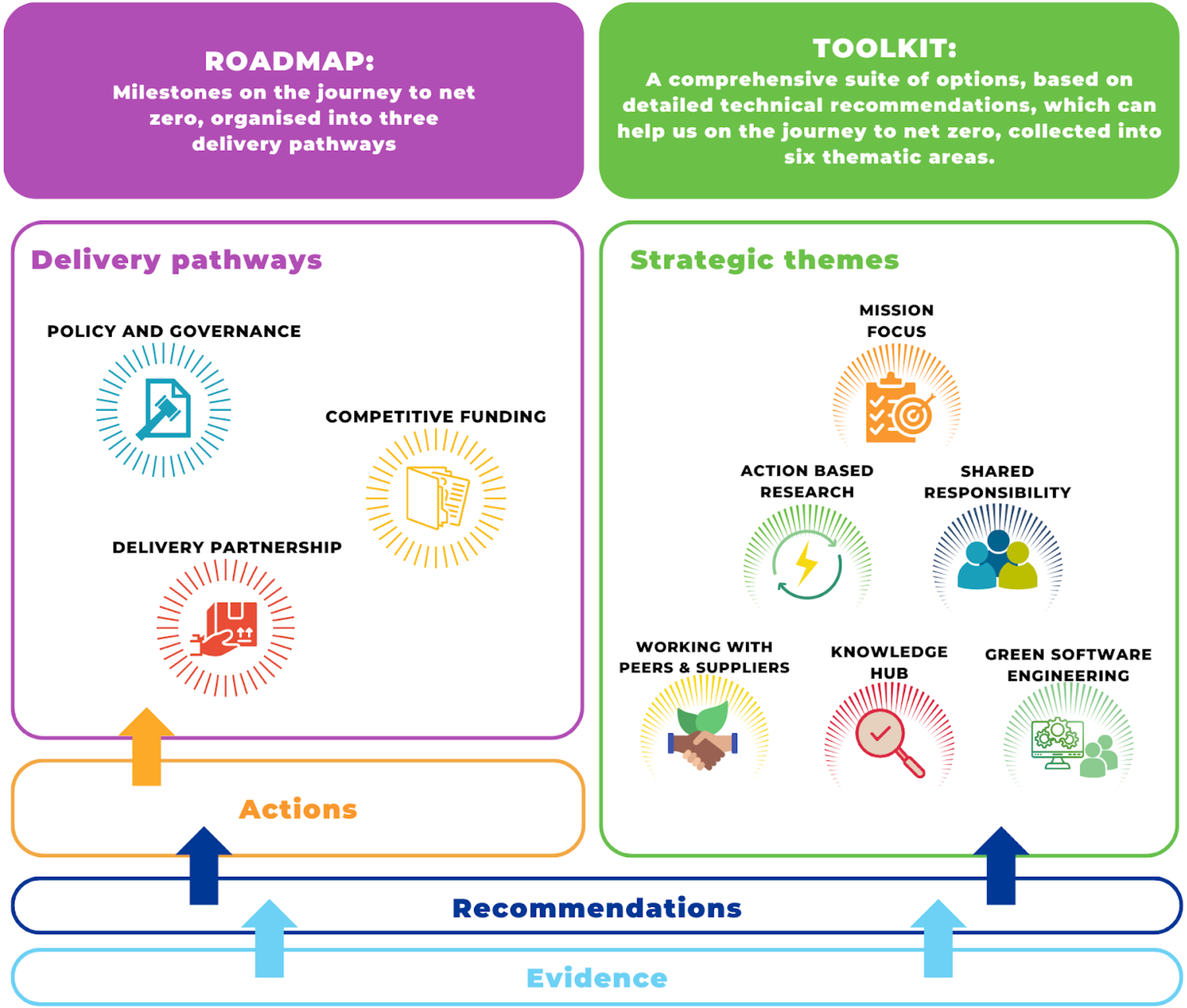
# UKRI DRI Net Zero Scoping Outputs

https://doi.org/10.5281/zenodo.8199984



# UKRI DRI Net Zero Scoping Roadmap

## 2024

**Policy and Governance**
- Review policy areas across UKRI and integrate net zero principles
- Create net zero action plans for DRI facilities
- Develop a timeline for the elimination of onsite fossil fuels

**Delivery Partnership**
- Establish net zero DRI task-force from within research community
- Formalise a map of DRI resources and their environmental impact profile

**Competitive Funding**
- Run funding calls and research fellowships with a sustainable DRI focus
- Fund research into the influence of usage patterns, hardware and software on Carbon intensity
- Fund research into carbon accounting tools
- Fund research into behaviour change strategies at all levels of the DRI

## 2028

**Policy and Governance**
- Implement UKRI policy on use of contracts and conditionalities to reduce emissions
- Implement UKRI policy requiring re-use of waste heat and recycling of hardware.
- Establish a financial and legal framework to facilitate multi-institution collaborations

**Delivery Partnership**
- Provide training in low-carbon DRI use to key stakeholder groups
- Develop technical standards for monitoring, evaluation and accreditation for DRI hardware and usage
- Adopt standards for Open Science principles and apply across the DRI

## 2030

**Policy and Governance**
- Mandate carbon reporting and sustainable accreditation across UKRI-DRI operations
- Integrate sustainable computing within DRI career development pathways

**Delivery Partnership**
- Adopt standards for research practice using DRI
- Ensure training in best practices for low-carbon DRI use
- Establish a centraliesd net zero DRI hub

**Competitive Funding**
- Resource and develop carbon emissions tracking capability

## 2040

**Policy and Governance**
- Implement a procurement framework that guarantees a sustainable supply chain

**Competitive Funding**
- Develop a single DRI interface reporting energy use and environmental footprint per job
- Develop and deploy green schedulers

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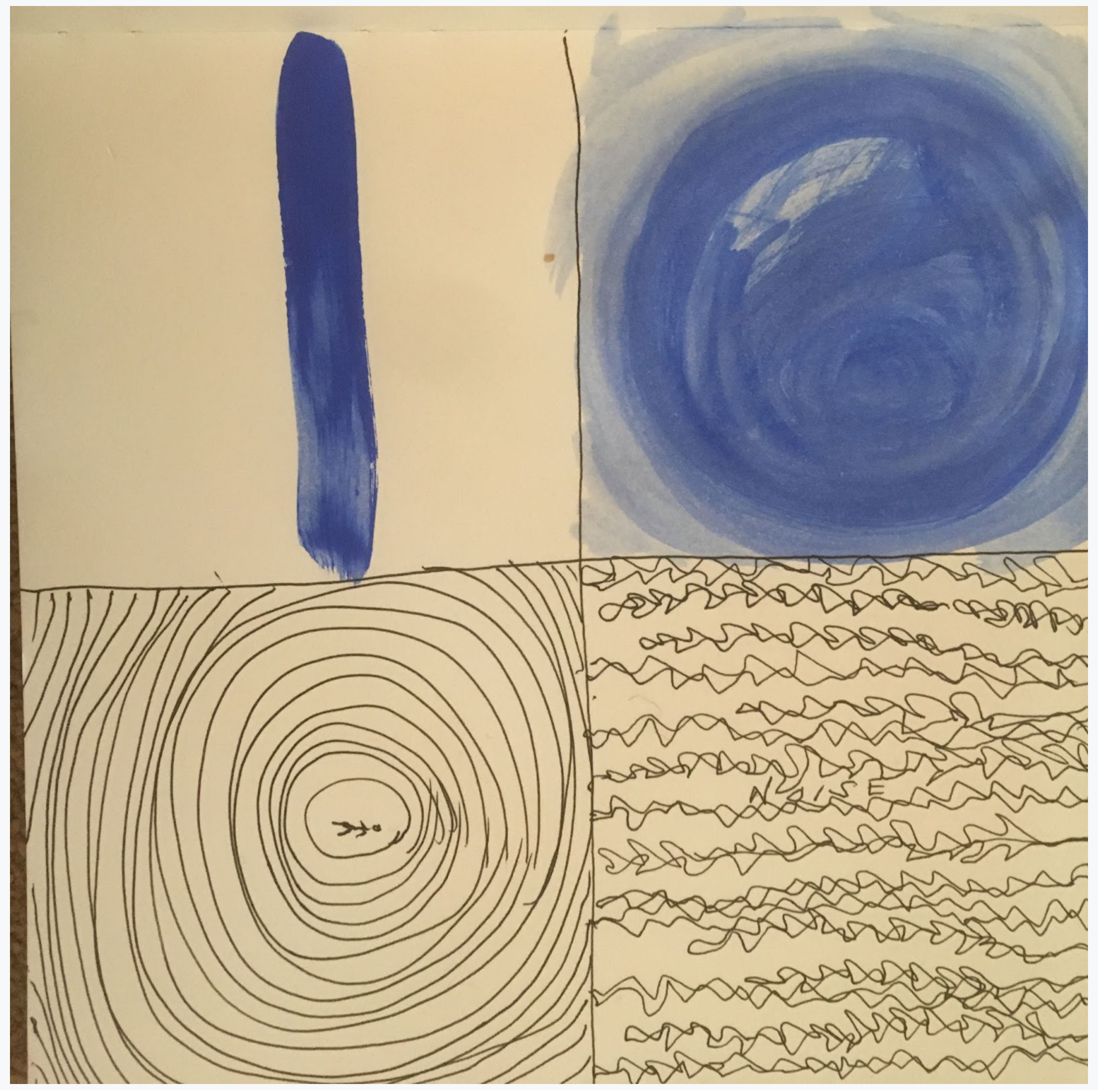
# UKRI DRI Net Zero Scoping Toolkit



Box 2.1.A: Six Strategic Themes that make up the toolkit

1. **Mission Focus**: continuous assessment and focus on the mission of achieving sustainability; active measures to counter the risk of enhanced demand negating efficiency gains.
2. **Recognition of shared responsibility**: mandate and empower all staff (from student to CEO) to take proportionate action to drive change and reduce the environmental impact of their work; community building; encourage discussion among colleagues and learn from others to foster positive changes in behaviour.
3. **Action-based-research**: work must start now with commitment appropriate to the climate emergency while recognising that there will be a need for regular checks and adjustments; focus on progress not perfection; small steps; learn from experience.
4. **Work with peers and suppliers**: through contracts, conditionalities, and understanding mutual benefits, to develop a low carbon supply chain [essential in the longer term]
5. **Build and Share Knowledge**: providing leadership, support and advice for business cases and large procurements feeding into reporting; central hub for information and institutional knowledge [also likely to create short term results]
6. **Green Software Engineering**: creating a body of expertise around green software engineering, providing training, developing tools, metrics, expert assessment, and standards to transform current approaches to writing code, and supporting codes running in data centres, such that GSE becomes the norm rather than an optional extra.

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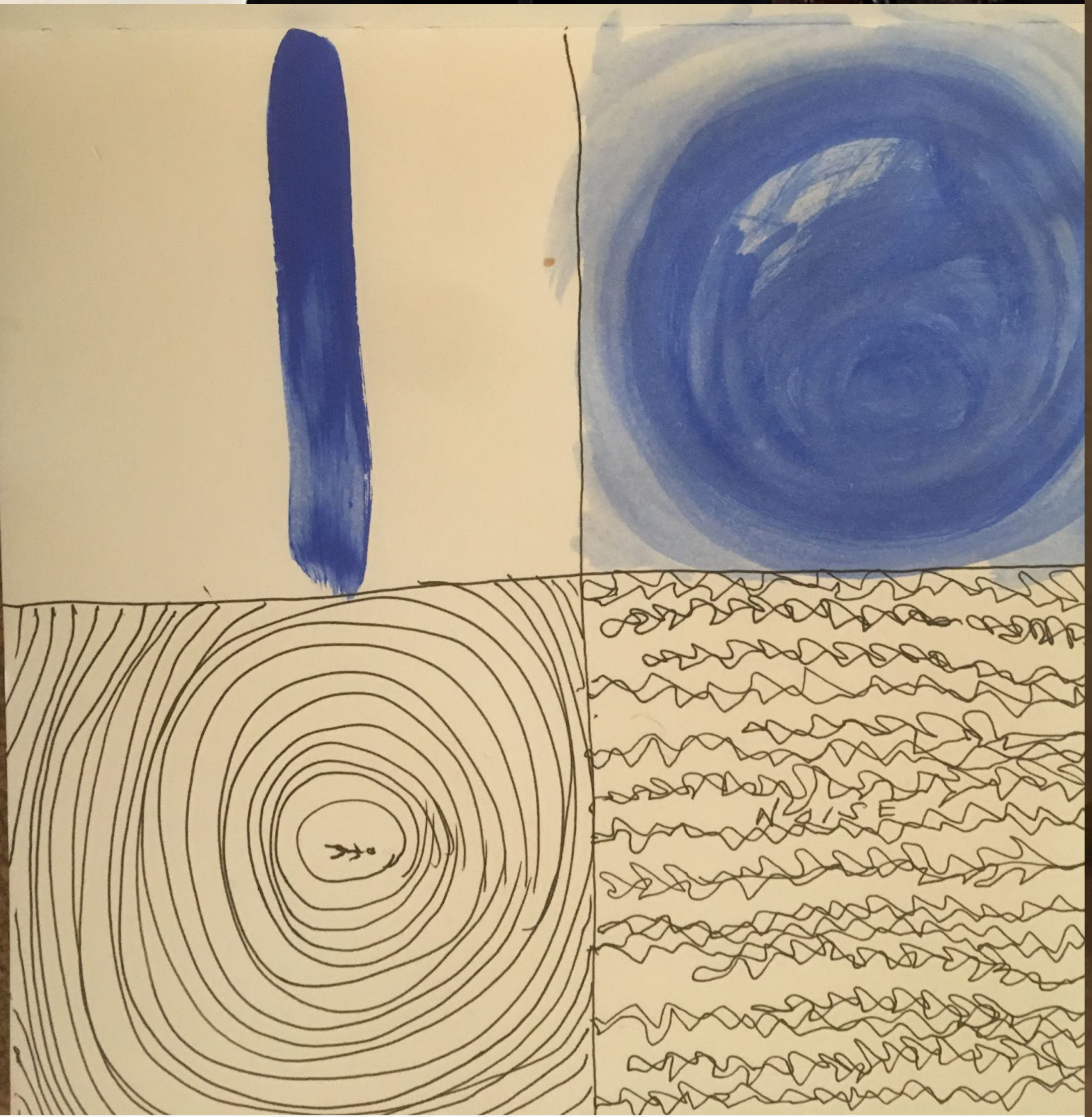

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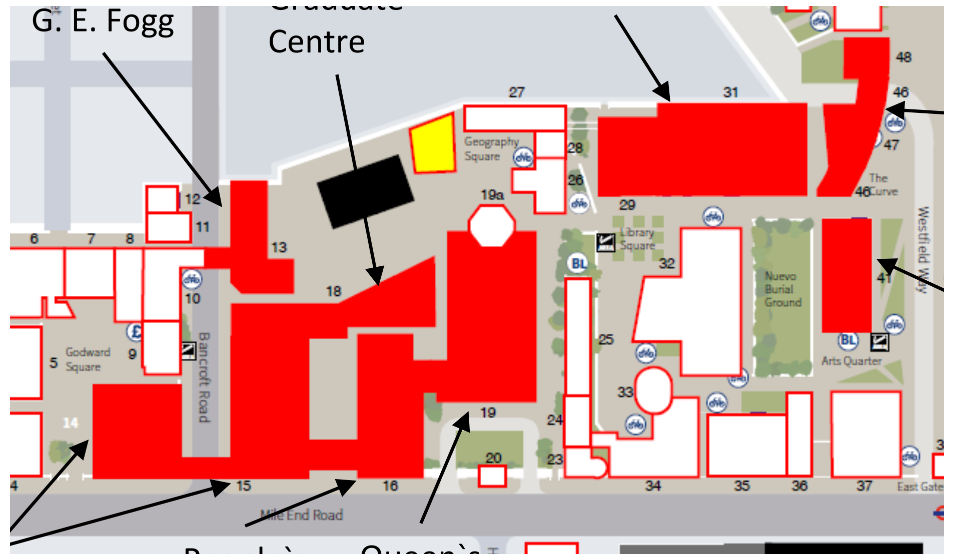
Artist: Paul Millhouse-Smith

# Backup Slides

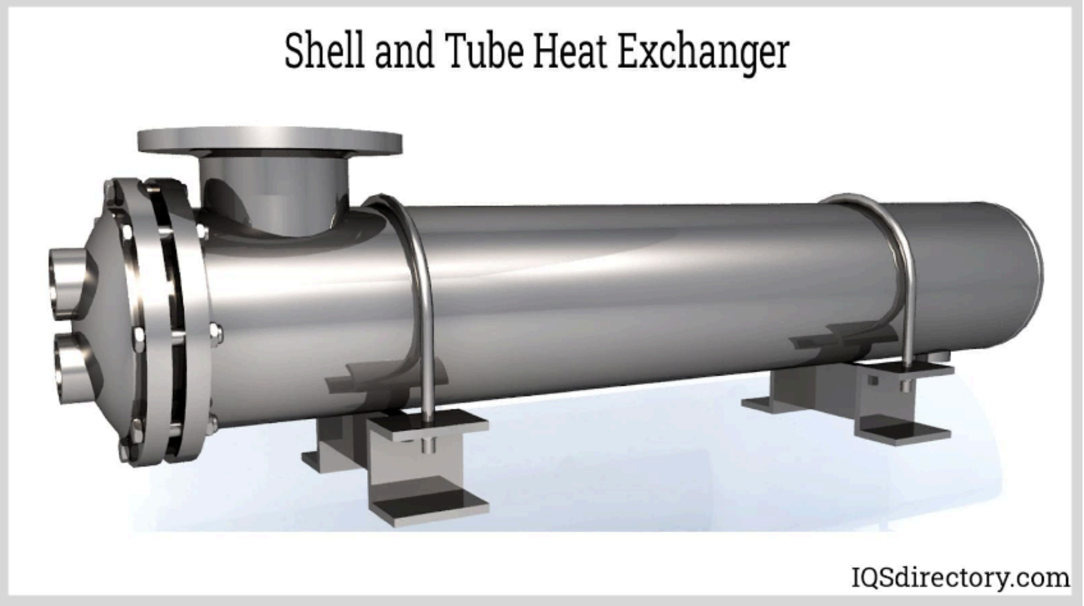
# Heat Recovery @ Queen Mary University of London




District heating ↔ Hot water store

75C

Cluster → 26C → Heat pump → 75C → Heat exchanger




17C

17

Hot water store

75C

Cold water store

Dry air cooler

Slide from Dr Daniel Traynor, QMUL