Cyfoeth Naturiol Cymru
Natural Resources Wales

Carbon Positive Project: Evaluating NRW's Mitigation Options

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- Securing our data and information.
- Having a well-resourced and proactive programme of evidence work.
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us.
- Communicating our evidence in an open and transparent way.

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Data presented within this report was correct at the time of writing. However, since the publication of this report new data may be available, which supersedes that used within this report.

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1. Crynodeb Gweithredol

Pwrpas Cyfoeth Naturiol Cymru (CNC) yw sicrhau bod adnoddau naturiol Cymru yn cael eu cynnal, eu hyrwyddo a’u defnyddio yn gynaliadwy, yn awr ac yn y dyfodol.

Ariannwyd Prosiect Carbon Bositif CNC yn wreiddiol gan Lywodraeth Cymru i gyflawni'r Prosiect Carbon Bositif er mwyn arwain y ffordd wrth ddatgarboneiddio ac i rannu ein dull a'n profiad i annog datgarboneiddio ymhellach ar draws sector cyhoeddus Cymru a thu hwnt. Mae'r Prosiect yn rhan o waith ehangach CNC ar newid yn yr hinsawdd, sy'n cynnwys asesu a rheoli risgiau hinsawdd ar draws ein cylch gwaith trwy addasu a galluogi datblygu ynni adnewyddadwy ar yr ystâd.

Nodi ein hopsiynau ar gyfer lliniaru
Yn seiliedig ar ganlyniadau’r cyfrifiad statws carbon net (gweler yr Adroddiad Technegol: Cyfrifo Statws Carbon Net CNC (2018)) rydym wedi nodi ble y dylid canolbwyntio’r ymdrech er mwyn nodi opsiynau ar gyfer lliniaru, h.y. y mesurau sydd ar gael i leihau ein heffaith carbon trwy:

1) **Leihau allyriadau carbon** trwy ddefnyddio llai a mabwysiadu dewisiadau carbon amgen is, o fewn y sefydliad yn ogystal â'n cadwyn gyflenwi, neu drwy.

2) **Wella’r broses dal a storio carbon a/neu amddiffyn stociau carbon** trwy reoli cynefinoedd allweddol, megis coetir a mawndir, ar yr ystâd er mwyn gwella faint o garbon sy'n cael ei storio bob blwyddyn (dal a storio carbon) a/neu i amddiffyn y storfeydd carbon presennol (ein stociau carbon).

Rydym wedi mabwysiadu pedwar categori sefydliadol er mwyn strwythuro ein dull o nodi a gwerthuso opsiynau lliniaru: **adeiladau, trafnidiaeth, tir ac asedau gweithredol**, a **chaffael**. Nodwyd opsiynau dan bob un o'r pedwar categori drwy:

- **Adolygu** llenyddiaeth gyhoeddedig.
- **Ymchwilio** i'r dulliau a ddefnyddir gan sefydliadau eraill.
- **Casglu** syniadau gan ein staff.
- **Deall** ein profiad blaenorol.
- **Archwilio**'r potensial i ehangu'r mesurau lliniaru presennol yn CNC.
- **Cyflawni** ystod o brosiectau arddangos.
- **Perfformio** dadansoddiad bwlch i ddeall opsiynau eraill er mwyn mynd i'r afael â meysydd allweddol ein heffaith carbon nad yw’r uchod yn ymdrin â hwy.

Rydym wedi ystyried ystod eang iawn o opsiynau posibl a allai fod yn briodol i'n sefydliad. Mae Tabl 1 isod yn dangos bod gan bob categori amrywiaeth o opsiynau allweddol posibl er mwyn lleihau ein heffaith garbon.

Tabl 1: Gwerthuso'r mesurau lliniaru a nodwyd

Categori sefydliadol	Blaenoriaethau lliniaru
Adeiladau	• Goleuadau LED • Uwchraddio systemau gwresogi (gan gynnwys gwres carbon isel) • Oeri ystafell y gweinydd • Rheoli ynni
Trafnidiaeth	• Cyflwyno technolegau allyriadau isel (gan gynnwys cerbydau trydan, hybrid a cherbydau amrediad estynedig) • Lleihau maint y fflyd • Cyflwyno systemau telematig • Seilwaith Cerbydau Trydan (EV*)* • Cymudo gweithwyr
Asedau tir a gweithredol	• Rheoli cynefinoedd (plannu coetir ac adfer mawndiroedd yn bennaf) er mwyn amddiffyn a gwella stociau carbon • Defnyddio'r ystâd i gynhyrchu ynni adnewyddadwy • Defnyddio trydan mewn asedau gweithredol, e.e. gorsafoedd pwmpio
Caffael	• Cryfhau'r polisi caffael, y canllawiau a'r gweithdrefnau presennol er mwyn cefnogi'n well yr hierarchaeth ymyriadau lliniaru caffael • Canolbwyntio ar gyflwyno meini prawf carbon wedi'u targedu i fframweithiau a chontractau allweddol sy'n gysylltiedig â mannau problemus o safbwynt allyriadau • Datblygu dulliau gweithredu newydd er mwyn helpu i ymgorffori ystyriaeth garbon mewn contractau a fframweithiau

Rydym wedi creu rhestr fer o fesurau lliniaru y nodwyd y gallent fod yn addas i'w gweithredu yn CNC i gyflawni datgarboneiddio yn y dyfodol fel rhan o’r Cynllun Galluogi Carbon Bositif a’i Gynllun Gweithredu ategol. Mae’r Cynllun Gweithredu’n gynllun byw, a fydd yn datblygu’r camau lliniaru a nodwyd. Er mwyn deall cyfraniad posib pob mesur a nodwyd tuag at gefnogi datgarboneiddio, cynhaliwyd gwerthusiad manwl gennym, gan ymchwilio a chasglu gwybodaeth am gostau ac arbedion ariannol, arbedion carbon neu ddaliad (budd carbon) a, lle bo’n bosibl, buddion ehangach y byddai pob mesur yn eu cyflawni.

Sylfaen gadarn o dystiolaeth ar gyfer gweithredu

Roedd casglu'r wybodaeth hon yn cynnwys cyfuniad o ymchwil wrth ddesg, ceisio profiad pobl eraill, gwerthuso canlyniadau ein prosiectau arddangos, a chomisiynu darnau o waith gydag arbenigwyr yn y diwydiant. Roedd y wybodaeth a gasglwyd yn cynnwys:

- **Budd carbon** – ar gyfer pob mesur, aethom ati i amcangyfrif y gostyngiadau posibl mewn allyriadau carbon neu'r capasiti dal a storio ychwanegol y byddai'n ei ddarparu bob blwyddyn a thros oes y mesur.

- **Costau ariannol** - ar gyfer pob mesur, aethom ati i amcangyfrif goblygiadau ariannol mabwysiadu, gan gynnwys:

    - cost cyfalaf

    - costau cynnal a chadw neu gylchol blynyddol

    - oes y mesur

    - cyfnod ad-dalu h.y. y cyfnod y mae'n ei gymryd i adennill costau buddsoddiad

    - cymorth ariannol posib, e.e. grantiau a chymhellion ariannol eraill

    - arbedion cost posibl, e.e. costau ynni is

- **Buddion ehangach** - gyda rhai mesurau, aethom ati hefyd i gofnodi ble byddai'r mesur yn sicrhau buddion ehangach, e.e. darparu gwell ansawdd dŵr, llai o lygredd aer, neu well amodau gwaith i'r staff. Er enghraifft, gallai mesur gweladwy fel gosod paneli solar PV ar adeiladau ddangos a chyfleu buddion cynaliadwyedd i'r sector cyhoeddus ehangach, ac ysbrydoli'r gymuned ehangach i weithredu er mwyn mynd i'r afael ag achosion newid yn yr hinsawdd.

O fewn y categorïau sefydliadol a fabwysiadwyd, comisiynwyd tri phrif asesiad gan arbenigwyr ar:

Adeiladau:

- **Defnydd ynni** - cynhaliwyd archwiliadau ar adeiladau er mwyn deall defnydd ynni ac effeithlonrwydd ein hadeiladau, a'r potensial y gallai technolegau carbon isel leihau allyriadau carbon. At hyn, aethom at i gomisiynu cyngor ar ddatblygu deunydd ymgyrch 'newid ymddygiad'.

Trafnidiaeth:

- **Datrysiadau trafnidiaeth allyriadau isel** - cynhaliwyd adolygiad strategol o garbon y fflyd er mwyn deall rôl bosibl technolegau allyriadau isel yn ein fflyd a'n peiriannau. Dadansoddwyd cyfansoddiad ein peiriannau a'n fflyd presennol ynghyd â manylion teithiau er mwyn nodi cyfleoedd i leihau ein defnydd o ddiesel a phetrol a'u hallyriadau cysylltiedig, mewn ffordd gost effeithiol. Roedd yr adolygiad yn ystyried opsiynau ar gyfer cerbydau allyriadau isel (e.e. cerbydau trydan), opsiynau tanwydd (e.e. biodanwydd) ac atebion meddalwedd (e.e. telemateg), yn ogystal â hyfforddiant ar gyfer gyrwyr a defnyddio cerbydau mewn ffyrdd mwy effeithlon er mwyn hwyluso gostyngiadau ym maint y fflyd.

Asedau tir a gweithredol:

- **Cynhyrchu ynni adnewyddadwy** - defnyddiwyd asesiad o adnoddau ynni adnewyddadwy er mwyn deall y potensial ar gyfer cynhyrchu ynni adnewyddadwy ar yr ystâd i gyflenwi ein hadeiladau a'n hasedau. Gallai hyn leihau dibyniaeth ein sefydliad ar drydan o'r grid a lleihau ein hallyriadau a'n costau ar yr un pryd. Roedd yr astudiaeth yn cynnwys asesiad adnoddau cyn-ymarferoldeb er mwyn deall potensial cynhyrchu ynni dŵr, gwynt ac ynni'r haul ar yr ystâd a'r asedau.

Caffael

Roedd mynd i'r afael â'n hallyriadau sy'n gysylltiedig â chaffael yn heriol oherwydd amrywiaeth y nwyddau a'r gwasanaethau sy'n cael eu prynu, nifer y cyflenwyr a ddefnyddiwn, a'n dylanwad cyfyngedig dros rai meysydd o'r gadwyn gyflenwi. Roedd yr heriau hyn yn golygu nad oedd yn bosibl nodi rhestr lawn o fesurau lliniaru yn yr un modd ag ar gyfer adeiladau, trafnidiaeth, ac asedau tir a gweithredol. Yn lle hynny, aethom ati i nodi ymyriadau generig o lenyddiaeth gyhoeddedig a dulliau gweithredu sefydliadau eraill, y gellid eu teilwra er mwyn diwallu gwahanol anghenion. Fe wnaethom hefyd ddarparu prosiectau arddangos er mwyn treialu rhai dulliau gweithredu newydd.

Buom yn ystyried yr ymyriadau generig hyn o ran polisi a gweithdrefnau caffael cyfredol CNC, a'n mannau problemus o ran allyriadau, a lluniwyd gennym dri math o gamau gweithredu er mwyn symud lliniaru yn ei flaen:

- **Cryfhau'r polisi, y canllawiau a'r gweithdrefnau caffael presennol**, e.e. ei gwneud yn ofynnol adolygu manylebau technegol effeithlonrwydd ynni yn rheolaidd wrth brynu offer er mwyn cadw i fyny â datblygiadau technolegol.

- Canolbwyntio ar gyflwyno **meini prawf carbon wedi'u targedu i fframweithiau a chontractau allweddol** sy'n gysylltiedig â **mannau problemus** o ran allyriadau, er enghraifft, ei gwneud yn ofynnol i gontractwyr peirianneg gwblhau offeryn cynllunio carbon i lywio dyluniad.

- Datblygu **dulliau newydd i helpu i nodi ac ymgorffori meini prawf carbon** mewn contractau a fframweithiau, gan gynnwys llunio rhestrau o feini prawf a awgrymir er mwyn arwain staff, e.e. lleihau allyriadau cysylltiedig â theithio mewn gwasanaethau contractwyr TGCh.

Mae'r camau a nodwyd gennym yn benodol ar gyfer mannau problemus o ran allyriadau CNC a gweithdrefnau caffael. Fodd bynnag, bydd yr ymagwedd yn drosglwyddadwy i sefydliadau eraill. Mae datblygu mesurau i leihau carbon wrth gaffael yn broses hirdymor sy'n gofyn am gydweithrediad rhwng caffael, cynaliadwyedd a chydweithwyr gweithredol. At hyn, mae'n gofyn am ymrwymiad i ddylanwadu ar gyflenwyr, ac archwilio'r gwelliannau sy'n bosibl trwy fframweithiau cenedlaethol sydd wedi'u pennu gan y Gwasanaeth Caffael Cenedlaethol a gweithio gyda Gwerth Cymru a Llywodraeth Cymru.

Deall graddfa fabwysiadu bosibl

Ar ôl i ni werthuso pob mesur, aethom ati i amcangyfrif ei raddfa fabwysiadu bosibl ar draws CNC er mwyn deall faint y gallai pob mesur gyfrannu at leihau effaith garbon gyffredinol y sefydliad. Cafodd y canlyniadau eu nodi gennym fel arbedion y flwyddyn ar draws y sefydliad cyfan. Un o'r heriau allweddol wrth werthuso potensial mesurau lliniaru yw sut i amcangyfrif graddfa'r defnydd sy'n bosibl ar draws sefydliad mawr ac amrywiol. Er mwyn mynd i'r afael â hyn, aethom ati i archwilio dwy raddfa fabwysiadu yn seiliedig ar wybodaeth gyfredol:

- **Uchafswm damcaniaethol** – dyma lefel dderbyn uchaf bosibl unrhyw fesur ar draws CNC heb ystyried unrhyw gyfyngiadau neu heriau wrth gyflawni'r mesur. Er enghraifft, gosod boeler biomas yn ein holl adeiladau.

- **Uchafswm dichonadwy** - dyma lefel dderbyn uchaf bosibl unrhyw fesur wrth ystyried rhai cyfyngiadau. Mae'r cyfyngiadau hyn yn cynnwys strategaethau a blaenoriaethau busnes presennol, perchnogaeth, parodrwydd o ran technoleg, a defnydd tir. Nid yw'r gost gweithredu yn dylanwadu ar yr uchafswm dichonadwy. Er enghraifft, gosod boeler biomas mewn dau o'r adeiladau a nodwyd fel rhai addas, allan o'r 15 adeilad CNC a archwiliwyd.

Blaenoriaethu a darparu

Bydd cyflawni datgarboneiddio ar draws y sefydliad yn heriol. Bydd angen newid diwylliant er mwyn ystyried carbon ochr yn ochr â blaenoriaethau mwy confensiynol fel cost ac amser, a bydd angen ymgorffori cryn dipyn o'r cyflenwi angenrheidiol o ran datgarboneiddio yng ngwaith gwneud penderfyniadau a gwaith ein staff, contractwyr a phartneriaid o ddydd i ddydd.

Fodd bynnag, bydd y sylfaen o dystiolaeth gadarn a'r cyfleoedd a nodwyd trwy werthuso opsiynau lliniaru yn helpu i greu rhaglen gyflenwi strategol, wedi'i chostio a'i blaenoriaethu er mwyn i CNC fynd i'r afael â'n heffaith garbon dros y 3-5 mlynedd nesaf.

Gwersi a ddysgwyd

Yn ogystal â'r gwersi categori-benodol a ddysgwyd yn y broses o nodi a gwerthuso mesurau lliniaru, gwelwyd rhai gwersi cyson a chyffredinol oedd yn amlygu pwysigrwydd:

- **Argaeledd data** a data cadarn er mwyn darparu sylfaen o dystiolaeth gadarn ar gyfer deall effaith carbon a nodi, datblygu a gwerthuso mesurau lliniaru.

- **Addasrwydd data** a chydnabod nad yw cyfrifo statws carbon net sefydliad yn wyddor fanwl gywir a rhaid adeiladu ar y wybodaeth orau sydd ar gael adeg y cyfrifiad.

- Roedd **amcangyfrifon costau** ac amcangyfrifon wrth ddesg o gostau mesurau lliniaru yn aml yn amrywio'n sylweddol o'u cymharu â'r costau gwirioneddol, a hynny'n fynych oherwydd ymarferoldeb safle-benodol.

- **Amcangyfrif amserlenni realistig** a'u rôl hanfodol wrth goladu data gweithgaredd.

- **Comisiynu arbenigwyr yn y diwydiant** a deall bylchau mewn sgiliau er mwyn tynnu sylw at ble y gallai fod angen cefnogaeth allanol.

- **Gweithio gydag eraill** a dysgu gan sefydliadau eraill sydd eisoes yn rheoli eu heffaith garbon.

- **Nodi opsiynau** a dewis strwythuro ein dull gweithredu gan ddefnyddio categorïau o fesurau mewn ffordd sy'n briodol i CNC.

- **Cyfathrebu clir a chyson** a'i rôl allweddol wrth gynnwys eraill yn y dasg o ddatgarboneiddio.
- **Cydberthynasau** sy’n hanfodol eu hadeiladu a'u cynnal er mwyn sicrhau bod y fenter yn cael ei chefnogi a'i hyrwyddo gan bob rhan o'r sefydliad.
- **Adolygu ac adrifiadau** a bod datgarboneiddio yn gofyn am ddull ailadroddol ac ymrwymiad tymor hir.
- **Canfyddiadau** a dealltwriaeth y gall dylanwadu ar flaenoriaethau canfyddedig ar gyfer mynd i'r afael ag effaith garbon ymhlith staff fod yn heriol.
- **Cyflawni prosiectau arddangos** a gweithio gyda chydweithwyr ar draws y sefydliad i helpu i gyfleu eu pwrpas ac arddangos eu potensial o safbwynt datgarboneiddio.

Mesurau lliniaru

Mae rhestr o'r mesurau lliniaru a nodwyd ar draws pob un o'r pedwar categori wedi’i chynnwys isod:

1. Adeiladau
Gwresogi ac oeri
Uwchraddio i foeler biomas
Uwchraddio boeler confensiynol
Uwchraddio gwresogyddion trydan confensiynol
Gosod rheolyddion newydd er mwyn gwneud y gorau o weithrediad boeleri
Optimeiddio gweithrediad boeleri neu amserlenni gwresogi
Gosod pwmp gwres ffynhonnell aer
Gosod rheolyddion ystafell sychu
Gwella effeithlonrwydd system aerdymheru ystafell y gweinydd
Codi tymheredd cynhwysydd rheweiddiedig

Goleuadau
Amnewid goleuadau presennol am rai LED

Rheoli ynni
Mabwysiadu strategaeth rheoli ynni wedi'i chefnogi gan fesuryddion a monitro (ar gyfer adeilad sydd â defnydd ynni cymedrol)
Gwella inswleiddio'r to
Optimeiddio foltedd
Gwaith cartref ychwanegol
Dŵr poeth - darparu pwynt defnyddio

2. Trafnidiaeth
Cerbydau allyriadau isel
Car trydan bach
Car trydan canolig
Fan drydan fach
Car hybrid plygio canolig
Cerbyd 4x4 plygio hybrid

Car petrol hybrid bach
Car petrol hybrid canolig
Cerbyd 4x4 petrol hybrid
Cerbyd bach amrediad estynedig
Gosod system delematig
Gosod gorsaf wefru cerbydau trydan

Peiriannau
Mesurau effeithlonrwydd tanwydd
Hyfforddiant ar gyfer gyrwyr
Cloddwyr diesel hybrid
Beiciau cwad trydan
Peiriannau torri gwair trydan (ar gyfer cronfeydd dŵr)
Biodiesel

3. Asedau tir a gweithredol

Rheoli Tir
Adfer mawn dwfn (nid yw'r adroddiad hwn yn ymdrin â'r mater hwn)
Plannu coetir (nid yw'r adroddiad hwn yn ymdrin â'r mater hwn)

Cynhyrchu ynni adnewyddadwy
Gosod PV solar ar adeiladau - hunan-gyflenwad i CNC
Hunan-gyflenwad solar i CNC
Gwynt ar raddfa fach - hunan-gyflenwad i CNC
Hydro - hunan-gyflenwad i CNC

Microgynhyrchu
Hydro Micro / gwynt micro + batri
Hydro micro + batri
Solar micro / gwynt + batri
Solar graddfa fach / ar ben to <5kW (gorsafoedd pwmpio)
Solar graddfa fach <5kW
Ôl-ffitio asedau gweithredol
Asedau ôl-ffitio - gorsafoedd pwmpio
Camera teledu cylch cyfyng

4. Caffael

Camau lliniaru caffael

Cryfhau polisi, arweiniad a gweithdrefnau caffael presennol CNC:

- Annog staff i ofyn iddynt eu hunain a ellid lleihau'r galw am nwyddau neu wasanaethau.

- Adolygu a diwygio manylebau technegol cysylltiedig ag ynni yn rheolaidd.

- Ystyried a oes nwyddau neu wasanaethau amgen ar gael sydd ag allyriadau is.

- Gweithio gyda chyflenwyr er mwyn deall a mynd i'r afael yn well ag allyriadau cadwyn gyflenwi mewn categorïau nwyddau a gwasanaethau problemus.

Cyflwyno meini prawf carbon targededig i fframweithiau a chontractau allweddol sy'n gysylltiedig â mannau problemus o ran allyriadau:

- Cynnal ymchwil bellach i gyfansoddiad allyriadau sy'n gysylltiedig â mannau problemus, a nodi cyfleoedd lliniaru o fewn y broses gaffael.
- Hyrwyddo prosiectau arddangos caffael a throsglwyddo dysgu i fframweithiau a mannau problemus eraill.

Datblygu dulliau newydd er mwyn ymgorffori ystyriaeth o garbon mewn contractau a fframweithiau:

- Nodi mathau o gontractau a chynhyrchion a allai gynyddu cynaliadwyedd cynhyrchion a lleihau allyriadau cysylltiedig.
- Datblygu rhestrau cyfeirio o feini prawf carbon awgrymedig ar gyfer mathau o gontract er mwyn arwain staff.
- Datblygu fersiwn wedi'i theilwra o'r Matrics Blaenoriaethu Cynaliadwyedd presennol er mwyn nodi a mewnosod meini prawf carbon i fframweithiau allweddol a chontractau.
- Defnyddio ymgysylltiad cyn y farchnad i osod meini prawf carbon fel rhan o fframweithiau neu grwpiau o fathau o gontractau.
- Helpu cyflenwyr i fodloni gofynion CNC wrth iddynt gael eu cyflwyno i fframweithiau neu fathau o gontractau penodol.
- Cyflwyno Safon Newid Hinsawdd ar gyfer caffael, gan gyflwyno'r gofynion sylfaenol ar allyriadau nwyon tŷ gwydr.
- Darparu hyfforddiant caffael cynaliadwy i'r holl staff.

1. Executive Summary

Natural Resources Wales' (NRW) purpose is to ensure that the environment and natural resources of Wales are sustainably maintained, enhanced and used, now and in the future.

NRW was originally funded by Welsh Government to deliver the Carbon Positive Project to lead the way in decarbonising and to share our approach and experience to encourage further decarbonisation across the Welsh public sector and beyond. The Project forms part of NRW's wider work on climate change, which includes assessing and managing climate risks across our remit through adaptation and enabling renewable energy development on the estate.

Identifying our options for mitigation

Based on the results of the net carbon status calculation (see Technical Report: *Calculating NRW's Net Carbon Status (2018)*), we identified where to focus effort to identify options for mitigation, i.e. measures available to reduce our carbon impact by:

1) **Reducing carbon emissions** by consuming less and adopting lower carbon alternatives, both within the organisation and our supply chain.

2) **Enhancing sequestration and/or protecting carbon stocks** by managing key habitats, such as woodland and peatland, on the estate to enhance the amount of carbon being stored each year (our sequestration) and/or to protect existing stores of carbon (our carbon stocks).

We adopted four organisational categories to structure our identification and evaluation of options for mitigation: **buildings, transport, land and operational assets,** and **procurement**. Options were identified under each of the four categories by:

- **Reviewing** published literature.
- **Researching** the approaches taken by other organisations.
- **Gathering** ideas from our staff.
- **Understanding** our previous experience.
- **Exploring** the potential to expand existing mitigation measures in NRW.
- **Delivering** a range of demonstration projects.
- **Performing** a gap analysis to understand other options to address key areas of our carbon impact not tackled by the above.

We considered a very broad range of potential options that might be appropriate to our organisation. Table 2 below shows that each category has a variety of potential key options to reduce our carbon impact.

Table 2: Evaluating the identified mitigation measures

Organisational category	Mitigation priorities
Buildings	• LED lighting • Upgrading heating systems (including low carbon heat) • Server room cooling • Energy management
Transport	• Introducing low-emission technologies (including electric vehicles, hybrids and range-extended vehicles) • Fleet downsizing • Introducing telematic systems • EV infrastructure • Employee commuting
Land and operational assets	• Management of habitats (mainly woodland planting and peatland restoration) to protect and enhance carbon stocks • Using the estate for renewable energy generation • Electricity use in operational assets, such as pumping stations
Procurement	• Strengthening existing procurement policy, guidance and procedures to better support the hierarchy of procurement mitigation interventions • Focusing on introducing targeted carbon criteria into key frameworks and contracts associated with emissions hotspots • Developing new approaches to help incorporate carbon consideration into contracts and frameworks

We created a shortlist of mitigation measures that were identified as potentially suitable for implementation in NRW to deliver decarbonisation in the future as part of the Carbon Positive Enabling Plan and its supporting Action Plan. The Action Plan is a live plan, which will take forward the identified mitigation actions. To understand the contribution each identified measure could make to support decarbonisation, we conducted a detailed evaluation, researching and collating information on financial costs and savings, carbon savings or capture (carbon benefit) and where possible the wider benefits each measure would deliver.

A robust evidence base for action

Gathering this information involved a combination of desk-based research, seeking the experience of others, evaluating the results from our demonstration projects, and commissioning pieces of work with industry experts. The information gathered included:

- **Carbon benefit** – for each measure we estimated the potential carbon emission reductions or additional sequestration it would provide on an annual basis and over the lifetime of the measure.

- **Financial costs** – for each measure, we estimated financial implications of adoption, including:
    - capital cost
    - annual maintenance or recurring costs
    - lifetime of the measure
    - payback period, i.e. the amount of time it takes to recover the cost of an investment
    - potential financial support, e.g. grants and other financial incentives
    - potential cost savings, e.g. reduced energy costs.

- **Wider benefits** – with some measures, we also recorded where the measure would deliver wider benefits, such as delivering improved water quality, reduced air pollution, or improved staff working conditions. For example, a visible measure such as installing building-mounted PV solar panels might demonstrate and communicate the benefits of sustainability to the wider public sector and inspire the wider community to act to address the causes of climate change.

Within the organisational categories adopted, we commissioned three main assessments by experts on:

Buildings:

- **Energy use** – building audits were carried out to understand the energy use and efficiency of our buildings, and the potential for low carbon technologies to reduce carbon emissions. We also commissioned advice on developing behavioural change campaign materials.

Transport:

- **Low-emission transport solutions** – a strategic fleet carbon review was undertaken to understand the potential role of low-emission technologies in our fleet and plant. The composition of our current fleet and plant, along with journey details, were analysed to identify opportunities to reduce our diesel and petrol use and their associated emissions in a cost-effective way. The review considered options for low-emission vehicles (e.g. electric vehicles), fuel options (e.g. biofuel) and software solutions (e.g. telematics), as well as driver training and more efficient vehicle use to facilitate reductions in fleet size.

Land and operational assets:

- **Renewable energy generation** – a renewable energy resource assessment was used to understand the potential for renewable energy generation on the estate to supply our buildings and assets. This could reduce our organisation's dependence on electricity from the grid while simultaneously reducing both our emissions and our costs. The study involved a pre-feasibility resource assessment to understand the hydro, wind and solar energy generation potential on the estate and assets.

Procurement

Tackling our procurement-related emissions was challenging because of the diversity of goods and services purchased, the number of suppliers we use, and our limited influence over some areas of the supply chain. These challenges meant it was not possible to identify a full list of mitigation measures in the same way as for buildings, transport, and land and operational assets. Instead, we identified generic interventions from published literature and approaches of other organisations, which could be tailored to meet different needs. We also delivered demonstration projects to trial some new approaches.

We considered these generic interventions in terms of NRW's current procurement policy and procedures, and our emissions hotspots, and came up with three types of action to progress mitigation:

- **Strengthening existing procurement policy, guidance and procedures**, such as requiring regular review of energy efficiency technical specifications in equipment purchases to keep pace with technological advances.
- Focusing on introducing **targeted carbon criteria into key frameworks and contracts** associated with emissions **hotspots**, e.g. requiring engineering contractors to complete a carbon planning tool to inform design.
- Developing **new approaches to help identify and incorporate carbon criteria** into contracts and frameworks, including creating lists of suggested criteria to guide staff, e.g. to reduce travel-related emissions in ICT contractor services.

The actions we identified are specific to NRW emissions hotspots and procurement procedures, however, the approach will be transferrable to other organisations. Developing measures to reduce carbon in procurement is a long-term process requiring collaboration between procurement, sustainability and operational colleagues. In addition, it requires a commitment to influence suppliers, and to explore the improvements possible through national frameworks set by the National Procurement Service and working with Value Wales and Welsh Government.

Understanding the potential scale of adoption

Once we had evaluated each measure, we estimated its potential scale of adoption across NRW to understand how much each measure could contribute to reducing the organisation's overall carbon impact. We expressed the results as savings per year across the whole of the organisation. One of the key challenges in evaluating the potential of mitigation measures is how to estimate the scale of uptake possible across a large and varied organisation. To address this, we explored two scales of adoption based upon current knowledge:

- **Theoretical maximum** – this is the highest possible uptake of a measure across NRW without considering any constraints or challenges to delivering the measure, e.g. installing a biomass boiler in all our buildings.
- **Feasible maximum** – this is the highest possible uptake of a measure when considering constraints. These constraints include existing business strategies and

priorities, ownership, technology readiness, and land use. The feasible maximum is not influenced by the cost of implementation.

Prioritisation and delivery

Achieving decarbonisation across the organisation will be challenging. A change in culture will be required to consider carbon alongside more conventional priorities such as cost and time, and much of the necessary delivery of decarbonisation will need to be incorporated within the day-to-day decision-making and work of our staff, contractors and partners.

However, the robust evidence base and the opportunities identified through the evaluation of mitigation options will help build a strategic, costed and prioritised programme of delivery for NRW to address our carbon impact over the next three to five years.

Lessons learnt

In addition to the category-specific lessons learned in the process of identifying and evaluating mitigation measures, there were some consistent and overarching lessons which highlighted the importance of:

- **Data availability** and sound data to provide a robust evidence base for understanding carbon impact and identifying, developing and evaluating mitigation measures.
- **Data suitability** and acknowledging that calculating an organisation's net carbon status is not an exact science and can only be built upon the best information available at the time of calculation.
- **Cost estimates** and that desk-based estimates of the costs of mitigation measures often varied significantly from actual costs due to site specific practicalities.
- **Estimating realistic timeframes** and its essential role in collating activity data.
- **Commissioning industry experts** and understanding skills gaps to highlight where external support may be required.
- **Working with others** and learning from other organisations already managing their carbon impact.
- **Identifying options** and choosing to structure our approach using categories of measures in a way that is appropriate for NRW.
- **Clear and consistent communication** and its key role in engaging others in decarbonisation.
- **Relationships** which are essential to build and maintain to ensure buy-in to the initiative and championing its delivery across the organisation.
- **Reviewing and iterations** and how decarbonisation requires an iterative approach and long-term commitment.

- **Perceptions** and understanding that influencing priorities for addressing carbon impact among staff can be challenging.

- **Delivering demonstration projects** and working with colleagues across the organisation to help communicate their purpose and showcase their potential for decarbonisation.

Mitigation measures

A list of the identified mitigation measures across all four categories is included below:

1. Buildings
Heating and cooling
Upgrade to biomass boiler
Upgrade conventional boiler
Upgrade conventional electric heaters
Install new controls to optimise boiler operation
Optimise boiler operation or heating schedules
Install air source heat pump
Install drying room controls
Improve server room air-conditioning efficiency
Raise the temperature of a refrigerated container

Lighting
Replace existing lights with LEDs

Energy management
Adopt an energy management strategy supported by metering and monitoring (for a building with average energy use)
Improve roof insulation
Voltage optimisation
Additional homeworking
Hot water – point-of-use provision

2. Transport
Low-emission vehicles
Small electric car
Medium electric car
Small electric van
Medium plug-in hybrid car
4x4 plug-in hybrid
Small petrol hybrid car
Medium petrol hybrid car
4x4 petrol hybrid
Small range extended vehicle
Introduce a fleet telematic system
Install electric vehicle charging station

Plant
Fuel efficiency measures
Driver training

Diesel hybrid excavators
Electric quad bikes
Electric mowers (for reservoirs)
Biodiesel

3. Land and operational assets
Land Management
Deep peat restoration (not covered within this report)
Woodland planting (not covered within this report)

Renewable energy generation
Install building-mounted solar PV – self-supply to NRW
Solar self-supply to NRW
Small-scale wind – self-supply to NRW
Hydro – self-supply to NRW

Microgeneration
Micro hydro / micro wind + battery
Micro hydro + battery
Micro solar / wind + battery
Small-scale / roof-mount solar < 5 kW (pumping stations)
Small-scale solar < 5 kW
Retrofitting operational assets
Retrofitting assets – pumping stations
CCTV camera

4. Procurement
Procurement mitigation actions

Strengthening existing NRW procurement policy, guidance and procedures to:

- Encourage staff to ask themselves whether demand for goods or services could be reduced.
- Regularly review and amend energy-related technical specifications.
- Consider whether there are lower emissions alternative goods or services available.
- Work with suppliers to better understand and jointly tackle supply-chain emissions in hotspot categories of goods and services.

Introducing targeted carbon criteria into key frameworks and contracts associated with emissions hotspots:

- Conduct further research into the composition of emissions associated with identified hotspots and identify opportunities for mitigation through the procurement process.
- Progress procurement demonstration projects and transfer learning to other frameworks and emissions hotspots.

Developing new approaches to help incorporate carbon consideration into contracts and frameworks by:

- Identifying contract and product types that could increase sustainability of products and reduce associated emissions.
- Developing reference lists of suggested carbon criteria for types of contract to guide staff.
- Developing a tailored version of the existing Sustainability Prioritisation Matrix (SPM) to identify and insert carbon criteria into key frameworks and contracts.
- Making use of pre-market engagement to pitch carbon criteria inclusion within frameworks or groups of contract types.
- Help suppliers meet NRW requirements as they are introduced to specific frameworks or types of contracts.
- Introducing a Climate Change Standard for procurement, introducing minimum requirements on greenhouse gas (GHG) emissions.
- Providing sustainable procurement training for all staff.

2. Introduction

2.1 The legislative context

This report has been prepared against the backdrop of new legislation, as well as a broader societal change in attitudes towards the need to address the issue of climate change.

The *Environment (Wales) Act 2016*[1] and the *Well-being of Future Generations (Wales) Act 2015*[2] together provide a legislative framework to enable the sustainable development of Wales. They do this by requiring the sustainable management of natural resources and providing a framework for improving the social, economic, environmental and cultural well-being of Wales.

Addressing climate change and accelerating decarbonisation in Wales are crucial to achieving the objectives of the Acts.

Upon its publication, the *Environment (Wales) Act* required the achievement of an overall 80% reduction in greenhouse gas (GHG) emissions by 2050.[3] Alongside this legislation, in 2017 the Cabinet Secretary for Energy Planning and Rural Affairs, set out two policy ambitions, which act as key drivers for decarbonisation action in NRW:

- A carbon neutral public sector by 2030.[4] The scope of this has not yet been defined but NRW has worked with the Welsh Government to explore options for its definition and measurement.

- By 2020, new renewable energy projects in Wales should have at least an element of local ownership.[5] By 2030, Wales should generate 70% of its electricity consumption from renewable energy, with one gigawatt of renewable electricity capacity in Wales being locally owned.

In March 2019, the Welsh Government published its *Prosperity for All: A Low Carbon Wales* delivery plan, which brought together 100 policies and proposals towards achieving a low-carbon Wales. [6] Shortly afterwards, the Minister for Environment, Energy and Rural Affairs, Lesley Griffiths AM, joined the First Minister of Scotland, the Irish Government and hundreds of local authorities spanning 13 countries in declaring a climate emergency, with the aim of instigating further climate change action both on a national and international level.

In June 2019, the Welsh Government accepted the Committee on Climate Change (CCC) recommendation for a 95% reduction in greenhouse gas emissions by 2050, whilst at the

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[1] Further information is available at: http://www.legislation.gov.uk/anaw/2016/3/contents/enacted
[2] Further information is available at: http://www.legislation.gov.uk/anaw/2015/2/contents/enacted
[3] Emissions of CO2, CH4, N2O, HFCs, PFCs and SF6 are reported as carbon dioxide equivalents (CO2e) based on their comparative global warming potential.
[4] https://gov.wales/welsh-public-sector-be-carbon-neutral-2030
[5] The definition of 'local ownership' will include public bodies. https://gov.wales/lesley-griffiths-high-ambition-clean-energy
[6] Further information is available at: https://gov.wales/sites/default/files/publications/2019-06/low-carbon-delivery-plan_1.pdf

same time announcing it would aim to go beyond this target to achieve net-zero emissions within the same timescale, matching the commitments of the UK Government, and superseding the initial target set in the *Environment Act*. New regulations are due to be brought to the Assembly in 2021 to amend the original 2050 target along with Wales' interim targets and carbon budgets, to reflect these new commitments.

The *Well-being of Future Generations Act's* seven well-being goals (a prosperous Wales, a resilient Wales, a healthier Wales, a more equal Wales, a Wales of cohesive communities, a Wales of vibrant culture and thriving Welsh Language, and a globally responsible Wales) provide a shared vision for Wales to work towards, which includes the development of a low carbon economy.

The Carbon Positive Project helps NRW deliver on its purpose of ensuring the natural resources of Wales are sustainably maintained, enhanced and used, now and in the future, along with the requirements of the *Environment Act* and its contribution to the *Well-being of Future Generations Act*, by:

- **Contributing** to achieving emissions reductions for the Welsh public sector to meet the current 2016–2020 Carbon Budget.
- **Showing leadership** in the public sector to push towards a carbon neutral Welsh public sector by 2030.
- **Supporting** the sustainable management of natural resources through mitigation measures that seek to optimise multiple benefits that contribute to maintaining resilient ecosystems and communities, including better working environments for our staff, greater recreational opportunities for communities, enhanced biodiversity, and improved air and water quality.
- **Stimulating** the move to a low carbon resource efficient economy by working with suppliers through our procurement and supply chains.
- **Contributing** to the delivery of the well-being goals, particularly the prosperous Wales and the resilient Wales goals, where addressing climate change is specifically mentioned, but also the globally responsible Wales goal.

Against this background, it is critical that NRW works closely with Welsh Government on the delivery of the Government's decarbonisation programme and energy policies and objectives.

2.2 Background

This report details the approach taken by Natural Resources Wales through its Carbon Positive Project (also referred to as the Project) to evaluate mitigation options to reduce the organisation's carbon impact. We used the results of our net carbon status calculation (Jones, 2018) to identify where to focus our efforts on reducing our carbon impact by:

- Reducing NRW's greenhouse gas emissions by consuming less and adopting lower emissions alternatives, both within the organisation and our supply chain.

- Managing, and where necessary restoring, key habitats, such as woodland and peatland on the estate, to enhance the amount of carbon being stored each year (our sequestration) and/or protecting existing stores of carbon (our carbon stocks).

As part of the organisation's net carbon status calculation, we mapped out the structure and activities of the organisation to identify potential sources of emissions and rationalised these into four high level categories for emissions calculation.[7] These four categories were then adopted to structure our evaluation of mitigation measures.

The four categories are:

- **Buildings**
- **Transport**
- **Land and operational assets**
- **Procurement**

This technical document sets out the rationale for methods used and the results of the evaluation of mitigation options. It details the overall approach followed, the individual methodologies followed for each organisational category, the measures identified, their carbon benefits and a cost analysis, and potential scales of adoption of measures across the organisation.

This document, coupled with the evaluating mitigation options spreadsheets, forms the audit trail for NRW's accounting and reporting practices for the evaluation of mitigation options to reduce our carbon impact, to provide the transparency necessary for the approach to be replicated internally in future.

The information within this report has been used to prioritise and evaluate the potential measures NRW may take forward to deliver decarbonisation in the future as part of the Carbon Positive Enabling Plan and its supporting Action Plan.

The Carbon Positive Project intends to disseminate this document throughout the public sector in Wales to encourage wider action on decarbonisation. Therefore, alongside the methodology for each organisational category, this report also details limitations associated with our approach, the challenges faced and lessons learned in carrying out the individual evaluations, which may be useful to other public sector organisations working to manage their own carbon impact. The report is structured as follows:

Chapter 2 Introduction provides the legislative context to the evaluation of mitigation options for NRW, together with NRW's work on climate change and this Carbon Positive Project.

Chapter 3 Method introduces and explains the approach to identifying and evaluating mitigation measures to reduce the carbon impact of the organisation.

[7] For further information, please see the Carbon Positive Project Technical Report: Calculating NRW's Net Carbon Status. Available online at: www.naturalresources.wales/carbonpositive

Chapter 4 Mitigation measures presents the results of the evaluation of individual mitigation measures in each of our four organisational categories, along with scenarios for feasible and theoretical scale of adoption across NRW.

Chapter 5 Discussion and conclusions considers the results in each of the organisational categories and overall lessons learned in the process of evaluating mitigation measures.

Chapter 6 Prioritisation and delivery sets out our planning for future implementation of measures with prioritisation, consideration of wider benefits, working with others, and monitoring and reporting.

2.3 Natural Resources Wales' work on climate change

NRW is committed to positive action on climate change. We recognise the importance of pursuing opportunities to minimise the effect our own activities have on emissions and storage of greenhouse gases – largely carbon dioxide, i.e. our carbon impact. Our corporate and annual business plans, which outline what we will do for Wales and for the environment, recognise the environmental challenges posed by climate change, and commit to reducing emissions, enhancing sequestration and protecting carbon stocks, both through our own activities and through our broader influence on the activities of others.

NRW has a unique and broad organisational remit, including being custodian and manager of 7% of Wales' land area, which encompasses water, woodlands, National Nature Reserves and flood defence schemes, plus, as an operator of our visitor centres, recreation facilities and a laboratory. In addition to being a land and water manager, NRW is an environmental advisor and regulator, it responds to environmental incidents and provides grant aid to others for sustainable land management activities. This breadth of remit brings challenges, for example in terms of GHG accounting, and opportunities to decarbonise by reducing our emissions, and protecting and enhancing the carbon captured on the land and water we manage (the estate).

The drive to improve NRW's net carbon status forms part of the organisation's contribution to Wales' transition to a low carbon economy. It is also a key element of NRW's contribution to meeting the seven goals of the *Well-being of Future Generations Act* and the carbon budgets and delivery of the Sustainable Management of Natural Resources (SMNR) of the *Environment Act*.

2.4 Our Carbon Positive Project

The Carbon Positive Project delivered a comprehensive approach to carbon management through five key steps:

1. **Calculating NRW's net carbon status**
    - Developing an approach to comprehensively calculate the organisation's net carbon status.

- Collating greenhouse gas emissions data from buildings, transport, management of the estate and the procurement of goods and services.

- Estimating carbon stocks and sequestration rates in the habitats on the estate.

2. **Evaluating options for mitigation**
   - Identifying and evaluating measures to reduce emissions, enhance sequestration and protect carbon stocks across the organisation and the estate.

   - Developing an approach for prioritising options for delivery through evaluating costs, carbon savings and wider benefits.

3. **Demonstration projects**
   - Twenty demonstration projects have been undertaken in each of the four categories of buildings, transport, land and assets, and procurement to demonstrate potential mitigation options, including:

     - LED lighting
     - Biomass boilers
     - Solar photovoltaic (PV)
     - Electric vehicles and charging points
     - Woodland planting
     - Peatland restoration
     - Trialling a carbon planning tool in our civil engineering contracts

The experience of delivering these, particularly the financial aspects, have contributed to our understanding of those measures, for example, fitting solar panels to some of our hydrometry and telemetry stations.

4. **Communications and working with others**
   - Learning from organisations managing their own carbon impact in new and ambitious ways.

   - Collaborating with our colleagues to gather ideas and work across the organisation to begin embedding carbon management into our activities.

   - Sharing our experience and approach, aiming to facilitate and encourage positive action on decarbonisation across Wales' public sector and beyond.

5. **Recording experience and planning future implementation**
   - Producing a series of publications to record and share our experience and approach, including:

     - *Carbon Positive Project Strategic Summary Report*
     - *Calculating NRW's Net Carbon Status Technical Report*
     - *Evaluating NRW's Mitigation Options Technical Report*
     - Demonstration project case studies.

   - Building our mitigation opportunities into a plan for implementation, to embed carbon management throughout NRW.

3. Method

3.1 Our approach

To identify and evaluate potential mitigation measures we drew on the experience of staff across the organisation, the experience and learning of other organisations managing their carbon impact and the advice of industry experts.

We followed a series of stages:

- **Understanding the organisation's emissions sources** and focal points for mitigation (see 3.2).
- **Identifying possible mitigation measures** applicable to the organisation's emissions sources (see 3.3).
- **Researching the financial costs and savings**, carbon savings and wider benefits (see 3.5 and 3.6)
- **Estimating the potential scale and feasibility** of the adoption of mitigation measures across the organisation (see 3.8)

The measures identified in this process were also used to inform and select the Carbon Positive Project's 'Demonstration Projects'.[8] These projects showcase some of the potential mitigation opportunities open to NRW. They helped to develop further understanding of costs, carbon savings and wider benefits of measures, and ensured we took early action to manage our carbon impact alongside building our evidence base for a more strategic implementation in future.

3.2 Understanding the organisation's emissions and priorities for mitigation

As set out in Section 2.4 above, the first step towards carbon management within NRW was to calculate the organisation's net carbon status. This involved the development of a GHG emissions inventory to quantify emissions from assets and operations, and estimating the carbon sequestered annually in the vegetation and soils of habitats on the NRW-managed estate.

After identifying assets and operations to be included, we defined which emission sources we were accounting for. All three emissions categories, known as scopes, were included within the NRW GHG inventory.[9] These are:

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[8] For further information, please see the Carbon Positive Project Demonstration Project Case Studies. Available online at: www.naturalresources.wales/carbonpositive

[9] Our GHG inventory went beyond the standard approach of solely considering direct emissions from our activities (scope 1 emissions) and electricity use (scope 2 emissions) to understanding the wider carbon impact of our organisation.

- **Scope 1** – direct GHG emissions to the atmosphere from sources owned or controlled by NRW, e.g. fuel combustion in owned boilers and vehicles

- **Scope 2** – indirect emissions to the atmosphere from the generation of electricity purchased by NRW for use in assets and buildings under our operational control

- **Scope 3** – other indirect emissions that arise from sources outside of NRW's operational control but which are a consequence of our activities, e.g. purchased materials, contractor services, employee commuting.

Alongside carbon losses and gains, carbon stocks – or the total carbon already stored in each type of habitat – was also estimated to provide an understanding of the estate's wider role in relation to carbon. Although existing carbon stocks do not form part of the net carbon status calculation for NRW, they were calculated and reported concurrently to provide a full understanding of the carbon impact of the estate.

The results of these emissions calculations showed that NRW can be considered a net carbon positive organisation, sequestering 9.5 times more carbon in habitats on the estate than it emitted as GHGs through its operations in the base calculation year 2015/16 (Jones, 2018). Despite this status, reducing GHG emissions from operations remains a key element of managing the organisation's carbon impact, alongside promoting sequestration and protecting existing carbon stocks. This focus on reducing emissions recognises that NRW can do more than rely on the role of sequestered carbon to manage its carbon impact.

The calculation estimated NRW's total emissions to be 41,304 tCO_2e. Purchased goods and services, and processing and transport of sold timber products, were identified as our main sources of emissions, together accounting for more than three-quarters of our overall emissions. This exercise established 2015/16 as NRW's baseline year.

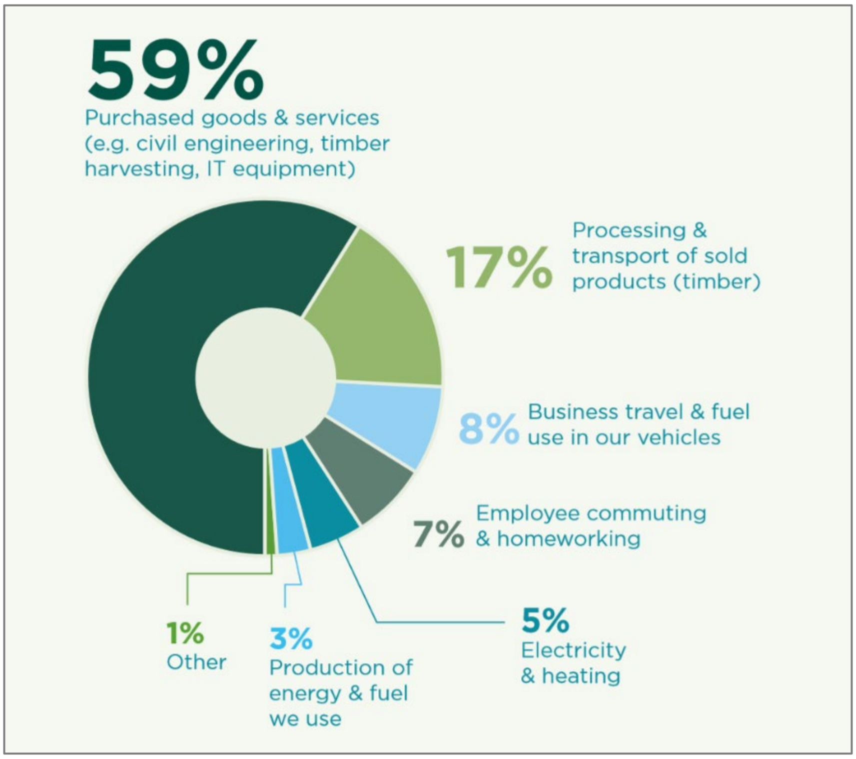

Figure 1: NRW's overall emissions by source

When considered in terms of NRW's organisational structure, four broad categories of emissions sources emerged which have been adopted to structure our approach to identifying and evaluating mitigation measures. They are:

- **Buildings** – evaluating the emissions reduction potential in our offices and depots
- **Transport** – evaluating the opportunities to reduce emissions resulting from use of transport across the business, including our own fleet and business travel
- **Land and operational assets** – evaluating measures to reduce the emissions associated with our land management and operational assets, as well as enhancing sequestration and protecting carbon stocks on NRW-managed land. This included understanding the potential contribution renewable energy generation could make
- **Procurement** – evaluating the opportunities to integrate carbon management criteria into NRW's procurement of goods and services to reduce embedded carbon emissions

Based on the emissions calculation, Table 3 below outlines our priorities to reducing our carbon impact across these four categories.

Table 3: Priorities across our four organisational categories

	Organisational category	Priorities based on our net carbon status calculation
1	Buildings	• Electricity use in offices and depots (scope 2) • Heating fuel use (scope 1)
2	Transport	• Fuel use (primarily diesel and petrol use across our fleet and plant) (scope 1) • Downstream timber haulage (scope 3) • Employee commuting (scope 3)
3	Land and operational assets	• Management of habitats, primarily peatland and woodland, to protect and enhance carbon stocks (scope 1) • Use of the estate for renewable energy generation • Electricity use in operational assets, such as pumping stations (scope 2)
4	Procurement	• Work carried out by contractors (e.g. forest harvesting, ICT) (scope 3) • Work carried out under various agreements (e.g. reservoir operating agreements) (scope 3)

Direct GHG emissions to the atmosphere from sources owned or controlled by NRW (scope 1) and indirect emissions to the atmosphere from the generation of electricity purchased by NRW for use in assets and buildings under our operational control (scope 2) may offer the most immediate opportunities for emissions mitigation. Our scope 1 and 2 emissions were found to be dominated by fleet fuel use (scope 1) and electricity emissions (scope 2). Therefore, priority mitigation options for evaluation include opportunities for low-emission vehicles and fuels to be incorporated into the fleet and exploring opportunities to reduce electricity use through behavioural change, equipment efficiencies and renewable energy generation on site.

However, the most significant element of our GHG inventory are other indirect emissions that arise from sources outside NRW's direct operational control but are a consequence of our activities (scope 3), e.g. purchased materials, contractor services, employee commute. Because these emissions lie outside of our direct control, they are likely to be the most challenging to influence. Mitigation opportunities for these include:

- Developing an organisational sustainable travel plan to reduce staff commute (and other travel) emissions.
- Incorporating criteria into frameworks to influence contractor emissions.
- Working on downstream harvest and transport of timber sold standing.
- Working on emission reductions on purchased goods and services.

3.3 Identifying mitigation measures

We identified possible mitigation measures available for NRW using the following sources:

- **Published literature** – desk-based research was carried out to collate information from existing published literature.
- **Approaches taken by other organisations** – we researched and engaged with organisations taking ambitious and innovative approaches to carbon management, including Manchester Fire and Rescue Service and the National Trust.
- **Ideas from our staff** – early in the project, we held six staff engagement sessions to bring together staff to contribute their ideas for mitigation measures. We maintained this engagement through regular all-staff Skype sessions, building support for the potential measures we were identifying.
- **Experience of our legacy bodies** – we sought staff experience of mitigation measures previously adopted in each of NRW's three legacy bodies to understand how we might learn from and build upon this.[10] We also explored the potential to expand **existing measures** in NRW.
- **Demonstration projects** – we delivered over 20 projects to demonstrate potential mitigation measures across the four categories of mitigation measures, providing real-world data.
- **Industry experts** – we worked with experts to support the identification of measures, costs, carbon savings, and to understand potential uptake.

[10] The Countryside Council for Wales, Environment Agency Wales and Forestry Commission Wales. https://naturalresources.wales/about-us/what-we-do/our-roles-and-responsibilities/?lang=en (accessed 11/12/2017)

Mitigation measures identified were aimed at managing the organisation's carbon impact by:

- **Reducing greenhouse gas emissions** through consuming less, increasing efficiencies or adopting lower emissions alternatives, either within the organisation or our supply chain, and/or

- **Enhancing sequestration and protecting carbon stocks** through habitat management decisions to increase annual uptake and storage of carbon and decrease losses from any existing stores.

For the other three organisational categories we sought to produce a comprehensive list of possible measures. In the buildings and transport categories, in particular, these initial lists were then narrowed prior to evaluation, i.e. data collection. This was generally to remove any measures considered unsuitable for NRW. Other reasons for not taking identified measures forward for evaluation included a need to gather further evidence or difficulty quantifying impacts, emerging technologies that would be better evaluated once more established, site-specific measures with limited scope for scale-up and small-scale measures that fell under a broader, overarching measure that had already been selected to be taken forward for evaluation.

Unlike the other three organisational categories, it was not possible to identify a comprehensive, evaluated list of mitigation measures for procurement. This was because of the varied nature of these emissions across all purchased products and services in the organisation's supply chain. Instead, we identified a generic list of interventions, from published literature and the approaches of other organisations, which could be tailored to meet different needs in NRW procurement guidelines or specific frameworks and contracts. We considered these generic interventions in terms of NRW's current procurement policy and procedures, and our supply chain emissions hotpots, to come up with some high-level actions for NRW to reduce carbon through procurement (see below).

3.4 Data collection

We worked with industry experts to support the identification of measures, estimation of cost and carbon savings, and to understand potential uptake and feasibility of measures for the organisation in the following areas of emissions:

- **Business travel emissions from NRW fleet vehicles** – we commissioned Cenex to conduct a strategic review of the NRW fleet from the emissions perspective, identifying mitigation opportunities for road and plant vehicles ranging from fleet rationalisation to replacement with low-emission vehicles.

- **Energy emission from heating and powering our buildings** – we commissioned the Carbon Trust to carry out energy audits of 15 prioritised NRW buildings, identifying potential energy efficiency measures and opportunities for renewable energy installations in and on our buildings.

- **Inefficiencies associated with staff energy use** – we worked with the Carbon Trust to develop a low-carbon behavioural change programme, identifying key areas where behavioural change campaigns could be focused to reduce emissions, covering the themes of management of heating and cooling, switching off electrical equipment and work-related travel.

- **Electricity emissions from powering our largest buildings and operational assets** – we commissioned Regen to carry out a desk-based renewable energy assessment of the NRW estate to identify small-scale renewable energy installation opportunities to provide power to our own offices and depots. They also explored, at a high level, the potential for micro renewables to be installed on NRW operational assets such as gauging stations and pumping stations to supply power directly to the asset.

- **Emissions and sequestration on our forest estate** – as part of our net carbon status calculation we commissioned Forest Research to model baseline and projected carbon stocks and annual sequestration in our commercial forests and non-commercial woodlands. As part of this, Forest Research indicated some high-level measures that the organisation could consider to reduce emissions and/or increase sequestration in this sector.

- **Emissions and sequestration in peatland estate** – as part of our net carbon status calculation, we commissioned the UK Centre for Ecology and Hydrology to map and estimate emissions and sequestration in deep peat habitats on the NRW estate and opportunities for mitigation through peatland restoration.

The results from this research are included in the relevant sections, except for the research on woodland management and peatland restoration that are reported in the technical report for our net carbon status (Jones, 2018) and have been published separately.

For each measure within the Buildings and Land and Operational Assets sections of the report, we collected a set of common metrics presented in Table 4: Sample of metrics recorded for mitigation measures below.

Table 4: Sample of metrics recorded for mitigation measures

	Carbon savings		**Cost analysis**				
Mitigation measure	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual maintenance / recurring costs (£)	Estimated annual savings (£)

These metrics are intended to facilitate future prioritisation of measures as part of the Action Plan for the organisation and are reported per individual unit of a measure, e.g. one boiler replacement, one electric vehicle, one hectare of peatland restoration.

Within the Transport section, the metrics are presented in a similar format to those of the Buildings and Land and Operational Assets (see the above table), but it also includes metrics tailored specifically to vehicle options, i.e. fuel type, comparator, size, annual reduction in CO_2e (%) WTW, annual reduction in CO_2e (tonnes) WTW, TCO (£) over a five-year period and TCO Savings (£) over a five-year period.

Transport-related emission reduction potential can be measured as tank to wheel (TTW) and well to wheel (WTW). TTW refers to CO_2e emissions from fossil fuel combustion released from the vehicle tailpipe and is classed as scope 1 emission under the greenhouse gas (GHG) reporting protocol and is the direct responsibility of NRW. On the other hand, WTW is an all-scope emission under GHG reporting protocol as it includes CO_2e emissions throughout the fuel's whole lifecycle, from extraction to combustion. Therefore, some elements are not the direct responsibility of NRW. For each measure, carbon savings have been given in WTW to demonstrate total lifecycle emissions and is in line with NRW's reporting of organisational carbon emissions.

Our evaluation of the measures applicable to procurement differed from the other three organisational categories, as it was not possible to attach carbon or cost-saving data to the generic intervention types identified for application to NRW policy and procedures. The Procurement section of this report (4.4) is therefore not structured under the same headings as the evaluation of mitigation measures for the other organisational emissions categories and no cost and carbon savings have been provided, only recommended actions.

A list of the chosen mitigation measures across all four categories is compiled in Table 5 below:

Table 5: Mitigation measures spanning all four categories

Buildings	**Carbon savings**		**Cost analysis**					
Mitigation measure	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual maintenance / recurring costs (£)	Estimated annual savings (£)
Renewable energy generation (self-supply)							
Install building-mounted solar PV (14.4 kWp NRW average array)	5.2	129.3	18,868	25	12.2	333	1,866
Heating and cooling							
Upgrade to biomass boiler (61 kW NRW average installation)	12.8	255.9	50,195	20	12.3	300	2,062
Upgrade conventional boiler (per boiler average)	2.3	46.7	4,833	20	11	n/a	509
Upgrade conventional electric	4.6	28.5	4,250	6.2	4.7	n/a	1,141

Buildings	Carbon savings		Cost analysis				
Mitigation measure	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual maintenance / recurring costs (£)	Estimated annual savings (£)
heaters (one building)							
Install new controls to optimise boiler operation (one building)	1	Lifetime not known	600	Not known	2.4	0	250
Optimise boiler operation or heating schedules (without new controls) (per building average)	0.9	Lifetime not known	0 (staff time only)	Not known	Immed iate	0	192
Install air source heat pump (per building average)	17	339.0	25,500	20	8.3	n/a	2,823
Installation of drying room controls (per building)	1.2	11.5	190	10	1.1	n/a	292
Improve server room air-conditioning efficiency (per air-conditioning unit average)	0.5	Lifetime not known	275	Lifetime not known	1.1	n/a	124.5
Raise the temperature of a refrigerated container (per unit)	0.1	Lifetime not known	0 (staff time only)	n/a	0	0	30
Lighting							
Replacement of existing lights with LEDs (2.51 kW NRW average installation)	3.8	75.3	8,070	20	8.2	Included in annual savings	1,042
Energy management							
Adopt an energy management strategy supported by metering and monitoring (for a building with average energy use)	0.9	n/a	0 (staff time)	n/a	n/a	n/a	250

Buildings	Carbon savings		Cost analysis				
Mitigation measure	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual maintenance / recurring costs (£)	Estimated annual savings (£)
Improve roof insulation (average installation of 322 m^2)	1.7	34.5	2,197	20	10	n/a	230
Voltage optimisation (at NRW's largest office building)	18.0	270.5	15,700	15	4.8	0	3,279
Additional homeworking (for a building with average staff numbers of 43.5)	5.7	n/a	0	n/a	n/a	Included in annual savings	0 (for the organisation) 10,220 (for staff)
Hot water – point of use provision (per building average)	1.7	33	700	20	2.4	n/a	298

Transport				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%) WTW[11]	Annual reduction in CO_2e (tonnes) WTW	TCO (£)[12], [13] over 5-year period	TCO Savings (£) over 5-year period
Low-emission technologies							
Small electric car (battery)	Electric	Diesel vehicle	Small	53	1.188	13,849	3,303
Medium electric car (battery)	Electric	Diesel vehicle	Medium	53	1.027	13,917	4,552
Small electric van (battery)	Electric	Diesel vehicle	Small	46	1.572	16,492	143

[11] WTW: well to wheel – All-scope emission under GHG reporting protocol as it includes CO_2e emissions though the fuel's whole lifecycle, from its extraction to combustion, with all processes between.
[12] TCO (Total Cost of Ownership) includes maintenance, management, infrastructure (i.e. charging stations for EV) and fuel and is on a lease basis.
[13] Fuel costs are based on typical mileage for each size of vehicle in NRW fleet.

Transport				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%) WTW[11]	Annual reduction in CO_2e (tonnes) WTW	TCO (£)[12], [13] over 5-year period	TCO Savings (£) over 5-year period
Medium plug-in hybrid car	Plug-in hybrid	Diesel vehicle	Medium	30	0.581	26,975	-8,506
4x4 plug-in hybrid	Plug-in hybrid	Diesel vehicle	4x4	43	1.723	27,431	-2,068
Small petrol hybrid car	Petrol hybrid	Diesel vehicle	Small	31	0.702	17,434	-281
Medium petrol hybrid car	Petrol hybrid	Diesel vehicle	Medium	31	0.599	17,046	1,423
4x4 petrol hybrid	Petrol hybrid	Diesel vehicle	4x4	26	1.037	25,768	-406
Small range extended vehicle (REEV)	REEV	Diesel vehicle	Small	32	0.721	19,200	-2,048
Implementation of biodiesel	Biodiesel	Diesel vehicle	n/a	6	7	n/a	-40,000
Telematic system							
Installing telematic system into car	Diesel	Non-telematic diesel vehicle	Medium and small[14]	15	0.3	17,347	463.50
Infrastructure							
Installation of EV charging station	Electric	Diesel vehicle	n/a	n/a	n/a	4,146[15]	n/a
Introduction of Skype	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Plant							
Quad bikes	Electric	Petrol plant	n/a	58	n/a	550	2,750
Chipper	Electric	Diesel plant	n/a	45[16]	n/a	10,000	n/a
Digger / dumper	Diesel-electric	Diesel plant		40[17]		130,000	
Mower	Biodiesel / Electric	Diesel plant		Variable[18]		32,905[19]	

[14] Mean for medium and small cars, as the numbers are very similar
[15] This is capital cost including available grant
[16] Mean for reduction given by Cenex, i.e. 40–50%.
[17] Up to a further 5% emission savings may be achievable with the implementation of a fuel reduction programme, including driver fuel efficiency training, as recommended by Cenex.
[18] Varies between 18% for biodiesel and 40–50% for electric, as noted by Cenex.
[19] Average (NRW CapEx history: there is a very wide variation in cost, between £8,800 to £75,000).

Transport				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%) WTW[11]	Annual reduction in CO_2e (tonnes) WTW	TCO (£)[12, 13] over 5-year period	TCO Savings (£) over 5-year period
Tractor	Diesel[20]	Diesel plant		25		42,000	

Land and Operational Assets									
Mitigation measure	**Average project capacity (MW)**	**Annual reduction in CO_2e (tonnes)**	**CO_2e saving over lifetime of the measure (tonnes)**	**Carbon cost metric (£/tCO_2e)**	**Indicative capital cost (£)**	**Lifetime (years)**	**Payback period (years)**	**Estimated annual maintenance / recurring costs (£)**	**Estimated annual savings (£)**
Renewable energy generation									
Solar self-supply to NRW >5 kW	0.01	3.7	72	3,352	12,300	20	10	140	1,364
Small-scale wind – self-supply to NRW >5 kW	0.0122	6.9	173	8,866	61,000	25	21	378	3,322
Hydro self-supply to NRW >5 kW	0.0083	14.0	702	6,831	95,833	50	19	1,583	6,658
Microgeneration									
Micro hydro / micro wind + battery <5 kW (on rain gauges)		3.1			11,730			190	
Micro hydro / micro wind + battery <5 kW		1.9			7,245			190	

[20] Measure involves implementation of fuel reduction programme, including driver fuel efficiency training, in line with Cenex recommendations.

(river level stations)									
Micro hydro + battery <5 kW (other FRM)		2.1			7,705			190	
Micro solar / wind + battery <5 kW (gauging stations)		0.9			537			16	
Micro solar / wind + battery <5 kW (flood warning sites)		0.9			518			16	
Small-scale / roof mount solar <5 kW (pumping stations)		4.8			2,886			16	
Small-scale solar <5 kW (other FRM)		3.5			2,091			16	
Small-scale solar <5 kW (H&T demo project)		0.022	0.22		2,085	10		0	
Retrofitting operational assets									
Retrofitting assets – pumping stations (pump replacement)		52				25	9		
CCTV camera (FRM)		0.03							

Procurement Mitigation Actions
Strengthening existing NRW procurement policy, guidance and procedures to better support the hierarchy of procurement mitigation interventions, through: • Using procurement guidance to encourage staff to ask themselves whether demand for goods or services could be reduced, including through tackling inefficiencies, and speaking to our Environmental Management System colleagues to address any inefficiencies through behavioural change measures. • Using procurement guidance to encourage teams and directorates to regularly review and amend energy-related technical specifications for equipment purchases, to reflect technological advances / latest standards and reduce in-use emissions.

• Using procurement guidance to encourage staff to consider whether there are lower emissions alternative goods or services available. This type of substitution could also be supported by encouraging suppliers to suggest lower emissions alternative approaches or products in their tender responses. • Encouraging procurement and other staff to work actively with suppliers to better understand and jointly tackle supply chain emissions in hotspot categories of goods and services. This needs to be supported by further work to disaggregate hotspot spend to identify suppliers or groups of suppliers for engagement
Focusing on introducing targeted carbon criteria into key frameworks and contracts associated with emissions hotspots: • Conduct further research into the breakdown of emissions associated with identified hotspots, and identify targeted opportunities for mitigation through the procurement process, in relation to: - The types of service provided through Service Level Agreements (SLAs) and Return On Assets (ROAs) and the opportunities to include emission reduction criteria in the high-level agreements and/or in individual contract specifications. - ICT contractor and consultant services. - Engineering contracts: the opportunity to extend the use of the carbon planning tool into other areas of engineering work – beyond the Civil Examination Framework Agreements (CEFA) framework – should be considered. - Fleet purchase, hire and maintenance. • Progress existing procurement demonstration projects and transfer learning to other frameworks and emissions hotspots: - Continue to trial and roll out use of the Carbon Planning Tool (CPT) for all projects completed through the CEFA framework. In support of this, continue to develop and refine the governance structure and internal processes needed to fully adopt the CPT. - Explore opportunities to expand the use of the CPT in other frameworks or to develop a similar tool for other contract types. - Make use of the results of the forestry emissions case study to steer further work internally and with contractors to identify mitigation opportunities and delivery mechanisms. - Pilot the approach of supplier engagement to manage supply chain emissions with key forestry contractors and transfer learning to other hotspots.
Developing new approaches to help incorporate carbon consideration into contracts and frameworks: • Identify contract and product types for which taking a product-service system approach to procurement, i.e. purchasing services rather than products, could increase the whole life sustainability of products and reduce associated emissions. • Consider developing reference lists of suggested carbon criteria for types of contract to guide staff, e.g. criteria aimed at tackling travel-related emissions which are likely to be a commonality in contractor services. • Explore the potential to develop a tailored version of the existing Sustainability Prioritisation Matrix (SPM) to support the identification and insertion of carbon criteria into key frameworks and types of contracts. • Make use of pre-market engagement to help us to pitch carbon criteria inclusion within frameworks or groups of contract types initially. • Make use of supplier training days and workshops to help suppliers meet NRW requirements as they are introduced to specific frameworks or types of contracts. • Consider the introduction of a Climate Change Standard for procurement, introducing minimum requirements on GHG emissions across all NRW’s procurement. It is likely that

this would need to be introduced incrementally, allowing smaller suppliers time to adapt to any requirements.

- Provide sustainable procurement training for all staff, e.g. the free online training course "Carbon literacy for procurers" provided by Loreus (undated). This could be incorporated into the existing e-learning programme requirement for all staff.

3.5 Carbon data

As set out in 3.4, we worked with industry experts to identify emission reduction measures. Outputs from their work included estimates of the GHG reduction of individual measures when adopted by NRW. All GHG emissions accounted for are reported in common units of carbon dioxide equivalents (CO_2e). These are typically reported annually and can usually be scaled over the lifetime of the measure. Reductions in emissions from some of the measures can be expressed as a percentage reduction in CO_2e compared to baseline emissions at the time of calculation.

3.6 Financial data

As with the carbon data, cost analysis of measures has been supported by industry experts. Details of data sources and what is and isn't accounted for with each measure e.g. feed-in tariff (FIT) payments, is provided in each relevant section.

Where relevant, the calculations take account of financial discounting or other payments, such as FITs.

Lifetime of measures was based on technical literature for each measure, e.g. for Solar PV it is taken from the CIBSE guide (The Chartered Institution of Building Services Engineers).

Estimated annual savings are based on the financial savings made by using the measure rather than existing system at the time of calculation, i.e. the current baseline.

Payback period describes the number of years it would take for the savings made by the measure to equal the initial capital cost.

3.7 Unevaluated measures

As we researched the carbon and financial implications of measures, it became clear that a significant number could not be evaluated using our standard set of metrics because of the difficulty of attaching financial costs and carbon savings to them. Many of these measures represented ways of working, e.g. behavioural change in offices. We recognise the value of these measures and their potential contribution to our carbon reduction. Although they have not been evaluated using costs and carbon savings, we have presented them as 'ways of working'.

Where these measures have a potentially significant role to play in the future development of decarbonisation across NRW, they should be included in the delivery of measures. It is recognised that it will be more difficult to estimate and monitor their impact. In some cases, more detailed investigation into individual ‘ways of working’ measures may be able to provide indicative cost and carbon savings, and this should be pursued, subject to time / cost benefit of doing so, as part of the delivery of measures.

3.8 Understanding potential scale

The final stage in identifying and evaluating mitigation measures was understanding opportunities for their uptake across the whole organisation, i.e. the potential to scale-up from the individual unit level. This will be used to inform delivery of decarbonisation measures across the organisation and provide an understanding of the potential of each measure to contribute to reducing our overall carbon impact.

Using the carbon savings and cost analysis for each individual unit of a measure, it is possible to estimate savings and costs across the organisation. The standard method for scaling up measures across all NRW buildings is outlined below, together with assumptions.

Although generally we have considered measures as stand-alone actions, this is not always the case. For instance, the scenario included in the Transport section based on the strategic fleet review conducted by Cenex is a scenario looking at the optimum combination of different measures, including introducing low-emission vehicles, reducing the overall number of fleet vehicles and trialling telematics technology. Energy audits carried out by the Carbon Trust to provide an evidence base for the Buildings section, focused on identifying a range of measures for each individual site reviewed, combining areas such as renewable energy generation (self-supply), heating and cooling, lighting and energy management.

The best savings are often made when measures are used together, e.g. a more efficient heating system together with a better insulated building. However, it will not always be possible to carry out one action and gain multiple benefits; it may be an either/or choice. In this exercise we have not considered the impacts and interactions between measures.

3.9 Feasible maximum

The feasible maximum is the highest uptake possible of a measure across NRW when considering constraints, based on best available evidence at the time of calculation. Constraints considered include existing business strategies and priorities, ownership, technology readiness and land use. The feasible maximum is not influenced by the cost of implementation.

3.10 Theoretical maximum

The theoretical maximum is the highest uptake possible of a measure across NRW without considering any constraints or challenges to delivering the measure.

For some measures, the theoretical maximum is the same as the feasible maximum. It is also the case that we have scenarios for the theoretical maximum produced by industry experts, e.g. for our fleet and operational plant review.

4. Mitigation measures

As explained in 3. Method, building upon the net carbon status calculation, we categorised measures for emissions mitigation, protecting carbon stocks and increasing sequestration. In this section of the report, individual mitigation measures are presented within each of the four categories:

- Buildings
- Transport
- Land and operational assets
- Procurement

Each category begins with a table summarising the results for all measures. This is followed by information on each mitigation measure: a description, carbon reduction potential, cost, potential scale of adoption across NRW (estate and operations), i.e. maximum and feasible, and examples of successful adoption elsewhere.

There are mitigation measures which were not progressed for further evaluation. The Buildings and Transport sections of this report (each covering the evaluation of measures for one of our organisational categories) contain a table of identified mitigation measures not taken forward for evaluation to date, and the reason for this.

For Buildings, examples and reasons include:

- Ground source heat pumps, because an existing NRW installation has not yielded any significant cost or emissions savings and building energy audits did not identify this as a recommended measure for any of our assessed buildings.

- Vertical axis wind turbines, due to higher costs and reduced efficiency compared to standard turbines.

- Reducing heating by one degree because this was considered one possible element of an energy management strategy which evaluated as an umbrella measure.

For Transport, examples and reasons include:

- Hydrogen fuel cell vehicles due to NRW being unsuccessful in securing an OLEV grant for a trial vehicle.

- All-terrain vehicles (ATVs) pending a feasibility study of electric ATVs, as recommended by Cenex, along with a lack of technology maturity among other technologies.

- Others, such as the development of a sustainable travel plan, were not considered to be a priority; however, we intend to implement the plan in future.

A full list of all measures not progressed to detailed evaluation at this stage is available in Table 21 for Buildings and Table 43: Summary of transport measures not being progressed to detailed evaluation for Transport. While they may not currently have been considered a priority or feasible for the organisation, they have not been ruled out. As a result, the list of measures not taken forward should be reviewed for their potential contributions to future iterations of this approach and we recommend that all measures identified are considered by other users of this report. With changes in technologies and costs, we expect to review the potential to implement some of the measures not progressed within NRW in the near future.

The Land and Operational Assets and Procurement sections of this report, meanwhile, do not include tables of this type. For Land and Operational Assets, this is due to the decision taken to focus solely on two main types of habitats on the NRW estate, namely woodland and deep peat (not covered in this report). For Procurement, the absence of a table listing measures not taken forward is as a result of no detailed evaluated mitigation measures being identified for this section.

It is recognised that, upon the publication of this report, there are gaps in the mitigation measures identified and discussed, including pumping station energy efficiency (pump replacement) under operational assets. We were unable to explore this further due to an ongoing internal review of pumping stations; however, we will continue to keep up to date with the progression of the review, with the view of addressing this as a measure at a later date.

There are also gaps in our existing evidence base, such as the evidence we have relating to buildings' energy efficiency. This is because we commissioned the Carbon Trust to conduct buildings audits during an internal accommodation review, which led to only the 15 buildings deemed to have a secure future within NRW at that time being audited. Our evidence for this section was therefore based on the findings of these 15 buildings alone, rather than all our occupied buildings. However, we aim to commission additional building audits within the near future, to ensure we further strengthen our evidence base and our approach to decarbonising our buildings.

With regards to our managed land, limited data availability impacted our ambition to produce a comprehensive estimate of existing carbon stocks and annual sequestration rates for all habitats on the estate considering the influence of key factors including previous land use, habitat management, and condition and soil type. For the majority of habitats, no central, comprehensive record of current and past management exists. It was therefore necessary to prioritise habitats for which we would produce more detailed calculation estimates, based on the anticipated carbon significance of habitats in terms of contribution to the estate totals, and fall back on default values for other habitats. We prioritised: woodland habitats which are 81% of the total estate area and will therefore play a crucial role in its carbon balance; bog and fen habitats on the estate given that these habitats can represent a significant carbon store and that in poor condition they can be a significant source of emissions. However, it is recognised that further research is required in future to address these gaps in our data and to explore the potential for further decarbonisation within our estate, including the potential within organo-mineral soils (peatlands with an organic layer of 40cm or less). Our work to evaluate the options for the habitats is on-going and is not covered in detail within this report.

4.1 Buildings

4.1.1 Buildings – category-specific method

We worked with industry experts to support the identification and evaluation of building efficiency and behavioural change measures, by the provision of cost and carbon saving data and to understand potential uptake / feasibility. Most of the identified and costed mitigation measures relating to building efficiency are opportunities presented in assessments performed by the Carbon Trust and are aimed at reducing our direct scope 1 and 2 emissions.

4.1.2 Individual building assessments

The Carbon Trust was commissioned to carry out energy assessments on buildings on 15 NRW sites: offices with associated workshops, stores, and one fish-rearing hatchery. The evaluation of emissions reduction potential in our buildings was conducted through building-specific assessments to identify energy-saving measures appropriate for those NRW buildings (leased and owned).

The energy-saving opportunities identified by the Carbon Trust were specific to each assessed building. Each building assessment provided several measures for making carbon savings and they were listed in a recommended order. Measures were considered in isolation and increased or reduced savings that would result from delivery of multiple measures were not calculated. Although this exercise to identify and evaluate measures and the presentation of the results in this report consider each measure separately, it makes sense to deliver them together.

The Carbon Trust presented prioritised resource reduction opportunities to save carbon and money, as well as improving comfort, e.g. levels of heating. These prioritised opportunities illustrate the importance of adjustments to the building and behavioural change, often before implementing an expensive or impressive-looking physical measure. For example, at our Cross Hands building the recommended measures are:

1. Energy management supported by metering and monitoring
2. Upgrade fluorescent lights to LED
3. Increase roof insulation
4. Upgrade the boiler
5. Optimise boiler operation
6. Install a second solar array

For each technology, data has been presented for a generic NRW measure. Where the measure had been recommended for more than one building, this has been calculated from the results of all the relevant building assessments, usually by taking the mean of each technology to understand cost and carbon savings. Where a measure was recommended for only one site, that information was used as the data for the measure.

In calculating cost estimates, the Carbon Trust made the following standard assumptions:

- 3.5% discount rate (HM Treasury Green Book[21])
- 3.5% energy price escalator
- Lifetime appropriate to individual measures

Information gathered as part of our demonstration projects has been used to ground truth the information on measures, e.g. installing LED lights, solar PV and a new building management system.

However, it is recognised that in order to strengthen our evidence base and bridge existing evidence gaps, further audits will need to be commissioned for remaining NRW sites in future. These should be with consideration given to our low-carbon heat options in accordance with the action with the public sector low-carbon heat target for 2030 in the Welsh Government's *Prosperity for All: A Low Carbon Wales* delivery plan.[22]

4.1.3 Other building efficiency measures

The Carbon Positive Project researched other potential building efficiency measures: use of voltage optimisation, increased homeworking and increased desk utilisation. Information sources and measure specific methods are given in the relevant results section below.

4.1.4 Behavioural change

We commissioned the Carbon Trust to research and design a low-carbon behavioural change programme. We wanted a programme to design effective campaigns that was based on robust data and behavioural psychology.

The results of this work have led to campaigns by our Communications and Facilities Teams, supported by EMS Teams, e.g. sustainable travel pages on our intranet and decluttering areas around radiators. However, these specific measures have not been progressed to detailed evaluation due to it being difficult to assign savings to individual measures, although it was identified that savings of between 5-10% of total energy use may be achieved with investment in an energy awareness campaign to a value equivalent to between 1–2% of annual energy spend (Carbon Trust, 2011).

4.1.5 Scale of adoption

We have attempted to estimate the potential scale and feasibility of uptake of mitigation measures across NRW. Using the costs and carbon savings for each measure, whether for an indicative NRW building, or per installation (e.g. boiler, air conditioning unit), it is possible to estimate savings and costs across the organisation. The standard method for scaling up building measures across all NRW buildings is outlined below, together with

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[21] HM Treasury (2018) The Green Book: Central Government Guidance on Appraisal and Evaluation https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf Accessed 23/3/18

[22] Welsh Government (2019) Prosperity for All: A Low Carbon Wales https://gov.wales/sites/default/files/publications/2019-06/low-carbon-delivery-plan_1.pdf

assumptions. Where a method has been used that is specific to a measure, it has been described with the measure maxima results.

4.1.6 Assumptions made for buildings measures

- Estimates of savings and costs presented by the Carbon Trust in their assessments of our buildings are a representative sample of all NRW buildings. Therefore, it is assumed to be appropriate to scale-up a generic measure to the number of NRW buildings.

- NRW has 63 buildings to which these measures will apply. This total of 63 buildings is based on the organisation’s environmental reporting (EMS) and excludes gauging stations, pumping stations and buildings with no power.

- Savings, financial and carbon, are in direct proportion to, e.g. the amount of electricity used (LED), kg coolant (server).

- Energy data is 2016/17 EMS data.

4.1.7 Feasible maximum

For most building measures, the feasible maximum is the sum of savings identified by Carbon Trust assessments for specific buildings.

Local expertise has been used to support scaling up some of the building measures. This is made clear for each measure in reporting the maximum scales of adoption considered feasible and theoretical.

As previously noted, only 15 buildings were assessed due to NRW’s accommodation review. As a result, the feasible maximum is what was thought possible at the time on those buildings deemed secure during the review. As decisions are made about the future of our other buildings, the feasible maximum may increase.

4.1.8 Theoretical maximum

The theoretical maximum uptake of a mitigation measure may have been calculated in one of the following ways. A full explanation is provided on the method for each individual building measure.

1. The theoretical maximum may be the same as the feasible maximum. This is the case where a measure is an energy-saving solution specific to one building. For example, separating an NRW heating system from the adjacent building.

2. The theoretical maximum carbon and cost savings that could be achieved has been calculated by multiplying the individual measure by the number of NRW buildings. For example, the theoretical maximum carbon and cost savings that could be achieved by optimising heating schedules in our buildings is calculated by multiplying the metrics for a generic NRW building by the total number of NRW buildings. This is a crude estimate that

does not take account of the type of heating system, existing schedules or any other variables.

3. The theoretical maximum has been calculated using both specific data (as for 1) and multiplication of generic measure data (as for 2). For example, the theoretical maximum savings that could be achieved across all air-conditioning units has been calculated as the sum of:

- estimated savings for the four specific buildings for which we have the Carbon Trust data: Maes y Ffynnon, Monmouth, Rhuddlan and Llandovery,
  and

- estimated savings for all other coolant systems calculated by multiplying the quantity (kg) of coolant used per year[23] by the mean savings per kg of coolant (based on the four specific buildings).

4.1.9 Lessons learnt and caveats

- **Uncertainty of future accommodation**: we are considering our medium to long-term accommodation arrangements. This has limited our ability to identify and deliver building efficiency measures as payback periods often affect the economic feasibility of applying building measures. It may also affect the savings that could be achieved by optimising heating schedules. This is because payback periods for measures may be longer than the intended period of retention of the building, damaging the business case for change.

- **Further building energy assessments**: it is recommended that energy opportunity assessments are carried out on all NRW buildings being retained. Additionally, it is recommended that energy efficiency and renewable generation potential are influential considerations when identifying potential future buildings, whether leased or owned.

- **Detailed implementation preparation**: further investigation into the technical possibility of applying measures will be required to inform implementation, including surveys of individual buildings and investigating any planning requirements.

4.1.10 Summary of mitigation measures for buildings

Table 6 presents a summary of the mitigation measures identified for NRW buildings. These measures are aimed at reducing our direct scope 1 and 2 emissions.

For each technology, data has been presented for a generic NRW measure. Where a measure was recommended for only one site, that information was used as the data for the measure. Where a measure was recommended for more than one building, this was calculated from the results of all the relevant building assessments[24], usually by taking the

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[23] 2015/16 EMS data
[24] Carried out by the Carbon Trust. See 4.1.2 for more information.

mean of each technology to understand cost and carbon savings. Detail is provided in the reporting of each individual measure, later in this part of the report.

The values presented have been produced specifically for NRW and may not represent technology averages. Some of the mitigation measures will be very specific to NRW and may not be applicable to other organisations' buildings.

'n/a' denotes where information was unavailable or is not applicable to the measure.

Table 6: Individual mitigation measures

	Carbon savings		Cost analysis				
Mitigation measure	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual maintenance / recurring costs (£)	Estimated annual savings (£)
Renewable energy generation (self-supply)							
Install building-mounted solar PV (14.4 kWp NRW average array)	5.2	129.3	18,868	25	12.2	333	1,866
Heating and cooling							
Upgrade to biomass boiler (61 kW NRW average installation)	12.8	255.9	50,195	20	12.3	300	2,062
Upgrade conventional boiler (per boiler average)	2.3	46.7	4,833	20	11	n/a	509
Upgrade conventional electric heaters (one building)	4.6	28.5	4,250	6.2	4.7	n/a	1,141
Install new controls to optimise boiler operation (one building)	1	Lifetime not known	600	Not known	2.4	0	250
Optimise boiler operation or heating schedules (without new controls) (per building average)	0.9	Lifetime not known	0 (staff time only)	Not known	Immediate	0	192
Install air source heat pump (per building average)	17	339.0	25,500	20	8.3	n/a	2,823
Installation of drying room controls (per building)	1.2	11.5	190	10	1.1	n/a	292

Mitigation measure	Carbon savings		Cost analysis				
	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual maintenance / recurring costs (£)	Estimated annual savings (£)
Improve server room air-conditioning efficiency (per air-conditioning unit average)	0.5	Lifetime not known	275	Lifetime not known	1.1	n/a	124.5
Raise the temperature of a refrigerated container (per unit)	0.1	Lifetime not known	0 (staff time only)	n/a	0	0	30
Lighting							
Replacement of existing lights with LEDs (2.51 kW NRW average installation)	3.8	75.3	8,070	20	8.2	Included in annual savings	1,042
Energy management							
Adopt an energy management strategy supported by metering and monitoring (for a building with average energy use)	0.9	n/a	0 (staff time)	n/a	n/a	n/a	250
Improve roof insulation (average installation of 322 m^2)	1.7	34.5	2,197	20	10	n/a	230
Voltage optimisation (at NRW's largest office building)	18.0	270.5	15,700	15	4.8	0	3,279
Additional homeworking (for a building with average staff numbers of 43.5)	5.7	n/a	0	n/a	n/a	Included in annual savings	0 (for the organisation) 10,220 (for staff)
Hot water – point of use provision (per building average)	1.7	33	700	20	2.4	n/a	298

4.1.11 Solar Photovoltaic (PV) installations

Table 7: Summary of costs and CO_2e reduction from an “NRW average” solar PV installation

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£) per array	Estimated annual savings (£)
Install building-mounted solar PV (14.4 kWp NRW average array)	5.2	129.3	18,868	25	12.2	333.3	1,866

1. Description of the measure
Solar PV panels[25] are a renewable energy technology that convert sunlight into electricity. Self-generation in this way reduces both costs and greenhouse gas emissions associated with fossil fuel extraction, production and transportation to generate electricity supplied through the grid. Building mounted solar PV is a common microgeneration option for buildings with suitable roof space.

Of the 15 NRW buildings assessed by the Carbon Trust, solar PV installations were recommended for 10. Recommended installations ranged in size from 4.5 to 29.5 kWp, producing between 7.5 and 75.7% of the buildings’ electricity demand. The summary metrics presented for this measure in Table 7 relate to the average installation size suggested for NRW buildings (14.4 kWp). The average cost and carbon savings per kWp installed across all suggested installations were scaled up to provide indicative metrics for an NRW average 14.4 kWp installation.

2. Emission reduction potential
Across all ten sites, based on the Carbon Trust assessments, a kWp of installed solar capacity is predicted to save an average 0.36 tonnes CO_2e annually. This assumes the electricity generated by the PV panel replaces existing electricity use that would otherwise have been drawn from grid electricity.

An NRW average installation of 14.4 kWp would be expected to save 5.2 tCO_2e annually, amounting to a saving of 129.3 tCO_2e over its expected 25-year life.[26]

3. Cost
Across all 10 sites, based on the Carbon Trust assessments, the average capital cost of solar PV installations was estimated to be £1,307 / kWp installed (including labour costs). An NRW average installation of 14.4 kWp would be expected to have an indicative capital cost of £18,868 and achieve annual energy savings of £1,866.

[25] In the Buildings section of this report, reference to ‘solar PV’ relates to building mounted solar PV panels on our office and depot buildings. Use of solar PV on NRW’s operational assets and the use of solar PV as a ground mounted technology are considered in the ‘Land and Operational Assets’ section of this report.
[26] CIBSE Guide F (2012): Energy Efficiency in Buildings https://www.cibse.org/Knowledge/knowledge-items/detail?id=a0q20000008I7oTAAS Accessed 16/11/17

The average payback time for an array was estimated at 12.2 years, accounting for capital costs, annual maintenance costs, annual electricity savings, feed-in tariff income at the higher rate for 20 years and inverter replacement in year 11.

The Carbon Trust noted that they estimated capital costs conservatively. As solar PV costs are decreasing over time, capital costs may be less than estimated, dependent on installation.

4. Scale of adoption possible in NRW

i) Feasible maximum

The estimated feasible maximum relates to the 10 solar PV installations recommended by the Carbon Trust across the 15 buildings assessed. The totals from each Carbon Trust building audit report where solar PV was recommended were summed to provide the numbers below. However, the fact that only 15 buildings were assessed due to our accommodation review has constrained the feasible maximum in this instance, as assessments were limited to what were known to be secure buildings. This feasible maximum may increase as decisions are made with regards to the future of additional buildings.

- Feasible maximum electricity production per year: 120,090 kWh
- Feasible maximum combined installation size: 144.4 kWp
- Feasible maximum capital cost: £192,350
- Feasible maximum cost savings per year: £20,383
- Feasible maximum carbon savings per year: 52.1 tCO_2e

ii) Theoretical maximum

Ideally, the theoretical maximum capacity of solar panels that could be installed on NRW buildings would be estimated based on available roof area. This data set does not currently exist, but could be gathered as part of any future refinement of options appraisal for solar PV across NRW. In its place, total internal area of a building could be used as a proxy. However, upon reviewing existing solar installations at NRW sites, there is no correlation between the total internal area of building (adjusted for number of floors) and the potential size of solar PV array.

In the absence of other evidence, we used the Carbon Trust data for recommended solar PV installations on assessed buildings to infer what could be possible at all other NRW buildings. We estimated the average proportion of building electricity demand that would be provided by the 10 recommended PV installations would be 33%. We assumed that this scale of generation would also be possible through PV installations at unassessed buildings, deducting contributions made by any existing PV installations. This maximum generation capacity was scaled down to two-thirds to reflect the fact that the Carbon Trust recommended installations at ten out of 15 assessed sites. This figure in kWh was converted to kWp, indicating the combined size of the installations needed across the NRW estate. This conversion was based on the estimated average annual yield factor of the Carbon Trust-recommended installations (826 kWh generated per kWp installed). These estimates are organisation-wide figures and cannot be disaggregated to specific buildings or numbers of arrays. The theoretical maximum includes the assumed maximum generation capacity at unassessed buildings in addition to all Carbon Trust-recommended installations (the feasible maximum). Indicative costs and carbon savings associated with this theoretical maximum have been scaled up based on per kWp averages:

- Theoretical maximum electricity production per year: 576,953 kWh
- Theoretical maximum combined installation size: 697.6 kWp
- Theoretical maximum capital cost: £915,144
- Theoretical maximum cost savings per year: £91,874
- Theoretical maximum carbon savings per year: 250.3 tCO_2e

5. Benefits beyond greenhouse gas savings

- Reduced electricity bills: by reducing the amount of electricity drawn from the grid, solar PV panels reduce electricity bills. The long lifespan of the technology (25 years) mean that cost savings continue for some time.

- Increased property value: the installation of PV on NRW-owned buildings may increase the sale price of the property as the renewable energy generation may be attractive to buyers.

- Education, influence and engagement: by installing renewable technologies NRW will demonstrate and communicate the benefits of sustainability to the wider public sector. The installations may inspire the wider community to act to address the causes of climate change.

6. Examples of successful adoption

Solar PV panels have been installed successfully at ten NRW properties, including two visitor centres. In total, NRW generates about 73,000 kWh/a (2017).

At Maes y Ffynnon office, Bangor, the roof-mounted solar PV panel generates approximately 25,000 kWh of electricity annually, which is approximately 6% of total electricity consumed.

PV panels have been fitted on some of NRW's hydrometry and telemetry stations (see Appendix A.7: Retrofitting NRW's operational assets with solar PV: https://cdn.naturalresources.wales/media/686779/case-study-8-retrofitting-nrws-operational-assets-with-solar-pv.pdf).

Published information is available on the use of solar PV panels by the National Trust[27] and Sainsbury's[28].

7. Technical considerations

i) Positioning

To generate the most energy, the PV panels should not be shaded and should face the sun for as much of the day as possible. The following surveys and checks must be made before installation:

Mechanical and structural survey[29]

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[27] Bennett, P (2012) on Solar Power Portal, National Trust commits to a solar future http://www.solarpowerportal.co.uk/news/national_trust_commits_to_a_solar_future_2356 Accessed 4/9/17

[28] Bennett, P (2012) on Solar Power Portal, Sainsbury's UK solar rollout makes it UK's largest rooftop PV operator https://www.solarpowerportal.co.uk/news/sainsburys_uk_solar_rollout_makes_it_europes_largest_pv_operator_2356 Accessed 4/9/17

[29] Energy audit reports of NRW buildings by the Carbon Trust, August 2016

- measuring the external and internal roof space
- assessing the type of roof structure for panel, wind and snow loading
- assessing the type of roof material (fibrous cement / ceramic tiles /slate tiles / steel roof sheets, etc)
- assessing and measuring any obstructions (chimneys, trees, etc)
- assessing access requirements for scaffolding

Electrical survey
- a thorough assessment of the building electrics
- an assessment of the existing distribution board
- earthing requirements
- distance from consumer unit to PV array
- potential location of the inverters and total generation meter
- potential upgrading required to consumer unit
- cable runs from PV system to inverters to consumer unit

ii) Distribution Network Operator (DNO) approval: permission is required to connect more than 3.68 kWp to a single-phase connection, more than 7.36 kWp to a two-phase connection, or more than 11 kWp to a three-phase connection. Permission is also required for multiple systems to be installed in a single area.

iii) Planning permission: contact local planning authority to determine if planning permission is required.

iv) Energy Performance Certificate: establish whether the site is a ‘relevant building’.

4.1.12 Upgrade to biomass boiler

Table 8: Summary of costs and CO_2e reduction from an “NRW average” boiler upgrade to biomass

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Upgrade to biomass boiler (61 kW)	12.8	255.9	50,195	20	12.3	300	2,062

1. Description
Biomass (wood-fuelled) boilers work most effectively at sites where there is a constant year-round heat demand, such as at leisure centres or hospitals, and a reliable local fuel supply. They are not usually suitable as the sole heating mechanism for offices which have variable heating needs, or at small sites because of the space needed for delivery and dry storage of fuel.

Within the NRW estate, there are six installed biomass boilers, three of which are at our largest visitor centres. These are likely to be our sites that most closely meet the constant heat demand and space requirements.

Of the 15 NRW buildings assessed by the Carbon Trust, biomass boilers were recommended as a possible option to reduce heating emissions at two sites. The summary metrics presented for this measure in Table 8 relate to the average installation size for NRW buildings (61 kW). The average cost and carbon savings per kW installed were based on the two suggested installations, supplemented by data for two existing biomass boilers on the NRW estate. These were scaled up to provide indicative metrics for an NRW average 61 kW installation.

2. Emission reduction potential

Across the two recommended and two supplemental installations, each installed kW is predicted to save an average 0.21 tCO_2e annually.

An NRW average installation of 61 kW would be expected to save 12.8 tCO_2e annually, amounting to savings of 255.9 tCO_2e over its expected 20-year life.

Using biomass to fuel a boiler can be a low-carbon alternative to oil, gas or liquid petroleum gas (LPG) boilers. The global warming impact of CO_2 emissions from combustion of wood fuel in a biomass boiler is considered to be net zero, because the CO_2 released was absorbed during the growth of the biomass (Ricardo-AEA and Carbon Smart, 2015). Although there are additional emissions associated with the production and transportation of wood fuel, these are lower than fossil fuel emissions.[30]

3. Cost

Based on the two Carbon Trust and two supplemental installations, the indicative capital cost of biomass boiler installation was estimated to be £823 / kW installed. The scope of the capital costs varied between the sites, with one including an automatic vacuum feeder and another including a supporting wet radiator system.

An NRW average installation of 61 kW would be expected to have an indicative capital cost of £50,195 and achieve annual energy savings of £2,062.

The average payback time for a boiler installation was estimated to be 12.3 years, accounting for capital costs, annual maintenance costs, annual fuel cost savings and receipt of Renewable Heat Incentive payments.[31]

4. Scale of adoption

i) Feasible maximum

The estimated feasible maximum relates to the two biomass boiler installations recommended by the Carbon Trust across the 15 buildings assessed. The totals from the two Carbon Trust building audit reports where biomass was recommended were summed to provide the numbers below.

[30] http://www.energysavingtrust.org.uk/renewable-energy/heat/biomass (accessed 13/11/17)
[31] https://www.ofgem.gov.uk/environmental-programmes/non-domestic-rhi

- Feasible maximum energy savings per year: 2,000 kWh[32]
- Feasible maximum combined installation size: 135 kW
- Feasible maximum capital cost: £94,263
- Feasible maximum cost savings per year: £6862
- Feasible maximum carbon savings per year: 28.6 tCO_2e

ii) Theoretical maximum
Based on the organisation's Environmental Management Systems records, we estimated that, at the time of writing, there were 27 additional buildings heated primarily by some form of fossil fuel that were not assessed during building energy audits. We used the Carbon Trust data for recommended biomass boiler upgrades to infer what might be possible in these other NRW buildings – we assumed that the same proportion of unassessed boilers / heaters could be upgraded to biomass as those that were assessed. Without building audits we were unable to make assumptions on potential biomass installation sizes; we therefore used the cost and carbon savings for the average installation given in Table 8 to provide a rough indication of savings possible in unassessed buildings. These were added to the feasible maximum Carbon Trust recommended upgrades to provide theoretical maxima possible across all NRW buildings:

- Theoretical maximum energy savings per year: 7,250 kWh
- Theoretical maximum number of upgrades: 7
- Theoretical maximum capital cost: £320,140
- Theoretical maximum cost savings per year: £16,141
- Theoretical maximum carbon savings per year: 86.2 tCO_2e

This theoretical maximum scenario is likely to be an overestimate of potential for biomass installations on the NRW estate given that it does not account for fuel supply availability, storage space or heat load profiles at the unassessed buildings. At both assessed sites for which the Carbon Trust recommended biomass boiler installations they also presented alternative potential heating upgrade measures which may prove more viable upon further site investigations.

5. Benefits beyond greenhouse gas savings
    - Many current heating systems are inefficient and due for replacement. Taking the opportunity to replace these with renewable technology will bring future cost benefits as well as carbon benefits.
    - The use of biomass boilers creates employment in the harvesting, preparing and delivery of wood.
    - Increased energy efficiency.
    - Wood grown on our own estates could be used to fuel the boilers.
    - Reduced fuel price volatility.

[32] The Carbon Trust estimated that one of the recommended biomass boiler installations would reduce heating energy demand but the other would not, providing emissions savings through the change in fuel rather than energy efficiency.

- Could use fuel from materials which may otherwise be disposed of as landfill.

- Increased awareness amongst staff of renewable technologies.

6. Examples of successful adoption
   - NRW Case Study: biomass boiler
   - Calke Abbey – National Trust[33]
   - East Coast Renewables[34]

7. Technical considerations
   - An in-depth site assessment would need to be carried out to determine if facilities exist for delivery and dry storage of the biomass fuel.

   - Planning permission may be needed at some offices if a facility would need to be built to accommodate the fuel storage.

   - Consideration would also need to be given to the current heating in the building. replacement of storage heaters would require installation of a wet radiator system, which would significantly increase the capital investment required.

4.1.13 Upgrade conventional boiler or electric heater

Table 9: Summary of average costs and CO_2e reduction from conventional boiler and electric heater upgrades recommended for NRW

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Upgrade conventional boiler (per boiler)	2.3	46.7	4,833	20	11	Not available	509
Upgrade conventional electric heaters (one building)	4.6	28.5	4,250	6.2	4.7	Not available	1,141

1. Description
Replacing conventional boilers or electric heaters towards the end of their serviceable lives will save fuel through the increased efficiency of conversion to heat. This could be

[33] National Trust (2013) Sustainable Technology Case Study: Biomass Boiler https://www.nationaltrust.org.uk/calke-abbey/documents/calke-abbey-biomass-boiler.pdf Accessed 27/03/2018
[34] East Coast Renewables: Guide to Biomass Heating http://www.adheating.co.uk/EastCoastRenewables%20Biomass%20Brochure.pdf Accessed 27/03/2018

replacement with a new high-efficiency boiler of the same fuel type or an alternative fuel type, e.g. from oil to LPG to reduce associated emissions.

Of the 15 NRW buildings assessed by the Carbon Trust, conventional boiler upgrades were recommended as a means of saving energy and reducing emissions at three sites, and an electric storage heater upgrade at one site. The three suggested boiler upgrades were the replacement of a kerosene boiler with a condensing LPG boiler, replacing two existing gas condensing boilers at the end of their lives with one new gas boiler, and replacing an existing oil burner at the end of its life with a new condensing oil boiler. The summary metrics presented for this measure in Table 9 are split by conventional boiler upgrade and electric storage heater upgrade. The metrics for boiler upgrades are averages across the three recommended sites, presented per boiler. For two of the boilers, no information on installation size was provided, therefore it was not possible to present metrics scaled up per kW installed to the average installation size, as with most other mitigation measures. The metrics for electric heater upgrade relates to a single building only (i.e. these are not average or typical figures).

2. Emission reduction potential

Replacing the old gas boilers was expected to increase boiler efficiency from 75% to 92% and would potentially reduce annual gas consumption by 18%. Similarly, oil consumption savings of 15% were expected through upgrading the old oil boiler to a new energy efficient unit. The three different boiler upgrades recommended by the Carbon Trust had emission reduction potentials ranging from 1.4 to 3 tCO_2e annually. The average annual reduction in emissions across the three installations was expected to be 2.3 tCO_2e.

Replacing the old electric storage heaters with new direct electric heaters at the site where this was recommended was estimated to reduce annual emissions by 4.6 tCO_2e.

3. Cost

The capital cost of conventional boiler upgrades across the three sites ranged from £2,500 for the oil burner upgrade to £7,000 for the kerosene to LPG boiler upgrade. The average capital cost of the three recommended installations was £4,833.

The average payback time for these conventional boiler upgrades was estimated to be 11 years, accounting for capital costs and annual fuel cost savings. It was not clear whether annual maintenance costs were accounted for within the annual cost savings.

The capital cost of the electric storage heater upgrade was estimated to be £11,220 for the installation of 17 x 2 Kw units.

4. Scale of adoption

i) Feasible maximum

The estimated feasible maximum relates to the three conventional boiler upgrades and one electric storage heater upgrade recommended by the Carbon Trust across the 15 buildings assessed. The totals from the four Carbon Trust building audit reports were summed to provide the numbers below.

- Feasible maximum energy savings per year: 40,438 kWh
- Feasible maximum number of upgrades: 4
- Feasible maximum capital cost: £18,750
- Feasible maximum cost savings per year: £2,669

- Feasible maximum carbon savings per year: 11.6 tCO_2e

ii) Theoretical maximum
Based on the organisation's Environmental Management Systems records we estimated that, at the time of writing, there were 15 additional oil or gas boiler heated NRW buildings and 11 additional electric heated buildings not assessed during building energy audits. We used the Carbon Trust data for recommended boiler and electric heater upgrades to infer what might be possible in these other NRW buildings – we assumed that the same proportion of unassessed boilers and heaters could be upgraded as for those that were assessed. Because we lacked information on installation size for the upgrades in assessed buildings, our average installation metrics in Table 9 are per boiler rather than for a specific average installation size scaled up per kW installed. The additional number of boilers and electric heaters that we assumed could be upgraded were multiplied by the metrics in Table 9 to provide a rough indication of the scale of carbon and cost savings possible in unassessed buildings. These were added to the feasible maximum Carbon Trust recommended upgrades to provide theoretical maxima possible across all NRW buildings:

- Theoretical maximum energy savings per year: 115,792 kWh
- Theoretical maximum number of upgrades: 12
- Theoretical maximum capital cost: £53,729
- Theoretical maximum cost savings per year: £7,626
- Theoretical maximum carbon savings per year: 33.2 tCO_2e

4.1.14 Optimise boiler operation or heating schedules

Table 10: Summary of average costs and CO_2e reduction from optimising boiler operation or heating schedules, both with and without the installation of new controls

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Install new controls to optimise boiler operation (one building)	1	Lifetime not known	600	Not known	2.4	0	250
Optimise boiler operation or heating schedules (without new controls) (per building)	0.9	Lifetime not known	0 (staff time only)	Not known	Immediate	0	192

1. Description
Optimising boiler operation or heating schedules provides low / no cost opportunities to reduce emissions and reduce costs associated with heating buildings. The key principle is to align heating more closely to occupancy and reduce the energy waste of heating

unoccupied or low occupancy space. This may include the use of seven-day timers, ensuring that weekend workers use a specific part of a building, creating zone controls to heat different parts of a building, using thermostats for occupied and unoccupied periods, installing optimum start controller, educating selected individuals to operate the boiler efficiently, and monitoring energy consumption.

Of the 15 NRW buildings assessed by the Carbon Trust, optimising boiler operation / heating schedules was recommended as a possible option to reduce heating emissions at six sites, with associated costs and carbon savings provided for four sites. The summary metrics presented for this measure in Table 10 relate to two options for optimisation of boiler operation / heating schedules across boiler and fuel types: 1) with, and 2) without the installation of new controls. The metrics for the installation of new controls relate to a single building only (i.e. these are not average or typical figures). The metrics for application without new controls are averages across the other three buildings for which the measure was recommended.

2. Emission reduction potential
Optimisation of boiler operation / heating schedules through the installation of new controls at the one building for which it was recommended was estimated to save 1 tCO_2e/year. Estimated annual emissions savings at the three other sites ranged from 0.3 to 2 tCO_2e/year with an average of 0.9 tCO_2e/year.

3. Cost
For the building where the installation of controls was recommended, the capital cost was estimated to be £600, and annual energy cost savings £250. The payback time would therefore be 2.4 years.

To implement this measure in the other three buildings, without controls, there was zero estimated capital cost, with the only cost implication being staff time. The average capital cost of this measure with the installation of controls was therefore estimated to be zero.

4. Scale of adoption
i) Feasible maximum
The feasible maximum relates to the four buildings for which optimisation of boiler operation and heating schedules were recommended. The totals from the four Carbon Trust building audit reports were summed to provide the numbers below:

- Feasible maximum energy savings per year: 23,073 kWh
- Feasible maximum number of buildings: 4
- Feasible maximum capital cost: £600
- Feasible maximum cost savings per year: £827
- Feasible maximum carbon savings per year: 3.6 tCO_2e

ii) Theoretical maximum
Based on the organisation's Environmental Management Systems records, we estimated that, at the time of writing, there were 36 additional heated buildings not assessed during building energy audits. We used the Carbon Trust data for recommended boiler or heating schedule optimisation to infer what might be possible in these other NRW buildings – we assumed that the same proportion of unassessed buildings could achieve energy savings through heating optimisation. Because we lacked information on percentage of heating energy saved through this measure at some of the assessed sites, it was not possible to

infer savings at unassessed sites in this way. Instead, we used the average savings across all four sites, per building, to provide a rough indication of the scale of cost and carbon savings that might be possible across all unassessed buildings. These were added to the feasible maximum Carbon Trust recommended upgrades to provide theoretical maxima possible across all NRW buildings:

- Theoretical maximum energy savings per year: 106,135.8 kWh
- Theoretical maximum number of buildings: 21
- Theoretical maximum capital cost: £2,760
- Theoretical maximum cost savings per year: £3,804
- Theoretical maximum carbon savings per year: 16.6 tCO_2e

4.1.15 Air source heat pump system

Table 11: Summary of average costs and CO_2e reductions from air source heat pump installations recommended for NRW

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Air source heat pump system (per building average)	17	339.0	25,500	20	8.3	Not given	2,823

1. Description
Air source heat pumps (ASHPs) are a form of low-carbon heating technology that extract heat from the outside air, even in cold weather. ASHPs are relatively easy to install in both new and existing buildings. They are most effective and economic in well-insulated properties. Although pumps run on electricity, they produce two to four times more heat energy than they use electrical energy.

Of the 15 NRW buildings assessed by the Carbon Trust, ASHP installations were recommended as energy-saving measures at two sites. Both buildings are portacabins currently heated by electric storage and/or convector heaters. The summary metrics presented in Table 11 are averages across the two buildings, presented per ASHP installation. No information on system size (kW) was provided, therefore it was not possible to present metrics scaled up per kW installed to the average installation size.

2. Emission reduction potential
Estimated annual emissions savings associated with the two recommended ASHP installations ranged from 5.9 to 28 tCO_2e, with an average of 16.95 tCO_2e. Details of the size of the installations in kW were not provided, therefore it is not possible to present indicative emissions savings per kW installed.

3. Cost
The capital cost of the recommended ASHP installations was £11,000 in one building and £40,000 in the other, with an average of £25,500. This difference in capital cost between the two installations reflects differences in installation size determined by building heat energy requirements.

Average annual energy cost savings were estimated to be £2,823, with an average payback time of 8.3 years. ASHPs require minimal maintenance; however, it was not clear from the building audit reports whether annual maintenance costs were accounted for within the annual cost savings, nor whether potential income from the Renewable Heat Incentive was included.

4. Scale of adoption
i) Feasible maximum
The estimated feasible maximum relates to the two ASHP installations recommended by the Carbon Trust across the 15 buildings assessed. The totals from the two building audit reports were summed to provide the numbers below:

- Feasible maximum energy savings per year: 73,371 kWh
- Feasible maximum number of ASHP installations: 2
- Feasible maximum capital cost: £51,000
- Feasible maximum cost savings per year: £5,646
- Feasible maximum carbon savings per year: 33.9 tCO_2e

ii) Theoretical maximum
Based on the organisation's EMS records we estimated that, at the time of writing, there were 16 unassessed heated buildings without access to mains gas and without an existing biomass boiler (i.e. heated by electric, LPG or oil), and therefore considered potential candidates for ASHP installation. We used the Carbon Trust data for recommended ASHP installations to infer what might be possible in these other NRW buildings – we assumed that the same proportion of unassessed buildings could achieve energy savings through an ASHP installation. Because we lacked information on installation sizes for the recommended sites, it was not possible to infer savings based on kW installed for unassessed buildings. Instead we used the average savings across the two assessed sites, per building. This approach fails to account for the size, energy use or fuel type of the unassessed buildings but provides a rough indication of the scale of cost and carbon savings that might be possible. These were added to the feasible maximum Carbon Trust recommended upgrades to provide theoretical maxima possible across all NRW buildings:

- Theoretical maximum energy savings per year: 241,076 kWh
- Theoretical maximum number of ASHP installations: 7
- Theoretical maximum capital cost: £167,571
- Theoretical maximum cost savings per year: £18,551
- Theoretical maximum carbon savings per year: 111.4 tCO_2e

5. Benefits beyond greenhouse gas savings
- Increased awareness among staff of renewable technologies.
- Many current heating systems are inefficient and due for replacement; taking the opportunity to replace these with renewable technology will bring future cost benefits as well as carbon benefits.
- Increased energy efficiency.

- Reduced fuel price volatility.
- Air source and ground source heat pumps can also provide a cooling function.

6. Examples of successful adoption
Grade II listed building:
https://www.nationaltrust.org.uk/hughenden/documents/hughenden-heat-pumps.pdf
https://www.nationaltrust.org.uk/the-needles-old-battery-and-new-battery/documents/the-needles-heat-pump.pdf

7. Technical considerations
- It is essential that buildings are well-insulated prior to ASHP installation to ensure maximum efficiency.
- A feasibility assessment would be required for individual buildings to see whether conditions are appropriate to install air source heat pump system.
- A suitable location is required to house an external unit.
- Noise created by the ASHP should be considered.

4.1.16 Installation of drying room controls

Table 12: Summary of average costs and CO_2e reductions from drying room control installations recommended for NRW

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Installation of drying room controls (per building)	1.2	11.5	190	10	1.1	Not estimated	292

1. Description
Drying rooms are used to dry out clothing and kit used in NRW's operations. This is for both health and safety, and biosecurity reasons. Where drying room heaters are poorly controlled and are consistently left on, energy savings can be made by installing controls to better match heating times to drying needs and minimise unnecessary use.

Of the 15 NRW buildings assessed by the Carbon Trust, drying rooms were present at three sites and the installation of controls to reduce heating energy use was recommended at two of these. At both sites it was observed that the heaters are rarely or never turned off. For one drying room with a convector heater, an auto shut-off push timer button was recommended to control the length of time the heater is left on. For the other, with an electrical fan heater, installation of a timer control was recommended to ensure switch off when not in use.

2. Emission reduction potential

The estimated annual energy savings possible through the two drying room control installations are 1600 kWh and 3540 kWh, with associated annual emissions savings of 0.7 and 1.6 tCO_2e, averaging 1.15 tCO_2e. The smaller saving relates to the installation of controls on a 2.4 kW heater, whilst the size of the heater was not specified for the other drying room.

3. Cost

The capital costs of the recommended controller installations were £50 in one drying room and £330 in the other, with an average of £190. The higher cost estimate includes installation of a new heater unit.

Average annual energy cost savings were estimated to be £292 with an average payback time of 1.1 years.

4. Scale of adoption

i) Feasible maximum

The estimated feasible maximum relates to the two dryer room control installations recommended by the Carbon Trust across the 15 buildings assessed. The totals from the two building audit reports were summed to provide the numbers below:

- Feasible maximum energy savings per year: 5,140 kWh
- Feasible maximum number of installations: 2
- Feasible maximum capital cost: £380
- Feasible maximum cost savings per year: £584
- Feasible maximum carbon savings per year: 2.3 tCO_2e

ii) Theoretical maximum

There is currently no record of the number of drying rooms in NRW buildings. Based on our EMS Team's knowledge of the NRW estate it was estimated that there are approximately 22 unassessed drying rooms. We assumed that the installation of controls could help to save energy in the same proportion of drying rooms for which the measure was recommended in assessed buildings. Without a record of drying room heater sizes, we applied the average costs and carbon savings from the application of this measure in the two assessed sites to this additional number of sites. These figures were added to the feasible maximum Carbon Trust recommended installations to provide a theoretical maximum for this measure across all NRW buildings:

- Theoretical maximum energy savings per year: 42,833 kWh
- Theoretical maximum number of installations: 17
- Theoretical maximum capital cost: £3,167
- Theoretical maximum cost savings per year: £4,867
- Theoretical maximum carbon savings per year: 19.2 tCO_2e

5. Examples of successful adoption

- Push-timer buttons are in use in Buckley and Rhuddlan drying rooms.

6. Technical considerations

Operation of the drying room must ensure that kit is fully dry (i.e. dry for 48 hours). This is for health and safety, and biosecurity reasons.

4.1.17 Improve server room air-conditioning efficiency

Table 13: Summary of average costs and CO_2e reductions from improvements in server room air-conditioning efficiency recommended for NRW

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Improve server room air-conditioning efficiency (per air-conditioning unit average)	0.5	Lifetime not known	275	Lifetime not known	1.1	Not given	124.5

1. Description
Improving the efficiency of server room cooling reduces the energy demand of keeping equipment within specified operating temperature ranges, providing a low-cost opportunity to reduce emissions and costs. This can be done through improved server room design or management of air-conditioning units. The aim is to tailor the cooling to the system it serves and reduce the energy waste of cooling unnecessary space.

Of the 15 NRW buildings assessed by the Carbon Trust, improvements to server room cooling were recommended for nine air conditioning units in four buildings. The suggested improvements varied by site, and were:

- Rationalising server room cooling through measures such as blacking out windows in server rooms to prevent heat gains.
- Improving server room layout by constructing a stud wall to contain the space being cooled.
- Increasing the temperature set point of the air-conditioning unit whilst staying within the operating range of the server.

The summary metrics presented for this measure in Table 13 are averages across the nine air-conditioning units for which improvements were recommended, presented per air-conditioning unit. These are all small or medium stationary air-conditioning units.

2. Emission reduction potential
The estimated annual energy savings possible through the recommended improvements to server room air-conditioning range from 501 to 2602 kWh per air-conditioning unit, with associated annual emissions ranging from 0.2 to 1.2 tCO_2e. The average annual emissions reduction across all nine units is 0.5 tCO_2e.

3. Cost
For eight out of the nine air-conditioning unit improvements recommended there were zero estimated capital costs. These improvements would require staff time to deliver changes in the management of server room cooling. For the ninth unit, capital costs related to the construction of a stud wall to reduce the area to be cooled. The average capital cost of the recommended air-conditioning improvements in server rooms was therefore £275 per air-conditioning unit.

Annual energy cost savings ranged from £60 to £260 per air-conditioning unit, with an average of £124.50. The average estimated payback time is 1.1 years.

4. Scale of adoption
i) Feasible maximum
The estimated feasible maximum relates to the nine air-conditioning units and four server rooms for which improvements were recommended by the Carbon Trust. The totals from these four building audit reports were summed to provide the numbers below:

- Feasible maximum energy savings per year: 9,546 kWh
- Feasible maximum number of air-conditioning units: 9 air-conditioning units in 4 server rooms
- Feasible maximum capital cost: £1,100
- Feasible maximum cost savings per year: £1,088
- Feasible maximum carbon savings per year: 4.4 tCO_2e

ii) Theoretical maximum
Based on the EMS inventory of equipment containing fluorinated gas or ozone-depleting substances, there are three additional air-conditioning units in server rooms in unassessed NRW buildings. We assumed that server room management could provide energy savings for the same proportion of air-conditioning units in unassessed as assessed buildings, i.e. could be applied to all units. We applied the average costs and carbon savings estimated per air-conditioning unit in assessed buildings to the three in unassessed buildings. These figures were added to the feasible maximum Carbon Trust recommended applications of this measure to provide a theoretical maximum across all NRW buildings:

- Theoretical maximum energy savings per year: 13,020 kWh
- Theoretical maximum number of air-conditioning units: 12 air-conditioning units in 7 server rooms
- Theoretical maximum capital cost: £1,925
- Theoretical maximum cost savings per year: £1,462
- Theoretical maximum carbon savings per year: 6 tCO_2e

This may be an underestimate of the maximum potential of this measure across the NRW buildings estate as it is possible that some of the air-conditioned server rooms have been classed as communication rooms and therefore not accounted for in this calculation.

5. Technical considerations

- Guidance from the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE)[35] has recommended that most modern servers can operate at the upper end of a temperature range of 18 to 27˚C. The specified operating range of equipment should be investigated with the IT department.

- Incrementally increasing the set points will reduce the risk of adverse effects as temperature approaches the upper limit of the ASHRAE-recommended operating range (27°C).

- The IT department should be included in decisions to alter server room temperatures.

- Risks include IT equipment operating at or beyond recommended temperature levels and increased fan operation in the IT equipment.

- Air-conditioning units must remain sufficiently cooled to prevent server equipment from overheating.

4.1.18 Raise the temperature of refrigerated containers (deer larders)

Table 14: Summary of the costs and CO_2e reductions resulting from raising the temperature of a refrigerated container

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Raise the temperature of a refrigerated container (per unit)	0.1	Lifetime not known	0 (staff time only)	n/a	0	0	30

1. Description

Management of refrigerated containers (e.g. deer larders) through measures such as reviewing operating hours, checking the operation of settings and sensors, and increasing the temperature set point may lead to operational energy savings. NRW aims to cool refrigerated containers used to store culled deer to 3°C. This may provide an opportunity to increase the temperature set points of containers, whilst maintaining a safe temperature adhering to food standards regulations.

[35] Guidance from the American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE) https://www.ashrae.org/home (accessed 15/11/17)

Of the 15 NRW buildings assessed by the Carbon Trust, two have refrigerated deer larders and energy management measures were recommended for one of these. Raising the temperature set point of this container to 4°C was suggested as an energy-saving measure. The summary metrics presented in Table 14 relate to the application of this measure to the one recommended deer larder (i.e. these are not average or typical figures).

2. Emission reduction potential
The estimated annual energy saving possible through applying this measure to the one refrigerated container is 280 kWh leading to annual emissions savings of 0.1 tCO_2e.

3. Cost
There was no capital cost associated with the recommended application of this measure to the one refrigerated container, with the only cost being staff time for delivery. The measure was predicted to achieve energy cost savings of £30 annually.

4. Scale of adoption
i) Feasible maximum
The estimated feasible maximum relates to the one deer larder for which this measure was recommended by the Carbon Trust:

- Feasible maximum energy savings per year: 280 kWh
- Feasible maximum number of containers: 1
- Feasible maximum capital cost: £0
- Feasible maximum cost savings per year: £30
- Feasible maximum carbon savings per year: 0.1 tCO_2e

ii) Theoretical maximum
Based on the EMS inventory of equipment containing fluorinated gas or ozone-depleting substances, there are two additional refrigerated containers (deer larders) in unassessed buildings. We assumed that management of refrigerated containers could provide energy savings for the same proportion of units in unassessed as assessed buildings (i.e. ½). We applied the cost and carbon savings estimated for the single assessed deer larder to the additional one in the unassessed building. These were added to the feasible maximum to provide a theoretical maximum for all NRW buildings:

- Theoretical maximum energy savings per year: 560 kWh
- Theoretical maximum number of containers: 2
- Theoretical maximum capital cost: £0
- Theoretical maximum cost savings per year: £60
- Theoretical maximum carbon savings per year: 0.2 tCO_2e

4.1.19 LED[36] lighting in offices

Table 15: Summary of costs and CO_2e reduction of an "NRW average" LED installation, replacing existing office lighting

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
LED lighting installation (2.51 kW)	3.8	75.3	8,070	20	8.2	Included in annual savings	1,042

1. Description
Lighting can account for up to 40% of electricity use in buildings. Outdated light fittings can be both energy inefficient and not deliver the required lighting for staff. Replacing T8 fluorescent lighting with LEDs can save up to 80% of electricity consumption and may improve the quality of lighting. LED lighting has a long economic life span and requires significantly less maintenance than traditional tubes, therefore maintenance savings may be made on top of expected energy savings. Further energy savings may be possible by installing movement-detecting infra-red sensors to the light fittings to ensure that lights are only switched on when they are needed (this was identified as an opportunity for NRW's Resolven office by the Carbon Trust).

Of the NRW buildings assessed by the Carbon Trust, LED installations were recommended for all 15. Detailed data on the range of suggested light fittings for the buildings were provided for 11 buildings. These 11 installations ranged in total combined LED rating size from 0.8 to 6.9 kW and provided an average reduction in the total operational wattage of installed lighting of 66.5%. The Carbon Trust assessments assumed that the number of lights and usage remained the same in each building but with pre-existing lamps and tubes replaced by lower wattage LEDs. The most common existing lighting across the 15 buildings assessed by the Carbon Trust was T8 fluorescent lamps. Other existing internal lights included T5 fluorescent tubes, 2D fluorescent lamps, halogen-based luminaries and a small number of compact fluorescent lamps. Where assessed, external light fittings were all SON-T sodium lamps.

The summary metrics presented for this measure in Table 15 relate to the average total installation size suggested for the 11 NRW buildings (2.51 kW). Electricity savings arising from this average installation were estimated based on the average percentage reduction in installed wattage and average operational hours for all light fixtures in the 11 offices with detailed data. The average capital cost per kW installed and average cost and carbon savings per kWh saved across the 11 installations were scaled up to provide indicative metrics for an installation with a combined rating of 2.51 kW.

[36] LED: light-emitting diode

2. Emission reduction potential
For the 11 buildings where a detailed breakdown of light fittings and associated energy use were provided, replacing the current lighting with LEDs would reduce building lighting electricity demand by an average of 68.3%.

An average NRW office LED installation (2.51 kW) in operation for 1674.4 hours (the average of all light fittings across the 11 buildings) would save approximately 8339.3 kWh of electricity annually, compared to current light fittings.

3. Cost
The financial calculations for LED lighting are based on Carbon Trust indicative costs for full luminaire and lamp or tube replacements with “mid-market quality products”. Across the 11 buildings with a detailed breakdown of lighting data, the average capital cost of full LED installations was estimated to be £3,218 per kW installed (including labour costs).

An NRW average installation of 2.51 kW would be expected to have an indicative capital cost of £8,070 and achieve annual cost savings of £1,042.

The average payback time was estimated to be 8.2 years, accounting for capital costs, annual electricity savings and annual maintenance savings.

The average cost of installation per kW used by the Carbon Trust varied between audits and is likely to reflect market changes during the period over which the buildings assessments were carried out.

For 11 of the 15 buildings that Carbon Trust have identified as suitable for LED lighting replacement and provided indicative costs, actual cost figures are available. A comparison of the cost figures shows considerable differences between indicative and actual costs for several of the buildings. However, as the mean of indicative costs (£8,592) and mean of actual costs (£8,983) are similar, and actual costs are not available for all 15 buildings, Carbon Trust indicative costs have been used for this calculation.

4. Scale of adoption
i) Feasible maximum
The estimated feasible maximum relates to the 15 office LED installations recommended by the Carbon Trust. The totals from each building audit report were summed to provide the numbers below.

- Feasible maximum electricity savings per year: 152,876 kWh
- Feasible maximum combined installation size: 42.9 kW[37]
- Feasible maximum capital cost: £128,884
- Feasible maximum cost savings per year: £18,949
- Feasible maximum carbon savings per year: 69.3 tCO_2e

[37] The total installation sizes for four buildings were not provided in the Carbon Trust assessment reports. To present the feasible maximum for the full set of 15 assessed buildings we estimated the size of these installations based on the electricity savings provided (kWh), the average operational hours of all other light fittings and the average reduction in installed wattage achieved through LED installation at the other 11 buildings.

As part of our Invest to Save programme, LED lighting has been or is being installed at 11 NRW properties. NRW is considering its long-term accommodation arrangements. This may affect the economic feasibility of installing LED lights in buildings. At present, the recommendations by Carbon Trust are considered the current feasible maximum. This should be reviewed in future to incorporate LED lighting into other buildings where feasible. There may also be technical constraints to installing LEDs in some buildings (see section g) below).

ii) Theoretical maximum
In the absence of individual energy audits for all NRW buildings, we used the Carbon Trust recommendations for LED installations in assessed buildings to infer what could be possible in all other NRW buildings. It was assumed that LEDs could be installed at all NRW buildings that use electricity, reflecting the recommendation that LEDs could be installed in all assessed buildings.

Using electricity data recorded as part of our Environmental Management System for 2016/17, and assuming that 29.9% of total building demand was used for lighting[38], we estimated the current electricity demand for lighting in all NRW buildings not audited. From this we estimated what the total electricity use would be across these buildings if all lights were replaced with LEDs, based on the NRW average percentage reduction in lighting electricity following LED installations in the Carbon Trust assessments. We estimated the corresponding installation size in kW assuming that the lights would be in use for the average number of hours that all NRW lights were operational across the Carbon Trust assessments. This estimated potential in non-audited buildings was added to the Carbon Trust-recommended installations to provide the theoretical maximum.

As with the “average NRW” installation presented in Table 15, the average capital cost per kW installed and average cost and carbon savings per kWh saved across the 11 installations were scaled up to provide indicative metrics for an installation with the combined theoretical maximum rating:

- Theoretical maximum electricity savings per year: 522,403.7 kWh
- Theoretical maximum combined installation size: 145.2 kW
- Theoretical maximum capital cost: £458,097
- Theoretical maximum cost savings per year: £65,112
- Theoretical maximum carbon savings per year: 236.2 tCO_2e

5. Benefits beyond greenhouse gas savings

- Environmentally friendly – LEDs do not contain pollutants, unlike fluorescent lighting which can use mercury or lead, which may pose a danger to the environment. They are also 100% recyclable and are considered “green” or Earth-friendly.

- No heat – LEDs emit no heat therefore there is no risk of burns or combustion compared with traditional lighting. The reduced heat also decreases the load on air conditioning systems.

[38] 29.9% was the average percentage of total building electricity demand used for lighting across the 11 NRW audited buildings for which the Carbon Trust provided a detailed breakdown of lighting recommendations.

- Better working environment – LED lights are designed to focus their light and can be directed to a specific location without the use of an external reflector, achieving higher application efficiency than conventional lighting. Well-designed LED illumination systems can deliver light more efficiently to the desired location thereby increasing staff well-being. Fluorescent tubes can also emit a low buzzing noise which can be distracting and annoying, LEDs operate silently.

- Long lifespan – LEDs have an extremely long lifespan in comparison to traditional fluorescent lighting. An eight-hour-a-day operation for LEDs would have a 20-year lifespan. They are also far more resistant to shock, vibrations and external impacts. Maintenance costs are therefore vastly reduced.

6. Examples of successful adoption

Published information on the use of LED lighting is available for:

- Lit up (an Energy Saving Trust field trial)[39]
- DECC[40]
- East Sussex County Council[41]
- NRW case study: LED lighting (see Appendix A: Demonstration project case studies)

7. Technical considerations

- Existing light fittings may not be suitable for LED.

- A like-for-like replacement may not be the most appropriate lighting design. consider requirements for each location

- There are many types of LED on the market; care should be taken to choose an appropriate make, supplier and installer

- There is likely to be disruption in office space during the installation period

- The Carbon Trust provides a link to literature about lighting options: http://www.carbontrust.com/resources/guides/energy-efficiency/lighting

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[39] Energy Saving Trust (2011) Lit up: an LED lighting field trial http://www.energysavingtrust.org.uk/sites/default/files/reports/LitupanLEDlightingfieldtrial.pdf Accessed 12/9/17

[40] Department of Energy and Climate Change (2014) Energy and Carbon Saving Case Study – LED lighting, URN 14D/296 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/341586/LED_lighting_case_study_1_1.pdf Accessed 23/3/18

[41]East Sussex County Council, https://sustainablebusiness.org.uk/wp-content/uploads/SBP-Case-Study-East_Sussex-LEDs.pdf Accessed 12/9/17

4.1.20 Energy management supported by metering and monitoring

Table 16: Summary of costs and CO_2e reductions associated with energy management through metering and monitoring in an "NRW average" building

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Adopt an energy management strategy supported by metering and monitoring (for a building with average energy use)	0.92	n/a	0 (staff time)	n/a	n/a	Not given	250

1. Description of the measure
Active management of energy use within an organisation can lead to significant savings. This is underpinned by metering and monitoring that allows patterns of energy use to be understood and analysed. Reviewing these data on a regular basis can highlight anomalies in usage and inefficiencies to be addressed. This should form part of a structured approach to energy management, e.g. within an energy strategy, which may also include a commitment to regularly maintain equipment, provide operating instruction for staff on equipment and ensure heating controls are understood.

Of the 15 buildings assessed by the Carbon Trust, adoption of an energy management strategy supported by metering and monitoring was recommended for five. We applied the average percentage energy savings from these five suggested buildings to the average energy use of all NRW buildings to provide a more representative possible energy saving. The summary metrics presented in Table 16 relate to these potential savings for an NRW average building.

The average cost and carbon savings per kWh saved across the five Carbon Trust suggested buildings were scaled up to provide indicative metrics for this NRW average building.

2. Emission reduction potential
The estimated average annual energy savings possible through energy management at the five buildings equates to 4% of total use at these sites. Applied to an NRW average building, i.e. with average energy use, this equates to a saving of 2,947 kWh annually, with associated annual emissions savings of 0.92 tCO_2e.

3. Cost
This measure was estimated to have no associated capital costs at the five recommended buildings, with the only investment being staff time.

Energy savings were estimated to result in cost savings of £250 annually for an average NRW building. No payback time was estimated given that the life of this measure is dependent upon continued management.

4. Scale of adoption

i) Feasible maximum

The estimated feasible maximum relates to the five buildings for which energy management was recommended by the Carbon Trust. The totals from the building audit reports were summed to provide the numbers below:

- Feasible maximum energy savings per year: 34,179 kWh
- Feasible maximum number of buildings: 5
- Feasible maximum capital cost: £0
- Feasible maximum cost savings per year: £3,551
- Feasible maximum carbon savings per year: 13.7 tCO_2e

ii) Theoretical maximum

Based on the organisation's EMS records we estimated that, at the time of writing, there were 55 additional buildings using some form of energy that were not assessed during building energy audits. We used the Carbon Trust data for recommended energy management to infer what might be possible in these other NRW buildings, assuming that the same proportion could achieve energy savings through improved energy management (5/15). We used the costs and carbon savings calculated for an average NRW building to provide a rough indication of what might be possible in these unassessed buildings. These were added to the feasible maximum Carbon Trust recommended upgrades to provide theoretical maxima possible across all NRW buildings:

- Theoretical maximum energy savings per year: 88,209 kWh
- Theoretical maximum number of buildings: 23
- Theoretical maximum capital cost: £0
- Theoretical maximum cost savings per year: £8,132
- Theoretical maximum carbon savings per year: 30.5 tCO_2e

This is likely to be an overestimate of the number of buildings where metering and monitoring could lead to savings as a number of the buildings are unmanned.

4.1.21 Improve roof insulation

Table 17: Summary of costs and CO_2e reduction of improving roof insulation in buildings

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Improve roof insulation (average installation of 322 m^2)	1.72	34.49	2,197	20	10	Not given	230

1. Description
Roof space insulation reduces heat loss from buildings. Reducing the amount of heating needed to keep a building interior at a chosen temperature results in a decrease in the amount of energy required and leads to associated reductions in costs and greenhouse gas emissions.

Of the 15 NRW buildings assessed by the Carbon Trust, improving roof insulation was recommended as an energy efficiency measure for four. Recommended installations ranged in size from 120 m^2 to 420 m^2 of insulation. The summary metrics presented in Table 17 relate to the average installation size suggested for NRW buildings (322 m^2 of roof space insulation). The average cost and carbon savings per m^2 installed across all suggested installations were scaled up to provide indicative metrics for an NRW average 322 m^2 of insulation.

2. Emission reduction potential
Across all four sites, based on the Carbon Trust assessments, installing a square meter of insulation is expected to save an average 20.3 kWh of energy and 0.005 tCO_2e.

An average NRW installation of 322 m^2 would be expected to save 1.72 tCO_2e annually, amounting to savings of 34.49 tCO_2e over its expected 20-year life.

3. Cost
Across all four sites, based on the Carbon Trust assessments, the average capital cost of insulation was estimated to be £6.83 / m^2 installed (including labour costs).

An average NRW installation of 322 m^2 of insulation would be expected to have an indicative capital cost of £2,197 and achieve annual energy savings of £230. The average payback was estimated at ten years, accounting for capitals costs, annual maintenance and energy savings.

4. Scale of adoption
i) Feasible maximum

The estimated feasible maximum relates to the four roof insulation improvements recommended by the Carbon Trust across the 15 buildings assessed. The totals from each Carbon Trust building audit report where roof insulation was recommended were summed to provide the numbers below:

- Feasible maximum energy savings per year: 21,142 kWh
- Feasible maximum combined installation size: 1,287 m^2
- Feasible maximum capital cost: £8,745
- Feasible maximum cost savings per year: £813
- Feasible maximum carbon savings per year: 5.9 tCO_2e

ii) Theoretical maximum
Based on the organisation's Environmental Management Systems records we estimated that, at the time of writing, there were 36 additional heated buildings not assessed through building energy audits. We assumed that improving roof insulation was a possible energy-saving measure for the same proportion of these unassessed buildings as for assessed buildings (4/15). We scaled up the cost and carbon savings for the average NRW installation given in Table 17 to provide a rough indication of the savings possible in these unassessed buildings. These were added to the feasible maximum Carbon Trust recommended upgrades to provide theoretical maxima possible across all NRW buildings:

- Theoretical maximum total energy saved per year: 83,892 kWh
- Theoretical maximum combined installation size: 4,376 m^2
- Theoretical maximum capital cost: £29,834
- Theoretical maximum cost savings per year: £3,023
- Theoretical maximum carbon savings per year: 22.5 tCO_2e

5. Benefits beyond greenhouse gas savings
- Constant and more comfortable temperature in offices and other buildings.
- Reduced noise levels, particularly on flat roofed buildings, e.g. from rain on roof.

6. Technical considerations
The Carbon Trust recommends that any insulation products or installers employed are approved by a reputable quality assurance authority such as the British Board of Agrément.

In order to avoid thermal bridging, wherever practical all areas of roof should be insulated to the same depth.

4.1.22 Voltage optimisation

Table 18: Summary of costs and CO_2e reduction through use of voltage optimisation at NRW's largest office building

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Voltage optimisation (at NRW's largest office building)	18.03	270.45	15,700	15	4.8	0	3,279

1. Description
Voltage optimisation reduces the voltage of power received from the distribution network, better matching the operating requirements of equipment and preventing oversupply. Carbon and cost savings result from reduced energy use and more efficient performance of electrical equipment.

The costs and carbon savings presented for this measure in Table 18 relate to estimated data from an initial assessment of potential savings using data loggers at NRW's largest office (in terms of electricity use and net internal area)[42], and do not therefore relate to an NRW average or typical building. These estimated savings are based on an 8% reduction in electricity use across the building.

These metrics have been included to demonstrate the potential of voltage optimisation as an energy-saving measure, however further work is needed to verify these initial figures. Internal feedback from staff on this measure has suggested that voltage correction and smoothing is already happening in the server room of this office, meaning that potential savings may be overestimated.

Further work is needed to understand the potential for this measure to be rolled out to other offices, based on whether voltage optimisation is already in place and whether appliances in each office would benefit from this approach. No scale-up in terms of the feasible and maximum potential uptake has been attempted for this measure. NRW's second largest office building in terms of electricity use has had voltage optimisation in place since 2010.

2. Benefits beyond greenhouse gas savings
Installing voltage optimisation equipment may protect appliances and prolong operational life.

[42] Based on a powerPerfector assessment (27/05/2016) and forward energy prices. https://powerperfector.com/our-solution-2/why-use-powerperfector/

3. Examples of successful adoption
- DEFRA installed 30 voltage optimisation units across their offices and laboratories from 2007 onwards.[43]
- The largest rollout of powerPerfector units in the public sector is within Her Majesty's Courts and Tribunals Service with 130 units across the country.
- Approximately 25 units have been installed at Environment Agency offices and laboratories. A range of case studies have been produced.[44]

4.1.23 Increased homeworking

Table 19: Summary of costs and CO_2e reduction associated with all staff in an average office working from home an additional day per week

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Additional homeworking (for a building with average staff numbers of 43.5)	5.65	n/a	0	n/a	n/a	Included in annual savings	0 (for the organisation) 10,220 (for staff)

1. Description
Carefully designed and implemented homeworking policies have the potential to reduce emissions through employee commuting whilst enabling office space rationalisation and subsequent office energy consumption savings. However, the emissions impact of homeworking is specific to each employee's circumstances and informed implementation is needed to avoid a perverse outcome such as an overall increase in emissions due to an increase in home energy consumption (Swift and Stephens, 2014).

No NRW specific analysis of homeworking potential has been carried out and we currently have no information on the baseline situation, i.e. staff numbers and frequency of current homeworking. The cost and carbon savings presented for this measure in Table 19 take account of commuting and home energy impacts only, and are derived from a Carbon Trust-specific homeworking scenario per employee (Swift and Stephens, 2014). The scenario assumes employees working from home heat just their home office for an extra four hours a day, and avoid emissions associated with an average commute. These figures per employee have been scaled up to the building level to reflect the average

[43] Edie.net http://www.edie.net/13677/pr/DEFRA---Voltage-Optimisation-Project-powerPerfector/14393 Accessed 12/10/17
[44] powerPerfector website: Case Studies http://powerperfector.com/case_studies/ Accessed 12/10/17

number of employees in an NRW building (based on data from the NRW internal staff directory).

2. Emission reduction potential
For an NRW building with average staff numbers (43.5 staff), if all staff worked from home for an additional day per week this would save 5.65 tCO_2e / year (accounting for commute and home energy emissions only). The Carbon Trust (Swift and Stephens, 2014) highlights that this is a specific scenario and that the emissions impact of homeworking will vary depending on mode and distance of commute and extent of home heating. For example, they state that heating the whole house for more than an hour and 15 minutes extra will outweigh the emissions savings through avoiding an average commute.

Additional and significant emissions savings could be achieved through office energy savings if increased homeworking, coupled with hotdesking, subsequently leads to a rationalisation and reduction of office space. These savings have not been calculated here in the absence of any evidence on current desk utilisation and the potential impacts of increased homeworking on office space within NRW. NRW has already adopted a hotdesking approach and rationalised space in some offices.

3. Cost
This measure will not lead to any direct cost savings for the organisation. Increased homeworking could allow for a rationalisation and reduction of office space and associated costs, although these have not been accounted for here. For an average NRW office (43.5 people), savings totalling £10,220 could be made by staff over a year by working from home for an additional day per week.

4. Scale of adoption
i) Feasible maximum
The feasible maximum scenario assumes that all NRW employees not classed as homeworkers work from home for an additional day per week and uses the same Carbon Trust (Swift and Stephens, 2014) scenario figures per employee as a basis for cost and carbon savings. These figures do not include potential savings that may be possible through a subsequent reduction in office space.

- Feasible maximum number of staff: all staff working from home one additional day
- Feasible maximum capital cost: £0
- Feasible maximum total cost savings per year: £0 for the organisation, £432,573 for staff
- Feasible maximum total carbon savings per year: 239.3 tCO_2e

ii) Theoretical maximum
The theoretical maximum scenario assumes that all NRW employees not classed as homeworkers work from home for an additional two days per week.

- Theoretical maximum number of staff: all staff working from home two additional days
- Feasible maximum capital cost: £0
- Feasible maximum total cost savings per year: £0 for the organisation, £865,147 for staff
- Feasible maximum total carbon savings per year: 478.6 tCO_2e

5. Benefits beyond greenhouse gas savings
- Reduced road traffic and air pollution
- Potential reduction of office space resulting in cost savings
- Higher staff satisfaction due to flexibility over working hours, combined with time saved by reduced commuting (better work-life balance)
- Higher staff productivity - the quiet environment provided by homeworking facilitates tasks demanding speed and focus

6. Examples of successful adoption
The following case studies can all be found in the Carbon Trust's Homeworking report (Swift and Stephens, 2014):
- BT Group
- Wokingham Borough Council
- Aberdeenshire Council
- O2

7. Technical considerations
- IT systems and equipment – employees will need to have suitable equipment to allow working away from the office.

4.1.24 Hot water management

Table 20: Summary of costs and CO_2e reductions associated with hot water management for an NRW average application

Technology	Annual reduction in CO_2e (tonnes)	CO_2e saving over lifetime of the measure (tonnes)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual recurring costs (£)	Estimated annual savings (£)
Hot water – point of use provision (per building average)	1.65	33	700	20	2.35	Not estimated	298

1. Description of the measure
Hot water management measures are aimed at reducing energy demand for hot water provision, often through preventing heat loss.

Of the 15 NRW buildings assessed by the Carbon Trust, hot water efficiency measures were recommended for two sites. Recommended measures included replacing an inefficient immersion hot water system with point of use water heaters at one site, preventing storage and distribution losses, as well as reducing water flow rates and insulating pipework at the other site to reduce water use and system heat loss. The summary metrics presented in Table 20 are averages for hot water management measures across the two sites, presented per building. There were no details given in terms of installation sizes or litres of water heated, therefore the summary statistics are given per building rather than per common unit.

2. Emission reduction potential
Estimated annual emissions savings through hot water management were expected to be 1.1 and 2.2 tCO_2e per building, with an average of 1.65 tCO_2e.

3. Cost
The estimated capital costs associated with hot water management were estimated to be £310 at one site and £1090 at the other, where hot water system replacement was recommended. The average installation cost was therefore £700 and the average annual cost saving £298 and payback time 2.4 years.

4. Scale of adoption
i) Feasible maximum
The feasible maximum relates to the two buildings for which hot water management measures were recommended. The totals from the two Carbon Trust building audit reports were summed to provide the numbers below:

- Feasible maximum energy savings per year: 9,222 kWh
- Feasible maximum number of buildings: 2
- Feasible maximum capital cost: £1,400
- Feasible maximum cost savings per year: £596
- Feasible maximum carbon savings per year: 3.3 tCO_2e

ii) Theoretical maximum
Based on the organisation's Environmental Management Systems records we estimated that, at the time of writing, there were 36 additional heated buildings not assessed during building energy audits. In the absence of records of which buildings heat water, we assumed that there was some form of water heating in all heated buildings. Of these, we assumed that the same proportion could achieve energy savings through hot water management as in Carbon Trust-assessed buildings. Because we lacked information on energy use for water heating, we scaled up the cost and carbon savings for the average NRW application of hot water management measures in Table 20 to provide a rough indication of the savings possible in these unassessed buildings. These were added to the feasible maximum Carbon Trust-recommended upgrades to provide theoretical maxima possible across all NRW buildings:

- Theoretical maximum total energy saved per year: 31,355 kWh
- Theoretical maximum number of buildings: 7
- Theoretical maximum capital cost: £4,760
- Theoretical maximum cost savings per year: £2,026
- Theoretical maximum carbon savings per year: 11.2 tCO_2e

4.1.25 Buildings measures not progressed to detailed evaluation to date

Table 21 lists further mitigation options that have been highlighted through the identification of mitigation options. These measures have not been progressed to detailed evaluation for NRW to date and so did not form part of the detailed options appraisal. However, they have not been ruled out entirely and, in future, the feasibility of these options should be reviewed regularly, and on a case-by-case basis, for their potential to contribute to reducing our carbon impact.

Table 21: Summary of buildings measures not being progressed to detailed evaluation

Further options highlighted through the identification of mitigation measures	Reason for the measure not being progressed to detailed evaluation
Unassessed renewable technologies	
Installation of combined heat and power (CHP) systems	Use of an online CHP assessment tool suggested that the energy demand at one of NRW's largest sites is not sufficient to make CHP feasible, therefore the measure was not evaluated further. The feasibility of micro CHP systems could be investigated.
Solar hot water systems	Not thought to be cost-effective in commercial buildings which typically have low hot water demands, therefore the measure was not evaluated further. One NRW site already has a solar hot water system and data relating to this installation may provide further insights on feasibility.
Ground source heat pumps	This was considered a very site-specific option, dependent upon local ground conditions. This measure is likely to require significant groundworks and space. An existing GSHP installation at an NRW site has not yielded any significant cost or emissions savings. Therefore, this measure was not evaluated further.
Energy management	
Heating management – reduce by 1˚C	Not evaluated individually but may form part of an energy management strategy as assessed in 4.1.20 Energy management supported by metering and monitoring.
Equipment operating instructions (e.g. for heating equipment) put in place where applicable	Not evaluated individually but may form part of an energy management strategy as assessed in 4.1.20 Energy management supported by metering and monitoring
Single 'off switch' points in rooms / offices	Not evaluated individually but may form part of an energy management strategy as assessed in 4.1.20.
Equipment audit and rationalisation, e.g. in terms of goods ratings with a view to replacing inefficient equipment or reviewing location	Not evaluated individually but may form part of an energy management strategy as assessed in 4.1.20.
Review efficiency of equipment and carry out regular maintenance	Not evaluated individually but may form part of an energy management strategy as assessed in 4.1.20. Site-specific examples suggested as part of the Carbon Trust

Further options highlighted through the identification of mitigation measures	Reason for the measure not being progressed to detailed evaluation
	building assessments include rationalising equipment in our hatchery, downsizing a motor in our hatchery, reviewing the location of refrigeration equipment at one site and replacing a missing valve in a kitchen at one site.
Install controls and sensors to reduce equipment energy use	Examples evaluated in main report include drying room switches, boiler controls, etc. Other examples, such as installing a timer to a kitchen extractor fan at one site and reviewing tap timer schedules, are site-specific and therefore not evaluated individually.
Installation of passive infrared sensors to control lighting	Recommended and costed for one audited building by the Carbon Trust. The EMS Team advised that sensors have already been installed in most offices, therefore this measure is likely to have limited scope for scale-up and was not evaluated further.
Electricity procurement strategy – changing tariff, e.g. to Economy 7 for sites with storage heaters consuming energy overnight	Tariff changes were recommended and costed for Gwydyr Uchaf.
Behavioural change	
Smart meters in individual offices/rooms to allow people to see their usage and the impact of their actions to reduce energy in real-time	Difficult to assign savings to individual measures but savings of 5% to 10% of total energy use may be achieved with investment in an energy awareness campaign equivalent to 1 to 2% of annual energy spend (Carbon Trust, 2011).
Encouraging less use of fans in summer	
Display in reception to show energy consumption the building uses / is using	
Encouraging less use of personal electric heaters in winter	
Monthly prize for most energy-efficient office	
Appoint energy champions	
Train cleaning staff to switch off lights / plugs / monitors, etc	
Other	
Replacement of the server system with a cloud-based system	This was costed in the Carbon Trust assessment for one of our largest offices; however, it was not taken forward for further evaluation as it was considered to displace rather than reduce emissions.

Further options highlighted through the identification of mitigation measures	Reason for the measure not being progressed to detailed evaluation
Separate heating system for NRW office from adjacent (non-NRW managed) building	Site-specific measure – no scale-up possible, costed in Carbon Trust report for the site.
Green roofs	Emissions reductions will be a co-benefit.
Common waste efficiency opportunities	Emissions reductions will be a co-benefit.
Common water efficiency opportunities	Emissions reductions will be a co-benefit.
Building fabric improvements	
Draughtproofing windows and doors	Smaller scale, site-specific measure.
Solar film on windows	Smaller scale, site-specific measure.
Window replacement	Smaller scale, site-specific measure, e.g. recommended due to wet rot at one site.

4.2 Transport

4.2.1 Introduction

The information presented in this section has been drawn from the Strategic Fleet Carbon Review (December 2017), work carried out for NRW by Cenex.

The calculation of NRW's net carbon status has shown diesel use to be the organisation's second highest source of emissions from its core activities and it is therefore a key focus of carbon reduction work moving forward. We commissioned Cenex to undertake a review of the carbon emissions resulting from our fleet and plant use and to identify areas where carbon dioxide (CO_2) emissions could be reduced. The review also considered the potential reductions of emissions which impact air quality, e.g. NO_x.

Cenex undertook a detailed review of the NRW fleet vehicles and a higher-level review of operational plant. This work helped to identify and evaluate mitigation measures for both fleet and plant machinery.

The work provided the costs and carbon savings data to inform our evaluation of mitigation options for vehicles used by NRW. It also developed potential uptake scenarios for fleet vehicles and operational plant (e.g. to achieve the greatest CO_2e emissions savings), which have informed the feasible and theoretical maxima. These scenarios were developed to represent value for money against baseline fleet expenditure and to be achievable without compromising NRW's ability to deliver its role.

In the following sections, we present a summary of the fleet and plant reviews undertaken. The full detail of the work commissioned by the Carbon Positive Project can be found in the NRW *Strategic Fleet Carbon Review* report (December 2017).[45] The 4.2.3 Fleet review is presented first, followed by the high-level 4.2.4 Plant review.

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[45] Available on the Carbon Positive Project webpages: https://cdn.naturalresources.wales/media/687416/eng-evidence-report-278-nrw-carbon-positive-project-nrw-strategic-fleet.pdf

Later in the Transport section, we consider other travel carried out by NRW staff in pursuance of their duties, e.g. train travel, as well as staff members' personal commutes to their place of work (4.2.4.15). However, to date, these measures have not progressed to detailed evaluation.

4.2.2 Lessons learnt

- For the plant review and scenarios, fuel use and subsequent emissions were estimated due to a lack of detailed data. Fuel consumption data would allow more accurate estimates to be made on the savings that could be made in the plant fleet and uncertainties in costs and savings in the scenarios could be reduced.

- In all the scenarios presented, Cenex made 'high-level' estimates for fuel use and emissions. Calculations were made based on the information provided to Cenex by NRW on its plant fleet. Operational information was limited to the total number of hours worked per year. No fuel consumption data for plant were available, therefore fuel consumption estimates were based on engine size and typical engine loading rates. To refine the scenarios for greater certainty of return, it was recommended that real world fuel consumption data should be gathered from the plant fleet to refine the presented scenarios.

4.2.3 Fleet review

4.2.3.1 Method

Cenex evaluated the NRW fleet, consisting of 584 vehicles undertaking 5.5 million miles per annum, emitting 1,645 tonnes of TTW CO_2e and 1,994 tonnes of WTW CO_2e per annum. The fleet comprises small vans (40%), cars (32%), 4x4 vehicles (22%), large vans (6%) and trucks (1%). 61% of vehicles are less than four years old and 94% of vehicles comply with Euro 5 and 6 standards.

Cenex undertook a high-level technology review to establish which technologies have the potential to deliver CO_2e savings at a similar or better total cost of ownership (TCO) to existing vehicles used in the fleet. Suitable technologies were taken forward to the detailed review stage where TCO and CO_2e emissions models were used to estimate the likely performance of low emission vehicles in the NRW fleet.

The fleet review used the following methodology:

- Fleet baselining – understanding composition of fleet and its operating patterns, mileage, fuel consumption and emissions (e.g. CO_2, NO_x).

- Suitability assessment – reviewing the range of alternative technologies and fuels which had potential to reduce carbon emissions at similar or lower costs and identifying suitable measures considering NRW fleet characteristics.

- Cost and emissions analysis – technologies and fuels which appeared to meet the financial and emission criteria were taken forward for a more thorough review.

- Scenario planning – implementation scenarios of recommended technologies were built to allow NRW to assess their impact on overall fleet costs and emissions.

- Making recommendations – Cenex put forward recommendations for technology implementation to inform future planning of decarbonisation measures in NRW.

4.2.3.2 Parameters and assumptions

As part of analysis of emissions and total cost of ownership (TCO)[46], the following parameters / assumptions were used:

- **Costs:** costs for the diesel and low-emission vehicles were provided from the UK Government Public Sector Procurement portal; these can be considered as broadly representative of the prices paid by NRW. Lease rates quoted are for a standard five-year, 10,000 miles per annum ownership profile.

- **Lease vs purchase:** due to capital constraints, NRW leases most fleet vehicles and future acquisitions of vehicles will largely be on a lease basis. Therefore, the assessment of costs has been based on lease costs, rather than purchase (ownership model). However, the cost benefits of an ownership model were explored as part of the review. Note: the values presented have been produced specifically for NRW and may not represent technology averages.

- **Vehicle lifetimes in the NRW fleet:** cars, small vans, 4x4s and large vans that make up the fleet are typically replaced every five years as part of NRW's fleet strategy.

- **Fuel consumption:** data for diesel vehicles was taken from the NRW fleet data set. Independent test data, either from Cenex track testing or real-world MPG data from Emission Analytics testing under different driving cycles, were used to translate NRW diesel fuel consumption to energy consumption in the low-emission vehicles. Manufacturers' performance and emissions data were not used, i.e. the comparison is made based on real world data on vehicle types.

- **Maintenance costs:** these were taken from the NRW fleet data set, with appropriate reduction / increase factors applied to represent the comparable maintenance cost of low-emission vehicles.

- **Insurance costs:** these were not accounted for in the model. NRW applies a flat rate insurance cost across all vehicle types and information from insurance brokers stated that alternatively fuelled vehicles were not subject to an insurance premium[47]and so alternative costings did not need to be modelled. [48]

- **Vehicle make / models:** alternative vehicle technologies assessed were selected to offer similar performance to the standard NRW fleet.

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[46] TCO (Total Cost of Ownership) includes maintenance, management, infrastructure (i.e. charging stations for EV) and fuel and is on a lease basis.
[47] Correspondence with Towergate Insurers, 30 March 2017.
[48] Correspondence with Towergate Insurers, 30 March 2017.

- **Annual mileage:** all analysis was undertaken at average fleet annual mileage.

- **Taxation:** vehicle (road) tax rates were included in the model.

- **Infrastructure:** this was included for the electric vehicle (EV) cost analysis and applied at a rate of £1,500 (purchase and installation of the charging unit). Each unit was dual-headed and assumed to feed two vehicles + £60 per annum data fees amortised over a ten-year period. No account of civil costs for cabling provision (i.e. groundworks) was included.

- **End of lease charges:** charges of £1,000 per vehicle were applied.

- **Inclusion of petrol vehicles:** the rationale behind the inclusion of petrol vehicles was based around the additional consideration of NO_x reductions and air quality improvements as an extra fleet factor.

- **Biodiesel:** this has been assessed using an emission factor for biodiesel from used cooking oil at a blend of B25.[49] B25 was used as this represents a lower risk blend of biodiesel which is supported by some manufacturers.

- **CO_2e emissions:** Were calculated based on applying UK government emission factors to fuel usage.[50]

Where additional specific parameters or assumptions are relevant for a measure and scaled-up scenarios, these are given in the appropriate section.

4.2.3.3 Results of fleet technology scanning exercise

A high-level assessment of the main low-emission alternative vehicle options was undertaken using the colour key described below. Technologies that have the potential to reduce emissions at a lower or similar cost were identified during this process.

Colour key:

- **Green** – technology available, with the potential to be commercially viable in certain applications.
- **Amber** – technology available, but not viable due to high costs, or is near market and unproven. The technology may be suitable for fleet trial / demonstration.
- **Red** – technology is not available or not viable.

[49] Emission factor for used cooking oil from Olleco declared under the Renewable Transport Fuels Obligation scheme.
[50] 2016 GHG Emission Factors for Company Reporting, DEFRA, accessed March 2017

Table 22: Technology scanning summary

Vehicle Classification	Electric				Gas			Liquid	
	Battery Electric	Hybrid Electric	Plug-in Hybrid	Range Extended Electric	ICE (CNG/Bio)	ICE (LPG)	Fuel Cell (Hydrogen)	Biodiesel	Petrol
Car	Green	Green	Green	Green	Red	Green	Amber	Green	Green
Small van (< 2.5t)	Green	Red	Amber	Red	Red	Amber	Amber	Green	Green
4x4	Amber	Green	Green	Red	Red	Red	Red	Green	Green
Large van (> 2.5t)	Amber	Red	Red	Red	Green	Red	Red	Green	Red
Truck (7.5t)	Amber	Amber	Red	Amber	Red	Amber	Red	Green	Red

Table 22 shows that for cars and small vans, electric vehicles have the potential to offer improved emission performance at a lower cost. As vehicles become heavier (large vans and trucks), the economics and availability of electric vehicles, including hybrids, diminishes with the most likely sources of reduced emissions coming from gas vehicles and biofuels.

The following technologies were deemed unsuitable for NRW and were not taken forward for further review:

1. For all vehicles – hydrogen technology. Hydrogen-powered vehicles were considered not to be currently economic, unless deployed as part of a grant-funded activity. The vehicles, their maintenance and hydrogen fuel are all more expensive than incumbent technology. It was noted that the University of South Wales has a H_2 refuelling facility in Baglan, which would be a good platform to build a future demonstration activity. Therefore, it may be possible for NRW to trial hydrogen technology in the fleet in its Llandarcy office in the future, subject to grant-funding.

2. For cars – compressed natural gas (CNG).

3. For small vans – hybrid electric, range extended electric, internal combustion engine (ICE) (CNG and LPG).

4. For 4x4s – battery electric, range extended electric, ICE (CNG and LPG).

5. For large vans – all electric vehicles, ICE (LPG), petrol.

6. For trucks – all electric vehicles, all gas-fuelled vehicles, petrol.

4.2.3.4 Presentation of identified potential mitigation measures

In this Transport section of the report, results are presented in a similar format to the Buildings metrics in terms of mitigation measure, carbon savings, and cost analysis, but with some metrics specific to vehicle options (see Table 23).

Table 23: Sample of metrics recorded for transport mitigation measures

				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%) WTW	Annual reduction in CO_2e (tonnes) WTW	TCO (£)[51], [52] over 5-year period	TCO Savings (£) over 5-year period

Emission reduction potential can be measured as tank to wheel (TTW) and well to wheel (WTW). TTW refers to CO_2e emissions from fossil fuel combustion released from the vehicle tailpipe and is classed as scope 1 emission under the Greenhouse Gas (GHG) (reporting) Protocol. TTW is the direct responsibility of NRW. WTW is an all-scope emission under the GHG Protocol as it includes CO_2e emissions through the fuel's whole lifecycle, from its extraction to combustion, with all processes between. For each measure, carbon savings have been given in WTW to demonstrate total lifecycle emissions and are in line with NRW's reporting of organisational carbon emissions.

4.2.3.5 Scale of adoption

Various scenarios were developed to discover what carbon and cost reductions could be achieved by the whole fleet, whilst continuing to perform operational activities – a summary of these scenarios and their potential savings are set out in Table 24 below. The scenarios were based on the recommended low-emission vehicles identified by Cenex and presented in the earlier section of this report. WTW emissions and TCO for different vehicles incorporated into the fleet were modelled as part of the assessment.

The three scenarios were:

- **Scenario 1 – Alternative Vehicle Adoption:** This looked to achieve the maximum reduction in CO_2e emissions by implementing recommended technologies across the current fleet.
- **Scenario 2 – Alternative Vehicle Adoption and Efficiency Improvement:** This modelled a cost-effective transition to a reduced sized fleet composed of low-emission vehicles. The reduction of fleet size by 100 vehicles resulted in higher

[51] TCO (Total Cost of Ownership) includes maintenance, management, infrastructure (i.e. charging stations for EV) and fuel and is on a lease basis.
[52] Fuel costs are based on typical mileage for each size of vehicle in NRW fleet.

utilisation of remaining vehicles and an associated increased annual mileage. Telemetry systems were included in this scenario.

- **Scenario 3 – Biodiesel-based Assessment:** This considered the potential to introduce biodiesel at major depots and 88 B25 biodiesel vehicles within the fleet. This scenario excluded vehicles suitable for electrification. Costs of biodiesel storage infrastructure and vehicle maintenance were included.

Table 24: Summary of annual CO_2e reduction of fleet scenarios

Fleet Scenario	Description	Annual reduction in CO_2e (%) WTW	Annual reduction in CO_2e (%) TTW	Annual TCO saving (%)	Annual TCO saving (£) (approximate)
1	Alternative vehicle adoption	26	49	5	117,000
1	Alternative vehicle adoption (without biodiesel)[53]	22	44	5	136,000
2	Alternative vehicle adoption and efficiency improvement (with biodiesel)	39	59	22	500,000
2	Alternative vehicle adoption and efficiency improvement (without biodiesel)[54]	33	52	22	508,000
3	Biodiesel-based assessment: entire fleet	4			
3	Biodiesel-based assessment: converting 88 vehicles to biodiesel[55]	18	23	-4	-20,000

These scenarios were used to provide the feasible and theoretical maxima scenarios:

- Feasible: the feasible maximum is based on the recommendations of Cenex in their ‘Scenario 2: Alternative vehicle adoption and efficiency improvement (without biodiesel)’. This scenario modelled a cost-effective transition to a reduced sized fleet composed of low-emission vehicles. The reduction of fleet size by 100 vehicles resulted in higher utilisation of remaining vehicles and an associated increased annual mileage. Telemetry systems were included in this scenario.

- Theoretical: as above, this is based on the recommendations of Cenex in their ‘Scenario 2: Alternative vehicle adoption and efficiency improvement (but includes the implementation of biodiesel)’. The theoretical maximum does not consider the impact on operations or whether any appropriate infrastructure is in place, e.g. charging points.

None of the scenarios included downsizing of vehicles, i.e. downsizing from medium-sized cars to small-sized cars; this is likely to yield additional cost and carbon reductions. Neither did any of the scenarios include hydrogen fuel cell vehicles, staff commute or promoting sustainable travel for work.

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[53] Without biodiesel, select vehicles remained diesel fuelled
[54] Without biodiesel, select vehicles remained diesel fuelled
[55] Savings compared to emissions of these 88 vehicles not converted

Both these organisation-wide scenarios include a reduction of the baseline fleet by 100 vehicles.

4.2.3.6 Summary of mitigation measures

Table 25 presents a summary of the mitigation measures identified for NRW's fleet. Plant is considered in 4.2.4. The values presented have been produced specifically for NRW's fleet operations, with mitigation measures based on a specific make and model as selected by our industry expert, and so may not reflect technology averages or be applicable to other organisations. Unless otherwise specified, the mitigation measure is for one vehicle.

Table 25: Summary of fleet mitigation measures

				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%) WTW[56]	Annual reduction in CO_2e (tonnes) WTW	TCO (£)[57], [58] over 5-year period	TCO Savings (£) over 5-year period
Low-emission technologies							
Small electric car (battery)	Electric	Diesel vehicle	Small	53%	1.188	13,849	3,303
Medium electric car (battery)	Electric	Diesel vehicle	Medium	53%	1.027	13,917	4,552
Small electric van (battery)	Electric	Diesel vehicle	Small	46%	1.572	16,492	143
Medium plug-in hybrid car	Plug-in hybrid	Diesel vehicle	Medium	30%	0.581	26,975	-8,506
4x4 plug-in hybrid	Plug-in hybrid	Diesel vehicle	4x4	43%	1.723	27,431	-2,068
Small petrol hybrid car	Petrol hybrid	Diesel vehicle	Small	31%	0.702	17,434	-281
Medium petrol hybrid car	Petrol hybrid	Diesel vehicle	Medium	31%	0.599	17,046	1,423
4x4 petrol hybrid	Petrol hybrid	Diesel vehicle	4x4	26%	1.037	25,768	-406

[56] WTW: well to wheel – All Scope emission under GHG reporting protocol as it includes CO_2e emissions through the fuel's whole lifecycle, from its extraction to combustion, with all processes between.
[57] Total Cost of Ownership (TCO) includes maintenance, management, infrastructure (i.e. charging stations for EV) and fuel and is on a lease basis.
[58] Fuel costs are based on typical mileage for each size of vehicle in NRW fleet.

Small range extended vehicle (REEV)	REEV	Diesel vehicle	Small	32%	0.721	19,200	-2,048
Implementation of biodiesel	Biodiesel	Diesel vehicle	n/a	6	7	n/a	-40,000
Telematic system							
Installing telematic system into car	Diesel	Non-telematic diesel vehicle	Medium and small[59]	15	0.3	17,347	463.50
Infrastructure							
Installation of EV charging station	Electric	Diesel vehicle	n/a			4,146[60]	
Introduction of Skype	n/a	n/a	n/a	n/a	n/a	n/a	n/a

4.2.3.7 Feasible and Theoretical Maxima

The Strategic Fleet Carbon Review identified potential scenarios for implementation of low-emission vehicles into the NRW fleet. These scenarios have been used to inform our feasible and theoretical maxima.

i) Feasible maximum
Scenario 2 (without biodiesel) – alternative vehicle adoption and efficiency improvement of a reduced sized fleet represents the feasible maximum reduction in CO_2e emissions and costs for a whole fleet scenario. This scenario was considered the feasible maximum because it resulted in the greatest reduction in CO_2e emissions attainable using our existing fleet technology. This scenario also offered the highest annual TCO savings of all modelled fleet scenarios.

Table 26: Summary of annual CO_2e reduction and TCO saving for feasible maximum scenario (i.e. Scenario 2 without biodiesel)

Fleet Scenario	Description	Annual reduction in CO_2e (%) WTW	Annual reduction in CO_2e (%) TTW	Annual TCO saving (%)	Annual TCO saving (£) (approximate)
2	Alternative vehicle adoption and efficiency improvement (without biodiesel)[61] [62]	33	52	22	508,000

[59] Mean for medium and small cars, as the numbers are very similar
[60] This is capital cost including available grant
[61] Without biodiesel, select vehicles remained diesel fuelled
[62] Reductions measured against baseline of current (2017) fleet

- WTW CO_2e annual emissions savings: 674 tonnes (33% on baseline).
- TTW CO_2e annual emissions savings: 867 tonnes (52% on baseline).

Detail on the scenario:

A total of 477 vehicles made up the fleet in the scenario, with 63% of them electric vehicles, while 69% overall were low-emission vehicles, i.e. EV, PHEV and petrol hybrid. The majority of the 100 vehicles removed from the modelled fleet were 4x4s.

The reductions on the baseline have been achieved through a reduction in vehicle numbers, electrification of suitable vehicles and use of telematics. Reducing fleet vehicle numbers delivered a reduction in cost but no CO_2e reduction. This is because fleet mileage and fuel consumption are assumed to remain constant and each vehicle has a higher utilisation. In this scenario, a 14% cost saving on the baseline fleet was made by a 17% reduction in vehicle numbers. This represents 65% of the total cost savings of this scenario.

Implementation of low-emission vehicles contributed 28% WTW (52% TTW) CO_2e saving and 5% TCO on total scenario savings, on the baseline. Telemetry provided 11% WTW (7% TTW) CO_2e saving and 3% TCO on total scenario savings, on the baseline.

ii) Theoretical maximum
Scenario 2 (with biodiesel) – alternative vehicle adoption and efficiency improvement of a reduced sized fleet, including implementation of biodiesel. This scenario would achieve the greatest CO_2e emissions reductions through the implementation of all recommended technologies in the current vehicle fleet (where practical), based on a business-as-usual scenario (same number of fleet vehicles and same total mileage of the fleet). This included a blend of EVs (324), petrol hybrids (23), plug-in hybrids (6) and B25 biodiesel (79). The inclusion of use of biodiesel increases the total costs by £8,000.

Table 27: Summary of annual CO_2e reduction and TCO saving for theoretical maximum (i.e. scenario 2 with biodiesel)

Fleet Scenario	Description	Annual reduction in CO_2e (%) WTW	Annual reduction in CO_2e (%) TTW	Annual TCO saving (%)	Annual TCO saving (£) (approximate)
2	Alternative vehicle adoption and efficiency improvement (with biodiesel)[63]	39	59	22	500,000

- WTW CO_2e annual emissions savings: 771 tonnes (39% on baseline).
- TTW CO_2e annual emissions savings: 920 tonnes (59% on baseline).

Detail on the scenario:

[63] Reductions measured against baseline of current (2017) fleet

The scenario used for the theoretical maximum was the same as the feasible maximum but also included the use of biodiesel. Therefore, the reduced fleet comprised 477 vehicles, with 63% of them electric vehicles, 69% overall are low emission (i.e. EV, PHEV, and petrol hybrid). In this scenario, 17% of the fleet vehicles were fuelled by biodiesel. This brought the proportion of low-emission vehicles in the fleet to 86%.

4.2.3.8 Electric cars

Table 28: Summary of costs and CO_2e reduction of electric cars

				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%) WTW[64]	Annual reduction in CO_2e (tonnes) WTW	TCO (£)[65]over 5-year period	TCO Savings (£) over 5-year period
Small electric car (battery)	Electric	Diesel vehicle	Small	53%	1.188	13,849	3,303
Medium electric car (battery)	Electric	Diesel vehicle	Medium	53%	1.027	13,917	4,552

1. Description
Battery-powered electric vehicles are a well-established technology. Cars powered wholly by electricity produce no emissions from the tailpipe. With fewer moving parts than a fossil fuel-powered internal combustion engine, maintenance is required at less frequent intervals, e.g. every 18,000 miles instead of 10,000 miles.

The driving range of battery-powered electric vehicles depends on the battery size as well as driving style and conditions. For example, a small electric vehicle such as the Renault ZOE, with a 22 kWh battery, has an estimated range of 55–75 miles; however, with a battery of 41 kWh, the ZOE 40 has an estimated range of 110–120 miles.

2. Emission reduction potential
Electric vehicles save 100% TTW[66] CO_2e and produce no nitrogen oxides (NO_X) and particulate matter (PM). In terms of total lifecycle emissions, WTW savings of 53% are predicted for electric cars, compared to diesel equivalents.

3. Cost
Total Cost of Ownership (TCO) has been used to make comparisons between different types of vehicles over their whole lifetimes. TCO includes maintenance, management,

[64] Well to wheel (WTW) – All Scope emission under GHG reporting protocol as it includes CO_2e emissions though the fuel's whole lifecycle, from its extraction to combustion, with all processes between.
[65] Total Cost of Ownership (TCO) includes maintenance, management, infrastructure (i.e. charging stations for EV) and fuel and is on a lease basis.
[66] Tank to Wheel (TTW) – refers to CO2e emissions from fossil fuel combustion released from the vehicle tailpipe and is classed as Scope 1 emission under the Greenhouse Gas (GHG) reporting protocol.

infrastructure (i.e. charging stations for EV) and fuel, and is on a lease basis. Fuel costs are based on typical mileage for each size of vehicle in NRW fleet.

Results from Cenex's model demonstrate a reduction in the total cost of ownership (TCO) by up to 25% for an electric car when compared to a similar diesel car. However, a car with a larger battery size with a greater range, e.g. Nissan Leaf 30 kWh battery, is likely to need a greater than present annual mileage to achieve TCO parity with a comparable diesel. The highest cost benefits from battery electric vehicles will be achieved by effective utilisation.

The UK government's Office for Low Emission Vehicles (OLEV[67]), part of the Department for Transport and Department for Business, Energy and Industrial Strategy, provides grants towards the cost of new electric and hybrid cars. The level of grant depends on the level of CO_2e emissions from the car.[68] For example, a Nissan Leaf is a category 1 car and benefits from a government OLEV grant of £4,500 per vehicle and therefore the resultant cost per vehicle excluding VAT is £10,196.

Electric charging costs have been included in the TCO. For information, electric charging costs approximately 2p per mile, which represents a significant saving when compared to petrol or diesel at approximately 9p per mile.

4. Scale of adoption
From an analysis of three months' journey data of our pool fleet at the most active eight offices, it was found that 43% of trips made by our fleet cars are under 50 miles and 65% are less than 100 miles. Due to this high quantity of journeys made within the range of electric vehicles, it would be possible to change a proportion of office-based fleet vehicles to electric vehicles without negatively affecting operational ability. In terms of suitability of this technology for our fleet and operations, electric cars were rated 'Good' in the Cenex Suitability Assessment.

i) Feasible maximum
Scenario 2 (without biodiesel) – alternative vehicle adoption and efficiency improvement of a reduced sized fleet represents the feasible maximum reduction in CO_2e emissions and costs for a whole fleet scenario. Telemetry was also applied across the vehicle types. The scenario did not include downsizing of vehicles; this is likely to yield additional cost and carbon reductions.

Small electric car (battery) in place of diesel equivalent

- Feasible maximum number of vehicles: 48
- Feasible maximum TCO savings (£) over 5-year period: £158,544
- Feasible maximum annual reduction in CO_2e (tonnes) WTW: 57.024 tCO_2e

Medium electric car (battery) in place of diesel equivalent

- Feasible maximum number of vehicles: 110
- Feasible maximum TCO savings (£) over 5-year period: £500,720
- Feasible maximum annual reduction in CO_2e (tonnes) WTW: 112.970 tCO_2e

[67] This was correct at the time of writing in 2017 but has since become the Office for Zero Emission Vehicles.
[68] https://www.gov.uk/plug-in-car-van-grants/what-youll-get Accessed 13/9/17

ii) Theoretical maximum
The theoretical maximum recommended for fleet is Scenario 2: Alternative vehicle adoption and efficiency improvement (with biodiesel). The theoretical maximum for this measure is therefore the same as the feasible maximum but also includes the use of biodiesel.

5. Examples of successful adoption
Our demonstration project that introduced three electric vehicles and six charging points provided 'real world' costs and carbon savings. It allowed us to better appreciate how alternative technologies could be incorporated into our fleet. Details of the project is included to illustrate the relevant mitigation measures.

4.2.3.9 Electric van

Table 29: Summary of costs and CO_2e reduction of electric van

				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%)	Annual reduction in CO_2e (tonnes)	TCO (£)[70] over 5-year period	TCO Savings (£) over 5-year period
Small electric van (battery)	Electric	Diesel vehicle	Small	46%	1.572	£16,492	£143

1. Description
Battery-powered electric vehicles are a well-established technology. Cars powered wholly by electricity produce no emissions from the tailpipe. With fewer moving parts than a fossil fuel-powered internal combustion engine, maintenance is required at less frequent intervals, e.g. every 18,000 miles instead of 10,000 miles.

The driving range of battery-powered electric vehicles depends on the battery size as well as driving style and conditions. No van-specific range examples were provided by Cenex, however, a small electric vehicle such as the Renault ZOE, with a 22 kWh battery, has an estimated range of 55–75 miles. With a battery of 41 kWh, the ZOE 40 has an estimated range of 110–120 miles.

2. Emission reduction potential
Electric vehicles save 100% TTW[71] CO_2e and produce no nitrogen oxides (NO_X) and particulate matter (PM). In terms of total lifecycle emissions, WTW savings of 46% are predicted for electric vans, compared to diesel equivalents.

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[69] Well to wheel (WTW) – All Scope emission under GHG reporting protocol as it includes CO_2e emissions though the fuel's whole lifecycle, from its extraction to combustion, with all processes between.
[70] Total Cost of Ownership (TCO) includes maintenance, management, infrastructure (i.e. charging stations for EV) and fuel and is on a lease basis.
[71] Tank to Wheel (TTW) – refers to CO_2e emissions from fossil fuel combustion released from the vehicle tailpipe and is classed as Scope 1 emission under the Greenhouse Gas (GHG) reporting protocol.

3. Cost
Total Cost of Ownership (TCO) has been used to make comparisons between different types of vehicles over their whole lifetimes. TCO includes maintenance, management, infrastructure (i.e. charging stations for EV) and fuel, and is on a lease basis. Fuel costs are based on typical mileage for each size of vehicle in NRW fleet.

TCO of electric vans is comparable to an equivalent NRW leased diesel (Citroen Nemo) when using the electric Renault Kangoo ZE. The highest cost benefits from battery electric vehicles will be achieved by effective utilisation.

UK government's Office for Low Emission Vehicles (OLEV)[67], part of Department for Transport and Department for Business, Energy and Industrial Strategy, provides grants towards the cost of new vans with CO_2 emissions of less than 75g / km. The grant will pay for a maximum of £8,000 or 20% of the value of the vehicle. According to Cenex, the purchase of a Renault Kangoo ZE would be £9,926. In comparison, the cost of a five-year lease for this particular make and model would be £16,492. The figures quoted by Cenex include the OLEV grant available for EV vehicles.

Electric charging costs have been included in the TCO. For information, electric charging costs approximately 2p per mile, which represents a significant saving when compared to petrol or diesel at approximately 9p per mile.

4. Scale of adoption
In terms of suitability of this technology for our fleet and operations, electric vans were rated 'Good' in the Cenex Suitability Assessment and Cenex recommends that they should be implemented where practical.

i) Feasible maximum
Scenario 2 (without biodiesel) – alternative vehicle adoption and efficiency improvement of a reduced sized fleet represents the feasible maximum reduction in CO_2e emissions and costs for a whole fleet scenario. Telemetry was also applied across the vehicle types. The scenario did not include downsizing of vehicles; this is likely to yield additional cost and carbon reductions.

- Feasible maximum number of vehicles: 166
- Feasible maximum TCO savings (£) over 5-year period: £23,738
- Feasible maximum annual reduction in CO_2e (tonnes) WTW: 260.952 tCO_2e

ii) Theoretical maximum
The theoretical maximum recommended for fleet is Scenario 2: Alternative vehicle adoption and efficiency improvement (with biodiesel). The theoretical maximum for this measure is therefore the same as the feasible maximum but also includes the use of biodiesel.

4.2.3.10 Plug-in hybrid car

Table 30: Summary of costs and CO_2e savings made by changing from comparable diesel car to plug-in hybrid car

				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%) WTW	Annual reduction in CO_2e (tonnes) WTW	TCO (£) over 5-year period	TCO Savings (£) over 5-year period
Medium plug-in hybrid car	Plug-in hybrid	Diesel vehicle	Medium	30%	0.581	26,975	-8,506

1. Description
Plug-in hybrid vehicles (sometimes referred to as PHEV) have a conventional engine and a battery. The main drive battery is charged from the electricity network. They offer a greater range than a purely electric vehicle whilst reducing TTW CO_2e emissions to zero for short journeys.

2. Emission reduction potential
Plug-in hybrid cars save 30% WTW CO_2e emissions in comparison to equivalent-sized diesel cars.

3. Cost
Total Cost of Ownership (TCO) has been used to make comparisons between different types of vehicles over their whole lifetimes. TCO includes maintenance, management, infrastructure (i.e. charging stations for EV) and fuel, and is on a lease basis. Fuel costs are based on typical mileage for each size of vehicle in NRW fleet.

The UK government's Office for Low Emission Vehicles (OLEV)[67], part of Department for Transport and Department for Business, Energy and Industrial Strategy, provides grants towards the cost of new electric and hybrid cars. The level of grant depends on the level of CO_2e emissions from the car.[72] For example, a Toyota Prius 1.8 VVTI plug-in car benefits from a government OLEV grant of £2,500 per vehicle. However, despite the available grant funding, the TCO for a medium PHEV would be £8,506 greater than a medium diesel equivalent.

4. Scale of adoption
Plug-in hybrid cars are not recommended for adoption into our fleet because they are uneconomical compared to other fleet cars and were rated 'Poor' in the Cenex Suitability Assessment on the grounds of cost. Therefore, no feasible nor theoretical maximum has been calculated for plug-in hybrid cars.

5. Examples of successful adoption
Case study (Cenex report p20): Environment Agency 2015

[72] https://www.gov.uk/plug-in-car-van-grants/what-youll-get Accessed 13/9/17

4.2.3.11 Plug-in hybrid 4x4

Table 31: Summary of costs and CO_2e savings made by changing from comparable diesel 4x4 to plug-in hybrid 4x4

				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%) WTW	Annual reduction in CO_2e (tonnes) WTW	TCO (£) over 5-year period	TCO Savings (£) over 5-year period
4x4 plug-in hybrid	Plug-in hybrid	Diesel vehicle	4x4	43%	1.723	27,431	-2,068

1. Description
See 4.2.3.10 above for a description of plug-in hybrid vehicles.

Alternative options to diesel 4x4 are lighter duty All Wheel Drive (AWD) vehicles. The savings made over comparable diesel 4x4 vehicles are mainly due to the improved economy of a smaller engine. Not all 4x4/AWD vehicles have comparable off-road capability and may not be suitable replacements. Cenex recommends that the plug-in hybrid 4x4/AWD is the most suitable alternative to a comparable diesel 4x4, due to it having the greatest CO_2e savings among the 4x4 alternatives.

2. Emission reduction potential
Plug-in hybrid 4x4/AWD vehicles can save 43% WTW CO_2e emissions in comparison to equivalent sized diesel vehicles.

3. Cost
Plug-in hybrid 4x4/AWD vehicles have a moderate increase in TCO (8%), compared to a diesel equivalent.

4. Scale of adoption
In terms of suitability of this technology for our fleet and operations, plug-in hybrid 4x4/AWD vehicles were 'recommended in certain circumstances' in the Cenex Suitability Assessment and Cenex recommends that they should be considered to replace the Dacia Duster currently in use in the fleet.

i) Feasible maximum
Scenario 2 (without biodiesel) – alternative vehicle adoption and efficiency improvement of a reduced sized fleet represents the feasible maximum reduction in CO_2e emissions and costs for a whole fleet scenario. Telemetry was also applied across the vehicle types. The scenario did not include downsizing of vehicles; this is likely to yield additional cost and carbon reductions.

- Feasible maximum number of vehicles: 6
- Feasible maximum TCO savings (£) over 5-year period: £-12,408
- Feasible maximum annual reduction in CO_2e (tonnes) WTW: 10.338 tCO_2e

ii) Theoretical maximum
The theoretical maximum recommended for fleet is Scenario 2: Alternative vehicle adoption and efficiency improvement (with biodiesel). The theoretical maximum for this measure is therefore the same as the feasible maximum but also includes the use of biodiesel.

4.2.3.12 Petrol hybrid cars

Table 32: Summary of costs and CO_2e savings made by changing from diesel to petrol hybrid cars

				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%) WTW	Annual reduction in CO_2e (tonnes) WTW	TCO (£) over 5-year period	TCO Savings (£) over 5-year period
Small petrol hybrid car	Petrol hybrid	Diesel vehicle	Small	31%	0.702	17,434	-281
Medium petrol hybrid car	Petrol hybrid	Diesel vehicle	Medium	31%	0.599	17,046	1,423

1. Description
Petrol hybrid vehicles have a conventional engine and a small battery, which recharges by regenerative braking. Due to the power provided by the battery at times, petrol hybrid vehicles offer a reduction in fossil fuel use and therefore reduction in CO_2e emissions.

2. Emission reduction potential
Petrol hybrid cars can save 31% WTW CO_2e emissions in comparison to equivalent sized diesel vehicles.

3. Cost
While a small petrol hybrid car would amount to a small increase in TCO of around 2% compared to a diesel equivalent, a medium petrol hybrid car would result in a TCO reduction of 8%.

4. Scale of adoption
In terms of suitability of this technology for our fleet and operations, petrol hybrid cars were rated ‘Good’ in the Cenex Suitability Assessment and Cenex recommends that they should be considered for higher mileage trips where an electric vehicle does not provide sufficient range.

i) Feasible maximum
Scenario 2 (without biodiesel) – alternative vehicle adoption and efficiency improvement of a reduced sized fleet represents the feasible maximum reduction in CO_2e emissions and costs for a whole fleet scenario. Telemetry was also applied across the vehicle types. The scenario did not include downsizing of vehicles; this is likely to yield additional cost and carbon reductions.

Small petrol hybrid car in place of diesel equivalent

- Feasible maximum number of vehicles: 13
- Feasible maximum TCO savings (£) over 5-year period: £-3,653
- Feasible maximum annual reduction in CO_2e (tonnes) WTW: 9.126 tCO_2e

Medium petrol hybrid car in place of diesel equivalent

- Feasible maximum number of vehicles: 10
- Feasible maximum TCO savings (£) over 5-year period: £14,230
- Feasible maximum annual reduction in CO_2e (tonnes) WTW: 5.990 tCO_2e

ii) Theoretical maximum
The theoretical maximum recommended for fleet is Scenario 2: Alternative vehicle adoption and efficiency improvement (with biodiesel). The theoretical maximum for this measure is therefore the same as the feasible maximum but also includes the use of biodiesel.

4.2.3.13 Petrol hybrid 4x4

Table 33: Summary of costs and CO_2e savings made by changing from diesel to petrol hybrid 4x4s

				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%) WTW	Annual reduction in CO_2e (tonnes) WTW	TCO (£) over 5-year period	TCO Savings (£) over 5-year period
4x4 petrol hybrid	Petrol hybrid	Diesel vehicle	4x4	26%	1.037	25,768	-406

1. Description
See 4.2.3.12 for a description of petrol hybrid vehicles.

Alternative options to diesel 4x4 are lighter duty All Wheel Drive (AWD) vehicles. The savings made over comparable diesel 4x4 vehicles are mainly due to the improved economy of a smaller engine. Not all 4x4/AWD vehicles have comparable off-road capability and may not be suitable replacements.

Currently, few 4x4 petrol hybrids are available from mainstream manufacturers. NRW does not use bunkered diesel, therefore petrol hybrids offer no operational restrictions or increased mileage.

2. Emission reduction potential
AWD petrol hybrids offer slightly better CO_2 emissions to diesel 4x4s as well as better air quality performance.

3. Cost
Cenex notes that a transition to petrol hybrid AWD would include a minor increase in TCO.

4. Scale of adoption
In terms of suitability of this technology for our fleet and operations, petrol hybrid 4x4s were rated 'Variable' in the Cenex Suitability Assessment and Cenex recommends that they should be considered for higher mileage trips where an electric vehicle does not provide sufficient range.

i) Feasible maximum
Scenario 2 (without biodiesel): Alternative vehicle adoption and efficiency improvement of a reduced sized fleet represents the feasible maximum reduction in CO_2e emissions and costs for a whole fleet scenario. Telemetry was also applied across the vehicle types. The scenario did not include downsizing of vehicles; this is likely to yield additional cost and carbon reductions.

This scenario has not identified petrol hybrid 4x4s as a measure. Instead, the Cenex report recommends that the plug-in hybrid 4x4/AWD is the most suitable alternative to a comparable diesel 4x4, due to it having the greatest CO_2e savings among the 4x4 alternatives. Therefore, there is no feasible maximum associated with a replacement of diesel 4x4 with a petrol hybrid alternative.

ii) Theoretical maximum
The theoretical maximum recommended for fleet is Scenario 2: Alternative vehicle adoption and efficiency improvement (with biodiesel). The theoretical maximum for this measure is therefore the same as the feasible maximum but also includes the use of biodiesel.

4.2.3.14 Small range-extended electric vehicle

Table 34: Summary of costs and CO_2e savings made by changing from diesel to small range-extended electric vehicle

				Carbon savings		Cost analysis	
Mitigation measure	Fuel type	Comparator	Size	Annual reduction in CO_2e (%) WTW	Annual reduction in CO_2e (tonnes) WTW	TCO (£) over 5-year period	TCO Savings (£) over 5-year period
Small range-extended electric vehicle (REEV)	REEV	Diesel vehicle	Small	32%	0.721	19,200	-2,048

1. Description
A range-extended electric vehicle (REEV) is a battery electric vehicle that runs and operates on electricity but includes an on-board ICE auxiliary power unit (APU) which provides additional miles of mobility through charging the battery 'on the go'. Range-extended and plug-in hybrid vehicles offer some zero-emission capability without the range restrictions of a pure battery electric vehicle. With a REEV, the propulsion technology is always electric; with a PHEV the propulsion technology can be electric or hybrid.

Availability for REEV is limited in the current market with only a few models released by mainstream manufacturers. There is only one small range-extended electric vehicle currently on the market (BMW i3 REx).

2. Emission reduction potential
The BMW i3 REx has a substantial all electric range before the engine starts resulting in CO_2e savings of 76% TTW and ~30% WTW.

3. Cost
The BMW i3 REx is an expensive vehicle resulting in a TCO increase of 12%, i.e. there is a cost of £2,048 over five-year period. For the NRW fleet, range-extended cars are uneconomic due to their high capital cost compared to the standard low-cost diesel vehicles currently being used.

4. Scale of adoption
There are no operational restrictions with REEV, which have good vehicle maturity and emission savings. However, they are considered unsuitable compared to conventional diesel fleet vehicles due to greater operational cost. Therefore, Cenex does not recommend them for high levels of penetration of the NRW fleet.

i) Feasible maximum
Scenario 2 (without biodiesel): Alternative vehicle adoption and efficiency improvement of a reduced-sized fleet represents the feasible maximum reduction in CO_2e emissions and costs for a whole fleet scenario. Telemetry was also applied across the vehicle types. The scenario did not include downsizing of vehicles; this is likely to yield additional cost and carbon reductions.

As none of the chosen scenarios included REEV, there is no feasible maximum for this measure of range-extended electric vehicle.

ii) Theoretical maximum
The theoretical maximum recommended for fleet is Scenario 2: Alternative vehicle adoption and efficiency improvement. (with biodiesel). The theoretical maximum for this measure is therefore the same as the feasible maximum but also includes the use of biodiesel.

5. Examples of successful adoption
Speedy Services and BMW i3 van (2016)

6. Technical considerations
Charging infrastructure is required. Low-cost wall-mounted units can be installed at depots / offices, employees' homes and work destinations (pending electricity supply). Where large penetrations of EVs exist around a single depot, smart (distributed) charging or power upgrades may be required and could make adoption uneconomic.

4.2.3.15 Implementation of biodiesel

Table 35: Implementation of biodiesel as described in Scenario 2: Alternative vehicle adoption and efficiency improvement (with biodiesel)

Fleet Scenario	Description	Annual reduction in CO_2e (%) WTW	Annual reduction in CO_2e (%) TTW	Annual TCO saving (%)	Annual TCO saving (£) (approximate)
2	Implementation of biodiesel as described in Scenario 2: Alternative vehicle adoption and efficiency improvement (with biodiesel)	6	7	n/a	-8,000

1. Description
In this scenario, 17% of the fleet vehicles would be fuelled by biodiesel, bringing the proportion of low-emission vehicles in the fleet to 86%. As part of Scenario 2: Alternative vehicle adoption and efficiency improvement (with biodiesel), 79 fleet vehicles would be fuelled by B25 biodiesel, comprising: small vans (22), 4x4s (49) and large vans (7). This would occur alongside the introduction of a blend of EVs (324), petrol hybrids (23) plug-in hybrids (6) and telemetry.

2. Emission reduction potential
Biodiesel: Variable depending on blend (circa 18% WTW CO_2e reduction available from B25 blend). Engine design, fuel quality and operational cycles are essential in assessing total emission with biodiesel – with some authors reporting increases in emitted NOx, particulates and CO.

3. Cost
The inclusion of use of biodiesel in this scenario increases the total costs by £8,000, from £500,000 to £508,000.

Annual TCO saving (%) is not available for this measure as it encompasses a number of different types of vehicles.

4. Scale of adoption
i) Feasible maximum
The implementation of biodiesel forms an additional part of the theoretical maximum for fleet. This measure is an all-fleet measure and therefore the theoretical and feasible maxima are the same.

ii) Theoretical maximum
- WTW CO_2e annual emissions savings: 97 tonnes (6% on baseline).
- TTW CO_2e annual emissions savings: 52 tonnes (7% on baseline).

4.2.3.16 Installing telematic system

Please note, in Table 36, data for TCO (£) over five-year period and TCO savings (£) over five-year period are not available for every measure. Where 'n/a' is given, the relevant data was not provided by Cenex because of the relatively small numbers of these vehicles within the NRW fleet.

Table 36: Summary of costs and CO_2e savings by installing telematic system in vehicles

	Carbon savings			Cost analysis		
Mitigation measure[73]	Annual reduction in CO_2e (%) WTW	Annual reduction in CO_2e (tonnes) WTW, per vehicle	Reduction in WTW CO_2e (tonnes) over 5-year period for whole fleet	TCO (£) over 5-year period	TCO savings (£) over 5-year period	Total 5-year saving (£) for whole fleet
Installing telematic system into small car	15	0.336	102	16,654	498	-12,295
Installing telematic system into medium car	15	0.290	170	18,040	429	-30,728
Installing telematic system into small van	15	0.513	469	n/a	n/a	-5,546
Installing telematic system into 4x4 van	15	0.600	39	n/a	n/a	2,641
Installing telematic system into 4x4 double cab pickup	15	0.814	399	n/a	n/a	47,559
Installing telematic system into large panel van	15	0.874	118	n/a	n/a	7,617
Installing telematic system into large double cab van	15	1.15	23	n/a	n/a	2,120

1. Description
To support the business case for adopting low-emission technologies, investment in telematics will generate a robust evidence base for future decisions and provide evidence for the scenarios outlined in this review.

Introducing a vehicle tracking and telematics system is a widely accepted method of reducing mileage, costs and accidents. Vehicle telemetry can provide meaningful information about the driver's performance by collecting data from the vehicle, leading to better fuel efficiency through driver feedback. Some of the other advantages of telemetry systems are:

- Providing accurate mileage data, avoiding over mileage and phantom mileage claims (from Grey Fleet).

[73] All telematic measures compared to non-telematic diesel equivalents in existing fleet.

- Analysing routes, both in real time and retrospectively, enabling better routing, scheduling, and minimising unnecessary detours.

- Helping to increase driver safety, particularly in reducing the reliance on mobile phones for lone-working procedures.

- Encouraging drivers to be responsible for their driving and to be more aware of bad habits, resulting in:
    - cost savings from reduction in insurance premiums and fuel use associated with certain driving habits
    - reduction in vehicle wear and tear
    - possible improved reputation with the public.

- Reducing any unauthorised private use of fleet vehicles.

At present, there are three main types and/or functions of telematic systems:

- Fleet Review Telemetry:
    - monitors fuel and/or energy consumption and tracks journey patterns
    - some systems can also be used to identify suitable EVs for their duty cycles, e.g. available from FleetCarma

- Driving Style Telemetry: rates driver's performance by collecting data from the vehicle, leading to driver feedback and in-cab coaching, e.g. available from Microlise.

- Driving Aid Telemetry: add-on warning dashboard in vehicles to provide real-time indicators of bad driving habit such as over revving and harsh braking, e.g. available from Lightfoot.

In addition, telemetry extends beyond vehicle tracking and into enterprise management. Today's telematics technology provides a way of controlling and organising vehicles and mobile workforces. Companies like FleetCarma provide a system which is good for optimising and tracking alternatively fuelled vehicles.

2. Emission reduction potential
Fleet telematics have the ability to reduce fleet CO_2e by around 15%. Telematics help to save fuel and identify which vehicles are appropriate for electrification.

As shown in Table 36, annual reduction in CO_2e (tonnes) ranges from 0.29 tCO_2e WTW (a medium car) to 1.15 tCO_2e WTW (a large double cab van).

If telemetry were applied to all vehicles, without alteration to the miles per annum (MPA) and fleet size, the total five-year CO_2e saving could be 1,320 tCO_2e WTW (1,072 tCO_2e TTW) with a total cost saving of £11,367.

Cenex carried out a sensitivity analysis and discovered that if utilisation were increased on low mileage vehicle groups[74], this would result in a 1,518 tCO_2e WTW (1,233 tCO_2e TTW) saving with a cost saving of £67,074 over the five-year period.

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[74] Small cars to 12,000 MPA, medium cars to 11,000 MPA and small vans to 10,000 MPA.

Alongside, and with the help of the introduction of telematics, NRW would also implement environmental benchmarking, utilising internal telemetry data to understand its own performance in the context of others', such as national best practice and that of similar external organisations. Depending on how NRW's performance will fare, this comparison could help to encourage further emission savings.

3. Cost
The capital and annual subscription costs have been derived from the Royal Mail and Vale of Glamorgan Council case studies. Furthermore, the fuel cost was taken as £0.94 per litre (excluding VAT) from the average UK price quoted in the AA fuel price report (average between February 2016–2017), and fuel savings were assumed as 15% (from average telematic company quoted figures and case study data[75]).

As stated by Cenex: 'Increased utilisation of vehicles would make telematics viable and yield cost savings.' With the current annual mileage, the telemetry system, regardless of the benefits, will not pay back. For the systems to break even, an average annual mileage of 12,000 miles per annum for small cars, 11,000 miles per annum for medium cars and 10,000 for small vans is required. The costs and saving calculations do not include any additional benefits of cost reductions associated with accident reduction and maintenance, which are difficult to quantify – case study evidence (see f) below) states accident rates drop by around 20 – 35%.

For the rest of the fleet (4x4s and large vans), there is no need for a sensitivity analysis by annual mileage as the current averages provide a considerable annual and lifetime fuel saving. In some cases, for example the 4x4 double cab pickup, telemetry can achieve over £47,000 in fuel saving alone over a five-year period.

4. Scale of adoption
i) Feasible maximum
Telemetry was also applied across the vehicle types as part of Scenario 2: Alternative vehicle adoption and efficiency improvement of a reduced sized fleet. The scenario did not include downsizing of vehicles; this is likely to yield additional cost and carbon reductions.

According to this scenario, applying telemetry to all vehicles in the baseline fleet, with fleet size and mileage remaining as for baseline, predicted savings are:

- Feasible maximum total carbon savings per year (WTW): 264 tCO_2e
- Feasible maximum total carbon savings per year (TTW): 214.40 tCO_2e
- Feasible maximum total cost savings (TCO) per year: £2,273.40

Over a five-year period, predicted savings are:

- Feasible maximum total carbon savings over five years (WTW): 1,320 tCO_2e
- Feasible maximum total carbon savings over five years (TTW): 1,072 tCO_2e
- Feasible maximum total cost savings (TCO) over five years: £11,367

[75] Royal Mail reduced its fuel use by over 10% and the Vale of Glamorgan Council achieved a fuel saving of between 10%–20%.

As noted in the Costs section above, the costs and saving calculations do not include cost reductions associated with accident reduction and maintenance.

ii) Theoretical maximum
The theoretical maximum recommended for fleet is Scenario 2: Alternative vehicle adoption and efficiency improvement (with biodiesel). The theoretical maximum for this measure is therefore the same as the feasible maximum but also includes the use of biodiesel.

As noted in the Costs section above, the costs and savings calculations do not include cost reductions associated with accident reduction and maintenance.

5. Benefits beyond greenhouse gas savings
According to the report by Cenex (p49), the benefits beyond GHG savings of implementing telemetry include:

- Safety: telematic systems provide additional benefits of accident reduction. These are difficult to quantify, but case study evidence (see f) Examples of successful adoption, below) states accident rates drop by around 20–35%.
- Maintenance: use of telemetry provides an additional benefit of maintenance reduction.

6. Examples of successful adoption
The following case studies are provided in the Cenex (2017) report:

- Royal Mail (2009)
- Vale of Glamorgan Council (2013)
- Morelli Group and ALD Automotive (2016)

7. Technical considerations
A minimum lifetime of ten years is expected from telemetry systems, due to their simple, low power and wireless nature. It is possible to re-use telemetry units at the end of a five-year period, as long as the telemetry provider is aware of the change of vehicle.

4.2.3.17 Installation of electric vehicle charging points

To realise the potential of EVs in the fleet, investment in charging infrastructure is essential. Scoping of, and management commitment to, appropriate electric vehicle charging infrastructure is required ahead of any further expansion / investment in electric vehicles.

There are currently six NRW locations where we have installed charging points: offices at Bangor, Buckley, Llandarcy and Haverfordwest, and visitor centres at Coed y Brenin and Bwlch Nant yr Arian.

According to the Cenex report, next steps should include conducting a feasibility study to identify and develop plans to expand electric vehicle charging infrastructure to support electrification of the fleet. This should take factors into account such as:

- Infrastructure capacity and charge rate requirements (13amp charging from existing electrical sockets is not a long-term solution for charging due to safety concerns).

- Commitment to charging infrastructure before purchase of vehicles is required.

- Electrical capacity at sites should be investigated to ensure suitability for installing charging infrastructure and any future implementation of electric vehicles.

- Groundwork requirements.

- Payment platforms and back office system requirements (e.g. 3G requirements, data requirements, etc.).

- The assumption could be made that each unit will service two vehicles (taking into account the vehicles which regularly visit the site).

Cost
Infrastructure costs included in the analysis of mitigation options for NRW's fleet was applied at a rate of £1,500 (purchase and installation of the charging unit). Each unit was assumed to have two sockets to feed two vehicles and included £60 per annum data fees (associated with payment platform services) amortised over a ten-year period. No account of civil costs for cabling provision (i.e. groundworks) was included. However, as part of a demonstration project, the Carbon Positive Project installed six charging points at six different locations, which involved groundworks. The average cost of these charging stations, including purchase of the charging units, installation, groundworks and labour, was £3,455 per unit. However, in future installations, bulk buy and installation will be used to ensure groundworks are cost-effective, which are anticipated to reduce this figure significantly.

4.2.3.18 Introduction of Skype

The final mitigation measure which forms part of the fleet review is the introduction of Skype software to staff members.

Contrary to the other measures included in this category, this particular measure was not featured in the review by Cenex and is included retrospectively, as it has already been implemented and in use within the organisation for a number of years. However, it was considered to be an important contributor towards our decarbonisation work and, as a result, included as a measure.

The software was introduced with the purpose of reducing the need for staff to attend face-to-face meetings away from their place of work, thus reducing GHG emissions and costs associated with business travel. The roll-out of Skype is reinforced by NRW's adoption of a 'travel decision tree', which prioritises the use of Skype and active and sustainable travel (walking, cycling and public transport) for meetings, before the use of fleet vehicles, with personal vehicles considered a last resort for business travel.

Although the direct impacts of the measure – such as cost and CO_2e savings made as a result of reduced business miles – are difficult to quantify, the data we do have indicates that the number of active users of Skype within the organisation increased by almost 75% between 2014 and 2015, and by a further 10% between 2015 and 2016. [76]

4.2.3.19 Sensitivity of mileage and ownership

A sensitivity analysis on mileage and length of ownership was conducted on cars and small vans where electrification has been recommended. Results show that electric TCO % savings increase with annual mileage. A target annual mileage scenario of 15,000 miles is also shown to demonstrate the effect of vehicle reduction and mileage increase activity across the fleet, which is an area currently under review by NRW.

For small electric vans, a target annual mileage of 15,000 (approximately double current mileage) or an ownership increase from five years to seven years results in TCO savings, which are not predicted under current mileage[77] or ownership conditions[78]. For electric cars, both small and medium, increasing annual mileage (i.e. through more effective utilisation of fleet vehicles) or ownership period slightly increases from existing positive % TCO savings.[79]

4.2.3.20 Fleet Best Practice

In addition to changes in technology, the assessment of NRW's fleet also highlighted the following options for emissions mitigation and potential cost savings:

- **Downsizing**: downsizing diesel cars can lead to TCO savings of up to £2,100 (11%) and 87 kg (8%) WTW CO_2 or 70 kg (8%) TTW CO_2 per vehicle.
- **Recommended next steps**: it is recommended that NRW reviews the size of vehicles used within its fleet and downsizes vehicles where this is practical.
- **Ownership Model**: analysis showed that changing to an ownership model for the diesel vehicles (compared to the current lease model) could result in five-year TCO savings per vehicle of £4,912 for small cars (Ford Fiesta), £8,059 for medium cars (Ford Focus), £3,322 for small vans (Citroen Nemo), £8,651 for 4x4s (Mitsubishi Outlander) and £8,160 for large vans (Ford Transit). Similar savings are also available for alternatively fuelled vehicles: for example, a £2,780 saving for purchasing medium car EVs (Nissan Leaf) rather than leasing, £2,587 for medium

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[76] Based on average annual number of active Skype users, as reported internally: 2014: 815; 2015: 1422; 2016: 1559.

[77] Small electric van mileage sensitivity: -4% TCO savings under current general annual mileage, increases to 11% TCO savings with target annual mileage of 15,000.

[78] Small electric van ownership sensitivity: -4% TCO savings under current general annual mileage in five-year ownership period, increases to 2.5% TCO savings with the same mileage in seven-year ownership period.

[79] Small electric car mileage sensitivity: 21% TCO savings under current general annual mileage, increases to 26% TCO savings with target annual mileage of 15,000; and to 24% TCO savings with the same current general mileage in seven-year ownership period.
Medium electric car mileage sensitivity: 26% TCO savings under current general annual mileage, increases to 32% TCO savings with target annual mileage of 15,000; and to 28% TCO savings with the same current general mileage in seven-year ownership period.

car petrol hybrids (Toyota Prius) and £6,264 for small EV vans (Nissan e-NV200). Due to capital constraints, NRW leases most fleet vehicles and future acquisitions of vehicles will largely be on a lease basis. It is recognised that significant TCO savings could be available if the organisation were able to pursue a vehicle-ownership model.

- **Recommended next steps:** vehicle ownership and lease prices were taken from the Government Procurement Portal. It is recommended that NRW investigates the savings available through its procurement process and undertakes a trial purchase of vehicles to confirm savings available through an ownership model.

- **Telematics:** fleet telematics can reduce fleet CO_2 by around 15%. A simple payback calculation showed that telematics are only economically viable in higher mileage vehicles. For low mileage vehicles, the annual cost increase per vehicle (£40–£50) is still a worthwhile investment to generate the robust evidence base (data and information) that telematics systems supply to inform future strategy. Furthermore, the cost analysis did not include costs associated with wider benefits of accident reduction and vehicle maintenance, which are difficult to quantify – case study evidence shows accident rates can drop by around 20–35%. Telematics help to save fuel and identify which vehicles are appropriate for electrification.

- **Recommended next steps:** It is recommended that a telematics technology trial is undertaken, especially in the 4x4 and large van categories where low carbon options are limited.

4.2.4 Plant review

4.2.4.1 Method

Our operational plant fleet includes tractors, all-terrain vehicles (ATVs) and quad bikes, diggers / dumpers, forklifts, mowers, chippers, and pumps. Cenex carried out a high-level review to understand the potential for emissions savings through reducing fuel use in our operational plant, whilst continuing to perform operational activities. This began with understanding usage, fuel consumption, emissions and operating patterns, before carrying out an assessment of low-emission vehicle technology.

In addition to assessing alternative technologies for our operational plant, Cenex developed scenarios to identify the costs and carbon savings of implementing mitigation measures in the whole plant fleet. It is from these that the feasible and theoretical maxima low-emission plant scenarios have been taken.

Cenex used the following method to carry out a high-level review of NRW's plant:

- Fleet baselining: understanding usage, fuel consumption, emissions and operating patterns
- Suitability assessment
- Costs and emissions analysis
- Scenario planning
- Recommendations

Data relating to fuel use from plant vehicles was not available from NRW, therefore Cenex estimated plant fuel consumption and CO_2 emissions based on engine size and operating patterns. In a number of instances, a lack of available data for our plant has led to gaps in our evidence. As a result, the majority of the mitigation measures identified for plant do not include the same level of data provided for fleet, such as reductions in CO_2e (WTW or otherwise), TCO savings, or detailed feasible and theoretical maxima. While Cenex was able to offer us recommendations with regards to mitigation measures for plant, we recognise that further evidence gathering may be required in future to fill these gaps.

4.2.4.2 Strategic plant carbon review

The scenarios presented in this section are based on high-level estimates of fuel use and emissions.

Table 37: Summary of annual CO_2e reduction of plant scenarios

Scenario	Description	Annual reduction in CO_2e (tonnes)	Annual reduction in CO_2e (%)	WTW[80] CO_2e (tonnes per annum)
Plant				
A	All electric quad bikes	21.352	58	15.8
B Low uptake	Mature technology adoption	7.858	9	76.132
B Medium uptake	Mature technology adoption	16.743	20	67.247
B High uptake	Mature technology adoption	32.852	39	51.138
C	Technology adoption to 2050		80	

1. Description
Various scenarios were developed to discover what carbon and cost reductions could be achieved by the whole plant fleet, whilst continuing to perform operational activities. The scenarios were based on the recommended low-emission vehicles identified by Cenex and presented in the earlier section of this report. Cenex modelled three low-emission plant scenarios to demonstrate the effect of implementing recommended technologies in the NRW fleet.

The three scenarios were:

- **Scenario A** – All-electric quad bikes: this scenario assumes that 80% of the quad bikes in the NRW fleet are replaced with 100% electric equivalents between 2017 and 2021.

- **Scenario B** – Mature technology adoption: this considers a single, hypothetical depot in three emission-reduction strategies. These three strategies involve the low,

[80] WTW: Well to wheel

medium, and high uptake of emission-reducing work practices and technologies between now and 2021 (with 2016 plant information as a baseline comparison).

- **Scenario C** – Technology adoption to 2050: this scenario assumes that NRW implements a progressive CO_2 reduction scheme with the aim of assisting the Welsh and UK governments in achieving their 2050 CO_2 reduction targets. A key element of the 2050 scenario is the complete elimination of fossil fuel use by 2040.

In all the scenarios, Cenex made 'high-level' estimates for fuel use and emissions. Calculations were made based on the information provided to Cenex by NRW on our plant fleet. Operational information was limited to the total number of hours worked per year. No fuel consumption data for plant was available therefore fuel consumption estimates were based on engine size and typical engine loading rates. To refine the scenarios for greater certainty of return, real world fuel consumption data should be gathered from the plant fleet to refine the presented scenarios.

The high-level plant review highlighted that emission savings at similar or better total cost of ownership (TCO) could be available from interventions such as implementing fuel efficiency measures and driver training, diesel hybrid excavators in the NRW operations, electric quads, electric mowers (for reservoirs) and biodiesel. For example, NRW could reduce its tractor-based fuel consumption, and resultant emissions, by at least 20% by implementing fuel efficient staff training policies. This could also result in a 12% reduction in total operating costs of these vehicles. These options should be subject to a more detailed review and trialled where necessary to establish accurate emission and cost savings.

2. Emission reduction potential
Annual emissions savings (see Table 37) were provided in terms of percentage reduction of our existing fleet emissions and as annual reduction in CO_2e (tonnes), except for technology adoption to 2050 (Scenario C).

Scenario C gave the greatest CO_2e emission reduction potential with an annual reduction of 80%, reflecting the aim of complete elimination of fossil fuel use by 2040. This is the theoretical maximum scenario for CO_2e emission reduction.

3. Cost
The mature technology adoption scenarios (B) show that for low uptake, an 11% fuel reduction and 9% WTW CO_2e saving can be achieved. The majority of the savings made are due to the fuel reduction programme, which has the best potential for cost-effective savings from large plant. Fuel consumption is reduced in the high-uptake scenario which results in a 22% saving.

Electric and hybrid plant products are expected to continue to mature and reduce in costs which will aid the business case.

4. Scale of adoption
i) Feasible maximum
Mature technology adoption (medium uptake), i.e. Scenario B, represents the feasible maximum reduction in CO_2e emissions and costs for NRW's plant fleet. This variation of Scenario B is the feasible maximum because it results in the greatest reduction in CO_2e emissions attainable by adopting mature technologies and without the use of biodiesel and

associated infrastructure. Savings are shown in Table 38: Summary of annual CO_2e reduction for feasible maximum scenario.

Scenario B, medium uptake of mature technologies, consists of:

- Electric quad bikes / ATV implemented
- Hybrid 21t excavator implemented
- Electric chipper purchased, completes 10% of light wood chipping located close to depot/power supply
- Excavator and tractor fuel reduction programme implemented in line with recommendations in Section 17 Plant Best Practice (Cenex p100), including driver training, allows a year-on-year 5% fuel reduction per annum.

Table 38: Summary of annual CO_2e reduction for feasible maximum scenario

Scenario	Description	Annual reduction in CO_2e (tonnes)	Annual reduction in CO_2e (%)	WTW[81] CO_2e (tonnes per annum)
Plant				
B Medium uptake	Mature technology adoption	16.743	20	67.247

Scenario B shows potential savings of adopting mature technologies around a single, hypothetical, depot. Analysis of the distribution of equipment in detail reveals that selecting a single 'representative' depot to reflect the entire NRW fleet was not possible; due to the large variation in numbers and types of plant kept at the various depots. Therefore, Cenex has based the numbers of plant on the median average numbers across the NRW depots.

ii) Theoretical maximum
The theoretical maximum reduction in CO_2e emissions and costs for a whole plant fleet scenario is Scenario C, i.e. technology adoption to 2050 to eliminate emissions. Cenex developed a 'maximum emission reductions possible' scenario to show the level of uptake required to achieve 80% emission target by 2050 (Table 39: Summary of annual CO_2e reduction and TCO saving for theoretical maximum plant scenario). A key element of the 2050 scenario is the complete elimination of fossil fuel use by 2040.

This scenario shows one, theoretically possible, pathway to eliminate fossil fuel use and WTW CO2e by 2050. This requires the aggressive adoption of B50 biofuels, and the purchase of new plant that can run on such fuels, between 2020 and 2025. Then another round of aggressive technology and fuel adoption from 2040 onwards to meet the zero CO2e emissions target. It should be noted that any strategy to eliminate fuel use by 2040 should be reassessed regularly as plant fuel and technology trends move away from direct fossil fuel use. Assumptions and steps required to achieve this scenario are given below in Table 39.

[81] WTW: Well to wheel

Table 39: Summary of annual CO_2e reduction and TCO saving for theoretical maximum plant scenario

Plant Scenario	Description	Annual reduction in CO_2e (tonnes)	Annual reduction in CO_2e (%)	WTW[82] CO_2e (tonnes per annum)	Annual TCO saving (£) (approximate)
C	Technology adoption to 2050		80		

Assumptions:

- The assumption is made that an intensive tractor and heavy plant training system is implemented in 2017/18 financial year to minimise emissions.
- Note that in 2020, the timescale changes, and the assumption is made that between 2020 and 2025, B50 compatible diesel-electric hybrids become the norm for the clear majority of plant equipment.
- The projection assumes that NRW aggressively pursues a major fleet restructuring exercise, to replace existing plant with the new biofueled hybrid equivalents.
- The next major reduction in emissions is achieved between 2035 and 2040. Drop-in biofuels (such as HVO) are widely available and can be combined with sustainably generated hydrogen gas, for combustion in a dedicated or dual fuel B100-H2-hybrid powertrain.
- It is assumed in this scenario that decarbonisation of the electricity and primary fuel supply (renewable diesel, green H2, etc) occurs in line with government projections and targets.

To achieve 80% emissions reductions targets under UK legislation, several steps are required:

- Implement low-emission technologies where operationally suitable (e.g. quad bikes), starting this year (2017).
- Implement fuel-efficiency programmes for drivers and operators, starting this year (2017).
- Implement a plant fleet replacement programme to comply with Stage-V NRMM emission standards from 2019 (if Stage-V equipment is not available before this date).
- Monitor and review the development of lower carbon plant, trialling technologies which show potential to reduce emissions at similar operating costs. Implement fuel

[82] WTW: Well to wheel

replacement with a WTW fuel that is operationally suitable after appropriate feasibility studies, fleet replacement and fuel storage strategies have been implemented. At the time of writing, the most likely replacement fuels (in order of technology maturity and proven track record in sustainable WTW emissions reductions) are:

- Biodiesel or renewable diesel (i.e. HVO[83])
- Biomethane (Park & Choi, 2017)[84]
- Green hydrogen internal combustion engine (ICE) vehicles (Niu et al., 2016)[85]

4.2.4.3 Parameters and assumptions

Calculations have been made based on the information provided to Cenex by NRW on its plant fleet.

- **Operational hours:** annual operational hours by engine size and vehicle type, based on usage data provided by NRW.
- **Estimated fuel consumption and emissions:** plant fuel consumption data was not available. Therefore, fuel consumption was estimated, based on the reported operational hours and engine size of the equipment. Please note, this provides indicative figures only.
- **Plant emission standards:** Non-Road Mobile Machinery (NRMM) regulations are an internationally standardised set of emission guidelines. The date when a piece of plant machinery was manufactured determines which stage of the standards a given item of machinery must comply with. At the time of writing Stage-IV (also called Tier-III or Tier-IV in reference to American legislation) is in effect.[86] The next set of emission standards (Stage-V) comes into force in 2019/2020. The majority of the NRW fleet is ten years old or more and, as such, it complies with Stage-III regulations on emission standards. The growing awareness of the impact of pollution in urban environments is driving companies, and organisations that commission work in urban environments, to specify Stage-IV, Stage-V and, in some cases, better than Stage-V emission standards for plant machinery used in the completion of the contracted work.

All new NRMM purchases will have to be Stage-V compliant from 2019 or 2020 onwards, depending on engine size (assuming the UK adheres to pre-existing EU legislative plans).

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[83] Hydrotreated vegetable oil

[84] Park, J. and Choi, J., "A numerical investigation of lean operation characteristics of spark ignition gas engine fuelled with biogas and added hydrogen under various boost pressures," Appl. Therm. Eng. 117:225–234, 2017, doi:10.1016/j.applthermaleng.2017.01.115.

[85] Niu, R., Yu, X., Du, Y., Xie, H., Wu, H., and Sun, Y., "Effect of hydrogen proportion on lean burn performance of a dual fuel SI engine using hydrogen direct-injection," *Fuel* 186:792–799, 2016, doi:10.1016/j.fuel.2016.09.021.

[86] DieselNet, "Emission Standards: Europe: Nonroad Engines" https://www.dieselnet.com/standards/eu/nonroad.php (accessed 15/03/18)

Public awareness, and the ever-increasing stringency of environmental compliance when bidding for procurement and construction projects, is having an impact on the resale value of the older plant. Cenex advised that any anticipated residual value estimates for older plants should be revisited if Stage-IV or Stage-V compliance becomes mandatory in the construction and agricultural sectors in the near future. NRW may decide to sell off Stage-III and Stage-IV plant earlier than planned, as their resale value may decrease rapidly once Stage-V legislation comes into effect.

4.2.4.4 Presentation of identified potential mitigation measures

Results of the plant technology assessment by Cenex are presented in this section in the following order:

- Fuel replacement.
- Plant technology suitability assessment.
- Plant technology summary of results: a summary of opportunities for each type of plant, assessed by fuel type and against operational requirements, emissions and costs.
- Individual measures:
    - Quad bikes
    - Chipper
    - Digger / dumper
    - Mower
    - Tractor
    - Additional plant assessed by Cenex.
- Fuel efficiency through plant best practice.
- Strategic plant carbon review: scale of adoption based on whole plant fleet scenarios.
- Transport measures that are not progressed to detailed evaluation, and the reasons for that.

Low-emission plant options are presented in scenarios to demonstrate the effect of implementing recommended technologies in the NRW fleet. It is from these that the feasible and theoretical maximum scenarios have been taken.

4.2.4.5 Fuel replacement

The definition of alternative or replacement fuels will vary depending on the exact application, but in the context of the NRW plant review, any fuel other than diesel or petrol is considered a replacement fuel. The basic concept of replacement fuels is quite straightforward. If an equivalent amount of energy can be released, with a reduction in either local or total emissions (preferably both), then it should be considered preferable to do so. Arguments around which replacement fuel to use centre around the six following points[87]:

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[87] Avinash, A., Subramaniam, D., and Murugesan, A., "Bio-diesel—A global scenario," *Renew. Sustain. Energy Rev.* 29:517–527, 2014, doi:10.1016/j.rser.2013.09.007.

- Cost of the fuel.
- Ease of use, e.g. plant or infrastructure changes.
- Operational requirements, e.g. more frequent maintenance or refuelling.
- True emissions measurement, e.g. OEM stated emissions compared to real world usage including slips, leaks and spills.
- Security and purity of supply, e.g. small-scale productions lack redundancy, the UK does not have sufficient capability to produce all its own biofuels.
- Other, wider, social, and environmental impacts. For example, rapeseed and soybean-based biodiesel crops utilise land traditionally used for food crops, and so increase the price of food globally. Note that biodiesel can be sourced from re-used cooking oil, which does not present a risk to land traditionally used for crops. NRW's use of biodiesel to date has been from re-used cooking oils and not virgin crops.

Biodiesel is the most widely-used replacement fuel that can achieve significant WTW reductions in CO_2e emissions. However, these reductions will be limited to the compatibility of different plant items and their usage patterns (i.e. minimum blend requirements and duration between plant usage). CO_2e reductions are also available from less mature technologies for plant, such as dual fuel green hydrogen combustion engines and biomethane. All options have an associated cost and will require the purchase of new plant equipment and, in some cases, modification after purchase. In addition, all are likely to require the bunkering of fuel at depot sites (and associated additional costs) and additional training for staff and operators at those sites.

It is recommended by Cenex that NRW considers its biodiesel policy and decides if it is willing to undertake the additional work required to achieve further CO_2e reduction using biodiesel vehicles and infrastructure at suitable deports. Biodiesel facilities can be extended to include several other items of plant, but the business case for the creation of biodiesel infrastructure and policies will be highly reliant on tractor operations, with excavators also being a contributing factor. Fingerpost, Pont y Garth and Rhuddlan depots should be assessed for the implementation of biodiesel (engine compatibility is critical). Success of biodiesel projects will be dependent on a depot-based champion with the knowledge, skill and authority to drive the changes.

4.2.4.6 Plant technology suitability assessment

Each category of plant was assessed regarding their suitability against the following fuels / powertrains.[88]

- Biodiesel
- Diesel – electric hybrid
- Electric
- Alternative fuel (HC) – this is a range of hydrocarbon-based fuels such as LPG and CNG

[88] Powertrain, the mechanism that transmits the drive from the engine of a vehicle to its axle.

- Hydrogen

The maturity of each fuel / powertrain technology is also assessed as shown in Table 40: Technology maturity level.

Table 40: Technology maturity level

Maturity level	Meaning
1	Basic principles and concepts
2	Experimental, laboratory-based, validation of concept
3	Pre-production, proof of concept prototype, field tested
4	Production ready, demonstration project underway or completed, CE approval in hand
5	Production ready, CE-approved, operational experience, real world use data available

The alternative technology sections for each class of vehicle will focus on Maturity Level Five solutions. Maturity Level Five represents market-ready solutions that NRW can adopt today. A summary of lower maturity level technologies will be detailed where possible. Maturity Level Four should also be of interest to NRW. Typically, these are units that have yet to break into the UK market, but are close to doing so. Such vehicles may well be eligible for a degree of grant funding for demonstration trials that could help to mitigate costs. NRW is advised to monitor emerging technologies, and relevant funding opportunities, on a yearly basis.

Where prices are considered, as far as possible supplier list prices have been quoted. NRW staff have stated that cheaper quad bikes (for example) are available. However, this does not reflect the publicly available list price for such equipment. For the ease of comparison, no purchasing discounts have been included in publicly listed prices, as NRW would have to negotiate this with individual suppliers. In some cases, suppliers would not provide a list price directly, and historic CapEx purchasing information, provided by NRW, has been used instead.

4.2.4.7 Plant technology summary of results

The operational, emission and costs (CapEx / OpEx) identified in the plant alternative vehicle technology study are summarised in a traffic light matrix in Table 41: Matrix classification system (plant technology).

Parameters of the traffic light classification are shown in Table 40: Technology maturity level.

The ‘Amber’ classification may still offer emission savings but is unlikely to result in cost savings and there may be parts of NRW’s operational requirements that cannot be completed by amber technologies. NRW may choose to pursue amber technologies in order to achieve emission savings and conduct further investigations to assess economic performance.

Table 41: Matrix classification system (plant technology)

Factor	Red	Amber	Green
Operational	Fails to meet operational requirements	Meets some operational requirements	Meets all operational requirements
Emissions	Higher CO_2e emission (in comparison to Stage-III)	Reduced CO_2e emission (in comparison to Stage-III)	Zero emissions at tailpipe
CapEx[89]	Significantly higher plant + infrastructure CapEx	Broadly similar plant + infrastructure CapEx	Potential CapEx saving (in comparison to Stage-III)
OpEx	Significantly higher operating costs	Broadly similar operating costs	Lower operating costs (in comparison to Stage-III)

In some cases, there is no information available for a suitable technology for a given NRW plant operation (e.g. electrified excavators suitable for NRW operations). Where there is insufficient data to make an informed decision, that block has been left grey in Table 42: NRW plant assessment summary by Cenex.

Table 42: NRW plant assessment summary by Cenex

Fuel	Factor	ATVs, Quads, Bikes	Chipper	Digger / Dumper	Forklift	Mower	Other	Tractor
Biodiesel	Operational	Amber	Amber	Amber	Amber	Amber	Red	Amber
	Emissions	Amber	Amber	Amber	Amber	Amber	Grey	Amber
	CapEx	Amber	Amber	Amber	Amber	Amber	Grey	Amber
	OpEx	Amber	Amber	Amber	Amber	Amber	Grey	Amber
Diesel – Electric Hybrid	Operational	Red	Red	Green	Green	Red	Red	Green
	Emissions	Grey	Grey	Amber	Amber	Grey	Grey	Amber
	CapEx	Grey	Grey	Red	Red	Grey	Grey	Red
	OpEx	Grey	Grey	Green	Green	Grey	Grey	Green
Electric	Operational	Green (Quads only)	Amber	Red	Amber	Red	Amber	Red
	Emissions	Green	Green	Grey	Green	Grey	Green	Grey
	CapEx	[90] Red	Amber	Grey	Red	Grey	Amber	Grey
	OpEx	Green	Green	Grey	Green	Grey	Green	Grey
Alternative hydro-carbon-based fuels	Operational	Amber (CNG)	Red	Amber (CNG)	Green (LPG)	Green (LPG)	Red	Amber (CNG)
	Emissions	Red	Grey	Red	Red	Red	Grey	Amber (Bio-methane)

[89] CapEx estimate compares reported NRW historic purchase price (where available) to manufacturers list price for proposed technology.
[90] For three-hour charge option

Fuel	Factor	ATVs, Quads, Bikes	Chipper	Digger / Dumper	Forklift	Mower	Other	Tractor
	CapEx	Red	Grey	Red	Green	Amber	Grey	Red
	OpEx	Red	Grey	Amber	Red	Red	Grey	Amber
Hydrogen	Operational	Red	Red	Amber	Green	Red	Red	Amber
	Emissions	Grey	Grey	Green	Green	Grey	Grey	Green
	CapEx	Grey	Grey	Red	Red	Grey	Grey	Red
	OpEx	Grey	Grey	Red	Red	Grey	Grey	Red

As mentioned in 0 Parameters and assumptions, analysis showed that much (51%) of the NRW plant fleet is at least ten years old. All new NRMM purchases will have to be Stage-V emissions compliant from 2019 or 2020 onwards, depending on engine size (assuming the UK adheres to pre-existing EU legislative plans). Modern plant engines offer improved fuel efficiency and emission improvements of approximately 15% compared to 2006 and older engines. Recommended next steps for diesel plant replacements are updating fleet replacement schedules to accelerate compliance with Stage-V NRMM, emission standards for all plant engines to reduce overall emissions and running costs. Some plant units may be well suited to end-of-life retrofits of alternative fuels and powertrains. These should be considered as technology demonstration projects prior to wider fleet roll-out.

4.2.4.8 Quad bikes

1. Description
The industry trend moving forward is for quad bikes to only use petrol (for example Quadzilla Ltd, the UK's largest quad bike supplier, has discontinued, or soon will be discontinuing, all diesel quad variants). NRW data provided to Cenex indicates that all quads in the fleet are petrol based. Therefore, the emission simulation scenario for quad bikes assumes that all quads in use from this point forward should be compared to petrol engine quads.

2. Emission reduction potential
NRW's existing fleet of 18 quad bikes consume nearly 14,000 litres of petrol each year, emitting 37 tonnes of CO_2e emissions annually.

Up to 80% quad replacement with EV alternatives could be achieved.

Electric quad bikes, such as those provided by Eco Charger, have been selected as a suitable replacement. The recommended 'Eliminator' all-electric quad has a 7.2 kWh battery, and a nominal 40 km range. This gives an effective 0.18 kWhs / km, assuming an average speed of 14.5 kmph (9 mph). Based on an estimated 12,586 operational hours (no idle time required for electric motors), an analysis indicated that electric quad bikes offer a 100% reduction in TTW CO_2e and a 58% saving on WTW CO_2e emissions.

3. Cost
Higher-priced electric quad bikes offer a payback period of 3.5 years resulting from reduced running costs.

The annual cost of power consumption of an all-electric quad bike fleet is £2,950 per year for the entire fleet, which represents a 77% saving in annual fuel costs (circa £550 TCO per annum per bike or £9,900 for 18 quad bikes).

Cenex was advised that a battery pack replacement is £1,500 and when used daily[91] battery packs can last up to five years. Typically, the battery packs for these quads consist of multiple battery units (up to six depending on variant). It is unlikely that all battery packs would need replacing at the same time. Replacing one battery a year after the first three years of operation is more likely. Therefore, it can be assumed that as a minimum an electric quad can be operated at around £550 lower TCO to a petrol quad, but it is likely that the light battery use of the NRW operational cycle will allow longer battery life allowing further savings to accumulate. If this proves to be true, the actual payback period will be less than that indicated (i.e. savings to NRW fleet operations will be even greater than indicated).

4. Scale of adoption
i) Feasible maximum

- Feasible maximum number of quad bike units: 18
- Feasible maximum annual reduction in CO_2e (tonnes): 21.4
- Feasible maximum annual reduction in in CO_2e: 58%
- Feasible maximum WTW CO_2e (tonnes per annum): 15.8
- Annual TCO saving (£) (approximate): £9,900

ii) Theoretical maximum
The theoretical maximum is the same as the feasible maximum in this case, as it gives 100% reduction in TTW CO_2e emissions. This would also be in line with Scenario C: zero emissions by 2050, and the need for a complete elimination of fossil fuel use by 2040 to help get there.

4.2.4.9 Chipper

1. Description
NRW's plant fleet includes 11 diesel chippers with built-in power source. Alternative technologies are biodiesel and electric.

All-electric chippers are available; however, it is not clear that these will be suitable for NRW use due to the requirement of a power supply to plug in the cable, and the smaller engine size of electric chippers.

Refuelling / recharging time
Biodiesel: like-for-like replacement.
Electric: cable power supply required

Operational restrictions and benefits

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[91] Eco Charger indicates this based on a six-hour day with a 30-minute rapid charge in the middle of each day, five days a week.

Biodiesel: increased maintenance regime, mineral diesel fuel and engine flush required before storage, fuel quality requires monitoring and managing.

Electric: operation from cable supply to power source required. Maximum power and size of branches are less than that available for diesel-powered chippers.

2. Emission reduction potential
Biodiesel: variable depending on blend (circa 18% WTW CO_2e reduction available from B25 blend). Engine design, fuel quality and operational cycles essential in assessing total emissions with biodiesel – with some authors reporting increases in emitted NOx, particulates and CO [3].

Electric: zero at tailpipe, normally around 40–50% WTW CO_2e savings.

3. Cost
Typical list prices are in the order of £10,000 (depending on operational requirements). Depending on availability it may be preferable to operate PTO[92] chippers (assuming Stage-V[93] compliant tractor units are available). Tracked independent chippers tend to operate on Stage-III or early Stage-IV compliant engines.

4. Scale of adoption
i) Feasible maximum
Electric chipper purchased and can complete 10% of light wood chipping located close to depot / power supply. This measure is included in both the Medium and High Uptake scenarios (B) of mature technology demonstration in the report by Cenex.

ii) Theoretical maximum
Technology adoption to 2050 (Scenario C): this scenario assumes that NRW implements a progressive CO_2 reduction scheme with the aim of assisting the Welsh and UK governments in achieving their 2050 CO_2 reduction targets. A key element of this is the complete elimination of fossil fuel use by 2040.

To achieve 80% emissions reductions targets under UK legislation, several steps are required:

- Implementation of low-mission technologies where operationally suitable, starting from 2017.
- Implementation of fuel-efficiency programmes for drivers and operators, starting from 2017.
- Implementation of a plant fleet replacement programme to comply with Stage-V NRMM emission standards from 2019 (if Stage-V equipment is not available before this date).

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[92] PTO, a power-take-off shaft that creates a mechanical linkage between the plant engine and the plant attachment.
[93] Stage-V are the emission standards for non-road mobile machinery and generator-powered devices that come into force from 2019 onwards.

- Monitoring and reviewing the development of lower carbon plant, trialling technologies which show potential to reduce emissions at similar operating costs. Implement fuel replacement with a WTW fuel that is operationally suitable after appropriate feasibility studies, fleet replacement and fuel storage strategies have been implemented. At the time of writing, the most likely replacement fuels (in order of technology maturity and proven track record in sustainable WTW emissions reductions) are:

    - Biodiesel or Renewable Diesel (i.e. HVO)
    - Biomethane
    - Green Hydrogen ICE vehicles.

5. Technical considerations
A PTO driven chipper could be used from a tractor or other vehicle; however, emissions will only be reduced if a lower carbon fuel powers the powered vehicle. In the PTO driven chipper scenario, fuel consumption rates, and therefore operational costs per hour of activity, will be higher than that used by a 1.8 litre chipper unit.

4.2.4.10 Digger / dumper

1. Description
NRW currently has 34 digger / dumper vehicles (including three not in service).

Alternative technologies for diggers / dumpers as identified by Cenex are biodiesel and diesel-electric hybrid.

Refuelling / recharging time: both are a like-for-like replacement.
Range: biodiesel is a like-for-like replacement; diesel-electric hybrid has up to 25% increased operational time (manufacturer’s claim) due to reduced fuelling time and increased slew speed. (Note this figure is likely to apply in cases where the housing slews continuously, with little or no track movement.)

Operational restrictions and benefits: biodiesel has an increased maintenance regime, mineral diesel fuel and engine flush required before storage and fuel quality requires monitoring and managing. However, diesel-electric hybrid has a reduced maintenance regime, regenerative power comes from slewing action – savings are maximised by slew-heavy operation.

22t Komatsu diesel-electric hybrid powertrain excavators have been on sale since 2008 and are now available in the UK. A diesel-electric hybrid system takes advantage of energy recovery systems to recharge the battery. Additional improvements are gained by ensuring the main diesel generator is operating in the most fuel-efficient way. This 22t Komatsu diesel-electric hybrid appears to be a close match to the 21t vehicle used by NRW.

Site dumpers: no hybrid systems are currently available.

2. Emission reduction potential

Biodiesel: variable depending on blend (circa 18% WTW CO_2e reduction available from B25 blend). Engine design, fuel quality and operational cycles are essential in assessing total emissions with biodiesel – with some authors reporting increases in emitted NOx, particulates and CO.

Diesel-electric hybrid: the manufacturer claims up to 40% reduction in fuel consumption and associated emissions (based on ‘real world customer experience’ since 2009). If the manufacturer claims are correct, anticipated savings are in the order of 50 to 60 litres of fuel per day. This equates to reduced CO_2e of 148kg per day or 7.4t of CO_2e per replaced vehicle per year (based on NRW 21t excavator operational profile).

3. Cost
The average cost is £130,000 for a 22t Komatsu diesel-electric hybrid power (compared to a £95,000 standard).

4. Scale of adoption
i) Feasible maximum
Scenario B involves the adoption of mature technologies around a single, hypothetical depot. Here, the scenario assumes a 21-tonne hybrid excavator implementation, leading to a potential reduction of up to 40% in fuel consumption and associated emissions, as well as the implementation of an excavator fuel-reduction programme in line with recommendations in Cenex’s Plant Best Practice recommendations (including driver training), allowing a year-on-year 5% fuel reduction.

ii) Theoretical maximum
Technology adoption to 2050 (Scenario C): this scenario assumes that NRW implements a progressive CO_2 reduction scheme with the aim of assisting the Welsh and UK governments in achieving their 2050 CO_2 reduction targets. A key element of this is the complete elimination of fossil fuel use by 2040.

To achieve 80% emissions reduction targets under UK legislation, several steps are required:

- Implementation of low-emission technologies where operationally suitable (e.g. quad bikes) starting from 2017.

- Implementation of fuel-efficiency programmes for drivers and operators, starting from 2017.

- Implementation of a plant fleet replacement programme to comply with Stage-V NRMM emission standards from 2019 (if Stage-V equipment is not available before this date).

- Monitoring and reviewing the development of lower carbon plant, trialling technologies which show potential to reduce emissions at similar operating costs. Implement fuel replacement with a WTW fuel that is operationally suitable after appropriate feasibility studies, fleet replacement and fuel storage strategies have been implemented. At the time of writing the most likely replacement fuels (in order of technology maturity and proven track record in sustainable WTW emissions reductions) are:

    - Biodiesel or Renewable Diesel (i.e. HVO)

- Biomethane
- Green Hydrogen ICE vehicles

5. Technical considerations
NRW's existing five, 21-tonne excavators are generally more than ten years old (with one exception). Electric-diesel hybrid excavators, in the 22-tonne and larger range, are available with up to 40% reduction in emissions and fuel costs.

Recommended next steps: manufacturers claim up to 40% reduction in emissions and operating costs (for high slew rate tasks). All 21t or larger excavators in the NRW plant fleet should undergo operational assessment of slew rates, to determine if there is a business case for immediate replacement.

No hybrid systems currently available for site dumpers. This situation should be monitored closely as JCB, Hitachi, Toyota, Wacker Neuson and many others are all in the process of hybridising their powertrains for construction equipment. There are no official announcements on timelines.

4.2.4.11 Mower

NRW has a total of 26 mowers, including one for disposal and one for which there is no detail. The fleet consists of 15 small (0.1–1.9 litre), eight medium (2.0–3.9 litre) and one large (4.0–6.0 litre) mower. NRW reports that operational requirements for the existing NRW mower fleet may not be well suited to electrification – NRW's typical grass-mowing activities involve steep embankments not suited to ride-on mowers, longer grass and mowing near riverbanks and on soft ground (again not suited to ride-on mowers). However, the grass-mowing standards at reservoirs for which NRW is responsible have recently been changed and, in light of this, it is recommended that electrification of mowers at reservoir sites should be considered, as operational experience of the new reservoir grass-cutting standard is gained.

1. Description
Alternative technologies available at Maturity level 5 (i.e. 'Production ready, CE-approved, operational experience, real world use data available'):

- Diesel: Stage IV emissions regulations engines
- Biodiesel
- Electric
- Alternative fuel (HC) LPG

In terms of range and refuelling / recharging time, biodiesel and alternative fuel (HC) are like-for-like replacements of existing diesel. Electric mowers would require a longer charging time, e.g. seven hours at 13 amps, and a range of operating time depending on battery capacity, e.g. two hours cutting time for large mowers. Additional infrastructure may be required for rapid charging. Additional site infrastructure would be needed at sites where LPG was used.

2. Emission reduction potential

Biodiesel: variable depending on blend (circa 18% WTW CO_2e reduction available from B25 blend). Engine design, fuel quality and operational cycles are essential in assessing total emissions with biodiesel – with some authors reporting increases in emitted NOx, particulates and CO.

Electric: 100% tailpipe reduction, WTW typically 40–50% CO_2e reduction (based on DEFRA UK 2016 national grid emission profile).
Alternative fuel (HC): LPG – no data available.

3. Cost
Average cost: £32,905 (NRW CapEx history: there is a very wide variation in cost, between £8,800 to £75,000).

4. Scale of adoption
i) Feasible maximum
Mowers are not included for change in Scenario B – adoption of mature technologies around a single, hypothetical depot, therefore a feasible maximum is not available for this measure.

ii) Theoretical maximum
Technology adoption to 2050 (Scenario C): This scenario assumes that NRW implements a progressive CO_2 reduction scheme with the aim of assisting the Welsh and UK governments in achieving their 2050 CO_2 reduction targets. A key element of this is the complete elimination of fossil fuel use by 2040.

To achieve 80% emissions reductions targets under UK legislation, several steps are required:

- Implementation of low-emission technologies where operationally suitable (e.g. quad bikes) starting from 2017.
- Implementation of fuel-efficiency programmes for drivers and operators, starting from 2017.
- Implementation of a plant fleet replacement programme to comply with Stage-V NRMM emission standards from 2019 (if Stage-V equipment is not available before this date).
- Monitoring and reviewing the development of lower carbon plant, trialling technologies which show potential to reduce emissions at similar operating costs. Implement fuel replacement with a WTW fuel that is operationally suitable after appropriate feasibility studies, fleet replacement and fuel storage strategies have been implemented. At the time of writing, the most likely replacement fuels (in order of technology maturity and proven track record in sustainable WTW emissions reductions) are:
    - Biodiesel or Renewable Diesel (i.e. HVO).
    - Biomethane.
    - Green Hydrogen ICE vehicles.

4.2.4.12 Tractor

1. Description
NRW has 27 tractors in its plant fleet: two small (0.1–2.9 litre), 13 medium (3.0–5.9 litre) and 12 large (6.0–9.0 titre) tractors, which are operational an average of 1,000 hours each per year.

Tractors are the largest emitters in the NRW plant fleet, consuming 62% of plant fleet fuel per year, with an estimated 780 tonnes of CO_2 being emitted from the NRW tractor fleet, 62% of the total NRW plant fleet CO_2 emissions of 1,270 tonnes.

The versatility of tractors is one of their key virtues. Not only do they provide dedicated operations, their ability to operate a variety of tools makes them one of the most versatile assets in the fleet. Furthermore, as can be clearly seen in Cenex's Strategic Fleet Carbon Review Report, tractor units are some of the largest capacity engines, with some of the largest hours of operation per year. This means they have a significant impact on the total emissions of the NRW plant fleet.

The same versatility means that operators can become complacent about optimising the tractor for a given task. As a simplification, it is true to say that a tractor will complete the tasks you set before it, regardless of how it is set up for operation. Fuel-efficient use of the tractor for a given task can make a significant difference to its fuel consumption, without significantly increasing the time taken to complete the task. In fact, for some operations, optimised setting of tools and tyres can improve overall output of work. For example, it has been shown for the use of heavy equipment in heavy soils, that wheel slip is largely eliminated, and output is increased (+3.5% per hectare/hour improvement) when tyre pressure and machinery settings are optimised for reduced fuel use.

Tyre inflation: it has been demonstrated that operating conditions change year-round, and that optimal tyre pressure for the type of soil being worked on can result in significant fuel savings – up to 10% has been reported (Hoy et al., 2014[94]). Correct tyre inflation can be performed at the depot at the start of each day, or in the field using additional equipment. It should also be kept in mind that a tractor's primary purpose is to provide power to implements where work is done. It has been shown, for ground-engaging equipment, that correct positioning on the implement frame can reduce load requirements on the engine by up to 45%. Ensuring all staff are well-trained on the correct fitting and use of tools can result in significant fuel savings.

Alternative technology available for tractors is biodiesel, which can provide a like-for-like replacement in terms of range and refuelling time, with no operational restrictions or benefits identified.

2. Emission reduction potential
Biodiesel: variable depending on blend (circa 18% WTW CO_2e reduction available from B25 blend). Engine design, fuel quality and operational cycles essential in assessing total emission with biodiesel – with some authors reporting increases in emitted NOx, particulates and CO.

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[94] Hoy, R., Rohrer, R., Liska, A., Luck, J., Isom, L., and Keshwani, D., "Agricultural Industry Advanced Vehicle Technology: Benchmark Study for Reduction in Petroleum Use," 2014.

3. Cost
Average cost: £42,000 (NRW historic CapEx).

4. Scale of adoption
i) Feasible maximum
Scenario B involves the adoption of mature technologies around a single, hypothetical depot. Here, the scenario assumes the implementation of a tractor fuel-reduction programme in line with recommendations in Cenex's Plant Best Practice recommendations (including driver training), allowing a year-on-year 5% fuel reduction.

Driver training can achieve up to 25% fuel and associated CO_2 savings for tractor units. This could result in a 12% reduction in total operating costs of these vehicles.

Recommended next steps include investigating the implementation of fuel-efficiency measures such as:

1. Fuel efficiency training with in-cab fuel monitors for drivers.
2. Optimised plant attachment fitting training.
3. Optimised tyre-pressures for operational-conditions training.
4. Regular staff training and assessment.

Changes to heavy plant depot day-to-day practices may be required to implement fully.

ii) Theoretical maximum
Technology adoption to 2050 (Scenario C): this scenario assumes that NRW implements a progressive CO_2 reduction scheme with the aim of assisting the Welsh and UK governments in achieving their 2050 CO_2 reduction targets. A key element of this is the complete elimination of fossil fuel use by 2040.

To achieve 80% emissions reductions targets under UK legislation, several steps are required:

- Implementation of low-emission technologies where operationally suitable (e.g. quad bikes) starting from 2017.

- Implementation of fuel-efficiency programmes for drivers and operators, starting from 2017.

- Implementation of a plant fleet replacement programme to comply with Stage-V NRMM emission standards from 2019 (if Stage-V equipment is not available before this date).

- Monitoring and reviewing the development of lower carbon plant, trialling technologies which show potential to reduce emissions at similar operating costs. Implement fuel replacement with a WTW fuel that is operationally suitable after appropriate feasibility studies, fleet replacement and fuel storage strategies have been implemented. At the time of writing, the most likely replacement fuels (in order of technology maturity and proven track record in sustainable WTW emissions reductions) are:

    - Biodiesel or Renewable Diesel (i.e. HVO).

- Biomethane.

- Green Hydrogen ICE vehicles.

4.2.4.13 Additional plant assessed by Cenex

In addition to the above measures, Cenex included the following in its high-level plant review. However, due to either a lack of available usage data, or the nominal contribution they make towards our overall plant emissions, we have not included them as detailed measures. Further information is available from the Cenex Strategic Fleet Carbon Review report:

- Plant attachment
- Tracked miniature dumper
- Pump
- All-terrain vehicles (ATVs) (additional information is included in 4.2.4.15)
- Forklift (additional information is included in 4.2.4.15).

4.2.4.14 Fuel efficiency through plant best practice

The information presented in this section (including metrics) has been drawn from the Strategic Fleet Carbon Review (December 2017), work carried out for NRW by Cenex.

The versatility of tractors is one of their key virtues. However, the same versatility means that operators can become complacent about optimising the tractor for a given task. Fuel-efficient use of the tractor for a given task can make a significant difference to its fuel consumption, without significantly increasing the time taken to complete the task. In fact, for some operations, optimised setting of tools and tyres can improve overall output of work. For example, it has been shown for the use of heavy equipment in heavy soils, that wheel slip is largely eliminated, and output is increased (+3.5% per hectare/hour improvement) when tyre pressure and machinery settings are optimised for reduced fuel use.

One key and cost-effective way to limit the emission from this section of the fleet is through good practice and driver training (Coates, 2002[95]; Mantoam et al., 2016[96]). Modern tractor operators are highly-skilled workers, who are required to make complex decisions when balancing the performance of the vehicle and attached machinery they operate.

The five listed targets – fuel consumption monitoring, tyre pressure, machine settings, ballast, engine speed – can each reliably save between 5 and 10% of total fuel use for most vehicles. NRW can reduce its tractor-based fuel consumption and resultant emissions by 20%, and possibly more, by adopting fuel-efficient training policies. Assuming fuel costs constitute 60% of operational costs for these vehicles, this would also

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[95] Coates, W.E., “Agricultural Machinery Management: Tractor performance,” https://cals.arizona.edu/crop/equipment/agmachinerymgt.html, 2002.
[96] Mantoam, E.J., Romanelli, T.L., and Gimenez, L.M., “Energy demand and greenhouse gases emissions in the life cycle of tractors,” *Biosyst. Eng.* 151:158–170, 2016, doi:10.1016/j.biosystemseng.2016.08.028

result in a 12% reduction in total operating costs. The anticipated savings could be used to implement a dedicated tractor fuel-reduction policy. Such a policy would need to include several key factors:

- A fuel-saving champion is appointed with the enthusiasm and authority to drive the programme forward from within NRW.
- Implementing schemes focused on fuel reduction through monitoring fuel consumption and optimising tyre pressures, machine setting, ballast, and engine speed.
- Clear explanation of the productivity, fuel cost, maintenance cost, environmental impacts, and driver health benefits of reduced fuel use to tractor operators, depot managers, and all other plant equipment stakeholders.
- Baseline measurements of current fuel consumption rates to be carried out by the operators.
- Professional fuel efficiency training by machinery and vehicle experts.
- An NRW implementation programme that supports fuel-efficient operations (e.g. additional time at depot to optimise tyre pressures and ballast loads at the start of each day).
- SMART fuel consumption targets as part of NRW employees' KPI and review processes.
- Procurement strategy to be linked to fuel-saving policies (e.g. tractors with in-cab fuel meter displays, central tyre inflation systems and compatible towed equipment).
- Recognition and rewards for significant fuel-saving activities by operators and depot managers.
- Ongoing depot-based training and 'tool-box talks' to share experiences and best practices, led by tractor operators with proven fuel-saving skills.
- Ongoing external expert training sessions on a regular basis (e.g. every four years) once the programme is established.

4.2.4.15 Transport measures not progressed to detailed evaluation to date

Table 43: Summary of transport measures not being progressed to detailed evaluation, lists further mitigation options that have been highlighted through the identification of mitigation options. These measures have not been progressed to detailed evaluation for NRW to date and so did not form part of the detailed options appraisal. However, they have not been ruled out entirely and, in future, the feasibility of these options should be reviewed regularly, and on a case-by-case basis, for their potential to contribute to reducing our carbon impact.

Table 43: Summary of transport measures not being progressed to detailed evaluation

Further options highlighted through the identification of mitigation measures	Reason for the measure not being progressed to detailed evaluation
Technological measures	
Hydrogen fuel cell vehicles	As part of investigations into low-emission technologies for the fleet, the Carbon Positive Project explored the potential for hydrogen fuel cell vehicles. The evaluation of cost, carbon savings and wider benefits were identified through the development and submission of a bid for an OLEV grant for a trial vehicle, which was unsuccessful.
Alternative hydrocarbon fuels: methane, propane and renewable diesels can be utilised for plant operations. Typically, those elements in the NRW fleet that are well-suited to alternative fossil fuels (LPG, CNG) do not perform enough operational hours per year to justify the changeover. (Cenex report p10)	Many of these are growing in availability as bio-derived alternatives (e.g. bioLPG, biomethane, renewable diesel). The use of a biofuel is very effective at reducing WTW CO_2. NRW should continue to monitor the development of bio-gas fuels and technologies with a view to trialling the technology when an economic plant and infrastructure provision is available. There are new technical developments for tractors and excavators that may warrant demonstration trials for bio-CNG technologies at NRW sites. These could be considered by NRW as non-economic technology demonstration projects in the shorter term. (Cenex report p10)
All-terrain vehicles (ATV)	HAULER® 1200X provides a fully electric ATV. John Deere Gator TE provides a fully electric ATV Desk-based feasibility study of other electric ATVs should be undertaken. **Diesel-Electric Hybrid** Maturity = Level 1: similar types of engines have been used in diesel electric mode, but no evidence was found to indicate their application in ATVs like those used in the NRW fleet. **Alternative Fuel (HC)** Maturity = Level 3: there is a thriving hobby community of agricultural engineers who have adapted ATVS and quads to run a wide range of alternative fuels, from LPG to homemade biomethane. None of these technologies are seriously being developed as saleable products. **Hydrogen** Maturity = Level 1: similar types of engines have been used in hydrogen combustion mode, but no evidence was found to indicate their application in ATVs like those used in the NRW fleet. (Cenex report p91)

Further options highlighted through the identification of mitigation measures	Reason for the measure not being progressed to detailed evaluation
Forklifts and telehandlers with up to around 30% (electric-hybrid) and 50% (fully electric) WTW emission reduction. (Cenex report section 21, p119)	Continue to monitor market offerings. There are no cost-effective alternatives. The very low usage rates for NRW forklifts and telehandlers make the business case for new technology replacement difficult to make. These lower-emission alternatives will be more expensive to operate on a total cost of ownership basis, unless utilisation can be significantly increased. There is a CapEx premium for the purchase of all electric or hybrid vehicles. For maximised CO_2 reduction, any future purchases of forklifts and telehandlers should prioritise diesel-electric hybrid vehicles and (if ground conditions are suitable) fully electric forklifts (if the cost is justifiable).
Downsizing vehicles, e.g. diesel car from medium to small, EV car from medium to small, hybrid car from medium to small, etc.	Although downsizing of vehicles was evaluated as part of the fleet review carried out by Cenex, the scenarios provided to NRW by Cenex did not include any downsizing of vehicles in the fleet. However, it advised that this should also be considered where possible to yield further costs and carbon savings.
Retrofit of eco-technology, e.g. driver aids and speed limiters.	This was evaluated along with the implementation of telemetry. Telemetry was ultimately considered to be the most appropriate option.
Create an app or use online booking system Cyfarch to facilitate lift-sharing / journey rationalisation between staff taking similar journeys.	This was identified as a measure but not prioritised at the time. However, it may be progressed in future.
Training and behaviour measures	
Travel for work by methods other than fleet and plant vehicles, e.g. by public transport, cycling and walking.	Measures to encourage further sustainable travel options for work to reduce fuel use were considered including: • increasing use of public transport, bikes and active travel through behavioural change • improving our vehicle booking system (Cyfarch), e.g. to increase lift-sharing Through a contract with the Carbon Trust, NRW organised a staff survey to find out how staff were commuting for work and what measures could be

Further options highlighted through the identification of mitigation measures	Reason for the measure not being progressed to detailed evaluation
	implemented to encourage further use of sustainable modes of travel in the future.
Staff commute	The costs and carbon savings potential of alternative travel and homeworking were evaluated using literature. Measures considered were: • increasing use of public transport, bikes and active travel through behavioural change. • improving cycle storage and facilities for active travel. • increasing amount of homeworking (presented in the Buildings category of this report: 4.1.23).
• Eco driver training for cars and vans • Tractor and plant unit driver training • Appoint 'fuel champion'	Eco driver training for cars, vans and tractors along with the appointment of a 'fuel champion' were also further investigated using desk-based research of online literature on previous case studies and contact with industry with relevant products / experience.
National car hire contract – increase cost-effectiveness and carbon reduction when ordering hire cars	Only a small proportion of our business travel is conducted using this method. As a result, this has not been considered a priority to date; however, it may be revisited in future. In order to take this measure forward we would need to assess our usage of hire cars. This could be done at the end of our existing contract.
NRW Sustainable Travel Plan	While this measure was not identified as a priority, it is one we intend to implement in future.

4.2.4.16 Transport discussion

The scenarios investigated by the review carried out by Cenex indicate that a significant proportion of NRW's fleet vehicles could become low emission, primarily through electrification. However, savings are restricted by the limited decarbonisation options available for high-emitting vehicles, i.e. large vans and 4x4s, which are the source of 44% of our fleet emissions.

It is recommended that NRW pursues electric cars and small vans as a priority, alongside further investigation on wider decarbonisation of the fleet (including plant). An interim switch to petrol from diesel will not yield carbon savings but would, alongside increasing electrification, have a significant impact on the NOx emissions from the fleet contributing to addressing air quality issues.

Low-emission technologies are developing fast, with new products regularly entering the market and existing products maturing and reducing in cost. For the hard-to-decarbonise vehicle classes of large vans and 4x4s, in particular, emerging low-emission options should be monitored, e.g. hydrogen vehicle options once appropriate fuelling infrastructure is available.

A key message is that scoping of, and management commitment to, appropriate electric vehicle charging infrastructure is required ahead of any further expansion / investment in electric vehicles.

To support the business case for adopting low-emission technologies, investment in telematics will generate a robust evidence base for future decisions and provide evidence for the scenarios outlined in this review.

Table 44: Analysis Showed and Recommended next steps

Analysis Showed	Recommended next steps
Cars	
Electric vehicles (EVs) are a good operational fit in the car fleet, saving 50% WTW (100% TTW) CO_2 whilst reducing the TCO by up to 25%, and providing 100% nitrogen oxides (NO_X) and particulate matter (PM) air quality emissions saving. EVs should be implemented into NRW's fleet where practical. Petrol hybrids can offer improvements on CO_2 at a similar or lower TCO where an EV is not a practical solution. Pool Fleet – an analysis of pool fleet car usage showed that 43% of daily trips are less than 50 miles. This indicates that a good proportion of office-based pool vehicles are also suitable for transition to EVs.	• Review individual vehicle mileages, preferably through the installation of telemetry systems, and develop an EV replacement strategy supported and informed by trialling of EVs. • Investigate site power requirements for installation of recharging infrastructure. • Analyse current Nissan Leaf performance data. • Trial petrol hybrids to confirm desk-top study results. Following a successful trial, petrol hybrids should be implemented in the car fleet where EVs are not practical due to range and charging limitations.
Small Vans	
EVs (e.g. Nissan e-NV200, Renault Kangoo ZE) are a good operational fit to the small van fleet, saving 50% WTW (100% TTW) CO_2 at a similar or better TCO. EVs should be implemented where practical.	Review individual vehicle mileages, preferably through the installation of telemetry systems, and develop an EV replacement strategy supported and informed by trialling of EVs and investigation of site power requirements.
4x4	
Reducing carbon from the 4x4s is challenging due to very poor availability of low-emission alternatives in this segment. A less robust 4x4 drive system is offered through modern All Wheel Drive (AWD) vehicles which may be suitable for some	Review fleet to assess where options are available to downgrade 4x4s to AWD vehicles. Consider biodiesel use (see Scenario 3 notes below).

Analysis Showed	Recommended next steps
applications currently carried out by 4x4s. AWD vehicles such as lower spec diesels (Dacia Duster), petrols (Seat Ateca), and PHEVs (Mitsubishi Outlander PHEV) all offer emission and TCO benefits. Due to the limited options available to decarbonise the 4x4 fleet, biodiesel use around depots with sufficient demand and security to justify the installation of a bunkered tank should be considered. Vehicle warranties require discussion with manufacturers and not all vehicles will be compatible.	
Large vans	
Reducing carbon from the large vans is challenging: CNG and electric options are available but significantly increase TCO.	Consider biodiesel use (see Scenario 3 notes below). Reassess in 12 months as large EV van market matures and renewable diesel drop-in fuels may start to come to market.

4.3 Land and operational assets

4.3.1 Land and operational assets – mitigation measures summary

We collated and appraised information on the opportunities to reduce emissions from fuel use and electricity use resulting from the management of our land and operational assets across the organisation. We investigated opportunities to enhance sequestration and protect existing carbon stocks on the land that NRW manages. We also considered the potential for renewable energy generation on the land NRW manages as a measure to reduce our reliance on grid electricity and to contribute to renewable energy generation in Wales.

It is important to note that within the net carbon status calculation, the sequestration and carbon stocks associated with land owned and managed by NRW is presented separately from emissions. Within this section of the report, we focus on the renewable energy options. Opportunities for sequestration and protecting carbon stocks across the habitats on the estate is not covered in detail within this report. The research on woodland management and peatland restoration are reported in the technical report for our net carbon status (Jones, 2018) and have been published separately. Our work to evaluate the options for the habitats is ongoing.

Due to the very different methods of calculating measures to reduce emissions, this part of the report is divided into the following sections:

- 4.3.3 Renewable energy generation on the estate for self-supply
- 4.3.5 Microgeneration renewable energy installations on NRW operational assets

Each sub-section includes the method used for assessment, information on expert input, and the measures identified.

4.3.2 Summary of mitigation measures for land and operational assets

Table 45: Summary of mitigation measures for land and operational assets presents a summary of the mitigation measures identified for renewable energy on land and operational assets that NRW manages.

Table 45: Summary of mitigation measures for land and operational assets

Mitigation measure	Average project capacity (MW)	Annual reduction in CO2e (tonnes)	CO2e saving over lifetime of the measure (tonnes)	Carbon cost metric (£/tCO2e)	Indicative capital cost (£)	Lifetime (years)	Payback period (years)	Estimated annual maintenance / recurring costs	Estimated annual savings (£)
Renewable energy generation									
Solar self-supply to NRW >5 kW	0.01	3.7	72	3,352	12,300	20	10	140	1,364
Small-scale wind self-supply to NRW >5 kW	0.0122	6.9	173	8,866	61,000	25	21	378	3,322
Hydro self-supply to NRW >5 kW	0.0083	14.0	702	6,831	95,833	50	19	1,583	6,658
Microgeneration									
Micro hydro / micro wind + battery <5 kW (on rain gauges)		3.1			11,730			190	
Micro hydro / micro wind + battery <5 kW (river level stations)		1.9			7,245			190	
Micro hydro + battery <5 kW (other FRM)		2.1			7,705			190	
Micro solar / wind + battery <5 kW (gauging stations)		0.9			537			16	
Micro solar / wind + battery <5 kW (flood warning sites)		0.9			518			16	
Small-scale / roof mount solar <5 kW (pumping stations)		4.8			2,886			16	
Small-scale solar <5 kW (other FRM)		3.5			2,091			16	
Small-scale solar <5 kW (H&T demo project)		0.022	0.22		2,085	10		0	
Retrofitting operational assets									
Retrofitting assets – pumping stations (pump replacement)		52				25	9		
CCTV camera (FRM)		0.03							

4.3.3 Renewable energy generation on the estate for self-supply

Building assets account for 67% of NRW's electricity usage, with offices, pumping stations and laboratory accounting for 58% of our annual electricity usage.

4.3.3.1 Introduction

The generation of renewable energy can provide carbon benefits either indirectly by increasing the amount of low-carbon electricity exported into the UK National Grid fuel mix, or directly through the self-supply of renewable energy generation to energy consuming sites, so as to reduce the demand for imported grid electricity.

As set out in the Greenhouse Gas Protocol and Defra's guidance on how to measure GHG emissions[97], self-supply of renewable electricity, generated at/adjacent to the point of use, can reduce the carbon footprint of an organisation.

This section identifies the sites where self-generated renewable energy can reduce the carbon emissions associated with the electricity use (drawn from grid electricity) on or adjacent to NRW assets.

NRW recognises the opportunities for generation of renewable energy should be considered alongside the requirement to reduce energy-related emissions through other means, such as more detailed energy management[98] or energy-efficiency measures[99] should be considered in parallel to energy-generation options.

4.3.3.2 Engaging industry experts to evaluate renewable energy opportunities for NRW

Through the Carbon Positive Project, NRW commissioned Regen[100] to produce a strategic pre-feasibility study to enable NRW to understand the overall potential for renewable energy generation on the NRW-managed estate, to facilitate a better understanding of the role renewable energy could play in supporting opportunities to decarbonise. The resulting study was a holistic, cross-technology review to assess the opportunities for renewable energy generation on land owned or managed by NRW and on/adjacent to the operational assets[101] that NRW owns or manages.

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[97] Further information is available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69282/pb13309-ghg-guidance-0909011.pdf

[98] Can be defined for the purposes of this report as the planning, monitoring, reporting and operation of energy consumption (or production) within a given organisation.

[99] For example, more efficient appliances, better thermostatic control of heating or staff behaviour etc.

[100] For details on Regen, see Regen website: https://www.regensw.co.uk/mission-and-theory-of-change

[101] For example, pumping stations and gauging stations.

Building-mounted renewable energy on NRW buildings was not considered within the study but was assessed separately through a series of building audits carried out as part of the wider Carbon Positive Project (see 5.4.1).

4.3.3.3 Technologies considered

The main renewable energy technologies within the scope of this assessment are:

- Ground-mounted solar PV
- Onshore wind
- Hydropower (low and high head)

Emerging generation technologies and technology variations were also reviewed, describing the technology, a summary of its market position and suitability for NRW's land and assets. The technologies that were assessed and their suitability is summarised in Table 46 below.

Table 46: Summary novel technology assessment for NRW

Novel / emerging technology	NRW suitability
Vertical axis wind turbines (VAWT)	Due to higher cost, reduced yield / efficiency and reliability, VAWT machines were not recommended for NRW to deploy unless there was a particularly noise-sensitive or space-restricted site.
Floating solar PV arrays	The mapping of NRW's estate showed that there were a number of bodies of water that sat within or adjacent to the NRW-managed estate. There is also potential to collaborate on a floating PV project with owners of adjacent bodies of water (i.e. Dŵr Cymru).
Bifacial (double-sided) solar PV	Other than a potential demonstration project to consider, bifacial solar is a research area and not yet commercially viable.
Energy harvesting devices	Whilst this technology may suit the very low power assets that NRW operates on its more remote sites, the scale of opportunity is very small and more traditional nano / pico generation solutions are likely to be more suitable and lucrative.

Battery storage

The study also undertook an assessment of energy storage as a complementary technology, reviewed some of the emerging technology variants in the market and assessed opportunities for microgeneration at low-power assets.

The potential for energy storage has been considered for identified self-generation sites as a supporting technology to provide additional benefit. For NRW's self-supply and microgeneration opportunities, installing storage 'behind the meter' for self-supply opportunities is a model where smaller scale storage is located with high-energy users (with or without on-site generation) 'behind the meter', to avoid peak energy costs and network charges as well as potentially providing parallel mains backup. This is another financially driven option, but with an additional opportunity to flex storage to align generation and demand profiles more closely.

The use of storage in this way could potentially:

- maximise self-consumption of self-supplied (renewable) generation (e.g. a solar PV installation), and/or
- cycle storage to reduce on-site demand during network peak charges to reduce the cost of grid electricity used.[102]

Table 47 below sets out the way battery storage could be used with the different self-supply technologies assessed within this section.

Table 47: Summary storage recommendations for self-supply generations opportunities

Technology	Storage recommendation
Solar PV	Consider co-locating storage for 'peak shaving' to maximise the self-consumption of generation on-site and to enable solar PV to mitigate evening peak network costs on any NRW sites that are subject to time-of-use tariff charges (Triads / Duos).
Wind	Consider co-locating storage to maximise self-consumption of generation on-site and to optimise the avoidance of evening peak network charges as above.
Hydro	

For small-scale battery storage, a benchmark of cost would be based around a number of off-the-shelf products that are available in the market, examples being the 14 kWh Tesla Powerwall[103], 3 kWh Moixa Smart Battery[104] and LG Chem Residential ESS Batteries[105]. These products fit with the indicative benchmark costs ranging between £600–£900 / kWh (2017 costs).[106]

Suitability of storage opportunities would need to be assessed on a site-by-site basis as part of the next steps to pursue self-supply opportunities, and so costs and carbon savings would depend on the scale of battery storage suitable at each site. Therefore, this assessment has not sought to incorporate battery storage costs/savings into the generation and cost figures for renewable energy seen in this section. However, within the microgeneration section, for some smaller operational sites, the use of small-scale solar and battery has been identified as the most suitable solution as a combined technology opportunity.

[102] This arrangement assumes that the user has a time of use element to their electricity tariff (day/night, evening peak etc.) rather than a flat single unit rate tariff.
[103] More information is available at: https://www.tesla.com/en_GB/powerwall
[104] More information is available at: http://www.moixa.com/products/
[105] More information is available at: http://www.lgchem.com/global/ess/ess/product-detail-PDEC0001
[106] The projected costs range are similar to the nominal £ / kWh costs of these products – for some of these products a 'price builder' or estimation can be used and as a result £600–£900 / kWh has been identified as a benchmark to target.

4.3.3.4 Technologies considered outside of scope of this assessment

A number of other established technologies were considered out of scope of the assessment (Table 48) and, as outlined above, roof / building mount PV is also out of scope and has been considered elsewhere in this report.[107]

Table 48: Renewable technologies considered as out of scope of this assessment

Technology	Rationale for out of scope
Biomass	The renewable energy study was a technology-based resource assessment, largely conducted through a mapping exercise. As such, the methodology cannot be applied effectively to identify opportunities for biomass production. An assessment of potential biomass production would involve more detailed investigation of current operational activities, marketing strategy and timber production to consider how these provide potential for the timber on the NRW-managed estate to produce chips and pellets for the biomass market. It is recommended that a dedicated study would be more suitable to better understand the potential for biomass production from the NRW-managed estate. The wider Carbon Positive Project, for which this study has been conducted, has considered the potential for biomass boilers to be installed in NRW offices and depots as a means of producing renewable heat, through building energy audits. Through work commissioned with Forest Research, it has also considered the carbon impact of current wood products including fuelwood, derived from timber on the estate, as part of the organisation's net carbon status calculation. Consideration of the potential carbon impact of increasing the harvest of offcuts and branch wood from the estate for biomass energy is also made by the work commissioned with Forest Research. It highlights that further investigation is required to understand the effect of harvesting non-stem material on long-term site sustainability, and on GHG emissions associated with increased disturbance of soil and litter, consideration of which should be included in any dedicated study into biomass production.

[107] Building mounted renewable energy generation has been considered through building specific audits as part of the wider Carbon Positive Project's work.

Technology	Rationale for out of scope
Anaerobic digestion	NRW's operation and business practice does not create resource to act as fuel for anaerobic digestion (AD) plants. NRW would need to source significant and sustainable levels of feedstock (such as sludge or food waste) in order to develop a strategy for AD across the NRW estate. This was therefore considered to be out of the scope of the methodology of the assessment.
Marine technologies (such as wave / tidal and offshore wind)	The remit of the study was to assess the potential to deploy renewable energy assets on the NRW estate. As NRW do not own any holding offshore, any marine technology options would have to be sited on third party-owned coastal or marine landholding and as such is out of the remit of the study.

4.3.3.5 Broader renewable energy generation on the NRW-managed estate

The study conducted by Regen for NRW also contributed to the evidence base available to support wider NRW work (e.g. as a land manager and advisor), including contributing work on the role and purpose of the NRW-managed estate and energy delivery activities, through understanding how the wider estate could contribute to renewable energy generation to support Wales' transition to a low-carbon economy. The methodology for this work is outlined in 8.4 Appendix D.

As set out in the Greenhouse Gas Protocol and Defra's guidance on how to measure GHG emissions[108], electricity generated and exported to the grid cannot be included in formal carbon accounting to reduce the carbon footprint of an organisation; the carbon benefit can only be used by the purchaser of the energy produced. Therefore, opportunities for renewable energy generation on the NRW-managed estate, which would be exported to the grid, could not contribute to improving NRW's net carbon status and so fall outside of the scope of the evaluation of NRW's mitigation options and this report.

NRW recognises the wider benefits and positive impact of its role in enabling renewable energy generation on the NRW-managed estate, which is exported to the grid (e.g. our role in the Pen y Cymoedd Wind Farm development). However, NRW does not seek to consider this as a carbon saving against its own carbon footprint. NRW recognises that some organisations (e.g. The Crown Estate[109]) consider electricity generated and exported to grid as "avoiding" carbon emissions – this is not part of formal corporate carbon footprint accounting but acknowledges the wider

[108] Further information is available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69282/pb13309-ghg-guidance-0909011.pdf

[109] The Crown Estate references the benefit of low carbon energy delivered on its estate as 'avoided emissions', see "Our Contribution" document available online at: https://www.thecrownestate.co.uk/media/2143/total-contribution-report-2013.pdf

benefit the generation provides (e.g. through reducing the grid average emissions factor). In future, and separately from the work to monitor and improve NRW's net carbon status, NRW may seek to recognise the wider carbon benefits of renewable energy developments on the estate which export to the grid. However, this is not considered further as part of the Carbon Positive Project's work.

4.3.3.6 Considering renewable energy generation as part of NRW's wider remit and the NRW-managed estate

Whilst renewable energy is one potential use of the NRW estate to support the achievement of climate change mitigation targets, any projects that are subsequently taken forward for development must be considered within NRW's wider remit and priorities, and in the context of the wider role and purpose of the NRW-managed estate.

NRW is a Welsh Government Sponsored Body. NRW's purpose is to ensure that the environment and natural resources of Wales are sustainably maintained, enhanced and used, now and in the future. As set out above, NRW has responsibilities to promote the Sustainable Management of Natural Resources (SMNR) and to support the seven well-being goals, as set out in the *Well-being of Future Generations (Wales) Act 2015*.

NRW has a broad remit and the estate it manages has multiple uses including:

- Timber production (managing the Welsh Government Woodland Estate (WGWE)
- Protected sites and conservation
- Recreation and access
- Flood risk management
- Energy production

It is recognised that the identification of areas of renewable energy generation potential could conflict with current land uses and the potential future requirements on the estate. It is acknowledged that investigation of renewable energy generation potential may require careful consideration of the balance of land use to protect wider interests and requirements, e.g. recreational use, maintenance of timber production, protecting and restoring peatlands or protecting existing and future improvements for the movement of fish. This consideration is part of wider work within NRW to better understand the role and purpose of the NRW-managed estate. The work of the Carbon Positive Project will support a robust, evidence-based approach behind future decisions regarding renewable energy generation and the role and purpose of the NRW-managed estate.

The following three sub-sections, on assumptions, lessons learnt and caveats, and wider benefits are common to both small-scale and microgeneration assessments presented in this section and so have been presented upfront to avoid duplication.

4.3.3.7 Assumptions

The assessment of renewable energy-generation opportunities is based on assumptions around the current planning and economic context, including subsidy levels and technology costs. There are a number of features of the current energy market that underpin these assumptions, including:

- The devolved national planning context in Wales – including any support structures in place for renewable energy development.

- Constraints on the distribution network – progressing some NRW opportunities will require consideration of the impact of grid issues on a site-by-site basis that is reviewed regularly, as areas become more constrained due to additional projects or less constrained due to strategic upgrades or drop out of projects.

- Changes to subsidy regimes – ongoing changes to the subsidy regime mean that the revenues included in the creation of the business case will change over time and will need to be reviewed regularly/at the point that further feasibility studies are due to be commissioned to fully understand the cost-benefit of opportunities at the time of decision-making.

- Technology costs and grid parity – costs associated with solar PV and wind technologies are likely to reduce over time. As a result, the costs underpinning the business case for the opportunities (wind and solar) in this study will need to be reviewed at the point of commissioning further studies. Hydropower costs are unlikely to change significantly in the foreseeable future.

- Transition to a smart / flexible energy system – the shift towards a smart and flexible energy system in the UK, and the considerations around storage as a complementary technology, may provide some solutions or methods to mitigate the current barriers to securing capacity to develop and connect renewable energy generation to the network in Wales. This will need to be reviewed and assessed further as projects develop.

It would be beneficial to review any changes to these assumptions prior to taking any opportunities forward as there is potential for these features of the current context to change, which could affect project risks and economics either positively or negatively.

4.3.3.8 Lessons learnt (renewable energy generation)

- NRW assets have limited electricity use, even those with the highest demand. Therefore, only smaller scale ground-mounted opportunities would be suitable to generate electricity for self-supply.

- NRW assets are known only as single points and may not accurately reflect the location of electrical distribution within a site, and the ease of connecting to that point.

- For NRW's smaller operational assets, refining electricity usage data and improved electricity meter reading strategy could be adopted to inform accurate scaling of options for generation.

- For the remaining 305 low electricity consuming assets, there are significant opportunities to roll out a bulk-buy scheme for microgeneration technologies. Site visits will be needed to verify the recommendations of this assessment and quotes obtained from relevant providers to achieve the best cost programme. However, NRW may wish to consider the cost to project manage and coordinate deployment of multiple very small opportunities weighed up alongside the benefits secured from any larger strategic opportunities.

- The method of financial benchmarking used means that some metrics are the same, which results in similar payback periods.

- Due to reductions in subsidies, the cost benefit considerations for each opportunity highlight the challenging project economics, particularly for wind and hydro. However, for solar (and some extent wind), technology costs are falling, so viable projects with low subsidy rates are starting to emerge. Hydropower costs on the other hand are unlikely to reduce in the near term. NRW should consider potential changes to costs and subsidies when reviewing the results of this assessment in the future.

- The opportunities identified through this assessment are based around established resource assessment methodologies and key industry benchmarks. In order to progress the outputs of the study further, more detailed feasibility assessments will be required prior to NRW being able to take any opportunities forward.

- In reviewing the potential generation choice for an asset where multiple technologies are potentially viable and suitable, NRW should consider its priorities, e.g. is lower cost a higher priority than visual impact? For example, the visual impact of hydro installations compared with wind turbines and solar arrays is significantly lower. Therefore, sites such as Coed y Brenin may favour a hydropower project due to this reduction in landscape impact; however, the less favourable project economics for hydro opportunities would need to be weighed against this.

- If it is decided to progress any of the small-scale opportunities identified at the six assets in the self-supply list, additional detailed site feasibility assessments will be needed, prior to any planning or pre-planning application. Work that may be needed includes:

  - Site visits to assess suitability and location of generation opportunity.
  - Landscape impact assessments.
  - Environmental Impact Assessments – e.g. impact on birds, bats and other ecology will need to be assessed on a site-by-site basis.
  - Studies on accessibility to the site.
  - For wind opportunities, Met Office Virtual Met Mast assessments to provide detailed wind climatology, increasing certainty of the wind resource available for specific sites.

- Engagement with the Distribution Network Operator (DNO) to assess the potential to connect new (or additional) generation capacity on site.
- Confirm land ownership arrangements for asset and surrounding land required to develop.
- Undertake a review of NRW operational assets and correlate with electricity billing for sites that have been removed or disconnected.[110]

4.3.3.9 Wider benefits of renewable energy generation

Renewable energy generation opportunities have the potential to provide benefits beyond greenhouse gas emissions reductions, including against both the *Well-being of Future Generations (Wales) Act* and the *Environment (Wales) Act*. Renewable energy schemes present opportunities for multiple benefits, which could include:

- Reduced costs of electricity
- Generation of income
- Supporting local supply chains and jobs for construction and maintenance
- Contributing to reducing global carbon emissions and improved air quality.

Partnership working between public sector bodies or with community energy schemes[111] could improve collaboration, engagement and participation in providing long-term action and building resilience (all are key ways of working under the *Well-being of Future Generations Act*). This is in addition to supporting the sustainable management of natural resources and contributing to meeting carbon budgets (both key responsibilities under the *Environment Act*). NRW recognises the potential opportunities and benefits from collaboration renewable energy generation and/or integration with the Well-being Plans and Area Statements.

4.3.4 Category specific method – ground-mounted self-supply renewable energy installations

4.3.4.1 Description

Opportunities for renewable energy generation on NRW-managed estate to self-supply to nearby NRW-owned or -managed assets which use electricity were assessed on a site-by-site basis using mapping and satellite imagery.

This involved considering the potential for small-scale on-site renewable electricity generation opportunities relating to reducing grid-imported electricity use at operational assets that NRW own or manage, such as offices, depots, pumping stations or river level monitoring assets. Only operational assets with over 5 kW

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[110] Future feasibility assessments for NRW operational assets will require more accurate energy usage data, to ensure that carbon reduction measures are introduced at the correct and appropriate sites.
[111] Supporting community energy schemes is recognised in NRW's remit letter for 2017/18, available online: https://naturalresources.wales/media/681432/ma-p-lg-0989-17-remit-letter-2017-18.pdf

average demand were assessed via this method as it was advised by Regen this is the minimum scale of demand appropriate for small-scale wind, hydropower and ground-mounted solar. For the remaining operational assets with an average demand below 5 kW, microgeneration opportunities were reviewed (set out in 4.3.5).

Technologies reviewed were: small-scale wind, ground-mounted solar and small hydropower. A resource assessment methodology was utilised based on industry good practice.

Opportunities identified were scaled to match the level of demand from NRW assets. Analysis of the usage profile of NRW's electricity-using assets, as well as their location and surrounding landholdings, were used to inform the suitability for renewable energy generation and suitable technology.

An assessment of energy storage as a complementary technology and a review of emerging technology variants in the market was also undertaken.

Opportunities to generate electricity for on-site use were reviewed, with the primary aim of reducing NRW's carbon footprint. A three-step method[112] was used to identify opportunities:

- **Step 1** – Electricity demand assessment: in order to assess the potential for generation to offset electricity demand, the first stage of the assessment was to review demand from NRW's electricity-consuming assets and to identify sites with higher levels of demand, as well as to estimate demand profiles for different types of asset.

- **Step 2** – Small-scale self-supply site assessment: an assessment of the potential for small-scale wind[113], small-scale ground-mounted solar[114] and small-scale hydropower[115] to supply electricity to sites with higher levels of demand (over 5 kW average demand). Due to the relatively limited demand from any of NRW's assets, these opportunities were small-scale and a site-finding approach using maps and satellite imagery was employed.

- **Step 3** – Microgeneration assessment: for sites with average demand below 5 kW, the asset type and its estimated demand profile was matched against the most suitable microgeneration technology. This is set out in 4.3.5.

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[112] Further detail on the method can be found in Appendix D: Further detail on methodology to identify self-supply opportunities.
[113] Small wind, for the purposes of this study, can be defined as turbines with rated power capacity between 1 kW and 10 kW.
[114] Small solar PV, for the purposes of this study, can be defined as arrays of capacity between 5 kW and 15 kW.
[115] Small hydro, for the purposes of this study, can be defined as turbines with rated power capacity between 5 kW and 10 kW.

4.3.4.2 Step 1 – Electricity demand assessment

Understanding NRW's electricity use in assets

Based on NRW's 2015/16 billed electricity data, energy consumption at NRW's 327 currently owned and operated operational assets was analysed, reviewing the annual consumption (in kWh) and calculating the average demand (in kW). In 2015/16 NRW consumed an estimated 4.9 GWh (4.9 million kWh)[116], based on 2015/16 billing data. A breakdown of the number of sites and annual consumption, by site category and site sub-type, can be seen in Table 49.

Table 49: NRW site summary showing number of sites and annual consumption

NRW Site Category	NRW Sub-Site Type	Number of sites	Annual Usage (kWh)
Building assets	Offices	25	1,986,138
	Laboratory	1	351,160
	Depot / workshop / training centre	40	285,135
	Hatchery	5	156,925
	Visitor centres	6	459,634
	Other buildings	13	30,733
	Total building assets	**90**	**3,269,725**
Pumping stations[117]	**Total pumping stations**	**22**	**494,823**
Other operational assets[118]	CCTV	7	36,190
	Gauging station	79	291,470
	Flood storage area	4	24,346
	Flood warning site	37	92,341
	Rain gauge	17	125,538
	River level station	33	180,971
	Sluice / slipway / tidal / penstock gates	4	59,966
	Other operational assets	34	309,109
	Total operational assets	**215**	**1,119,931**
	Total – all sites	**327**	**4,884,479**

Figure 2: shows the percentages of NRW's annual electricity consumption by each of the asset categories and sub site types based on 2015/16 electricity billing data. It shows that building assets account for 67% of NRW's electricity usage. Looking in more detail at the sub-site types, NRW's offices, pumping stations and laboratory accounted for 58% of NRW's electricity usage in 2015/16.

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[116] Note, it is recognised that a limitation in the billed data is that in some cases, billing data may have overestimated the electricity use for small un-manned sites. Further feasibility studies into opportunities should seek to revisit actual usage data to confirm the average demand is suitable for the technology recommended.
[117] Note that 25 pumping stations are shown in NRW's operational assets register, but the electricity billing data shows 22 sites. Any future work should seek to refine the billed data to clarify/confirm all asset types.
[118] The naming convention for NRW assets in this table and the report represents the name used on electricity bills. Any future feasibility study should seek to review and rename categories of sites where appropriate.

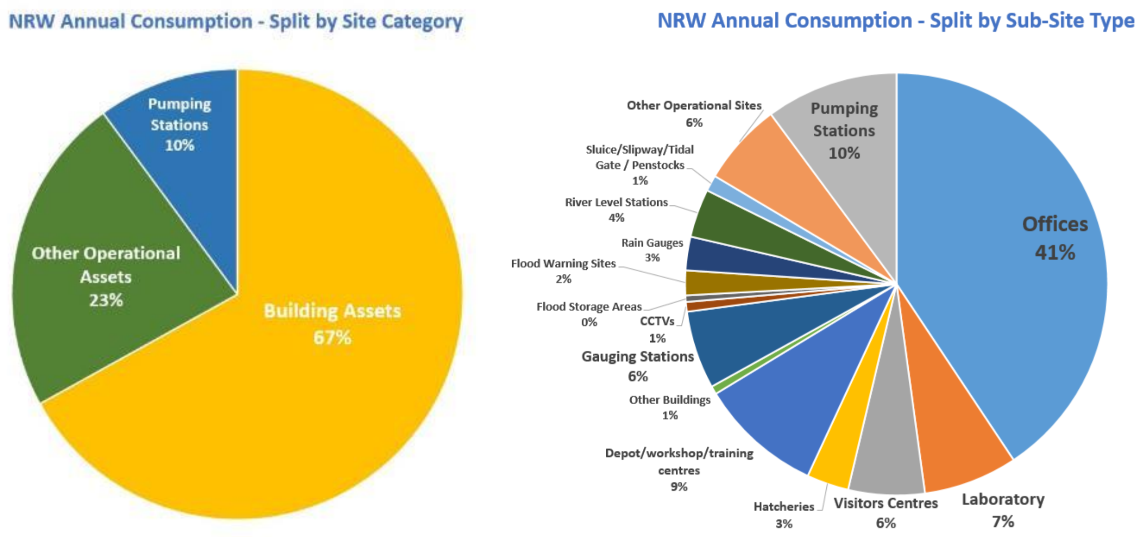

Figure 2: NRW annual consumption split by site-sub category type

Twenty-two assets were identified from the 2015/16 electricity billing data with an average demand of over 5 kW, shown in Table 50 below. These sites represent 57% of all NRW's imported electricity use and therefore are a priority for mitigation opportunities.

At the time of this study (2018), two of the identified assets had been closed due to an ongoing accommodation review in NRW. Therefore, there were 20 live assets with average demand over 5 kW (largely offices, depots and pumping stations).

The remaining 305 assets have an average demand of less than 5 kW. NRW electricity-consuming assets with an average demand below 5 kW were considered to have insufficient demand to be suitable for our small-scale technology assessment. For these sites below 5 kW, microgeneration technologies (either building- or ground-mounted) were recommended and a review of the potential for deployment was carried out (see 4.3.5).

Table 50: 22 NRW assets with an average demand above 5 kW – showing annual consumption and average demand

No.	Site Name	Site Type[119]	Annual electricity use (kWh)[120]	Derived average demand (kW)[121]
1	Maes y Ffynnon, Bangor	Building	416,720	47.57
2	Cambria House (Tŷ Cambria) Office, Cardiff	Building	378,386	43.19
3	Llanelli Laboratory, Llanelli[122]	Building	351,160	40.09
4	Rivers House, St Mellons	Building	194,997	22.26
5	Deeside Area Office, Buckley	Building	167,875	19.16
6	Llandarcy Development Site (Llandarcy Office, Swansea)	Building	130,430	14.89
7	Parc Menai Office, Bangor[123]	Building	126,398	14.43
8	Coed y Brenin Visitor Centre	Building	109,284	12.48
9	Bwlch Nant yr Arian Visitor Centre	Building	90,303	10.31
10	Cynrig Salmon Hatchery	Building	84,634	9.66
11	Noah's Ark Pumping Station, Undy	Pumping station	80,363	9.17
12	Aberystwyth Office (WG Building)	Building	80,201	9.16
13	Dolgellau Government Buildings (Dolgellau Office)	Building	68,318	7.80
14	Gwydyr Uchaf Office, Llanrwst	Building	66,848	7.63
15	Gronant Pumping Station, Prestatyn	Pumping station	59,971	6.85
16	Powys Flood Water Pump, Sychpwll	Pumping station	58,906	6.72
17	Garwnant Visitor Centre	Building	54,156	6.18

[119] 'Site Type' is an indicative categorisation of the type of NRW asset seen in the list of assets. This categorisation was conducted using the name of sites given on the billed data. In some cases, where the name on the billed data was not clear in identifying the type of asset, this has been categorised as 'other operational asset'. It is known that in the case of smaller operational assets (e.g. rain gauges), the name on the billed data will not be an accurate reflection of the type of asset, or that different descriptions for similar asset types may have been used, e.g. by different operational teams, which may have resulted in similar assets being identified as different types of asset. Therefore, any future work should revisit the categorisation of types of assets seen here, in collaboration with operational staff, to ensure the suitability of taking forward recommendations for smaller operational assets advised in this study.
[120] Based on 2015/16 billing data from NRW electricity suppliers. The total annual electricity usage for these 22 sites in 2015/16 was 2,770,844 kWh.
[121] Derived by dividing annual electricity use by number of hours in a year (8760).
[122] As part of the NRW Accommodation Review, this site has been closed and new laboratory facilities opened at Swansea University and therefore renewable energy opportunities were not considered for this site. Given the similarity of activities within the new site, it is considered that the new laboratory may have a similar energy usage, therefore some analysis of energy use was carried out as an asset type as detailed in Appendix B.5: Laboratory Site – Llanelli Laboratory.
[123] As part of the NRW Accommodation Review, the main building of this site is no longer occupied, with staff having been moved to Maes y Ffynnon and therefore renewable energy opportunities were not considered for this site.

No.	Site Name	Site Type[119]	Annual electricity use (kWh)[120]	Derived average demand (kW)[121]
18	Southern Area Office, Monmouth	Building	53,276	6.08
19	Plas Gwendraeth, Cross Hands Depot	Building	52,874	6.04
20	Clawdd Newydd Conservancy, Ruthin	Building	50,253	5.74
21	Land Drainage Pumping Station, Deeside Industrial Park, Burton, Puddington	Pumping station	49,333	5.63
22	Hawthorn Rise, Haverfordwest	Building	46,158	5.27

Identifying energy demand profiles to guide technology suitability
The likely energy demand profiles of the twenty live assets with an average demand above 5 kW were then considered. A representative sample of asset types where half-hourly electricity use data was available was used to outline the likely energy demand profile of each asset to guide the assessment of suitable technologies for each site.

Analysis of half hourly (HH) electricity consumption data was undertaken (where HH data was available).[124] Using a HH data analysis model and HH datasets for NRW offices, laboratory, a pumping station, hatchery and three visitor centres, the following were produced:

- Daily kWh consumption trend
- Profiled an annual average day
- Profiled seasonal average days
- Summarised suitability for renewable energy technology
- Highlighted abnormal / exceptional usage or demand periods for further investigation as part of energy management.

Sites reviewed were:

- Noah's Ark Pumping Station
- Tŷ Cambria (Cambria House) Office
- Buckley Office
- Resolven Office / Depot (assumed to be building only) – Resolven was used to represent depots
- Llanelli Laboratory
- Cynrig Salmon Hatchery
- Garwnant, Coed y Brenin and Bwlch Nant yr Arian Visitor Centres

[124] Note the limitation that HH data was only available for 2016/17 year and billed data used for total energy use was for the 2015/16 year. This presents limitations on the conclusions that can be drawn between the two analyses as energy use may have varied between years.

Further detail on the analysis can be found in Appendix B: Analysis of half-hourly electricity use data from a cross section of NRW assets with an average demand above 5 kW.

Understanding interannual variation in electricity use in pumping stations
An analysis of inter-annual variation in electricity use in pumping stations was also undertaken. Monthly electricity bills for 22 of NRW's pumping station sites[125] were collated between 2011 and mid-2016. Using this billing data, an indicative inter-annual view of pumping station consumption was established, providing both a profile of usage within individual years, as well as comparison between years. Further detail on this analysis can be found in Appendix C: Assessment of inter-annual variability in electricity use at NRW's pumping station assets.

The analysis shows that:

- There can be a notable variance in electricity costs / usage within a given year (seasonal variation). This variability reflects the operation of sites as pumping stations and the link between energy consumption of the sites and water level conditions (and so pumping requirements) within and between years.

- Demand is linked to rainfall and water levels. Therefore, the most obvious potential generation technology match could be hydropower, given that hydro resource and requirement for land drainage / other water abstraction for pumping is well matched.

- Analysing the monthly profile of specific sites year-on-year, there is notable variation in billed costs within, as well as between, each of the years. This implies that more than one generation technology may be suitable to meet consumption at pumping stations (i.e. wind or solar). Given the buildings present at pumping stations, this could mean there is also the potential for roof-mounted solar.

It is recommended that future feasibility studies should utilise more detailed kWh consumption data and usage profiles are reviewed in more detail to assess the generation technology that is best suited on a site-by-site basis.

Identifying suitable renewable technologies
From analysing the consumption data for the example sites provided, recommendations were made around the most appropriate generation technology for each of the NRW site types. Note, this suitability assessment is based purely on consumption profile analysis and does not include any specific site location assessments. However, suitability of these recommendations at individual sites was then considered further.

[125] Electricity consumption of 22 pumping stations was available and analysed.

Table 51: Generation technology suitability matrix table for NRW assets

	Type of NRW Asset Demand Profile[126]				
Technology	**Office Building**	**Pumping Station**	**Laboratory**	**Visitor Centre**	**Hatchery**
Small-scale solar PV	**Good Suitability**	**Potential Suitability**	**Good Suitability**	**Good Suitability**	**Good Suitability**
Small-scale hydro	**Low Suitability**	**Potential Suitability**	**Low Suitability**	**Potential Suitability**	**Potential Suitability**
Small-scale wind	**Potential Suitability**	**Potential Suitability**	**Potential Suitability**	**Potential Suitability**	**Low Suitability**

4.3.4.3 Step 2 – small-scale self-supply site assessment

For the high-electricity-consuming assets highlighted in Table 50: 22 NRW assets with an average demand above 5 kW – showing annual consumption and average demand, the process of assessing the potential to site small-scale, ground-mounted generation to directly supply these sites is outlined in this section.

Each of the 20 live assets with an average demand above 5 kW were assessed on a site-by-site basis for their potential to be supplied by on-site small-scale wind, ground-mounted solar and small-scale hydropower, for the purpose of self-supply to the NRW asset.

NRW's electricity consuming assets have low usage, when compared to commercial electricity users in other sectors. Due to the low consumption at individual sites, a site-finding approach was the most suitable methodology to identify small-scale ground-mounted opportunities for self-supply. A bespoke method was used, which involved using mapping and satellite imagery to assess the potential resource and necessary site conditions on a site-by-site basis and to match with the electricity demand at the site, e.g. space for a solar array.

4.3.4.4 Exploring potential demand clustering

Clustering smaller electricity consuming assets together can enable one generation asset located in a central point to be 'partitioned' to connect and supply multiple smaller assets concurrently, provided that they are of sufficient scale and in very close proximity to each other.

The majority of NRW's electricity consuming assets are of too-small-scale for clustering to be viable (i.e. below 5 kW average annual demand) and often not

[126] A cross-section of NRW assets (offices, laboratory, pumping station, visitor centre and salmon hatchery) were analysed. Demand at other operational assets, e.g. gauging stations, is minimal and thus consumption analysis would be more challenges and would not provide worthwhile recommendations.

located in close proximity to each other, therefore the cost of clustering would likely exceed any benefit.

As a result, NRW's 20 live assets with an average demand above 5 kW were reviewed for potential clusters. There were no sites that were within reasonable proximity to one another to enable clustering of demand to feasibly work. As a result, the potential for onsite generation was reviewed on a site-by-site basis for the 20 live assets / sites with a demand above 5 kW.

4.3.4.5 Exploring potential private wire opportunities

Any existing renewable energy projects in close proximity to all 327 NRW electricity consuming assets were also reviewed to establish whether there might be private wire opportunities from third party-owned generation assets. Five hundred metres was considered a feasible distance over which private wire supply could be considered. There were no existing renewable generation installations within 500 m of any NRW electricity-consuming assets.

4.3.4.6 Method

Identifying opportunities

For the 20 live NRW assets, the asset was mapped and assessed for whether there is any NRW-managed land / watercourse within 500 m of the asset.

For information, existing renewable energy installations on the asset (notably rooftop solar) were recorded where these were identifiable. This information is important to understand the existing renewable energy generation at sites, as siting additional renewable energy alongside existing generation could result in excess generation which would then be exported to the grid.

The following three-step site-finding approach was followed to identify opportunities for self-supply, small-scale, ground-mounted solar and wind (hydropower is considered separately in this section):

Step 1: map relevant constraints for each technology.

Step 2: visually review the estate directly associated with the 20 assets and any areas of NRW-managed estate (once constraints have been excluded) within 500 m of the asset for available space / resource for an installation.

Step 3: record any additional considerations relevant to each technology.

For hydropower assessment, a more bespoke approach was required, which was based on visual inspection of mapping and satellite imagery to identify suitable head and flow opportunities. Details of the approach for each technology are set out below.

4.3.4.7 Estimating potential installed capacity

Once opportunities had been identified for each technology, the installed capacity and generation potential were estimated, following the methodology set out below:

For solar PV – the potential adjacent ground-mount land area was measured and a solar capacity (to the nearest 5 kW) was identified that could fit within the land area and also aligned with the operational site's average demand.[127] The annual generation was then calculated using a capacity factor of 10.9 per cent based on Regen's Solar PV Model for PV Irradiance Zone 5, as all five shortlisted sites for solar fall within this zone (see Figure 3 below).

For small-scale wind – for the one potential wind site, an indicative small-scale wind turbine product was chosen (a Kingspan KW6 6.1 kW turbine), which provided the option to tether two machines together and still keep hub / tip heights below a level that would require more extensive impact assessments. Using the published power curve for the KW6 and an average wind speed at the location of the NRW electricity-consuming asset (using the wind resource data set[128]), an annual generation value was calculated for two x KW6 turbines for the site.

For micro hydro – from assessing nearby water intakes and available head (in metres) at the suitable NRW electricity-consuming assets (in metres), potential hydropower capacity was calculated. A 50 per cent power factor[129] was then used to calculate annual generation.

[127] i.e. utilising a land area sufficient to meet the electricity needs of the asset, rather than to maximise the capacity of the adjacent land area.
[128] UK Wind Speed Database (NOABL).
[129] This method is based on 50% capacity factor. Actual capacity factor will depend on installed capacity and water availability. How large to design a scheme relative to available flow is a commercial decision, typical capacity factors range from 30 to 60%. 50% has been used based on expert experience following from typical actual capacity factors for schemes designed for a peak flow of 1.0 x Q_{mean} as per the sizing method used in this study.

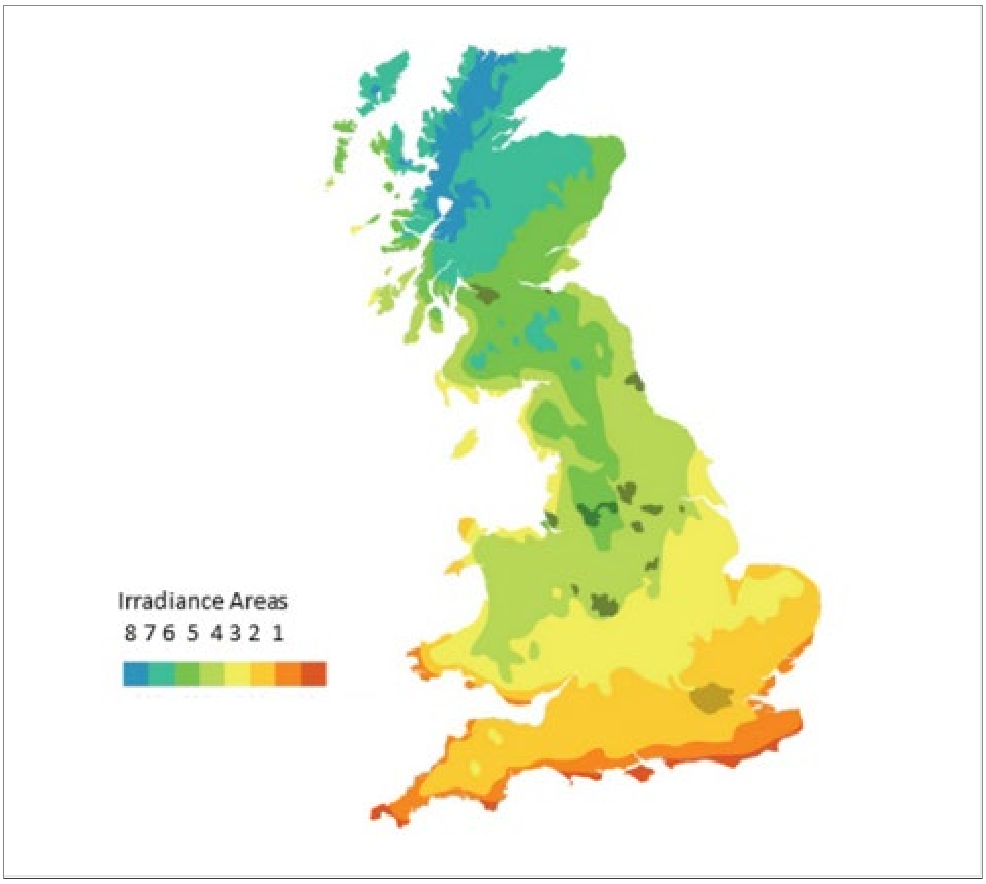

Figure 3: Solar PV irradiance zone map used to determine the capacity factor and annual solar generation potential

4.3.4.8 Cost-benefit analysis

Financial costs and benefits of each opportunity and the carbon impacts were estimated.

4.3.4.9 Costs

For solar PV – an indicative small-scale solar cost benchmark of £1,230 / kW was used to calculate capital costs and an Operation and Maintenance (O&M) cost benchmark of £14 / kW was used to calculate annual operating costs.

For wind – an indicative small-scale wind cost benchmark of £5,000 / kW was used to calculate the capital cost and an O&M cost benchmark of £31 / kW was used to calculate annual operating costs.

For hydro – an indicative small-scale hydro cost benchmark of £11,500 / kW was used to calculate the capital cost and an O&M cost benchmark of £195 / kW was used to calculate annual operating costs.

4.3.4.10 Financial benefits

For each technology:

- The annual generation (kWh) and relevant FIT subsidy[130] technology band rate (p / kWh) was used to calculate annual subsidy income.
- The annual generation (kWh) and an import electricity unit rate of 10.5p / kWh was used to calculate annual import electricity offset savings (i.e. cost savings from self-generation rather than drawing electricity from the grid).

4.3.4.11 Carbon benefit

For self-supply generation, the user of this energy (i.e. NRW) is able to claim the carbon emissions savings associated with the use of self-generated renewable energy, against its own carbon footprint.

For all technologies, the annual generation (kWh) and carbon emission conversion factor for Generation + Transmission & Distribution[131] (0.38443 kgCO_2e / kWh) was used to calculate annual carbon emission savings for each of the self-supply opportunities.

4.3.4.12 Payback

Non-inflated and inflated payback and NPV were calculated for each of the self-supply opportunities.

- Basic (non-inflated) NPV was calculated over 20 years[132], calculated using: up front capital costs, fixed / flat annual benefits, a discount rate of 3.5%[133] and MS Excel in-built NPV function.

- Inflated NPV was calculated over 20 years using the following values: project duration (all techs) – 20 years[132], discount rate – 3.5%[133], FIT income & O&M cost indexation of RPI – 2.5%, electricity price escalation – 3.5%.

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[130] See Ofgem FIT rate tables, available online at: https://www.ofgem.gov.uk/environmental-programmes/fit/fit-tariff-rates

[131] See BEIS GHG conversion factors 2017, available online at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2017

[132] NPV duration is set at 20 years to reflect FIT subsidy length across all technologies for consistency of analysis. In reality, renewable energy project lifetimes can be longer, but beyond 20 years, further consideration would need to be given to capital re-investment and reconditioning of plant. As such Regen considers the use of a 20-year period to be appropriate for this assessment.

[133] See UK government (HM Treasury) Green Book supplementary guidance on discounting, available online at: https://www.gov.uk/government/publications/green-book-supplementary-guidance-discounting

4.3.4.13 Results

Twenty NRW top electricity-consuming assets were reviewed for ground-mounted self-supply generation opportunities. Nine self-supply generation options for small-scale solar, and wind or hydro were identified across six NRW assets, which are summarised in Table 52. The availability and scale of ground-mounted self-supply opportunities were primarily constrained by a lack of available space on-site or near each electricity-using asset. However, further opportunities exist for microgeneration, particularly roof-mounted solar PV, in relation to the top consuming assets and the remaining electricity-consuming assets (with a demand below 5 kW), which are discussed in 4.3.5.

For each of the six top consuming assets with opportunities for small-scale generation, the scale of the on-site demand was reviewed, and the potential scale of the technology was matched accordingly, with the aim that the majority or totality of the electricity generated would be used on-site. This means that sites could potentially avoid the grid constraint issues experienced by sites seeking an export connection. Relatively low average demand at the NRW assets means that the scale of the technology recommended is small.

The potential capacity, generation and additional project details for the six identified opportunities are included in Table 53: Ground-mounted solar self-supply opportunities, Table 54: Wind self-supply opportunity and Table 55: Hydro self-supply opportunities. Figures in Appendix E: Self-supply opportunities – site maps illustrate the suggested location[134] of each NRW electricity-consuming asset with a ground-mounted self-supply opportunity.

[134] Identifying specific locations for the self-supply opportunities via feasibility assessments should be a priority under next steps.

Table 52: Small-scale ground-mounted self-supply generation opportunities for NRW electricity-consuming assets above 5 kW annual average demand (including existing generation and microgeneration (microgen) opportunities)

Asset name[135]	Average annual demand (kW)	NRW- managed land / watercourse available onsite or within 500 m	Small-scale solar / wind opportunities	Solar or wind opportunity identified?	Small-scale Hydro opportunities	Hydro opportunity identified?	Existing renewable energy installations	Additional generation potential identified (i.e. rooftop solar)
Maes y Ffynnon, Bangor	47.6	N	No available space on site or NRW-managed estate nearby (within 500 m).	N	No suitable resource on site	N	Roof-mounted solar – generated 24,864 kWh in 2015/16.	N
Cambria House, Cardiff (Tŷ Cambria)	43.2	N	No available space on site or NRW-managed estate nearby (within 500 m), in built-up urban area.	N	No suitable resource on site	N	Roof-mounted solar – generated 5,055 kWh in 2015/16.	N
Rivers House, St Mellons	22.3	N	No available space on site or NRW-managed estate nearby (within 500 m). Would recommend investigation of a collaborative rooftop solar or solar carport project with other organisations in St. Mellons Business Park.	N	No suitable resource on site	N	None	Y

[135] Asset names are taken from billed data, in some cases alternative names for sites have been provided in brackets for clarity.

Asset name[135]	Average annual demand (kW)	NRW- managed land / watercourse available onsite or within 500 m	Small-scale solar / wind opportunities	Solar or wind opportunity identified?	Small-scale Hydro opportunities	Hydro opportunity identified?	Existing renewable energy installations	Additional generation potential identified (i.e. rooftop solar)
Deeside Area Office (Buckley)	19.2	N	Small grass area north of site possible solar array (max 10 kW). Would need site visit to investigate issues with tree shading.	Y	No suitable resource on site	N	None	N
Llandarcy Development Site (Maes Newydd)	14.9	N	No NRW-managed estate nearby (within 500 m). Access to develop on the land around the asset is unknown, there may be space for a small array north of the building. Further investigation required to determine size of opportunity. Already has rooftop solar installed, solar carport possible.	Y	No suitable resource on site	N	Roof- mounted solar – generated 12,010 kWh in 2015/16.	Y

Asset name[135]	Average annual demand (kW)	NRW- managed land / watercourse available onsite or within 500 m	Small-scale solar / wind opportunities	Solar or wind opportunity identified?	Small-scale Hydro opportunities	Hydro opportunity identified?	Existing renewable energy installations	Additional generation potential identified (i.e. rooftop solar)
Dolgefeiliau (Coed y Brenin Visitor Centre)	12.5	Y	Potential for solar array (5 kW), in addition to the existing 8 kW (estimated) roof-mounted installation, would need site visit from installer. Asset demand analysis indicates solar as the preferred technology. Wind project not suitable due to windspeeds – (NOABL) 3 m/s at 10 m or 3.6 m/s at 25 m.	Y	A self-supply site of around 5 kW could be installed here using multiple intakes and 70m head.	Y	Roof- mounted solar – generated 7,936 kWh in 2015/16.	N

Asset name[135]	Average annual demand (kW)	NRW- managed land / watercourse available onsite or within 500 m	Small-scale solar / wind opportunities	Solar or wind opportunity identified?	Small-scale Hydro opportunities	Hydro opportunity identified?	Existing renewable energy installations	Additional generation potential identified (i.e. rooftop solar)
Bwlch Nant yr Arian (Visitor Centre)	10.3	Y	Potential for solar array (10 kW) or wind development (12 kW). Windspeeds (NOABL) 5.2 m/s at 10 m and 6 m/s at 25 m. 150 m cable distance between visitor centre and generation opportunity proposed location, could make economic viability of project challenging. Good solar carport opportunity, in closer proximity to asset.	Y	Closest longlisted standalone site 0.8km away. This could self-supply but cable distance will make a project economically challenging. Intake of this site may be single bank ownership. No additional site available on a smaller 5 kW threshold.	Y	None	Y
Cynrig Salmon Hatchery	9.7	Y	Primary recommendation would be rooftop solar. Potential space for 10 kW array – would require site visit.	Y	No longlisted standalone opportunities in proximity. There is an existing weir and presumed access rights and abstraction licensed for hatchery, and presumed flow. It may be possible to increase the abstraction to 700 l/s and use a small low head hydro turbine such as	Y	None	Y

Asset name[135]	Average annual demand (kW)	NRW- managed land / watercourse available onsite or within 500 m	Small-scale solar / wind opportunities	Solar or wind opportunity identified?	Small-scale Hydro opportunities	Hydro opportunity identified?	Existing renewable energy installations	Additional generation potential identified (i.e. rooftop solar)
					a screw turbine to deliver around 10 kW.			
Noah's Ark Pumping Station, Undy	9.2	N	No NRW-managed estate nearby (within 500 m). Unclear of land ownership around site as only point data available, recommend site visit to identify if any suitable adjacent land is available. Note: springtime peak demand, minimal demand in summer and autumn.	N	No suitable resource	N	None	N
Aberystwyth Office (WG Building)	9.2	N	No NRW-managed estate nearby (within 500 m). Recommend further investigation of rooftop solar PV or potential for a solar carport. Note, this is also a shared building with WG, which may provide opportunities.	N	No suitable resource	N	Unknown (WG-managed building)	Y
Government Buildings, Dolgellau	7.8	N	No NRW-managed estate nearby (within 500 m). Recommend further investigation of rooftop solar.	N	No suitable resource	N	Unknown (shared building)	Y

Asset name[135]	Average annual demand (kW)	NRW- managed land / watercourse available onsite or within 500 m	Small-scale solar / wind opportunities	Solar or wind opportunity identified?	Small-scale Hydro opportunities	Hydro opportunity identified?	Existing renewable energy installations	Additional generation potential identified (i.e. rooftop solar)
Gwydyr Uchaf Office, Llanrwst	7.6	Y	NRW-managed estate available onsite or nearby (within 500 m), currently heavily forested resulting in too much shading for solar and surface roughness (turbulent air) would be too high for small-scale wind[136] and heavily impacts on turbine efficiency and financial viability of the project. Therefore site not suitable for small-scale solar / wind projects at this stage.	N	No longlisted standalone sites nearby (a suitable site was excluded due to ancient woodland considerations). Potential self-supply opportunity using an abstraction above Grey Mare's Tail waterfall, and existing open channel to the site, and potentially 15 m head from here. The inlet and channel are out of NRW-managed estate so not shortlisted before, but the channel is extant and rights could exist to access to the inlet and therefore an opportunity on the NRW-managed estate may	Y	None	N

[136] The cost of removal of sufficient forestry for the purposes of enabling wind (tree barriers to wind) or solar (shading) would likely be excessive compared to the size of the array that would be sized to meet the average demand of 7–10 kW. However, future work should seek to consider the local NRW Forest Design Plan for the land adjacent to the site to understand any intentions to clearfell the area in future.

Asset name[135]	Average annual demand (kW)	NRW- managed land / watercourse available onsite or within 500 m	Small-scale solar / wind opportunities	Solar or wind opportunity identified?	Small-scale Hydro opportunities	Hydro opportunity identified?	Existing renewable energy installations	Additional generation potential identified (i.e. rooftop solar)
					exist. Power may be c. 10 kW. Further detailed analysis is required.			
Gronant Pumping Station, Prestatyn	6.8	N	No NRW-managed estate nearby (within 500 m). Golf course next to asset would likely make wind development challenging.[137]	N	No suitable resource	N	None	N
Flood water pump, Sarn Wen, Powys	6.7	N	No NRW-managed estate nearby (within 500 m). Unclear of land ownership around site as only point data available, recommend site visit to identify if any suitable adjacent land is available.	N	No suitable resource	N	None	N

[137] Industry experience is that golf courses tend to present a planning barrier to wind turbine development, due to potential landscape impacts.

Asset name[135]	Average annual demand (kW)	NRW- managed land / watercourse available onsite or within 500 m	Small-scale solar / wind opportunities	Solar or wind opportunity identified?	Small-scale Hydro opportunities	Hydro opportunity identified?	Existing renewable energy installations	Additional generation potential identified (i.e. rooftop solar)
Garwnant Visitor Centre	6.2	N	Already has 10 kW solar array.[138] Small-scale wind project not suitable due to the topography, subsequent windspeeds and cable distances.	N	27.1 kW hydro already installed, suggesting that the suitable hydro resource has already been exploited.	N	10 kW solar array generated 9,423 kW and 27.1 kW micro-hydro in 2015/16	N
Southern Area Office (Hadnock Road, Monmouth)	6.1	N	No available NRW-managed estate nearby (within 500 m). Would recommend rooftop solar. Potential private wire opportunity with Mayhill Industrial Estate	N	No suitable resource	N	Roof- mounted solar PV installation planned for 2017/18.	Y
Plas Gwendraeth (Heol Mawr, Cross Hands, Llanelli)	6.0	N	No available NRW-managed estate onsite or nearby (within 500 m). Already has rooftop solar.	N	No suitable resource	N	Roof- mounted solar – generated 1,644 kWh in 2015/16. Extension to solar PV	N

[138] A 10 kW solar array supplying the site with a residual average demand of 6.2 kW means there is the likelihood that additional ground-mount solar (higher cost than roof-mount) may export to the grid, which the local DNO would potentially not permit and would not constitute a self-supply opportunity. Analysis of midday half-hourly consumption data would be required, in order to establish the potential for any additional solar PV to self-supply.

Asset name[135]	Average annual demand (kW)	NRW- managed land / watercourse available onsite or within 500 m	Small-scale solar / wind opportunities	Solar or wind opportunity identified?	Small-scale Hydro opportunities	Hydro opportunity identified?	Existing renewable energy installations	Additional generation potential identified (i.e. rooftop solar)
							planned for 2017/18.	
North Wales Conservancy (Clawdd Newydd, Ruthin)	5.7	Y	Solar array opportunity (up to 15 kW). Also opportunity for rooftop solar.	Y	No suitable resource	N	Roof- mounted solar PV installation planned for 2017/18.	Y
Land Drainage Pumping Station (Deeside Industrial Park, Burton, Puddington)	5.6	N	No NRW-managed estate nearby (within 500m). Unclear of land ownership around site as only point data available. Recommend site visit to identify if any suitable adjacent land is available.	N	No suitable resource	N	None	N
Llys Afon, Hawthorn Rise (Haverfordwest)	5.3	N	No available NRW-managed estate onsite or nearby (within 500 m). Very close proximity to housing. Would recommend rooftop solar.	N	No suitable resource	N	Roof- mounted solar PV installation planned for 2017/18.	Y

All opportunities and recommendations are made as part of a desk-based study and will require further studies to understand feasibility. Although the assessment did not include a rooftop solar assessment, where opportunities could be seen through the site-finding process, these have been recorded for information. This identification of microgeneration opportunities is not exhaustive and additional opportunities could be identified through site visits. It is acknowledged that those opportunities identified for both rooftop solar and small-scale technologies would require site-specific investigations, e.g. site visits, to progress further.

4.3.4.14 Self-supply site assessment results by technology

Ground-mounted solar PV

Table 53: Ground-mount solar self-supply opportunities

NRW asset	Billed electricity use in 2015/16 (kWh)	Estimated average demand (kW)	Solar capacity (kW)	Potential annual generation (kWh)	Benchmark technology capital costs (£)[139]	Annual O&M OpEx Costs (£)[140]	Gross Annual Benefit (£) (Import Offset Savings and FIT)	Annual Carbon Savings (tCO_2e)[141]	Non-inflated Payback (Years)
Deeside Area Office (Buckley office)	167,875	19	10	9,548	£12,300	£140	£1,364	3.7	10
Coed y Brenin Visitor Centre	109,284	12	5	4,774	£6,150	£70	£682	1.8	10
Bwlch Nant yr Arian Visitor Centre	90,303	10	10	9,548	£12,300	£140	£1,364	3.7	10

[139] A PV capital cost benchmark (10 kW solar PV band from BEIS PV cost data 2017) of £1.23k / kW was used to determine an indicative capital cost.
[140] An O&M cost benchmark of £14 /kW (10 kW solar PV band from NREL RE estimate of cost 2016) was used to determine an indicative annual O&M cost.
[141] As self-supply opportunities estimated saved carbon emissions are based on 'fully delivered' or combined electricity emissions factors for both generation, and transmission distribution losses.

NRW asset	Billed electricity use in 2015/16 (kWh)	Estimated average demand (kW)	Solar capacity (kW)	Potential annual generation (kWh)	Benchmark technology capital costs (£)[139]	Annual O&M OpEx Costs (£)[140]	Gross Annual Benefit (£) (Import Offset Savings and FIT)	Annual Carbon Savings (tCO_2e)[141]	Non-inflated Payback (Years)
Cynrig Salmon Hatchery	84,634	10	10	9,548	£12,300	£140	£1,364	3.7	10
North Wales Conservancy (Clawddnewydd office)	50,253	6	15	14,323	£18,450	£210	£2,045	5.5	10
TOTAL	**502,349**	**--**	**50**	**43,441**	**£61,500**	**£700**	**£6,819**	**18.4**	**--**

Comments
Additional considerations for these solar opportunities include landscape and environmental designations. Three assets are located within designated landscapes:

- Coed y Brenin Visitor Centre (Snowdonia National Park)
- Cynrig Salmon Hatchery (Brecon Beacons National Park)
- Gwydyr Uchaf Office (Snowdonia National Park).

Opportunities at these sites would require additional consideration of impacts in future feasibility studies for these options.

As shown on the maps in Appendix E: Self-supply opportunities – site maps, the River Usk SAC and SSSI River Usk Tributaries sit adjacent to Cynrig Salmon Hatchery and the River Afon Eden (Afon Eden – Cors Goch Trawsfynydd SAC) sits adjacent to Coed y Brenin Visitor Centre. Gwydyr Uchaf Office is also adjacent to Gwydir Uchaf Chapel (a registered ancient monument). Opportunities for these sites would require additional consideration of impacts to these designations, through future feasibility studies.

Wind

Table 54: Wind self-supply opportunity

NRW asset	Electricity use in 2015/16 (kWh)	Average demand (kW)	Wind capacity (kW)[142]	Potential annual generation (kWh)[143]	Benchmark technology cost (£)[144]	O&M OpEx Costs (£)[145]	Gross Annual Benefit (Import Offset Savings and FIT) (£)	Carbon Savings (tCO2e)	Non-Inflated Payback (Years)
Bwlch Nant yr Arian Visitor Centre	90,303	10	12.2	17,900	£61,000	£378	£3322	6.9	21

[142] Based on indicative turbine model Kingspan KW6 capacity of 6.1 kW
[143] Based on NOABL average wind speed of 5.2 m / s at 10 m, and KW6 power curve
[144] Based on indicative capital cost benchmark of £5 k / kW (Renewables First <10 kW cost benchmark)
[145] Based on NREL O&M cost benchmark <10 kW wind of £31 / kW

Comments
Bwlch Nant yr Arian was the only site identified as suitable for small-scale wind. Although the Bwlch Nant yr Arian Visitor Centre has the opportunity for wind and solar, the usage profile assessed in the site demand analysis (seen in Appendix B: Analysis of half-hourly electricity use data from a cross section of NRW assets with an average demand above 5 kW) suggests the typical generation from a wind installation would be more suited to meeting on-site demand than solar. For this site, the Kingspan KW6 turbine (6.1 kW capacity) has been used as an example turbine well-suited to rural locations, to provide estimated costs and carbon savings – an installation of two turbines is proposed as part of the opportunity at Bwlch Nant yr Arian. There is also the potential for NRW to consider installing both solar and wind technology, as the wind turbine alone does not generate sufficient energy to meet the annual consumption of the site. Thus, a combined wind and solar installation (should sufficient land be available) would be an option for NRW to consider.

There were no identified environmental or heritage considerations on or adjacent to the site.

Hydropower

Table 55: Hydro self-supply opportunities

NRW asset	Electricity use in 2015/16 (kWh)	Average demand (kW)	Hydro capacity (kW)	Potential annual generation (kWh)[146]	Benchmark technology cost (£)[147]	O&M OpEx Costs (£)[148]	Gross Annual Benefit (£)	Carbon Savings (tCO2e)	Non-inflated Payback (Years)
Coed y Brenin Visitor Centre	109,284	12	5	21,900	£57,500	£950	£3,995	8.4	**19**
Cynrig Salmon Hatchery	84,634	10	10	43,800	£115,000	£1,900	£7,989	16.8	**19**
Gwydyr Uchaf Office, Llanrwst	66,848	8	10	43,800	£115,000	£1,900	£7,989	16.8	**19**
TOTALS	**260,766**	**--**	**25**	**109,500**	**£287,500**	**£4,750**	**£19,973**	**42**	**--**

146 Based on 50% capacity factor. Actual capacity factor will depend on installed capacity and water availability. How large to design a scheme relative to available flow is a commercial decision, typical capacity factors range from 30 to 60%. 50% has been used based on expert experience following from typical actual capacity factors for schemes designed for a peak flow of 1.0 x Q_{mean} as per the sizing method used in this study.

147 Based on BHA Analysis of Small Scale Hydro Costs (2015) <15 kW capital cost benchmark of £11.5k / kW. Available at: http://www.british-hydro.org/News/AnalysisofHydroCosts_v600.pdf

148 Based on BHA Analysis of Small Scale Hydro Costs (2015) <15 kW annual O&M cost benchmark of £190 / kW. Available at: http://www.british-hydro.org/News/AnalysisofHydroCosts_v600.pdf

Comments
The closest longlisted site to Coed y Brenin was 1.8 km away. A self-supply opportunity of around 5 kW could be installed using multiple intakes and 70 m head.

There is an existing weir and presumed access rights and abstraction licensed for Cynrig Hatchery, and presumed flow. It may therefore be possible to increase the abstraction to 700 l/s and use a small low head hydro turbine such as a screw turbine to deliver around 10 kW.

There are no longlisted standalone sites nearby to Gwydyr Uchaf Office due to ancient woodland in the area of potentially suitable sites. This asset has a potential self-supply opportunity however, using an abstraction above Grey Mare's Tail waterfall, and existing open channel to the site, and potentially 15 m head. The inlet and channel are outside of the boundary of the NRW-managed estate so are not shortlisted before, but the channel is extant and rights could exist to access to the inlet. The potential power may be around 10 kW.

As mentioned above, Coed y Brenin and Cynrig Salmon Hatchery fall within Snowdonia and Brecon Beacons National Parks respectively, and Afon Eden-Cors Goch Trawsfynydd SAC (adjacent to Coed y Brenin) and the River Usk SAC (adjacent to Cynrig).

With regards to Cynrig Salmon Hatchery, due to potential existing infrastructure and existing abstraction at this location, it has been flagged as a potential opportunity for further investigation.

Consideration of the impact and planning risk of these as small-scale (10 kW or lower) opportunities should be included as part of any next stage feasibility studies.

4.3.4.15 Emission reduction potential

If all nine opportunities were delivered this could deliver estimated emissions savings of 67 tCO_2e per year.

This saving is achieved through the reduction in use of grid electricity. The nine opportunities have an estimated total capacity of 87.2 kW, which could generate an estimated 175 MWh annually; offsetting the requirement to use 175 MWh of grid electricity.

4.3.4.16 Cost

If all nine opportunities were delivered the estimated capital cost is £410,000, with an annual operation and maintenance cost of £5,828.

The installations are predicted to generate a cost saving of £30,114 through a combination of cost savings from reduced use of grid electricity (import offset) and feed-in tariff (FIT) payments.

4.3.4.17 Scale of adoption

The method for identifying ground-mounted renewable energy opportunities has identified suitable sites due to their availability of land and electricity demand at site. Therefore, there is no potential to scale-up the estimates to other NRW sites and the scale of adoption is considered to be all nine opportunities identified.

4.3.4.18 Feasible maximum and theoretical maximum

Given the modest number of sites where ground-mounted installations are possible, the feasible and theoretical maximum has been set as the same – all nine opportunities identified – subject to feasibility following site-specific surveys. This gives a potential carbon saving of 67 tCO_2e per year at a capital cost of £410,000.

4.3.4.19 Assumptions

See 4.3.3.7 Assumptions.

4.3.4.20 Lessons learnt

See 4.3.3.8 Lessons learnt.

4.3.4.21 Summary of mitigation measures for ground-mounted self-supply installations

Table 56: Summary table of shortlisted self-supply site opportunities

The table below outlines the sites where potential for installations of ground-mounted technologies have been identified. It also gives estimated generation, carbon benefit, costs, cost savings and payback / NPV.

NRW asset	Average demand (kW)	Technology	Capacity (kW)	Annual generation (kWh)	Annual Carbon Emissions Savings (tCO2e)	Estimated Capital costs (£)	Estimated Annual O&M costs (£)	Estimated Annual Gross Benefit (£)	Non-inflated Payback (Years)	Non-inflated NPV (£)
Deeside Area Office (Buckley)	19	Solar PV	10	9,548	3.7	£12,300	£140	£1,364	10	£5,089
Coed y Brenin Visitor Centre	12	Solar PV	5	4,774	1.8	£6,150	£70	£682	10	£2,545
Bwlch Nant yr Arian Visitor Centre	10	Solar PV	10	9,548	3.7	£12,300	£140	£1,364	10	£5,089
Cynrig Salmon Hatchery	10	Solar PV	10	9,548	3.7	£12,300	£140	£1,364	10	£5,089
North Wales Conservancy	6	Solar PV	15	14,323	5.5	£18,450	£210	£2,045	10	£7,634
Bwlch Nant yr Arian Visitor Centre	10	Wind	12.2	17,900	6.9	£61,000	£378	£3,322	21	-£19,158

Coed y Brenin Visitor Centre	12	Hydro	5	21,900	8.4	£57,500	£950	£3,995	19	-£14,229
Cynrig Salmon Hatchery	10	Hydro	10	43,800	16.8	£115,000	£1,900	£7,989	19	-£28,459
Gwydyr Uchaf Office (Llanrwst)	8	Hydro	10	43,800	16.8	£115,000	£1,900	£7,989	19	-£28,459
Totals	**--**	**--**	**87.2**	**175,141**	**67.3**	**£410,000**	**£5,828**	**£30,114**	**--**	

4.3.4.22 Benefits beyond greenhouse gas savings

See 4.3.3.9 Wider benefits of renewable energy generation.

4.3.4.23 Examples of successful adoption

- A 17 kW hydropower scheme was installed into the watercourse alongside NRW's Garwnant Visitor Centre in 2017.
- Cambridgeshire County Council's renewable energy programme.
- The NHS Sustainability Unit's work, e.g. wind energy at Kings Lynn Hospital.

4.3.4.24 Technical considerations

For self-supply sites, the next steps, where appropriate, may include:

- Site visits to assess suitability and location of generation opportunity. A feasibility assessment would be required for individual opportunities identified to confirm location and that conditions are appropriate to install the proposed identified technology.
- A feasibility assessment for the potential benefits of installing battery storage alongside the renewable technologies.
- Landscape impact assessments.
- Environmental Impact Assessments, e.g. impact on birds, bats and other ecology will need to be assessed on a site-by-site basis.
- Studies on accessibility to the site.
- For wind opportunities, Met Office Virtual Met Mast assessments to provide detailed wind climatology, increasing certainty of the wind resource available for specific sites.
- Engagement with the DNO to assess the potential to connect new (or additional) generation capacity on site.
- Confirming ownership of asset and surrounding land required for development.

4.3.5 Category specific method – microgeneration renewable energy installations on NRW operational assets

4.3.5.1 Description

For NRW's assets that had an average demand below 5 kW, an assessment and market review of microgeneration assets was completed; reviewing micro wind, micro hydro and small-scale solar deployment options (both building and ground-mounted, including single solar panel cabinets and kiosks) to align with NRW's very low electricity consuming assets (e.g. hydrometry and telemetry assets).

Bulk buying of microgeneration technologies for NRW assets with lower electricity demand was considered. Microgeneration considerations for these assets were assessed based on suitability of technology type against estimated electricity demand profile of asset types. The specification, some examples of products available to buy and discussion around the suitability of these technologies to meet NRW's usage at sites with low average electricity demand were then considered.

The analysis of NRW's electricity consuming assets highlighted that a high number of sites have low (<5 kW) average annual demand and are classed as low energy consuming assets. These assets with demand below 5 kW were not assessed for small-scale ground-mount opportunities because their demand is considered insufficient to warrant self-supply from a small-scale ground-mounted PV, small wind turbine or small hydro turbine. This is because the generation from such technologies would exceed on-site demand. Therefore, microgeneration technologies[149] were considered to be more appropriate to consider for self-supply these assets.

4.3.5.2 Step 3 – Microgeneration assessment method

Understanding NRW's low-energy consuming assets
Electricity consumption data provided for NRW's 327 assets (buildings and operational assets) was reviewed, which showed 305 assets were classed as low-energy consuming assets with an average annual electricity demand of less than 5 kW. Of these 305 low energy consuming assets, around 220 have an average demand of less than 1 kW and some are into the hundreds of Watts of annual average power demand – these are considered to be 'very low consuming assets' for the purpose of identifying opportunities. These very low-energy assets predominantly fall within NRW site category of 'Other operational assets' (e.g. gauging stations, flood storage areas), described in Table 61: Overview of the potential opportunities that could be considered as a bulk programmes of small / micro scale installations.

The nature of the equipment at NRW's low-energy consuming assets (<5 kW) was also reviewed, showing a range of physical site premises, from small brick buildings housing land drainage pumping stations or rain gauging stations, through to small

[149] E.g. roof-mounted solar PV, micro-scale ground-mounted PV, micro-wind and micro-hydro.

cabinets or kiosks by the side of a bridge. Some of these assets are powered by mains grid (230V AC) supplies, with others (such as small or remote telemetry outstations) being reliant on trickle-charged battery supplies.

The equipment within these types of sites was also understood. The types of equipment are varied, with the main consumers being pumps at pumping station sites and actuators / motors at sites such as sluice gates or flood alleviation mechanical sites. In addition to these, there are a number of low-power electronic devices, including:

- GSM or satellite modem and associated communications equipment
- Ultrasonic water level and flow level sensor devices
- Water quality monitoring devices
- Pressure transducers
- Programmable Logic Controllers (PLCs)
- River gauging winches

Figure 4: Cilfrew gauging station with solar PV array

Identifying suitable renewable technologies
In order to provide recommendations to include low-energy consumption sites, the following method was adopted:

- **Small and microgeneration market review:** reviewing the scale and cost of suitable small and microgeneration technologies and products.

- **Technology cost summary:** capturing £ / kW average cost benchmarks for small-scale generation.

- **Site to technology suitability matching:** utilising the type of operational site and an indicative locational consideration, a preferential small/micro generation technology was assigned to each of the <5 kW NRW operational assets.

- **Carbon benefit calculation:**
    - established rounded kW values for each of the <5 kW NRW operational asset.
    - utilised averages of existing capacity factors for each for standalone technologies.
    - calculated carbon emission savings using stated emission conversion factors and derived annual kWh values for each of the <5 kW operational assets.

The results of this process are summarised in Table 61: Overview of the potential opportunities that could be considered as a bulk programmes of small / micro scale installations.

4.3.5.3 Results

Small and microgeneration market review
A high-level market review of technology option for NRW's low (<5 kW) and very low- (<1 kW) energy consuming sites shows that there are a number of microgeneration solutions that could be deployed at this scale. These include small and micro wind, solar, and hydro, as set out below.

Small and micro wind
Micro wind can be defined as wind turbines with rated power capacity between 100 W and 1 kW. Small wind, for the purposes of this study, can be defined as turbines with rated power capacity between 1 kW and 10 kW.

There are a number of 'off-the-shelf' wind turbines available with varying power outputs. The majority of these turbines have internal power electronics allowing them to output DC at 12V, 24V or 48V. For these types of devices, an inverter will be required if any surplus generation is to be exported to the grid. Wind turbines in the 5 kW–8 kW range, both horizontal axis (HAWT) and vertical axis (VAWT) wind turbines, may be well-suited to provide backup power in conjunction with a long duration battery capable of bridging the intermittency gap. This potential option of trickle-charging an off-grid battery using a micro turbine DC generator is a solution that can be deployed at both small and micro scales. The energy in the charged battery can then be drawn upon, by the NRW low-power on-site equipment at will / point of use. A number of applications of this nature can be seen in the marine sector, where micro wind turbines or PV panels are used to charge on-board batteries.[150]

[150] For example, on boats, floating platforms, remote/harbour buildings, or offshore oil rigs.

The potential to connect a small or micro wind generator in parallel to a grid supply at NRW's smaller sites also presents itself, whereby intermittent wind generation is supplemented by imported grid electricity. This scale is akin to domestic scale roof / wall mount wind.

While commercially mature small and micro turbines can be purchased, the industry continues to work on improving durability and reducing device costs. A number of providers were reviewed in the study and it has been noted that the cheaper solutions are usually less established and supported in terms of warranties (e.g. two years), and therefore potentially less reliable.

It was considered that more expensive solutions would be more likely to provide a higher level of reliability and supported by more robust manufacturer warranties (e.g. five years). Less risk associated with the reliability of technology will increase the confidence in the business case (e.g. lifetime of the measure and return on investment). In general, turbines advertised for marine applications as mentioned above will be more rugged and reliable. A small-scale vertical axis turbine (VAWT) was also reviewed as an alternative micro wind design.

Some examples of available systems are presented in Table 57 and Table 58, it should be noted that these are a neutral sample of products on the market and are not intended to be recommendations for purchase. There are many products available to buy and consideration would need to be made at a project planning stage to review and purchase according to internal procurement procedures.

Table 57: Summary of sample small wind turbine products

Example Small Wind Turbines	Specification	Cost (inc VAT[151])
Aeolos 3 kW Turbine http://www.windturbinestar.com/3kwh-aeolos-wind-turbine.html	3 kW 120/220V AC 4.8 m rotor diameter Five-year warranty	**£3,920[152]**
AirForce 1 1 kW Turbine http://www.futurenergy.co.uk/turbine.html	1 kW Three phase AC 1.8 m rotor diameter Two-year warranty	**£1,200[153]**
QuietRevolution Qr6 VAWT https://www.quietrevolution.com/products/	7.5 kW Inverter output (220V AC) 3.1 m diameter, 5.5 m tall Requires 15 m or 18 m mast Five-year warranty	**£39,000 (+mast)[154]**

[151] VAT assumed at 20%.
[152] Note that at the time of writing (March 2018) this model had now become 'price on application' and so VAT could not be confirmed. Therefore, VAT has been assumed to be included within the price at 20%. Any future work on microgeneration opportunities should seek to revisit costs at the time.
[153] Note that at the time of writing (March 2018) the cost of this model had not changed.
[154] Note that at the time of writing (March 2018) this model had now become 'price on application' and so VAT could not be confirmed. Therefore, VAT has been assumed to be included within the price at 20%. Any future work on microgeneration opportunities should seek to revisit costs at the time.

Table 58: Summary of sample micro wind turbine products

Example Micro Wind Turbines	Specification	Cost (inc VAT[155])
Leading Edge LE-600 Turbine https://www.leadingedgepower.com/shop/products/wind-turbines/le-600-wind-turbine-12-24-48v-1013011.html	600 W 12/24/48V DC 1.54 m diameter blades Two-year warranty	**£1,000[156]**
Leading Edge LE-v50 VAWT https://www.leadingedgepower.com/shop/products/wind-turbines/le-v50-vertical-axis-wind-turbine-1013843.html	70 W 12/24/48V DC 270 mm rotor diameter Two-year warranty	**£780-960**

Small and micro solar

The small-scale solar PV industry is well-developed and solar has been available to install at a huge range of capacities; predominantly down to its very modular nature, solar is easy to configure to meet the requirements of the installer, from panels integrated into equipment to individual 100 W panels through to 50 MW+ large scale solar farms.

With this in mind, small- and micro-scale solar is simply a matter of module configuration and associated equipment, specifically a charge controller for battery charging if off-grid or an inverter for exporting (or parallel operation) of energy to the grid. For the purposes of this study, micro-scale solar is considered to be up to 2 kW[157] and small-scale solar is considered to be up to around 15 kW[158].

Many smaller configurations of solar systems are available to purchase as pre-packaged kits. These will come with panels, charge controller, cabling and mounting brackets, etc. In some cases, these kits are better value for money than purchasing the components individually. Some examples are outlined below.

155 VAT assumed at 20%.

156 Note that at the time of writing (March 2018) this model cost £1,075.14. (including VAT assumed at 20%). Any future work on microgeneration opportunities should seek to revisit costs at the time.

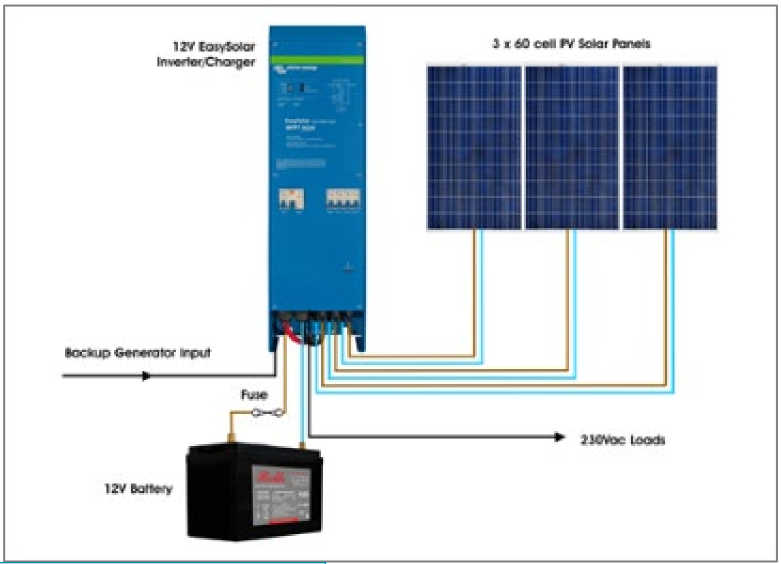
157 2 kW is roughly the smallest scale that a roof-mounted array would be based on reviewing installations installed within the feed-in tariff register.

158 There is no agreed definition of small-scale solar. 15 kW is used for the purpose of this study for consistency with wind.

12V/24V PV
2.4kWh battery
230V AC output

£2,218.82

http://www.windandsun.co.uk/products/Kits/EasySolar-Off-Grid-Kits



Solar cabinet
3 x 10W panels (12V)

Price on request

http://streamlinemeasurement.net/wp-content/uploads/2015/02/Solar-Cabinet.pdf

Figure 5: Wind and Sun EasySolar Kit

There are examples of 'off-the-shelf' enclosures with solar panels included, enabling low-power remote electronic devices / outstations to be installed within them and powered by the panels, which would be suitable for some NRW operational assets. These units are very similar to the example of the existing NRW solar GRP enclosure at Coytrahen Gauging Station.

As part of the wider Carbon Positive Project, demonstration projects are being delivered to showcase the mitigation measures open to NRW. These projects will also help to refine the costs and carbon savings estimates for mitigation options.

The Carbon Positive Project supported the delivery of a demonstration project to retrofit 42 operational assets with low energy use with micro solar, summary information per project is shown in Table 59 below.

Table 59: Indicative micro solar installation figures (average per unit retrofitted and for 42 units installed) (NRW sourced information)

	Capital Cost	Project lifetime	Annual Estimated Generation (kWh)	Annual carbon saving (tCO_2e)	Lifetime carbon saving (tCO_2e)	Estimated Annual cost saving (£)
Per unit retrofitted	£2,048.57	10 years	57	0.022	0.22	£6

	Capital Cost	Project lifetime	Annual Estimated Generation (kWh)	Annual carbon saving (tCO_2e)	Lifetime carbon saving (tCO_2e)	Estimated Annual cost saving (£)
Total for 42 units	£70,900	10 years	2394	0.92	9.24	£252

Small and micro hydro
The smaller scale of hydro generation tends to focus on in-river installations or lower head flows as the resource to drive the small turbine. This scale is generally enough to power a household and so many devices target the domestic market. Compared to solar and wind, micro / pico hydro is a far less developed technology. This is perhaps related to the locational restrictions to access hydro resource or bespoke nature of the need for hydropower at very small scale.

For the purposes of this microgeneration section, definitions of smaller scale hydro[159] are as follows:

Pico hydro = up to 5kW
Micro hydro = 5 kW–25 kW

Despite this lesser scale of development, a number of turbines can be found that provide power in this range. As with larger scale devices, the main factors to consider for hydro are head and flow rate. If a suitable resource exists with regards to both parameters, even at the smaller scale, hydro can be a well-matched solution in terms of generation yield and consistent power output.

Where NRW's small-scale (i.e. <5 kW) power requirements are concerned, a selection of pico hydro generators available on the market are outlined in Table 60 below.

Table 60: Examples of small and micro hydro turbines

Small and Micro/Pico Hydro Turbines	Specification	Cost[160]
PowerSpout Turgo 1.3 kW Turbine http://www.aurorapower.net/products/categoryid/4/list/1/level/a/productid/292.aspx	1.3 kW Designed for 12/24/48V batteries Two-year warranty (Available in US)	£1,470

[159] See Renewables First mini vs small hydro definitions: https://www.renewablesfirst.co.uk/hydropower/hydropower-learning-centre/what-is-the-difference-between-micro-mini-and-small-hydro/
[160] Indicative costs only; detailed costs including shipping to specific locations and taxes would need to be obtained directly.

PowerSpout Low Head Turbine http://www.aurorapower.net/products/categoryid/4/list/1/level/a/productid/242.aspx	200 W-1.5 kW 80-400V DC Two-year warranty (Available in US)	**£1,545**
HiPower Micro Hydro Turbine Range http://www.hipowerhydro.com/price_list.html	2–4 kW 240V Two-year warranty (Available in US)	**£6,180**

Figure 6: Examples of PowerSpout pico hydro turbines

With regards to installing micro / pico hydro on some of the hydrometric sites (e.g. river level / gauging stations), many of NRW's hydrometric sites are on leased land, which may preclude any developments. In addition to this, there are potentially some risks around impact to flow measurement accuracy. Any next steps to progress micro / pico hydro opportunities should include engagement with relevant NRW specialists and an assessment of which sites are used for flow measurement.

Understanding opportunities for bulk deployment

Using the outputs of the microgeneration product market review (see above), an average of the product costs was used to inform an indicative £ / kW cost benchmark for each technology.

For micro wind opportunities specifically, the two VAWT products listed above were not included in this average price, due to the disproportionately high cost when compared to traditional HAWT models. NRW could consider VAWT models if there was a particularly sensitive site, from a noise or visual impact perspective.

For micro solar PV, BEIS Solar PV cost data[161] was used to wholly inform the cost benchmark. The costs benchmarks were then used to inform an indicative capital cost for each of NRW's <5 kW technology opportunities.

For micro wind and hydro, an allowance for additional assumed MEICA (mechanical, electrical, instrumentation, control and automation) costs for installation of 10% was added; this was an indicative value sourced from industry experience and contacts.

From reviewing some of the small and micro scale technologies on the market and the analysis of NRW's site demand, an overview of the potential opportunities that could be considered as a bulk programme of small / micro scale installations is detailed in Table 61.

4.3.5.4 Emission reduction potential

If all 305 identified opportunities were installed, this would yield an emissions saving of 224 tCO_2e per year.

This saving is achieved through the reduction in use of grid electricity. The 305 opportunities have an estimated total capacity of 320 kW, which could generate an estimated 589 MWh annually; offsetting the requirement to use 589 MWh of grid electricity.

4.3.5.5 Cost

If all 305 identified opportunities were installed, the estimated capital cost is £570,432.

The installations are predicted to generate an estimated cost saving of £61,848 through a combination of cost savings from reduced use of grid electricity (import offset) and any feed-in tariff (FIT) payments where appropriate.[162]

4.3.5.6 Scale of adoption

NRW has 305 operational assets with an average annual electricity demand of less than 5 kW. Therefore, 305 (assets) is considered to be the maximum scale of adoption for microgeneration renewable energy technologies in NRW.

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[161] https://www.gov.uk/government/statistics/solar-pv-cost-data

[162] Annual FIT income was calculated using the annual kWh generation values outlined for each of the site opportunities and multiplied this by the relevant p / kWh FIT rates published by Ofgem, available online: https://www.ofgem.gov.uk/environmental-programmes/fit/fit-tariff-rates. As the timescale of the potential to deploy any of the identified project opportunities is currently uncertain, the analysis is based on the published rates for July–September 2018 as an indicative date.

As the assessment has demonstrated potential (at a high-level review) to implement renewable energy generation at all 305 sites, the feasible and theoretical maximum has been set as the same – all 305 opportunities – subject to feasibility following site specific surveys. Further investigation of opportunities may see the maxima reduce or could highlight the potential for a staged approach to delivery on the ground. This gives a potential carbon saving of 224 tCO_2e per year at a capital cost of £570,432.

4.3.5.7 Assumptions

See 4.3.3.7 Assumptions.

Feasible Maximum and Theoretical Maximum
As the assessment has demonstrated potential (at a high level review) to implement renewable energy generation at all 305 sites, the feasible and theoretical maximum has been set as the same – all 305 opportunities – subject to feasibility following site specific surveys. Further investigation of opportunities may see the maxima reduce or could highlight the potential for a staged approach to delivery on the ground. This gives a potential carbon saving of 224 tCO_2e per year at a capital cost of £570,432.

4.3.5.8 Lessons learnt

See 4.3.3.8 Lessons learnt.

4.3.5.9 Summary of mitigation measures for installations on NRW operational assets

Table 61: Overview of the potential opportunities that could be considered as a bulk programme of small / micro scale installations

High level technology option	NRW site category	NRW small site types[163]	Number	Estimated Capital Costs	Estimated Annual Generation (MWh)	Estimated Annual Carbon Savings (tCO_2e)	Estimated Annual Cost Savings
Small-scale solar	Buildings	Offices Depots / training centres Workshops Visitor centre	55	£143,375	78	28.7	£8,198
	Pumping stations	Pumping stations	18	£53,650	29	10.8	£3,068
Small-scale solar + Small-scale battery	Other operational sites	Other operational sites (e.g. telemetry stations, remote sites, VHF radios)	27	£115,000	46	18	£4,866
Micro wind turbine	Other operational sites	CCTV sites Flood warning sites Gauging stations[164] Rain gauges River level station Sluice / tidal gates Toilet blocks	188	£221,117	337	129	£35,599
Micro hydro turbine	Other operational sites	Fish hatchery Flood storage area Other operational sites (e.g. River outfalls, weir monitors, water treatment works)	15	£35,760	96	37	£10,118
TOTALS			**305**	**£570,432**	**589**	**225**	**£61,848**

[163] The naming convention for NRW assets in this table and the report represents the name used on electricity bills. Any future feasibility study should seek to review and rename categories of sites where appropriate.
[164] To note, gauging stations tend to have small working areas, which likely precludes micro-hydro.

The table is grouped by high-level technology options and shows the potential number, costs, generation, carbon and cost savings for implementing small / micro scale renewable energy technologies onto NRW assets which have an average annual demand of less than 5 kW.

4.3.5.10 Benefits beyond greenhouse gas savings

See 4.3.3.9 Wider benefits of renewable energy generation.

4.3.5.11 Examples of successful adoption

Retrofit installation of solar PV at 43 of NRW's hydrometry and telemetry assets as part of the Carbon Positive Project's Appendix A7 (Section 8.1).

NRW has also already deployed a variety of micro-scale generation assets at a number of sites. For example, NRW's North and Mid Operations directorate has deployed micro-scale generation (predominantly solar PV) at 76 sites (including river level stations and pumping stations).

United Utilities has generated over 18% of its electricity requirements from renewables largely from self-supply solar energy on its assets.

4.3.5.12 Technical considerations

For microgeneration opportunities, the next steps, where appropriate, may include:

- Refining the electricity bill data to confirm ownership of each asset, ratifying with NRW databases of assets (e.g. AMX) and that the electricity use is correct.
- Identifying sites where renewable technologies have already been installed, including where installations may be due an upgrade shortly.
- A feasibility assessment by Operations staff to confirm the opportunities highlighted in this study and to identify any additional requirements for installations.
- Confirming ownership of any surrounding land required for development.
- Development of a bulk-buy and installation strategy across the Operations directorate to take advantage of cost and labour savings.
- A feasibility assessment for the potential benefits of installing battery storage alongside the renewable technologies.

4.4 Procurement

4.4.1 Introduction

NRW's net carbon status calculation has shown that GHG emissions associated with purchased goods and services are much greater than those arising directly from the use of our buildings and fleet, as is frequently the case in organisational carbon footprints (Clear About Carbon, 2012; GHG Protocol, 2012). Supply chain emissions associated with goods and services purchased by NRW were estimated to be 22,667 tCO_2e in the baseline year (55% of the organisation's overall emissions), and therefore represent a priority area for mitigation to improve the organisation's net carbon status. The scale of these emissions, coupled with their dispersed nature across multiple locations, organisations and processes, along with a lack of direct control, presents a challenge for delivering mitigation. Despite the challenges, NRW can influence supply chain emissions through its procurement procedures. Carbon-conscious procurement has the potential to influence both indirect supply chain emissions, e.g. through working with suppliers, and the organisations' direct emissions, e.g. through the selection of equipment that is more energy efficient in use.

Unlike the majority of mitigation opportunities identified within the buildings, transport, land and operational assets categories, procurement mitigation measures are typically not technology led. Instead, they principally rely on incorporating low-carbon criteria into procurement procedures, and to be most effective, also involve working with individual suppliers or groups of suppliers (e.g. on a framework) to influence their own mitigation actions. Due to these differences, this section of the report is not structured under the same headings as the buildings, transport, and land and operational assets sections. Instead, it identifies:

- NRW's procurement emissions hotspots as a starting point to focus emission mitigation efforts.
- Key concepts and approaches for tackling procurement-related emissions.
- Case studies[165] on their practical application to some NRW emissions hotspots categories.
- Mechanisms for delivery of measures.
- Strategic mitigation actions for NRW.

4.4.2 NRW's procurement emissions hotspots

The starting point in addressing organisational procurement emissions is to identify which purchased goods and services have the greatest embodied GHG emissions (Clear About Carbon, 2012). NRW's net carbon status calculation included a high-level analysis of emissions associated with NRW's spend on goods and services, based on industry average emission factors for 75 categories of goods and services. Although these broad emission categories introduce a high level of uncertainty to

[165] These were delivered as Demonstration Projects as part of the wider Carbon Positive Project to showcase potential mitigation measures available to NRW. Further information can be found in the Carbon Positive Project Demonstration Project Case Study documents available on our webpages.

emissions estimates, the differences in the magnitude of estimated emissions for different categories of goods and service highlight emission hotspots, upon which mitigation efforts can initially be focused.

The technical report on NRW's net carbon status details the breakdown of NRW's total procurement-related emissions by grouped categories of goods and services, as shown in Table 62: Detailed breakdown of emissions associated with goods and services purchased by NRW (scope 3, category 1). The largest contributing broad procurement categories are:

- Work carried out by contractors (35.0%[166] (7,942 tCO_2e))
- ICT related (17.8% (4,042 tCO_2e))
- Service level agreements and reservoir operating agreements (13.8% (3,118 tCO_2e))
- Materials (12.8% (2,896 tCO_2e))

Identifying hotspots by broad product groupings can mask significant individual contributions from sub-categories, account or product codes. To explore this, the top five sub-categories (or categories where they did not contain sub-categories) contributing to emissions (highlighted in **bold** in Table 62) were broken down where possible by account and product codes. Table 63 shows the top ten account and product codes contributing to GHG emissions. It was not possible to disaggregate every broad grouping further into sub-categories, account codes or product codes as this level of detail was not always needed / used in the spend analysis of emissions. Because of this there remains an element of grouping bias in hotspot identification, which is a limitation of the approach. However, in considering both tables, some consistent hotspots can be seen, upon which efforts could be targeted, regardless of groupings used for reporting. These are:

- Service level agreements (SLAs), i.e. services provided by other agencies like Environment Agency and Forest Research and reservoir operating agreements (ROAs) (NRW account codes 21021 – reservoir operating agreements and 21022 – service level agreements). We do not currently have any further information on the contributions of different types of agreement within this. Further research internally into the types of service provided in this category would help to identify opportunities to include emission reduction criteria in the high-level agreements and/or in individual contract specifications.

- Forestry-related contractors (in particular, account codes 21009 – direct programme harvesting felling contractors; 21016 – forest road contractors; 21012 – restocking preparation contractors). Based on the results of the spend analysis for forestry contractors, we conducted a case study to improve emissions estimates from all forestry activities, see Appendix A.4: Refining emissions estimated for the forestry operations supply chain under Section 8.1 for a summary of the work and possible next steps for mitigation.

[166] As a percentage of the total emissions associated with the procurement of goods and services in NRW (i.e. Greenhouse Gas Protocol scope 3, category 1 emissions).

- ICT contractor and consultant services (in particular, product code 21017-0001 – ICT contractors). Further work with ICT and procurement colleagues would help to better understand the breakdown of emissions in this area and opportunities for mitigation through procurement procedures.

- Flood asset delivery (product code 21017-0003 framework – Water and Environment Management: lot 4 asset delivery[167]). Based on the spend analysis results for flood asset delivery projects, i.e. the design and build of NRW's flood schemes, we have worked with our Projects Delivery Team to re-introduce the Environment Agency's carbon planning tool for use by contractors employed through our Civil Engineering Framework Agreement (CEFA) (which has replaced the previous framework mentioned in this product code description). See Appendix A8 (Section 8.1) for a case study on how this requirement is being incorporated into procurement procedures for these projects.

- Engineering contractors (product code 21007-0017 – generic (non-contract) – engineering contractors). Further work with procurement and operational colleagues would help to better understand the breakdown of emissions and opportunities for mitigation through the procurement process. It is possible that the use of the carbon planning tool (identified above) could be extended to other areas of engineering work in future, beyond the CEFA framework, e.g. within our forest operations engineering works.

- Fleet purchase hire and maintenance (in particular 23008-0004 – plant hire). Further work with fleet and procurement colleagues would help to better understand the breakdown of emissions and opportunities for mitigation through procurement procedures.

Table 62: Detailed breakdown of emissions associated with goods and services purchased by NRW (scope 3, category 1).

Please note, this excludes some emissions associated with purchased goods and services that are reported under other scope three categories under the GHG Protocol (see the NRW technical report on calculating our net carbon status for details (NRW, 2018)).

Category of goods or services	Associated GHG emissions (t CO_2e)
Contractors and services	7941.60
Contractors and services – Forest harvesting	**2474.45**
Contractors and services – Engineering	**1676.25**
Contractors and services – Flood asset delivery	1379.39
Contractors and services – Forest restocking	781.43
Contractors and services – Forest road contractors	662.20
Contractors and services – Maintenance work, e.g. fencing, vegetation clearance	365.65

[167] This framework is now known in NRW as the Civil Engineering Framework Agreement (CEFA).

Category of goods or services	Associated GHG emissions (t CO_2e)
Contractors and services – Other contractors e.g. pollution clean up	318.50
Contractors and services – Survey work, e.g. tree health, aerial surveys	81.52
Contractors and services – Flood-related services, e.g. dredging	76.12
Contractors and services – Wildlife and conservation	65.17
Contractors and services – Forest thinning	50.63
Contractors and services – Marine services	10.30
ICT	4042.07
ICT – Contractor and consultant services	**2365.05**
ICT – Hardware, software and peripherals	1044.58
ICT – Telecommunications	531.22
ICT – Data services and licences	101.22
Service level agreements and reservoir operating agreements	**3118.06**
Materials	2895.79
Materials – Construction	968.50
Materials – Chemicals, gases, paints and lab supplies	765.45
Materials – Livestock, fish and vegetation related	426.46
Materials – Visitor-related	368.25
Materials – Equipment maintenance and components	235.75
Materials – Monitoring equipment	95.45
Materials – Promotion, exhibition materials and signage	35.92
Fleet purchase, hire and maintenance	**1466.54**
Facilities management, office equipment and land agent fees	840.41
Land management and related consultants	539.31
Land management and related consultants – Surveying, design, engineering and construction	257.29
Land management and related consultants – Environmental services	154.31
Land management and related consultants – Other land management consultants	80.95
Land management and related consultants – Landscape, species and fisheries	46.76
Other consultants	450.41
Other consultants – Other, e.g. engagement and accreditation	435.11
Other consultants – Economic and management consultants	14.58
Other consultants – Facilities management	0.49
Other consultants – People services, e.g. health and pensions	0.24
Temp agency staff	334.89
Accommodation, subsistence and events	301.61
Advertising, marketing and translation services	180.56
Bank, audit and legal fees	174.73

Category of goods or services	Associated GHG emissions (t CO_2e)
Training, conference and professional body fees	141.74
Protective and corporate clothing	94.58
Other payments including licences	47.18
Health services (eye tests, DSE, etc.)	42.53
Insurance and repairs	41.13
Pension services	9.85
Water supply	4.26
Total	**22667.26**

Table 63: The top ten NRW account and product codes contributing GHG emissions in the spend analysis of purchased goods and services.

It was not possible to disaggregate every broad grouping further into account codes or product codes as this level of detail was not always needed / used in the spend analysis of emissions.

NRW Code Description[168]	Account or Product Code	Associated GHG emissions (t CO_2e)
Service level agreements and reservoir operating agreements	21021 and 21022	3118.06
Direct Programme Harvesting Felling Contractor	21009	2196.97
Contractors (other) – ICT Contractors	21017-0001	2148.83
Contractors (other) Framework – Water and Environment Management[4]: lot 4 asset delivery	21017-0003	1379.39
Contractors (other) Generic (non-contract) – Engineering Contractors	21017-0017	1211.01
Forest Roads Contractors	21016	662.20
Fleet Service and Repairs	23001	545.07
Restocking Preparation Contractors	21012	502.70
Plant Hire Framework – Low Loader and Lorry Hire & Sourcing of Aggregates: lot 3	23008-0004	479.55
Consultants Accreditation Services (not training)	21018-0001	431.01

4.4.3 Broad interventions available to tackle procurement related emissions

Having identified high-level emissions hotspots, the next steps are to understand which activities associated with each product or service contribute the greatest

[168] Correct as of 2015/16 financial year.

emissions, and to understand available options to try to reduce emissions through procurement. The Clear About Carbon project (2012)[169] identified a hierarchy of procurement interventions to reduce an organisation's direct and indirect emissions:

- **Reducing demand** – reducing the quantity of goods and services consumed by challenging the need for purchases and tackling inefficiencies. Existing NRW procurement guidance for staff challenges the business need for the purchase as a first step in the process of planning a purchase. This should possibly be strengthened from the carbon perspective to encourage staff to ask themselves whether demand could be reduced through tackling inefficiencies, which is particularly relevant to repeat purchases, e.g. staff are being encouraged to use secure print to reduce printer paper waste associated with uncollected print outs, reducing the need to purchase paper. Procurement guidance should be strengthened to encourage staff purchasing goods and services to speak to Environmental Management System (EMS) colleagues to tackle identified inefficiencies through behavioural change measures and decrease the procurement need.

- **Reducing in-use emissions** – reducing the energy use of equipment through procuring more efficient units. This is relevant to all energy-using equipment purchased by the organisation, from the bulk buy of computer monitors to one-off purchases of large pieces of plant machinery. This can be achieved through explicitly including energy efficiency criteria in technical specifications in tenders that are regularly reviewed and amended to reflect technological advances in energy efficiency and the latest standards. These specifications should also be applied to equipment supplied and installed by contractors, e.g. light fittings installed by our building maintenance contractor. The extent to which emission reductions can be achieved will vary between categories of products, for example NRW is already purchasing Energy Star labelled computer monitors and has an environmental objective for new cars purchased to emit less than 100g CO_2 / km.

  The task of **reducing in-use emissions** through procurement procedures is facilitated by the wealth of existing documentation on this topic and existing energy efficiency standards and labelling schemes, such as the Energy Star labelling of energy efficient office equipment, which is supported by databases of energy-efficient models and specifications (EU Energy Star, undated).[170] Purchasing products that meet existing labelling and standard requirements simplifies procurement procedures to reduce in-use emissions, through avoiding the need to define award criteria, contract clauses, etc. in relation to technical specifications (Baron, 2016). NRW's procurement guidance should

[169] Clear About Carbon was a project to improve knowledge and skills for carbon mitigation in the public and private sectors in Cornwall, with a focus on procurement. As part of the Department for Environment Food and Rural Affairs National Sustainable Public Procurement Programme the project published some carbon literacy resources to mainstream and disseminate their approach and learning at the national level.

[170] Other useful resources include the Topten website (Topten International Group, 2017), detailing the most energy efficient equipment on the market in Europe, providing procurement guidelines and even technical specifications that can be inserted directly into tender documents. Also, the Sustainable Procurement Platform, which provides reference materials including a compilation of low carbon-procurement tender documents (ICLEI – Local Governments for Sustainability, undated), and the European Commission Green Public Procurement good practice case studies and toolkit (EC, 2017).

be used to lead the way on encouraging teams and directorates to regularly review energy-related technical specifications for equipment purchases. NRW's existing whole-life costing approach to estimating the cost of purchases in procurement should facilitate the move to more energy-efficient equipment, which may have higher up-front costs than less efficient models, compensated for by operational cost savings through reduced energy use.

- **Substitution and innovation** – purchasing an equivalent or innovative alternative product or service with lower associated emissions. This could be relevant to a multitude of NRW purchases. One example already instigated by the Project and NRW's Facilities Team is the move of our electricity supplies to a 100% renewable supply with a single provider. This was achieved in tandem with a range of other Welsh public sector organisations, through a National Procurement Service Framework. The primary mechanism for encouraging substitution and innovation in procurement procedures is to include carbon-related criteria into the quality criteria in tender documents, with a high associated weighting applied in the evaluation process (i.e. moving away from assessment based primarily on cost at the point of procurement). Procurement guidance should encourage staff purchasing goods and services to consider whether there are lower emissions alternatives available. Suppliers should also be encouraged in tender documents to suggest lower emissions alternative approaches or products in their tender responses.

- **Supply chain management** – influencing and working with suppliers to alter their practices and reduce their GHG impact in supplying the products or services. The Greenhouse Gas Protocol guidelines (Bhatia et al., 2011) suggests partnering with suppliers to achieve emission reductions in the supply chain. This is based on encouraging suppliers to collect raw data on their own emissions, developing GHG estimates for their organisation, products or services. This would allow joint working between NRW and the supplier on priority areas of the supply chain for emission reductions. However, the time and resources required for this approach may be prohibitive; working to reduce emissions associated with groups of products with common characteristics may be more practical (Holme*s* et al., 2010). This may be more feasible for NRW given the variety and number of suppliers used. Further work to disaggregate hotspot spend would be needed to identify suppliers or groups of suppliers for NRW to engage with to achieve emission reductions. NRW may not currently have the procurement staff resource considered necessary to work actively with suppliers in this way; however, reprioritisation or allocation of staff time would help to progress the objective of supply chain management for effective GHG mitigation. As with substitution and innovation, supply chain emissions should be influenced through the inclusion of carbon-related quality criteria in tender documents, with a high associated weighting applied in the evaluation process. Existing examples in procurement guidance available to staff include suggested sustainability criteria asking tenderers to provide details of how they minimise packaging, how their products are environmentally friendly, etc. These can be tailored for individual purchases and should be targeted at tackling the highest carbon areas of the supply chain of a product or service. Through gateway or quality criteria, or possibly special conditions of contract, there is an opportunity to require suppliers to estimate the carbon impact of their goods and services. Examples could include the addition of gateway criteria asking whether an organisation has an accredited Environmental Management System, which includes a corporate carbon footprint, or a special condition asking ICT consultants to fill in a spreadsheet calculating the transport emissions associated with the service provided to NRW.

4.4.4 Understanding NRW procurement procedures

Applying this hierarchy of procurement interventions to NRW purchases of specific goods and services requires an understanding of the available mechanisms for delivery within existing procurement procedures, and a capacity to assess carbon criteria in returned tender documents. Figure 7 illustrates the procurement structure within which NRW operates. At the Wales level, the National Procurement Service (NPS) sets up frameworks for Welsh Public Sector procurement for common categories of spend. Similarly, the UK Crown Commercial Service (CCS) provides common frameworks for public sector procurement at the UK level. NRW also has its own frameworks, which allow for more efficient procurement of frequently purchased goods and services. Existing frameworks provide agreed terms and conditions with suppliers or groups of suppliers, for specific categories of goods or services, avoiding the need for a full tendering process. Within NRW procurement guidance, the use of NPS frameworks is mandatory where a relevant framework exists, and the use of NRW frameworks is mandatory where relevant in the absence of an NPS framework. Use of CCS frameworks is advised in the absence of either. Where no suitable framework is available, goods are procured through open competition based on individual contracts and the complexity of the tendering process is proportionate to the value of the purchase (as shown in Figure 7).

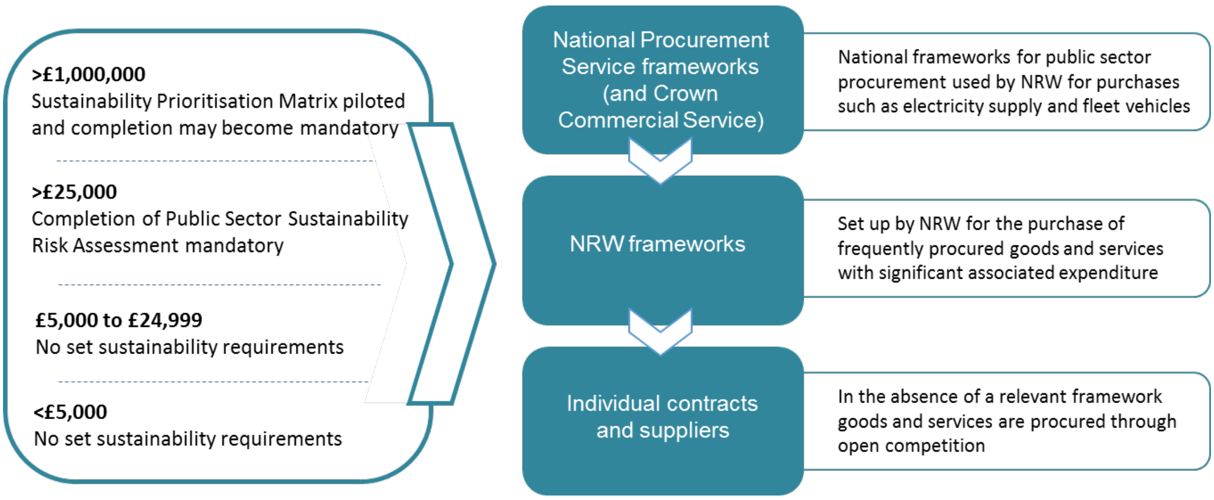

Figure 7: The current procurement structure in which NRW operates, including procurement thresholds and existing sustainability requirements

Figure 7 also shows current sustainability requirements applicable within each NRW procurement band. Currently, there are no set sustainability requirements for purchases up to £24,999 in value and setting environmental quality criteria is discretionary. It is mandatory that the Public Sector Sustainability Risk Assessment (SRA) is completed for all purchases over £25,000 in value. An SRA is completed by the purchaser (NRW staff) with input from procurement and possibly EMS Teams, and identifies, amongst others, key environmental impacts of the goods or services being procured. For key issues identified, some possible actions to address them are suggested, which should then be used to inform contract specifications and evaluation criteria. Possible issues such as energy use and travel are highlighted in the SRA with some specific actions related to GHG impacts suggested, e.g. where travel is identified as a significant sustainability risk as part of a contract, suggested actions include ensuring the provider has a sustainable travel plan or requiring the service provider to carbon offset all travel. However, there is some evidence that the SRA is currently only loosely integrated into Welsh public sector procurement and is possibly in danger of becoming a stand-alone tick-box activity (Walker et al., 2016); consequently its efficacy in reducing emissions may be limited. The SRA does not include GHG emissions as a specific high-level impact category for consideration. This suggests there is significant potential to improve the consideration of carbon in purchases over £25,000 in value.

A Sustainability Prioritisation Matrix (SPM)[171] has been piloted on contracts over £1 million in value, and its introduction as a mandatory requirement is currently being considered by our Procurement Team. The SPM is used to identify individual activities that will be undertaken within the contract and assess the environmental and socio-economic impact of each against set impact categories including carbon. This process highlights the expected areas of greatest environmental and socio-economic impacts within the contract, and is used to inform the inclusion of specific mitigation actions as criteria within the contract specification.

Expanding and embedding the approach of inserting targeted criteria as requirements into procurement procedures is needed to tackle GHG emissions arising in our supply chain. For individual contracts, there is potential to insert more generic carbon criteria for any value of purchase, although requirements need to be proportionate to the level of spend, for example:

- for purchases under £5,000, there is potential to include a carbon requirement when approaching a supplier for a quote.

- for purchases between £5,000 and £24,999, carbon criteria can be inserted into the invitation to quote and weighted appropriately in the evaluation criteria.

- for purchases over £25,000, carbon criteria can be inserted into tender documents and appropriately weighted in evaluation criteria.

- Similarly, for larger spends through frameworks, requirements can be included in the technical questions posed to suppliers in the sustainability section of tender documents for new NRW frameworks, and possibly appended to

[171] The Sustainability Prioritisation Matrix is largely based on the Department for Environment, Food and Rural Affairs' Sustainable Procurement Prioritisation Tool (DEFRA, 2012), which was developed to identify priority product categories on which to focus time and resources to embed sustainable procurement within organisations.

existing frameworks (see carbon planning tool example in Appendix A.8: Trialling a carbon planning tool to reduce contractor emissions in flood defence construction projects: https://cdn.naturalresources.wales/media/685956/case-study-1-carbon-planning-tool.pdf, which is a requirement on contractors in the NRW Civil Engineering Framework Agreement (CEFA)).

4.4.5 Tackling NRW procurement emissions

By taking a hotspots approach to address emissions, NRW will need to develop tailored and targeted carbon criteria for key frameworks and types of contracts to effect reductions. Although time and resource intensive, this approach will provide the knowledge and experience necessary to expand carbon consideration into procurement procedures more widely, possibly developing lists of priority criteria for types of contract, e.g. criteria aimed at tackling travel-related emissions which are likely to be a commonality in areas such as ICT contractor services and building maintenance contracts. It is possible that the SPM could be simplified to fulfil this function – identifying individual activities within the contract or framework likely to have the greatest emissions impact and potential mitigation opportunities that could be included as criteria within the contract specification.

Other public bodies following a hotspots or targeted approach to tackling procurement-related emissions include the NHS, Highways England and Environment Agency. The NHS Sustainable Development Strategy for 2013–2016 included an action to reduce embedded carbon associated with their five key emissions hotspots in their supply chain, through working with suppliers (NHS, 2013). Highways England requires all suppliers delivering maintenance and improvement work on the network to complete a carbon tool quarterly to allow them to monitor and manage their supply chain emissions (Highways England, 2015). The tool is a single spreadsheet which collates information on the use of ten categories of materials and services in the contract, including construction materials, energy use and transport. Using a similar carbon planning tool requirement for contractors, the Environment Agency is achieving emission savings of over 40% per project in the construction of flood defences.

An alternative or complementary approach to inserting tailored criteria into tenders and frameworks, or groups of tenders and frameworks, is to introduce common, top-down guidance and policy on carbon emissions across an organisation's purchasing portfolio. For example, the communications service company BT has a target to reduce its carbon footprint by 80% by 2020 from 1996 levels. As part of this aim, the company developed its own Climate Change Standard for procurement in 2011, which, as a minimum, requires all BT suppliers to: have a policy to address climate change; actively measure and report their GHG emissions; set targets to reduce emissions and report on progress; and drive similar engagement with their own suppliers (BT, 2017). Prior to the introduction of the standard, BT held carbon reduction workshops for suppliers. For NRW, introducing a set of generic top-down low-carbon requirements, coupled with some tailored bottom-up criteria in the frameworks and contracts of hotspot purchases, would make significant inroads to address NRW's procurement related emissions. It is likely that the introduction of a high-level carbon procurement policy would need to be implemented incrementally to allow smaller suppliers to adapt over a period of time to any requirements.

Introducing carbon requirements into tendering processes can sometimes be considered challenging from the perspective of ensuring fair and open competition, with a possible risk of hindering competition (Baron, 2016). However, the existing procurement structure and policies within which NRW operates already facilitate carbon-conscious procurement in many cases and could be further utilised to improve it:

- NRW's procurement policy for 2016/17 requires whole-life costing of goods and services, including operating costs. Examples of operating costs that can be accounted for include energy consumption and environmental costs such as GHGs and climate change mitigation costs. The ability to monetise environmental costs in this way could allow GHG impacts to be considered alongside cost attributes in the tendering and awarding process. Whole-life costing also facilitates the purchase of energy efficient equipment.

- Procurement guidance for staff includes examples of suggested questions for inclusion in the invitation to quote for purchases under £25,000 in value, which could feasibly be built upon or used as a template for more carbon specific criteria. Examples include pass / fail criteria on whether the supplier has a certified Environmental Management System, and sustainability-related quality criteria, such as whether the supplier has an environmental policy statement and commitment to improvement.

- Procurement guidance for staff includes suggested key performance measures for monitoring performance against the specification during the contract, which include environmental measures such as carbon reduction.

- The mandatory SRA for purchases over £25,000 in value encourages the inclusion of demanding "push the boundary" actions in tender documents to address key identified lifecycle impact of the contract.

- Favouring energy-efficient equipment in procurement procedures is a well-established practice and considerable guidance exists on this topic, including the European Commission's Green Public Procurement Toolkit, which includes a legal module on how and where environmental criteria can be integrated into public procurement (European Commission, 2016).

- Market dialogue with potential suppliers prior to going out to tender can help gauge the capacity of the market to deliver on requirements (Baron, 2016). NRW procurement guidance encourages the use of pre-market engagement where appropriate and could help to pitch carbon criteria inclusion within frameworks or groups of contract types.

- Similarly, supplier training days and workshops are currently used to help suppliers meet NRW requirements and could be a useful tool to help suppliers deliver on any carbon requirements added to frameworks.

NRW also has the potential to increase the sustainability of its procurement through innovative contract design, for example purchasing services rather than products where appropriate (known as product-service systems). This type of contract, e.g. purchasing lighting as a service rather than light bulb products, means that the supplier retains ownership of more of the product lifecycle and therefore has an incentive to increase product quality and durability (United Nations Environment Programme (UNEP), 2015), providing a solution that won't need servicing or replacing as often. This type of contract can promote closed-loop procurement whereby the supplier takes back and re-uses or recycles the used product, reducing demand for raw materials. As an organisation, we should seek to identify contract and product types where this model may increase whole-life sustainability of products and reduce associated emissions. Common product examples for which closed-loop procurement is used include carpeting, textiles and ICT equipment (UNEP et al., 2011).

4.4.5.1 Existing NRW case studies on tackling procurement related emissions

The Carbon Positive Project has delivered two procurement demonstration projects to deliver action on some identified emission hotspots areas.

4.4.5.2 Carbon planning tool case study

We have been working with our Projects Delivery and Procurement Teams to re-introduce the use of the Environment Agency's carbon planning tool "ERIC" into NRW for the design and build of flood defence schemes. The Environment Agency and their contractors are achieving over 40% emission reductions against baseline designs using the tool for major flood defence schemes.

The tool consists of two components: a carbon modelling tool (CMT), which is a simple spreadsheet providing high-level estimates of the carbon impacts of different asset design options to inform design selection, and a carbon calculator (CC) which is a detailed bottom-up spreadsheet recording the energy, transport and material carbon impacts of the construction process to drive reductions against the baseline design. Design consultants are employed through an NPS framework, therefore in the short term a requirement for consultants to complete the CMT for asset design options will be included in the scope for work. In the longer term, NRW may seek to influence the NPS framework to include this requirement, providing a stronger impetus for suppliers and extending the positive influence to other organisations using the framework. The production of guidance on the use of CMT, and engagement with suppliers on relevant NRW lots to make them aware of this additional requirement in advance of its introduction, will facilitate the use of the tool by consultants. NRW's Civil Engineering Framework Agreement (CEFA) for construction contractors includes a requirement for the CC to be completed during the delivery phase and submitted to NRW. We are now trialling the use of the tool on larger projects with the aim of applying it to all projects built through the CEFA framework in time.

A number of supporting actions needed for full implementation of the carbon planning tool have been delivered or are underway including: training for Projects Delivery Team project managers in the use of the tool, enabling them in turn to train other team members and support contractors in completing the tool; training for procurement staff to help embed it within procurement; working to develop a governance structure for the use of the tool including how we encourage consideration of CMT results in design selection as part of the business case; and determining who is responsible for ensuring effective use of the CC by contractors to secure carbon reductions. Project managers within our Projects Delivery Team will be working with consultants to ensure new schemes are designed using the CMT, informing the business case for design choice, and with contractors to ensure completion of the CC during and after construction. In the long term, our ambition is to include a requirement for use of the tool by contractors in NRW's Forestry Engineering Framework (if asset types are transferable), and for a simplified version of the tool to be a requirement on NRW's Asset Maintenance Framework for lots relating to engineering related maintenance. It may also be possible to expand the use of the tool to other contracts requiring the use of materials or to develop a similar tool for use on other contract types.

4.4.5.3 Improving emissions estimates for forestry activities case study

Having identified forest harvesting, forest road and forest restocking activities as significant sources of contractor-related emissions through the spend analysis, we carried out a case study to better estimate emissions associated with forestry activities undertaken on the Welsh Government Woodland Estate (WGWE). This approach went beyond the spend-based analysis used to estimate the emissions from our supply chain as part of the net carbon status calculation, to better understand the 'real-world' emissions specific to NRW and target mitigation actions for the organisation. The Carbon Positive Project worked with forestry colleagues to identify a list of forestry activities undertaken either in-house or by contractors on the estate. We developed proxy emission factors for each type of forestry activity using data on machine and material use to deliver the South West Region forestry work programme in the baseline year 2015/16. This was based on records held for the SW Region and interviews with NRW managers and contractors. These proxy emission factors (e.g. tree harvesting emissions per m^3 timber harvested and ground preparation emissions per tree planted) were then applied to the work programme of the whole WGWE for the year to estimate total estate emissions. Total emissions were allocated between NRW, contractors and standing sales based on the proportion of each activity carried out by each.

The results show that timber haulage is the main source of operational emissions on the WGWE, with approximately half arising from haulage by contractors and half from haulage of timber sold standing. Forest civil engineering activities are the second largest source of emissions on the WGWE, primarily from the provision of harvesting facilities, grading roads and aggregate haulage. Over half of all WGWE forestry operational emissions arise from work completed by contractors on NRW's behalf,

demonstrating the importance of utilising procurement frameworks and contracts as a means of influencing the organisation’s indirect, supply chain emissions.
The next steps are to work with forestry colleagues to identify potential mitigation measures, such as use of biofuel in forestry plant (NRW and contractors), strategic logistics using GPS trackers in lorries, and to determine how measures can be integrated as requirements into relevant contracts and frameworks. Supplier engagement may also help to determine possible innovative mitigation measures and how contractors can help to deliver these.

4.4.5.4 Next steps: suggested actions for NRW

A summary of the recommended actions for NRW to reduce procurement-related emissions are:

Table 64: Procurement Mitigation Actions

<table>
<tr><th>Procurement Mitigation Actions</th></tr>
<tr><td>Strengthening existing NRW procurement policy, guidance and procedures to better support the hierarchy of procurement mitigation interventions, through:

Using procurement guidance to encourage staff to ask themselves whether demand for goods or services could be reduced, including through tackling inefficiencies, and speaking to our Environmental Management System colleagues to address any inefficiencies through behavioural change measures.
Using procurement guidance to encourage teams and directorates to regularly review and amend energy-related technical specifications for equipment purchases, to reflect technological advances / latest standards and reduce in-use emissions.
Using procurement guidance to encourage staff to consider whether there are lower emissions alternative goods or services available. This type of substitution could also be supported by encouraging suppliers to suggest lower emissions alternative approaches or products in their tender responses.
Encouraging procurement and other staff to work actively with suppliers to better understand and jointly tackle supply chain emissions in hotspot categories of goods and services. This needs to be supported by further work to disaggregate hotspot spend to identify suppliers or groups of suppliers for engagement.
</td></tr>
<tr><td>Focusing on introducing targeted carbon criteria into key frameworks and contracts associated with emissions hotspots:

Conduct further research into the breakdown of emissions associated with identified hotspots, and identify targeted opportunities for mitigation through the procurement process, in relation to:

The types of service provided through SLAs and ROAs and the opportunities to include emission reduction criteria in the high-level agreements and/or in individual contract specifications.
ICT contractor and consultant services.

</td></tr>
</table>

- Engineering contracts. The opportunity to extend the use of the carbon planning tool into other areas of engineering work (beyond the CEFA framework) should be considered. - Fleet purchase, hire and maintenance. • Progress existing procurement demonstration projects and transfer learning to other frameworks and emissions hotspots: - Continue to trial and roll out use of the CPT for all projects completed through the CEFA framework. In support of this, continue to develop and refine the governance structure and internal processes needed to fully adopt the CPT. - Explore opportunities to expand the use of the CPT in other frameworks or to develop a similar tool for other contract types. - Make use of the results of the forestry emissions case study to steer further work internally and with contractors to identify mitigation opportunities and delivery mechanisms. - Pilot the approach of supplier engagement to manage supply chain emissions with key forestry contractors and transfer learning to other hotspots.
Developing new approaches to help incorporate carbon consideration into contracts and frameworks: • Identify contract and product types for which taking a product-service system approach to procurement (i.e. purchasing services rather than products) could increase the whole life sustainability of products and reduce associated emissions. • Consider developing reference lists of suggested carbon criteria for types of contract to guide staff, e.g. criteria aimed at tackling travel-related emissions which are likely to be a commonality in contractor services. • Explore the potential to develop a tailored version of the existing SPM to support the identification and insertion of carbon criteria into key frameworks and types of contracts. • Make use of pre-market engagement to help us to pitch carbon criteria inclusion within frameworks or groups of contract types initially. • Make use of supplier training days and workshops to help suppliers meet NRW requirements as they are introduced to specific frameworks or types of contracts. • Consider the introduction of a Climate Change Standard for procurement, introducing minimum requirements on GHG emissions across all NRW's procurement. It is likely that this would need to be introduced incrementally, allowing smaller suppliers time to adapt to any requirements. • Provide sustainable procurement training for all staff, e.g. the free online training course "Carbon literacy for procurers" provided by Loreus (undated). This could be incorporated into the existing e-learning programme requirement for all staff.

Table 64: Procurement Mitigation Actions includes several targeted actions for reducing emissions relating to identified emissions hotspots or existing procurement guidelines. Research by the United Nations Environment Programme into the

sustainable procurement practices of 41 national governments highlights that top-down approaches are the strongest drivers for implementation including policy commitment, strong organisational leadership and mandatory rules (UNEP, 2017). Therefore, for emissions mitigation actions to be effectively embedded within procurement processes it is likely that high-level organisational commitment and steer will be needed, either relating specifically to emission reduction or as one element of a wider sustainable procurement commitment. The above list considers emission reductions as a standalone priority; however, it is recognised that our procurement processes are a facilitator to deliver on numerous economic, social and environmental priorities. Sustainable procurement involves balancing these factors, and tools such as the SPM help to achieve this. Several of the suggested actions may be resource intensive and having sufficient numbers of well-trained staff is crucial to deliver sustainable procurement (UNEP, 2017). With a top-down driver for emission reduction, the emphasis will be on all staff to embed and monitor mitigation considerations within their own contracts. Ultimately, sustainable procurement should be achieved incrementally, with the pace of adoption set by the maturity of the supply market, the development of a policy framework, the degree of staff training (including the ability to monitor and evaluate) and the level of organisational commitment (UNEP, 2011).

5. Discussion and conclusions

This report records the approach taken, and the results attained, by the Carbon Positive Project in identifying and evaluating options to mitigate NRW's carbon impact. It provides both part of the evidence base needed for NRW to develop an Enabling Plan to reduce organisational emissions, increase carbon sequestration and protect existing carbon stocks, and a reference, based on practical experience, for other organisations seeking to mitigate their own carbon impact.

5.1 Options to mitigate carbon impact

Based on the results of our net carbon status calculation[172], we identified where to focus efforts to identify measures available to reduce our carbon impact by either reducing carbon emissions or by enhancing sequestration and protecting carbon stocks. There are opportunities to reduce our carbon emissions by consuming less and adopting lower carbon alternatives, both within the organisation and our supply chain, across all four categories: Buildings, Transport, Land and Operational Assets, and Procurement. There are also opportunities to enhance the amount of carbon being stored each year and to protect existing stores of carbon by managing habitats on the estate.

Mitigation measures have been assessed, calculated and reported by category, i.e. Buildings, Transport, Land and Operational Assets and Procurement.

As part of the process of establishing our priorities and their delivery, it is important that we understand the extent of our influence. For example, reducing direct GHG emissions from sources owned or controlled by NRW from fleet fuel use (scope 1) and indirect emissions from the generation of electricity purchased by NRW (scope 2) may well be easiest for us to influence. Although both scopes combined represent less than 12% of our GHG inventory, as they lie within our direct control, they offer the most immediate opportunities for emissions mitigation.

In contrast, the most difficult to influence are those falling under scope 3 emissions, as they lie outside our direct control. However, they also represent the largest proportion of our GHG inventory, i.e. 88.2%. This magnitude highlights the need for NRW to influence its upstream emissions.

The overarching principles of this report comprise:

- Reduction, e.g. reducing the number of vehicles in our fleet, reducing energy wastage in our buildings.
- Energy efficiency, i.e. using energy as efficiently as possible, for example by upgrading lighting and heating systems.

[172] Technical Report: Calculating NRW's Net Carbon Status (2018)

- Generation of renewable energy.
- Enhancing sequestration and protecting carbon stocks.
- Learning from our experience, i.e. from demonstration projects.

A number of challenges and uncertainties may impact on our ability to deliver the identified mitigation measures, including:

- Changes to energy costs.
- The long-term future of individual NRW sites as part of the ongoing Accommodation Review.
- The feasibility of scaling up adoption opportunities.
- Difficulties in comparing mitigation measures, e.g. different measurements for the different categories. However, we have attempted to make them comparable wherever possible.

Continuing the approach taken to evaluate possible mitigation options, results are discussed by category (below).

5.2 Buildings

Electricity emissions are a significant component of scope 1 and 2 emissions.

As explained in our Technical Report: Net Carbon Status (Section 4.5), the review of electricity consumption and supply conducted for scope 2 calculations helped to catalyse an organisational move to a 100% renewable supply for all assets. If Renewable Energy Guarantees of Origin (REGO) certification is supplied, this could mean that an emission factor of zero is applied to all NRW electricity purchased in future scope 2 emission calculations.

However, tariffs may change, and this does not guarantee that the organisation will continue to purchase 100% renewable in future. Opportunities for reducing electricity use through behavioural change, equipment efficiencies and opportunities for generation of renewable energy on site should still be explored as means of reducing scope 2 emissions. These avenues will provide long-term cost saving and energy security benefits, not possible by purchasing renewable energy through the national grid.

Information gathered as part of our demonstration projects was used to ground truth the information on measures, for instance installing LED lighting in offices (see Appendix A1, Section 8.1), solar PV and a new building management system.

Recommended next steps:
Although no formal Recommended next steps were given by the Carbon Trust for the Buildings category as a whole, the next steps we have identified internally is to define the standard we want to achieve for our buildings by 2030 with regards to energy

performance, focussing on our top 20 highest consuming sites. We will then develop a costed pathway for delivery for those buildings.

We will also compile the individual measures recommended by the Carbon Trust for each audited site, which will be transferred to our Facilities Teams to enable their adoption as a broader action plan.

5.3 Transport

As identified in the calculation of NRW's net carbon status[173], the most significant contribution to scope 1 and 2 emissions is fuel combustion in NRW-owned road vehicles and plant. The composition and size of the NRW fleet has altered considerably following the baseline year, with a reduction in the size of the fleet[174] and termination of our leased cars. A shift is expected from scope 3 lease car emissions to scope 1 owned car emissions. Scope 1 and 2 emissions are likely to be easiest for NRW to influence and may offer the most immediate opportunities for emissions mitigation.

Introducing electric vehicles and charging infrastructure into NRW as a demonstration project has shown that staff are willing to take up new technologies such as EVs. Additionally, the exercise raised the profile of the project – and climate change mitigation in general.

As part of the Strategic Fleet Review[175], various scenarios were developed to discover what carbon and cost reductions could be achieved by the whole fleet, whilst continuing to perform operational activities. It was concluded that while a significant proportion of our fleet could become low emission, savings are restricted by the limited decarbonisation options available for high-emitting vehicles. This applies to large vans and 4x4s which, collectively, are the source of 44% of our fleet emissions. For plant vehicles, the high-level review of NRW's plant highlighted that emission savings at similar or better total cost of ownership (TCO) could be available from interventions, such as implementing fuel-efficiency measures and driver training, diesel hybrid excavators in the NRW operations, electric quads, electric mowers (for reservoirs) and biodiesel.

5.3.1 Fleet (non-plant)

A high-level results summary and recommended actions are presented below.

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[173] Technical Report: Calculating NRW's Net Carbon Status (2018), Section 7.2

[174] In 2015/16, the NRW vehicle fleet comprised 899 road vehicles and 204 pool vehicles. By 2016/17, this had been reduced to 432 road vehicles and 193 pool vehicles following a review of the fleet and a strategic decision by the organisation to terminate our lease agreement for cars allocated to specific members of staff

[175] Cenex (December 2017) NRW Strategic Fleet Carbon Review https://cdn.naturalresources.wales/media/687416/eng-evidence-report-278-nrw-carbon-positive-project-nrw-strategic-fleet.pdf

5.3.2 Cars

EVs are a good operational fit in the car fleet, saving around 50% WTW (100% TTW) CO_2 at a lower TCO (cost saving). EVs should be implemented where practical and with the appropriate charging infrastructure. Petrol hybrids can offer improvements in CO_2 at a similar or lower TCO where an EV is not a practical solution (i.e. where longer journeys are required or charging infrastructure cannot be accommodated). An analysis of pool fleet car usage showed that 43% of daily trips are less than 50 miles, and this indicates that a significant proportion of office-based pool vehicles are suitable for transition to EVs.

Charging Infrastructure:

- **Charging at 13 amp** from existing electrical sockets is not a long-term solution for charging due to safety concerns.
- **Appropriate infrastructure** for charging needs to be in place prior to purchasing /integrating EVs.
- **Electrical capacity** at sites should be investigated to ensure they are suitable for installing charging infrastructure and any future implementation of electric vehicles.
- **Groundwork requirements** must be considered.
- **Consideration of payment platforms and back office system requirements** (e.g. 3G requirements, data requirements, etc.) are essential and may require championing from senior management.

Recommended next steps:

- **Review** individual vehicle mileages, preferably through the installation of telemetry systems, and develop an EV replacement strategy supported and informed by trialling of EVs.
- **Investigate** site power capacity / requirements for installation of recharging infrastructure.
- **Analyse** current performance data of three Nissan Leafs introduced into the fleet in May 2017.
- **Trial** petrol hybrids to confirm desk-top study results. Following a successful trial, petrol hybrids should be implemented in the car fleet where EVs are not practical due to range and charging limitations.

5.3.3 Small vans

EVs are a good operational fit to the small van fleet, saving 50% WTW (100% TTW) CO_2 at a similar or better TCO. EVs should be implemented where practical.

Recommended next steps:

- **Review** individual vehicle mileages, preferably through the installation of telemetry systems, and develop an EV replacement strategy supported and informed by trialling of EVs and investigation of site power requirements.

5.3.4 4x4

Reducing carbon from 4x4s is challenging due to very poor availability of low-emission alternatives. A less robust 4x4 drive system is offered through modern All Wheel Drive (AWD) vehicles, which may be suitable for some 4x4 applications. Where this is the case, lower spec diesels, petrols, and plug-in hybrid EVs (PHEVs) all offer emission and TCO benefit.

Recommended next steps:

- **Review** fleet to assess where options to downgrade 4x4s to AWD are available.
- **Consider** biodiesel use (see biodiesel Scenario 3 summary note below).

5.3.5 Large vans

Reducing carbon from large vans is challenging: CNG and electric options are available but significantly increase TCO.

Recommended next steps:

- **Consider** biodiesel use (see biodiesel Scenario 3 summary notes below). Reassess this advice in 12-months as the large EV van market matures and renewable diesel drop-in fuels may start to come to market.

5.3.6 Fleet best practice

In addition to changes in technology, this review also highlighted that downsizing diesel cars can lead to TCO savings of £2,000, and 87 kg (8%) WTW (or 70 kg (8%) TTW) CO_2 per vehicle per annum. Due to capital constraints, NRW leases most fleet vehicles. Significant TCO savings could be available if vehicles were to be switched to an ownership model. Analysis showed that changing to an ownership model for the diesel vehicles (compared to the current lease model) could result in five-year TCO savings per vehicle of £4,912 for small cars (Ford Fiesta), £8,059 for medium cars (Ford Focus), £3,322 for small vans (Citroen Nemo), £8,651 for 4x4s (Mitsubishi Outlander) and £8,160 for large vans (Ford Transit).

Savings are available for alternatively fuelled vehicles: for example, a £2,780 saving for purchasing medium car EVs (Nissan Leaf) rather than leasing, £2,587 for medium car petrol hybrids (Toyota Prius) and £6,264 for small EV vans (Nissan e-NV200).

This could assist in funding low-emission vehicle implementation and infrastructure. Fleet telematics have the ability to reduce fleet CO_2 by around 15%, whilst a simple payback calculation showed that telematics were only economically viable in higher mileage vehicles. For low-mileage vehicles, the annual cost increase per vehicles (£40–£50) is still a worthwhile investment to generate the robust evidence base that telematics systems supply to inform future strategy. Furthermore, the cost analysis did not include costs associated with wider benefits of accident reduction and vehicle maintenance, which are difficult to quantify – case study evidence showed accident rates can drop by around 20–35%. If NRW progresses to a high EV implementation scenario, telematics will be required to assess potential vehicles more accurately.

5.3.7 Implementation scenarios

To demonstrate the effect of the recommended technologies on CO_2 emissions, three implementation scenarios were considered:

- **Scenario 1** – Alternative Vehicle Adoption is a scenario focused on achieving the lowest CO_2 emissions through the implementation of all recommended technologies in the current fleet (where practical). This was based on a business-as-usual scenario (the same number of fleet vehicles and annual mileage).

  It included a blend of:
  - 324 EVs
  - 6 PHEVs
  - 23 petrol hybrids
  - 88 biodiesels
  - 136 diesel vehicles

  This scenario achieved a fleet WTW CO_2 reduction of 26%, a TTW CO_2 reduction of 49% and resulted in a 5% overall TCO saving (around £117,000). Without the biodiesel option, where the select vehicles remain diesel, a fleet WTW CO_2 reduction of 22%, TTW CO_2 reduction of 44% and a similar 5% overall TCO saving are available (a saving of around £136,000 per annum).

- **Scenario 2** – Alternative Vehicle and Efficiency Improvement is a scenario focused on a cost-effective transition to low-emission vehicles and was considered with a reduction in fleet size where a total of 100 vehicles were removed (based on NRW fleet reduction targets – where most reduction is in the 4x4 category), leaving 477 vehicles in the reduced fleet in the scenario. This scenario assumed the same annual mileage overall and so resulted in an increase of the annual mileage of the other vehicles. This is due to higher utilisation of a smaller number of vehicles. Telemetry system uptake was also used in this analysis to give a 15% fuel saving in each vehicle.

  This scenario included a blend of:
  - 301 EVs
  - 23 petrol hybrids
  - 6 plug-in hybrids

- 79 B25 biodiesel

Totalling 409 low-emission vehicles (85% reduced fleet), it achieved a fleet WTW CO_2 reduction of 39%, a TTW CO_2 reduction of 59% and resulted in a 22% overall TCO saving (a saving of around £500,000 per annum). Without the biodiesel option, where the select vehicles remain diesel, a fleet WTW CO2 reduction of 33%, a TTW CO_2 reduction of 52% and a similar overall TCO saving are available (a saving of around £508,000 per annum).

- **Scenario 3** – Biodiesel Based Assessment is a scenario looking in more detail at B25 depot biodiesel implementation. Here, it was shown that between two to six NRW sites potentially have sufficient demand to justify bunkered biodiesel storage. Vehicles that were suitable for electrification were not included in this analysis. Across these sites an increase in costs would be incurred when additional costs of storage tanks, tank cleaning, fuel inspections and vehicle maintenance were considered. Furthermore, NRW would need to consider varied manufacturer support and additional fuel management risks associated with biodiesel blends and increased fleet costs (e.g. associated with maintenance).

  Large mixed fleets that operate biodiesel successfully employ a number of options, including:
  - use biodiesel in vehicles once they are out of the manufacturer warranty,
  - operate at risk invalidating the engine warranty.
  - purchase only compliant and warranted vehicles.

  Fleets which successfully operate with biodiesel require a dedicated champion of the technology to overcome challenges and manage fuel quality. In conclusion, the uptake of 88 B25 biodiesel vehicles would achieve a WTW CO2 reduction of 18%, (23% for TTW) at an additional TCO increase of 4% (an additional cost of around £20,000 per annum) when compared to not converting these 88 vehicles. Implementing biodiesel across these sites would reduce the emissions of the entire fleet by 4%.

5.3.8 Fleet conclusions

The scenarios indicated that a significant proportion of the NRW fleet could become low emission. However, emission savings are currently limited by the fact that high-emitting vehicles (large vans and 4x4s) have limited decarbonisation options.

Recommended next steps:

In order to pursue the carbon savings modelled / estimated within this report, it is recommended that NRW considers the following steps:

- Reduce vehicle numbers in the fleet and install telematics on all vehicles.
- Vehicle number reductions increase the overall annual mileage of individual fleet vehicles which assists the case for technology change.

- Develop a strategy for implementation of low-emission technologies outlined in this study. This must include appropriate charging infrastructure for the number of vehicles proposed for introduction into the fleet, which must be installed prior to commitment to EVs.

- Undertake a telematics technology introduction across the fleet. This is especially important for the 4x4 and large van categories where low carbon options are limited.

- Reassess opportunities in 12 months to consider the maturing supply of large panel van EVs, bioLPG availability, and a renewable diesel fuel, HVO (hydro-treated vegetable oil), which can ‘drop-in’ to forecourt diesel with no effect on manufacturers’ warranties or servicing regimes.

5.3.9 Plant

The scenarios explored showed:

- Electric quad bikes offer a 100% reduction in TTW CO_2 and a 58% saving in WTW CO_2 emissions. The annual cost of power consumption of an all-electric quad bike fleet is £2,950 per year for the entire fleet, which represents a 77% saving in annual fuel costs (circa £550 per annum per bike).

- In a high-uptake scenario of mature technology at a single, hypothetical depot representative of NRW, a fuel consumption saving of 22% can be achieved and WTW CO_2 emissions could reduce by 39%, which is in large part to the adoption of B30 biodiesel.

- A further scenario showed that 80% WTW CO_2 emissions savings through plant machinery by 2050 would be possible through a combination of implementing market-ready technology (from 2017), fuel-efficiency programmes (from 2017), fleet replacement to comply with Stage-V NRMM emission standards (from 2019), and operating a strategy to implement fuel-replacement options, e.g. biodiesel, biomethane, hydrogen, as they become mature technologies.

To maximise CO_2 savings from plant the following strategy is recommended:

- **Step 1** – Undertake detailed technology assessment
The high-level review highlighted that emission savings at similar or better TCO could be available from interventions such as implementing fuel-efficiency measures and driver training, investigating the performance of diesel hybrid excavators in the NRW operations, implementing electric quads, electric mowers (for reservoirs) and the implementation of biodiesel blends into compatible plant machines. All these options should be subject to a more detailed review and trialled where necessary. Part of this detailed review should assess if the utilisation of assets can be increased, which would assist in the payback of alternative technology options.

- **Step 2** – Implement fuel saving technologies

Following a more detailed review and successful trial of Step 1 technologies above, NRW should set a technology implementation plan. Where low-emission plant alternatives are not available or uneconomic, NRW should include a plant fleet replacement programme to comply with Stage-V NRMM emission standards from 2019 (if Stage-V equipment is not available before this date).

- **Step 3** – Continue to monitor technology availability
  NRW should continue to monitor low-emission plant options taking into account new product offerings on an annual basis. For example:

  - Electric and hybrid plant products are expected to continue to mature and reduce in costs, which will aid the business case.
  - Biofuels such as biomethane, bioLPG and renewable diesel (i.e. 'drop-in diesel' fuels fully compatible with manufacturers' engines and warranties) are expected to be more widely available in the marketplace over the next five years.

5.4 Land and operational assets

As identified in the Technical Report: Calculating NRW's Net Carbon Status[176] – and given NRW's responsibility as owner and manager of 7% of Wales' land – estimating the carbon sequestered in the vegetation and soils of habitats on our owned and managed estate was seen as a vital part of understanding the organisation's overall carbon status.

This exercise informed us that enhancing our sequestration and protecting our carbon stocks by managing key habitats, such as our woodland and peatland, could have a vastly more significant impact on our net carbon status than implementing mitigation measures to address scope 1 and 2 emissions, which may usually be considered, and would often be considered the more obvious choice. The research on woodland management and peatland restoration are reported elsewhere in the Technical Report for our net carbon status (Jones, 2018) and has been published separately. Our work to evaluate the options for all the habitats is ongoing.

5.4.1 Renewable energy generation

In order to better understand the potential for renewable energy generation on NRW's estate, Regen was commissioned to carry out an assessment of the opportunities. Regen's methodology involved assessing the potential renewable energy resource on NRW-managed estate and identifying shortlisted site opportunities for standalone and self-supply opportunities. It was based upon best practice and was tailored to meet NRW's objectives.

More detailed site-specific studies and business cases would need to be developed if opportunities are to be taken forward. It is also recommended that the results should

[176] Technical Report: Calculating NRW's Net Carbon Status (2018), Section 7.3

be scrutinised in more detail to consider any additional priorities of NRW, e.g. to further understand the implications of any identified opportunities on the wider role(s) of NRW as the statutory nature conservation body. Any future work on opportunities will require collaboration between specialists across NRW and with partner bodies (e.g. local planning authorities, DNOs) as required.

The outputs of the study, i.e. the spreadsheets and GIS maps accompanying the report, can be used by NRW to support further analysis of opportunities, e.g. identifying where opportunities occur on deep peat habitats or where opportunities are adjacent to other public sector assets. They will also enable NRW to revisit this work in the future to take account of changing priorities or emerging / additional information, e.g. they are structured so that information can be filtered and sorted to allow consideration of different priorities.

5.4.2 Standalone assessment

The results from the resource assessments (see Appendix F2 in Section 8.6) saw a very large theoretical maximum capacity estimated. The results initially identified 363 individual opportunities, totalling 1,200 MW of capacity, generating over 2TWh (terawatt hours) annually, avoiding over 716,000 tCO_2e of annual carbon emissions and generating c. £118million of estimated gross annual income across the NRW-managed estate, at an indicative capital cost of c. £1.2billion.

Through the application of additional considerations at this pre-feasibility stage, such as designated landscapes, a theoretical feasible capacity was estimated. After applying the three shortlisting screens that assessed the additional considerations (i.e. landscape and environmental designations for solar and wind, and comparison with previous NRW assessments for hydro), network connection proximity and financial performance (i.e. non-inflated NPV), 88 sites remained, totalling 341MW, generating 643GWh and avoiding carbon emission of 226,000 tCO_2e annually, with an estimated capital cost of £365million and generating £38million of financial benefit per annum.

This assessment showed wind (2MW+) and solar installations presented the greatest opportunity for renewable energy generation potential on the NRW estate. Hydro (both high head and low head) was shown to be less favourable than other technologies, but still presented some small opportunities.

Recommended next steps:

- For the shortlisted standalone sites, undertake key project feasibility assessments to assess the headroom on the network in more detail and to clarify the type of land ownership (leasehold or freehold).
- For sites that remain favourable following these assessments (and any strategic considerations), technical and environmental assessments should be completed, to determine the feasibility of these opportunities in detail.
- NRW may wish to take a strategic programme approach to the next steps for standalone sites, due to the number of opportunities across the technology

variants. This could include coordinating future feasibility work across technologies to ensure a single, consistent approach is taken for the whole NRW-managed estate. Any such programme will require consideration of the role and purpose of the NRW-managed estate, strategic landscape and environmental considerations and whether a Strategic Environmental Assessment (SEA) is required before taking forward any opportunities.

5.4.3 Self-supply assessment

NRW's assets with over 5 kW electricity consumption were identified (as outlined in 4.3.4 Category specific method – ground mounted self-supply renewable energy installations) and opportunities for these 20 assets to accommodate generation technologies of a scale suitable to meet on site demand were assessed.

The results from this assessment suggested nine potential self-supply opportunities, totalling 87.2 kW at six of NRW's assets (buildings, visitor centres and hatchery), to be supplied with up to an estimated 175,141 kWh of renewable energy and yielding 67.3 tCO_2e of direct carbon savings per annum, through generating electricity which would otherwise have been imported from the grid. According to the assessment, the self-generation provides an OpEx benefit of £30,114 per annum from electricity cost savings and subsidy income payments; however, it should be noted that it has since been announced that from March 31 2019 onwards, the feed-in tariff (FIT) would be closed to new applications. The total capital investment to install all the identified opportunities is £410,000. Some of the locations identified have multiple technologies to consider, i.e. opportunities for co-location.

Recommended next steps (for shortlisted sites):

- Site visits to assess suitability and location of generation opportunity.
- Landscape impact assessments.
- Environmental Impact Assessments, e.g. impact on birds, bats and other ecology will need to be assessed on a site-by-site basis.
- Studies on accessibility to the site.
- For wind opportunities, Met Office Virtual Met Mast assessments to provide detailed wind climatology.
- Engagement with the DNO to assess the potential to connect new (or additional) generation capacity on.
- Confirming land-ownership arrangements for asset and surrounding land required for development .
- Confirmation of the assets ongoing viability to support investment.

With the relatively low number of opportunities identified, there is the potential to undertake detailed feasibility assessments and site visits for all of the sites identified, and to consider this alongside other assessments – such as roof-mount / building-mount studies – that are being undertaken in parallel.

5.4.4 Microgeneration assessment

In addition to the site-specific self-supply opportunities that were identified, the outcome of the assessment of NRW's low-energy sites in Category specific method – microgeneration renewable energy installations on NRW operational assets shows the potential to develop a programme of delivery to deploy a number of microgeneration technologies on NRW's electricity-consuming assets with average demand of less than 5 kW. These show an indicative additional generation capacity of 320 kW, generating 589 MWh (589,000 kWh), an estimated £62k of indicative annual cost savings and reducing carbon emissions by 224 tCO_2e annually, at an estimated capital cost of £570k.

Whilst the review of the market for microgeneration technologies suggested some products to consider, Regen recommended that NRW should review the type of microgeneration assets already installed across its estate and consult with an electrical contractor to assess the most appropriate technology choices to deploy on each category of site.

NRW may also wish to consider separating any microgeneration rollout into two programmes:

- Programme One – upgrading / replacing existing assets (such as older generation solar panels on telemetry outstations / flood monitoring sites).
- Programme Two – deploying microgeneration on sites that have no existing generation assets.

5.5 Procurement

As identified in the calculation of NRW's net carbon status[177], scope 3 emissions account for the most significant element of NRW's GHG inventory at 88%. The largest contributing category to scope 3 emissions is purchased goods and services (22,667 tCO_2e). The magnitude of emissions associated with purchased goods and services highlights the need for NRW to influence upstream emissions. Levers available to us to do this may include incorporating emissions considerations into internal procurement policy and specific criteria into frameworks, and contract specifications, providing this adheres to procurement regulations. The GHG Protocol (Bhatia et al., 2011) recommends working with suppliers to account for and manage supply-chain emissions.

To demonstrate the potential for working within procurement to reduce emissions, having identified NRW's flood scheme construction activities as significant areas of contractor emissions, we delivered a demonstration project (Appendix A8, Section

[177] Technical Report: Calculating NRW's Net Carbon Status (2018), Section 7.2

8.1) to reintroduce the use of the Environment Agency's carbon planning tool 'ERIC' into NRW flood asset construction projects. This type of approach could be replicated for other types of work contracted out by NRW, e.g. engineering work and forestry operations. Investigating or improving on the results of the spend-based analysis for goods and services could enable the identification of frameworks, account codes, product codes and subsequently suppliers to focus engagement efforts to reduce NRW's upstream emissions.

However, in terms of understanding what could be achieved for scope 3 emissions, it is recognised that this will be very challenging, because it involves relying on suppliers and other contractors to implement the necessary changes.

Recommended next steps: see 4.4.5.4

5.6 Overall lessons learnt

In addition to the category-specific lessons learned in the process of identifying and evaluating mitigation measures, there were some consistent and overarching lessons:

- **Data availability:** sound data is essential to providing a robust evidence base for understanding carbon impact and identifying, developing and evaluating mitigation measures. For example, our Environmental Management System (EMS) gave a strong basis upon which to build our net carbon status calculation. Where this information wasn't already collected consistently or was partial for the organisation, it was challenging to source quickly and efficiently as it was often held by different individuals across an organisation.

- **Data suitability:** the calculation of an organisation's net carbon status is not an exact science and must be built upon best information available at the time of calculation. Assumptions are an inevitable part of any approach to decarbonisation. It is important to be clear on the assumptions made and to apply them consistently to enable confident comparisons between measures, e.g. between emissions sources or mitigation measures. Differences in assumptions, and calculation method between measures and categories of measures, can make comparisons problematic. Once assumptions have been made, it's important to accept them and move forward with confidence.

- **Cost estimates:** we found that desk-based estimates of the costs of mitigation measures often varied significantly from actual costs, often due to site-specific practicalities.

- **Estimating realistic timeframe:** the time needed to collate activity data should not be underestimated, particularly for dispersed sources such as electricity use data.

- **Commissioning industry experts:** internal expertise is essential but can often be limited, particularly in areas where factors such as technology, process, market, or science change quickly. To deliver work effectively, an understanding of skills gaps is essential to highlighting where external support may be required.

- **Working with others:** at the beginning of the project, we benefitted from talking to other organisations who had taken ambitious and innovative approaches to decarbonisation. Communicating with, and learning from, other organisations already managing their carbon impact helped to inform our approach and reduce time spent on developing methods to deliver our own GHG inventory.

- **Identifying options:** we chose to structure our approach using categories of measures, rather than GHG scopes. This was felt to be a more natural grouping for measures in relation to the organisational structure. It is a practical method and will lead into the prioritisation and delivery of measures. However, it may make it less easy to identify and quantify the impact measures may make on each emissions scope.

- **Communication:** clear and consistent communications play a key role in engaging others in decarbonisation. It is important to be clear about terminology and what is included within definitions. Regular communications are important to make others aware of the work, how they can contribute and why it should be delivered. The requirements for activity data to produce a comprehensive organisational GHG inventory are considerable, and we couldn't have developed and accessed the requisite datasets without the co-operation of colleagues from across the organisation. Keeping others informed on the aims and progress of the project was crucial to ensure their input. Having this general awareness of the project across the organisation helped when identifying and contacting individuals with access to specific data.

- **Relationships:** it is essential to build and maintain strong relationships across the organisation to ensure that teams from across the organisation support the initiative and champion its delivery.

- **Reviewing and iterations:** decarbonisation requires an iterative approach and long-term commitment. This will require delivering fully the opportunities available now, maintaining under review the evaluation of mitigation options and building new opportunities into implementation plans as they arise.

  The identification and evaluation of mitigation measures was concurrent with calculating our net carbon status and delivering demonstration projects. This allowed learning and results from each part of the project to influence and direct the other parts.

  NRW should consider periodically reviewing the organisation's net carbon status and carbon stock calculations to account for: revisions and improvements to emissions and sequestration factors and calculation methods in the scientific literature; changes in NRW land management approaches and habitat condition; changes to the organisational boundary as assets and activities under NRW's operational control evolve over time.

- **Perceptions:** it can be difficult to influence perceived priorities for addressing carbon impact. For example, many of our staff perceived lights and computer monitors being left on as our key priority for change, as they may not be aware of the carbon impact associated with areas of the organisation they do not engage with (e.g. procurement, timber haulage).

- **Delivering our demonstration projects:** working with colleagues across the organisation helped to communicate the purpose of the project and showcase the potential for decarbonisation. The interest generated through delivering demonstration projects, raised the profile of decarbonisation in the organisation and resulted in others, both within and outside the organisation, coming forward to get involved.

6. Prioritisation and delivery

6.1 Planning future implementation

The opportunities identified through the evaluation of mitigation options will help build a strategic, costed and prioritised programme of delivery for NRW to address our carbon impact over the next three to five years. Supported by a robust evidence base, this programme will facilitate delivering necessary action for decarbonisation across our organisation.

Achieving decarbonisation across the organisation will be challenging. As well as delivering capital projects, implementing a change in culture will be required to ensure carbon is considered alongside more conventional priorities such as cost and time. Much of the necessary delivery of decarbonisation will need to be incorporated within the day-to-day decision making and work of our staff, contractors and partners.

Use of data has been a valuable factor in identifying which measures will have most impact, rather than basing our actions purely on perceptions. For example, the ability to quantify how the carbon stored on our estate compares to our annual current emissions has informed us that protecting carbon stocks could have a considerably greater impact on our overall carbon status than making visible changes to our offices that staff see on a daily basis, such as implementing solar PV panels or transitioning to an electrified fleet.

Following the identification of mitigation measures, further work is required ahead of delivery, including a detailed study on some measures to transform them into action.

A detailed business case and project plan would need to be developed for each measure as a necessary pre-requisite step prior to their delivery, which will consider practicalities and details such as:

- Building specific audits
- (Local) operational needs
- Environmental assessments, permits, planning requirements
- Other benefits.

6.2 Prioritising measures for delivery

Mitigation measures will be prioritised using:

- **Carbon benefit** – using the total carbon savings or sequestration over the lifetime of the measure.

- **Costs** – understanding the lifetime cost of each measure by calculating the Net Present Value (NPV)[178] where possible.[179]

This will allow us to prioritise measures based on which of the options would provide the greatest carbon benefit for the least cost.

As part of our consideration and where suitable, we are considering Marginal Abatement Cost Curves (MACCs)[180] to help prioritise measures. An example MACC of an NRW office is seen below in Figure 8. Each bar represents a low carbon option. Here the width and height of the bars represents the carbon reduction and cost per tCO_2e saved, respectively, relative to business as usual.

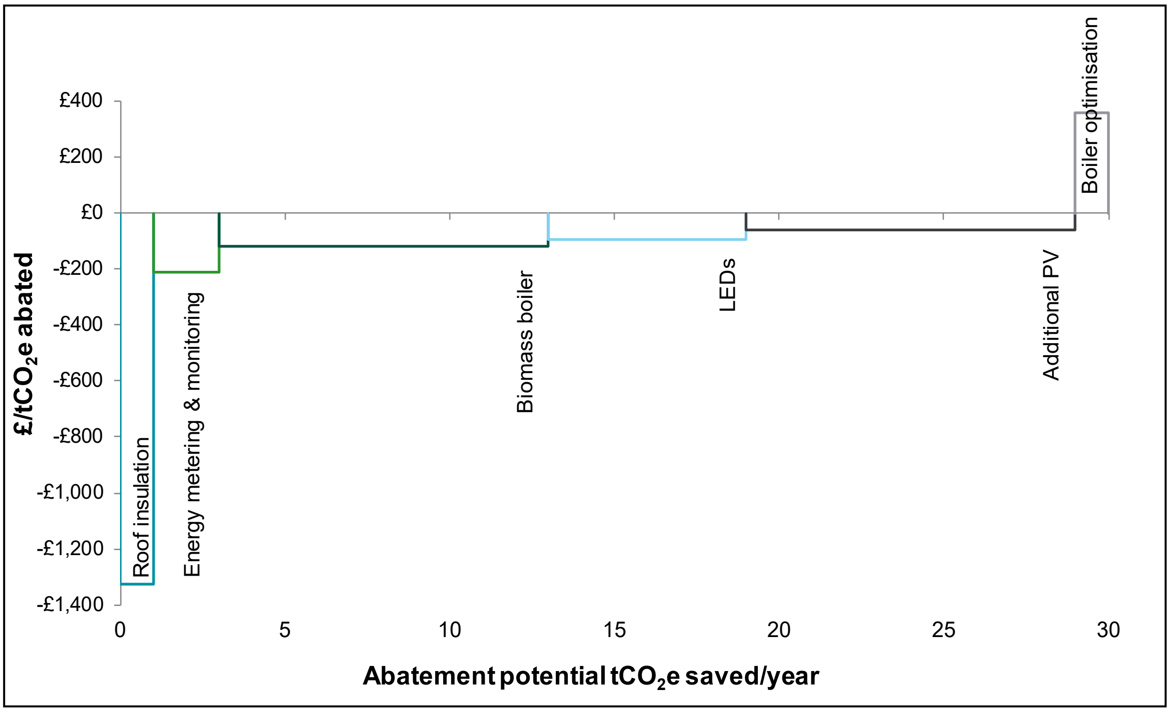

Figure 8: Example of an NRW office Marginal Abatement Cost Curve (MACC)

6.3 Delivering wider benefits

Alongside financial cost and carbon benefit, we will recognise and seek to maximise the wider benefits these measures can provide beyond decarbonisation. This will strengthen the business case to deliver mitigation measures and maximise our contributions to the well-being goals.

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178 Net Present Value (NPV) is a financial measurement used to determine the current value of costs and savings over the lifetime of a project. Further information is available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf

179 To provide a cost per unit of carbon benefit achieved, the Net Present Value (NPV) is divided by the tonnes of carbon dioxide equivalent (tCO_2e) saved over the lifetime of the measure.

180 A MACC is a graphical tool used to help prioritise emissions mitigation (abatement) measures for delivery.

6.4 Enabling Plan and Action Plan

Following this report – and playing an important role in the delivery of decarbonisation across the organisation – are NRW's Carbon Positive Enabling Plan and Action Plan.

These plans will utilise the evidence presented in this report to prioritise areas to investigate and evaluate the potential measures we may take forward. In addition, they will help to develop internal goals and targets, and to embed and incorporate carbon reduction into internal process, decision making, spending and culture.

The Enabling Plan sets out the organisation's strategic long-term ambition for decarbonisation, which is to:

- **Ensure our operations are decarbonised** and that we have optimised carbon storage on the land that we own and manage through delivering action to reduce emissions, enhance sequestration and protect carbon stocks.

- **Share our experience** of decarbonisation with others to facilitate accelerated decarbonisation in Wales to meet national and international obligations to address climate change.

Meanwhile, supporting the Enabling Plan is the Action Plan, which sets out a programme for the mitigation measures identified in this report. It will reflect the prioritisation of mitigation measures for delivery, as well as the delivery of wider benefits referred to in sections 6.2 and 6.3.

The first of these plans covers the period 2017–2022 to align with the NRW Corporate Plan.

6.5 Monitoring and reporting

As a requirement for future reporting, mechanisms will need to be put in place to both record and monitor the status and progress for measures implemented. In addition, we will need to review which measures are considered to have been a success and what learning can be taken from them.

This will be particularly important to reflect any changes in the Welsh five-yearly Carbon Budgets and relevant actions within the Welsh Low Carbon Delivery Plans, e.g. to contribute to a carbon neutral public sector by 2030.

To facilitate this, cooperation will be required between relevant teams, including Carbon Positive, EMS and Facilities, to enable the gathering and sharing of data, as well as ensuring that learning from project implementation is shared internally.

Part of the role of monitoring will be fulfilled by the Carbon Positive Action Plan, which supports the strategic Carbon Positive Enabling Plan, and will act as a living document to enable us to record which mitigation measures will be (or have been) implemented. The Action Plan will be regularly reviewed to ensure it is kept up to date.

The net carbon status calculation has provided a baseline estimate of the organisation's greenhouse gas emissions and carbon sequestration against which progress can be monitored over time. This calculation should be periodically revisited to provide a comprehensive overview of decarbonisation progress. It would be important to review towards the end of the Action Plan period to form a baseline for the next Action Plan. To facilitate this, we will seek to build on and streamline existing emissions data collection and reporting procedures and develop new ones where needed.

6.6 Working with others

We will continue to follow SMNR principles, e.g. working with others.
We will need to interact with, regulate, work with and influence a wide range of groups and organisations to explore potential decarbonisation opportunities, including:

- private sector
- individuals
- public sector
- government
- third sector

We will also explore how NRW's attitude towards all its areas of work considers carbon, such as supporting local / community energy schemes where appropriate.

As an organisation seeking to demonstrate leadership in how the public sector can reduce its carbon emissions to tackle climate change, NRW will address the requirements of the *Environment (Wales) Act* and the *Well-being of Future Generations Act* in our decarbonisation programme to deliver the actions in Prosperity for All: A Low Carbon Wales Delivery Plan and work towards our contribution to the Welsh public sector ambition for carbon neutrality by 2030, and a Wales with net-zero emissions by 2050.

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8. Appendices

8.1 Appendix A: Demonstration project case studies

Appendix A.1: Replacement of legacy lights with light-emitting diodes (LEDs) in the NRW buildings estate:

https://cdn.naturalresources.wales/media/686955/case-study-6-led-installations.pdf

Appendix A.2: Installation of roof- mounted solar photovoltaic (PV) arrays on the NRW buildings estate:

https://cdn.naturalresources.wales/media/686954/case-study-5-solar-pv-installations.pdf

Appendix A.3: Introducing electric vehicles and charging infrastructure into NRW:

https://cdn.naturalresources.wales/media/686738/case-study-7-electric-vehicles-and-charging-infrastructure.pdf

Appendix A.4: Refining emissions estimates for the forestry operations supply chain:

https://cdn.naturalresources.wales/media/685957/case-study-2-forestry-operations-emissions.pdf

Appendix A.5: Re-wetting an area of degraded raised bog at Cors Fochno, using low-elevation contour bunding:

https://cdn.naturalresources.wales/media/685958/case-study-3-peatland-restoration-using-bunding.pdf

Appendix A.6: Trialling methods for rapid establishment of Sphagnum moss to restore an area of degraded bog at Cors Fochno: https://cdn.naturalresources.wales/media/685959/case-study-4-peatland-restoration-moss-establishment-trials.pdf

Appendix A.7: Retrofitting NRW's operational assets with solar PV: https://cdn.naturalresources.wales/media/686779/case-study-8-retrofitting-nrws-operational-assets-with-solar-pv.pdf

Appendix A.8: Trialling a carbon planning tool to reduce contractor emissions in flood defence construction projects: https://cdn.naturalresources.wales/media/685956/case-study-1-carbon-planning-tool.pdf

8.2 Appendix B: Analysis of half-hourly electricity use data from a cross section of NRW assets with an average demand above 5 kW

Analysis of half-hourly (HH) data for each of these sites is set out in the sections below.

Appendix B.1: Pumping station site – Noah's Ark Pumping Station

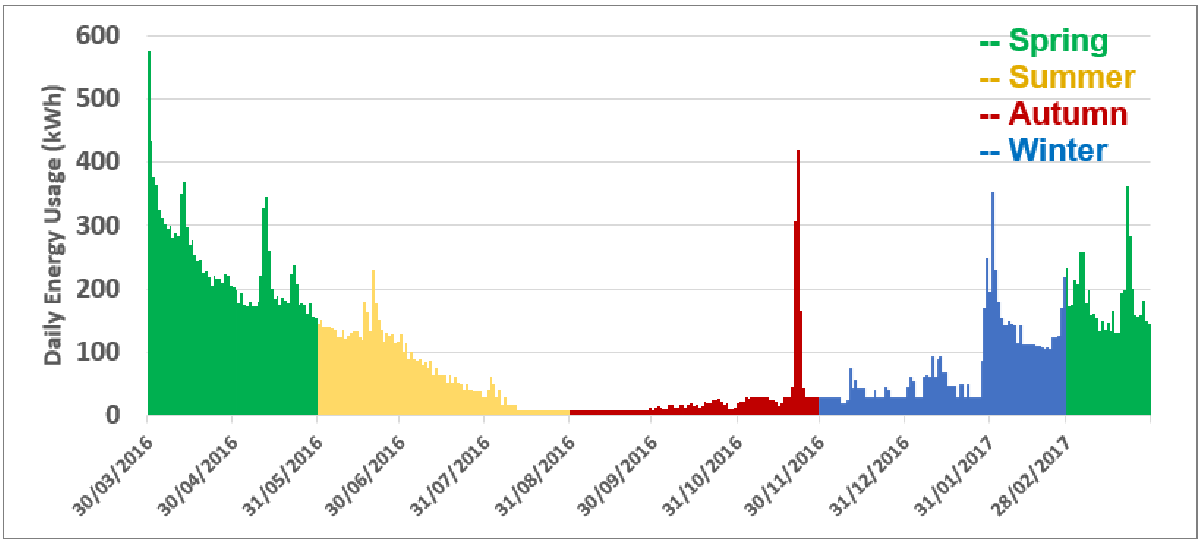

Figure 9: Noah's Ark Pumping Station – Daily kWh (Mar 2016–Mar 2017)

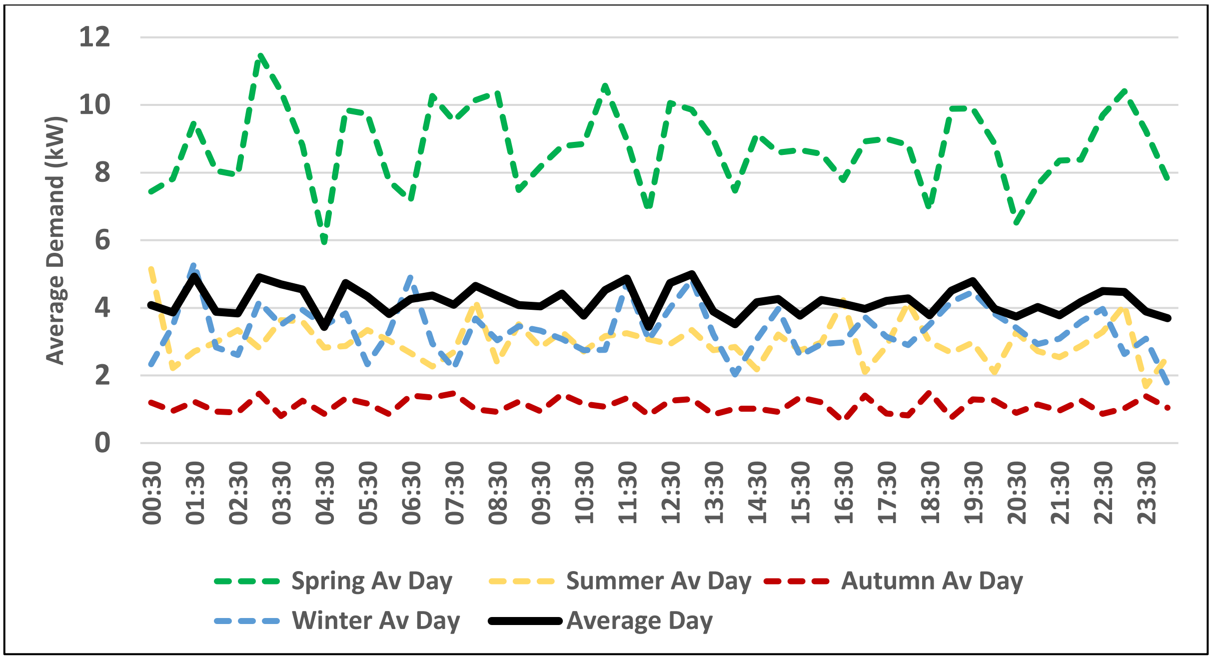

Figure 10: Noah's Ark Pumping Station – Average Daily HH Demand Profile (with representative days within each season highlighted)

Appendix B.1.1: Comments

This asset has a consistent pattern of peaks and troughs for its usage profile, reflecting the pumping equipment's sporadic usage, baseload 'dormant' demand and potentially reactive spikes in usage presumed to be due to weather. The daily usage and average demand trends clearly show an increased springtime usage in the 2016/17 financial year analysed. This is most likely to be weather-related operation, but whilst the spring demand profile uses more power overall, there is little variation between night and day, and no obvious 'peak time' use.

If site conditions and availability permit, hydro or wind power may be a suitable option for this site. Small-scale solar may also be viable; however, as the demand of a summer average day is around 3 kW, an appropriately sized roof-mounted PV system may be a more suitable option for the building.[181]

Appendix B.2: Office site – Tŷ Cambria (Cambria House) Office

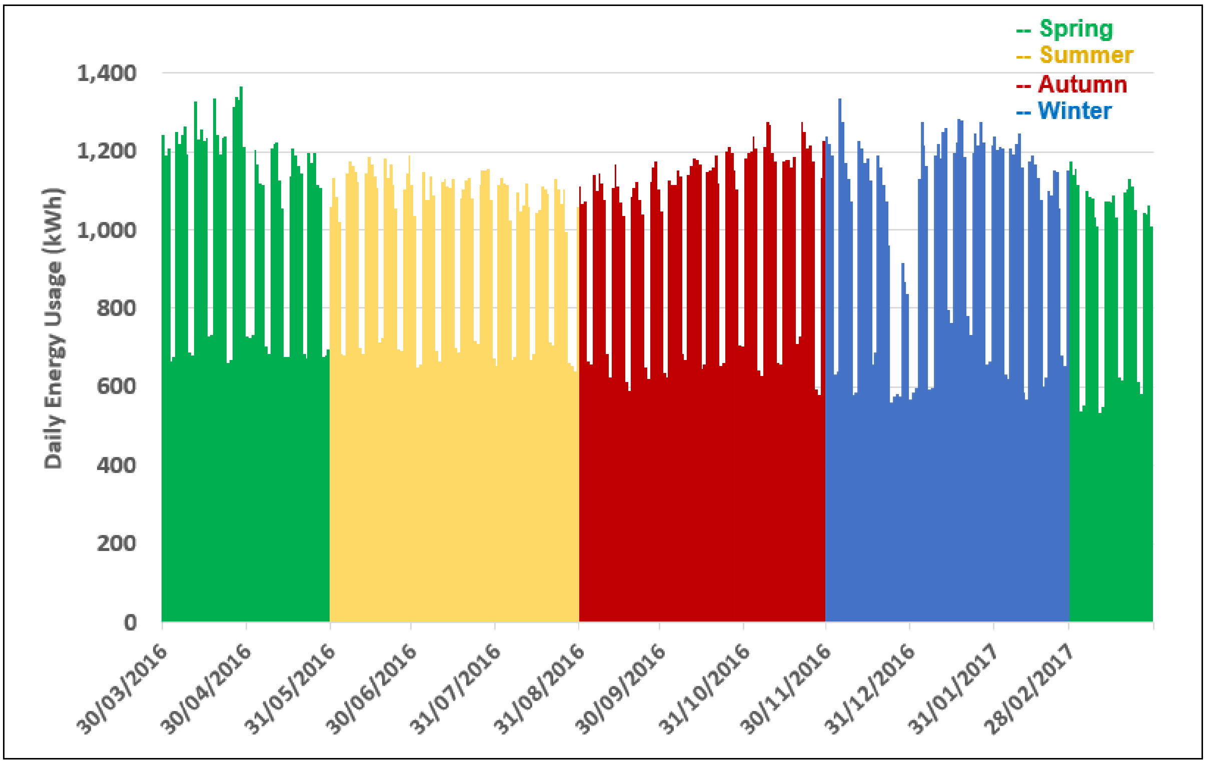

Figure 11: Tŷ Cambria (Cambria House) Office – Daily kWh (Mar 2016–Mar 2017)

[181] Roof-mounted PV is out of scope of this assessment but has been highlighted for future work.

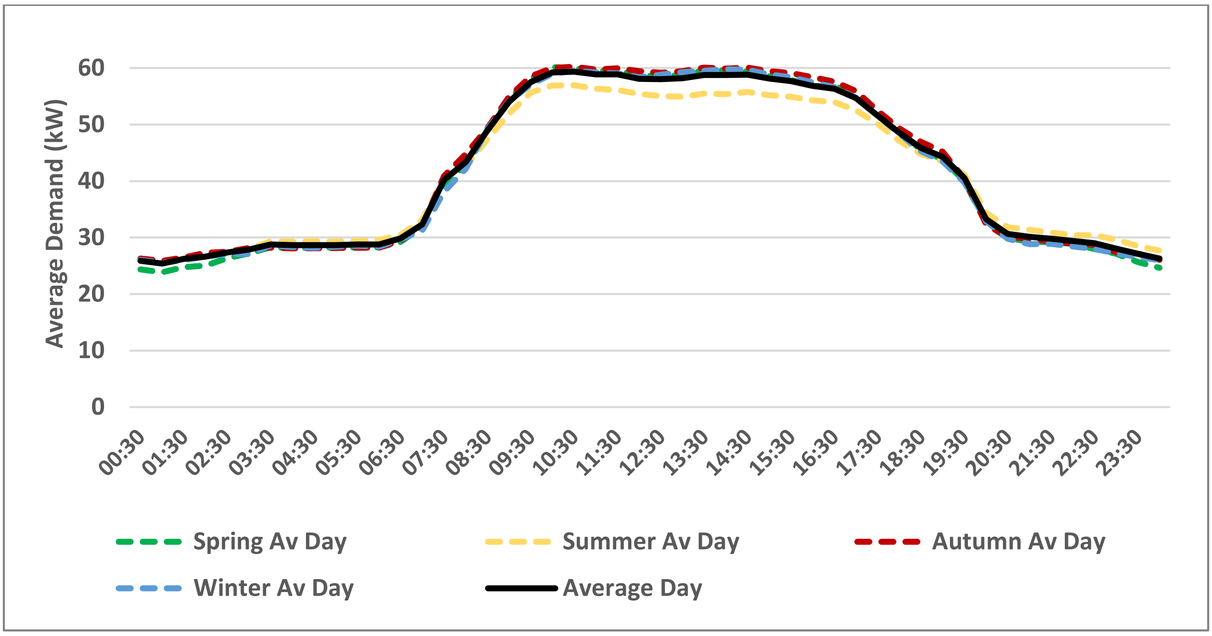

Figure 12: Tŷ Cambria (Cambria House) Office – Average Daily HH Demand Profile (with representative days within each season highlighted)

Appendix B.2.1: Comments

Tŷ Cambria (Cambria House) office shows a typical office annual usage, showing the fluctuation between weekday and weekend consumption, though with very little variation between the seasons, suggesting fairly consistently operated or high efficiency heating / cooling systems using electricity. The daily profiles are therefore similar between seasons and show a notable baseload (approx. 42% of peak demand) and staff occupancy-related rise in daytime demand. This type of occupancy-related demand aligns well with solar PV generation profiles, due to the middle of the day peak in occupancy and demand mirroring the peak PV output.

From the analysis of self-supply opportunities, this office already has rooftop solar PV installed. The potential to install additional ground-mounted generation near this building is not an option, due to the urban Cardiff location of the office and the lack of nearby NRW-managed estate to host potential ground-mount PV or a solar car port. Further investigation of building-mounted measures are outside of the scope of this assessment but have been highlighted for future work.

Appendix B.3: Office site – Buckley Office

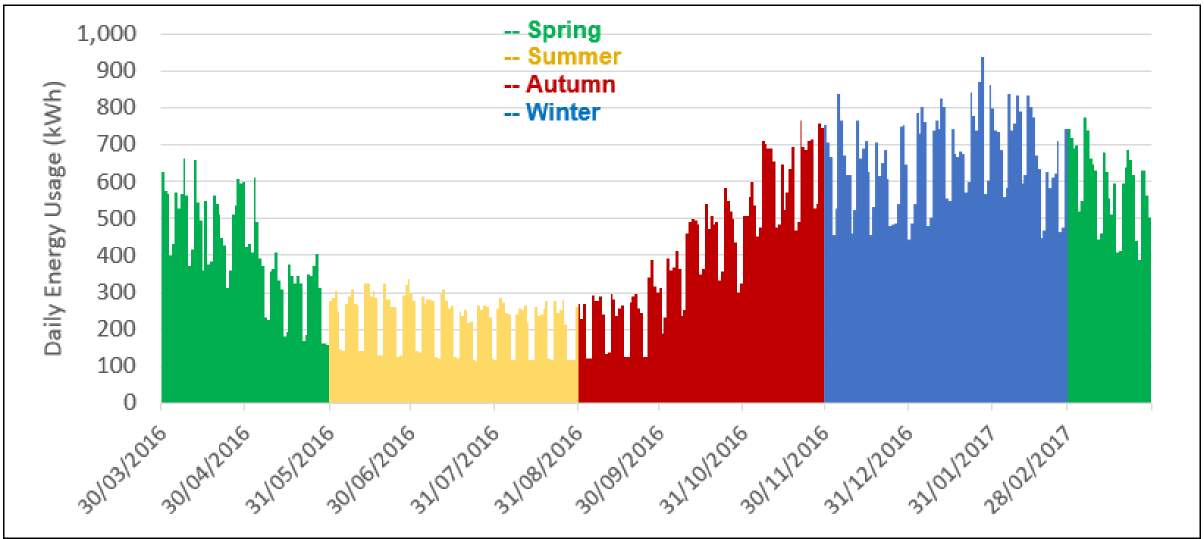

Figure 13: Buckley Offices – Daily kWh (Mar 2016–Mar 2017)

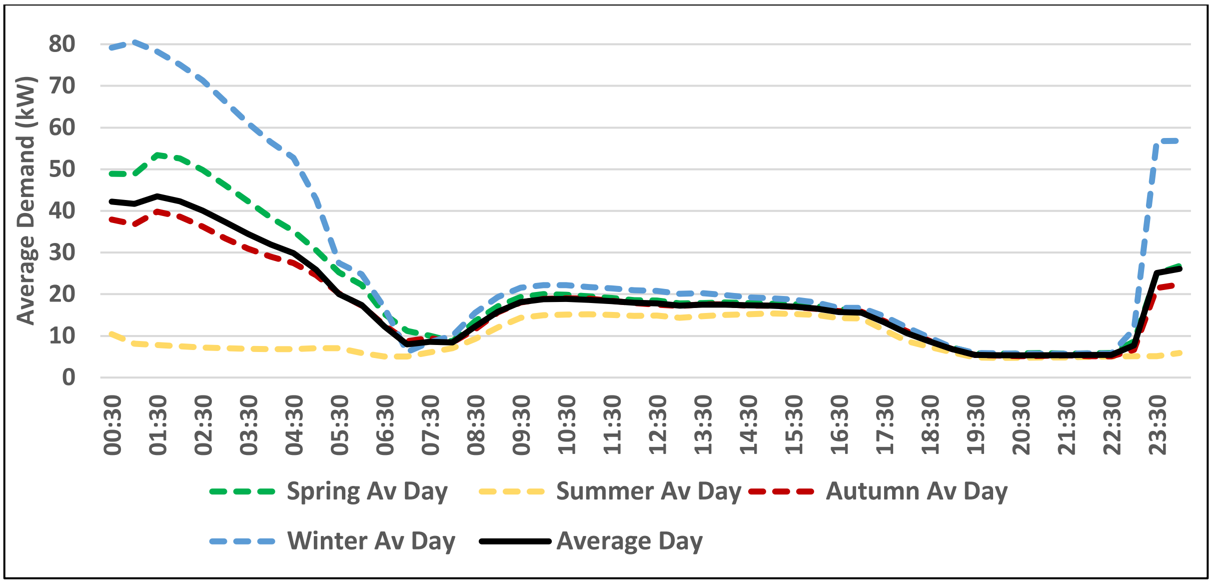

Figure 14: Buckley Office – Average Daily HH Demand Profile (with representative days within each season highlighted)

Appendix B.3.1: Comments

Whilst there is some distinct occupancy-related demand during the day, the significantly high peaks in demand are shown as being overnight in all seasons except summer. From liaising with NRW staff, this is almost certainly due to high demand night storage heating, which would explain the stark variance in overnight consumption in winter compared to summer.

As with other office buildings, small / medium solar would still be a firmly viable option to consider. From the analysis of small-scale ground-mount opportunities, a small (up to 10 kW) ground-mount solar array in a grassed area north of the site is a viable option to consider (see 4.3.4.21 Summary of mitigation measures for ground-mounted self-supply installations). As with other sites, a roof-mounted solar array should also be considered, although this is outside of the scope of this assessment but has been highlighted for future work. It is known that NRW is conducting building audits, outside of the scope of this study to pursue additional means of carbon reduction for buildings. This includes investigating the potential for alternative heating solutions and insulation, which may help reduce the overnight demand identified here. This would then likely mean that the site has a more suitable profile for solar.

Appendix B.4: Office Site – Resolven Office / Depot (assumed to be building only)

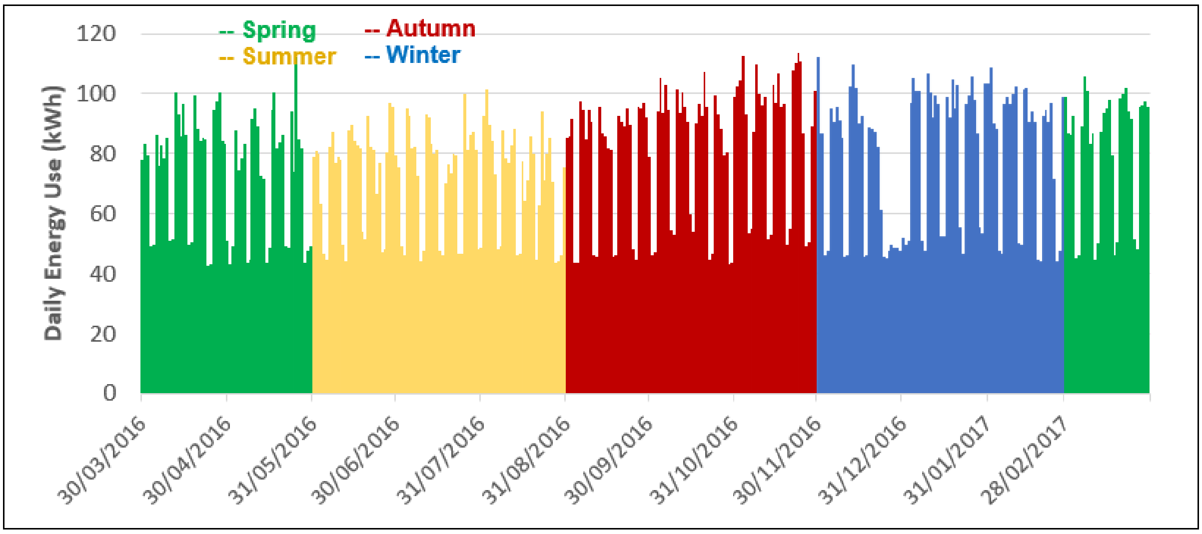

Figure 15: Resolven Office – Daily kWh (Mar 2016–Mar 2017)

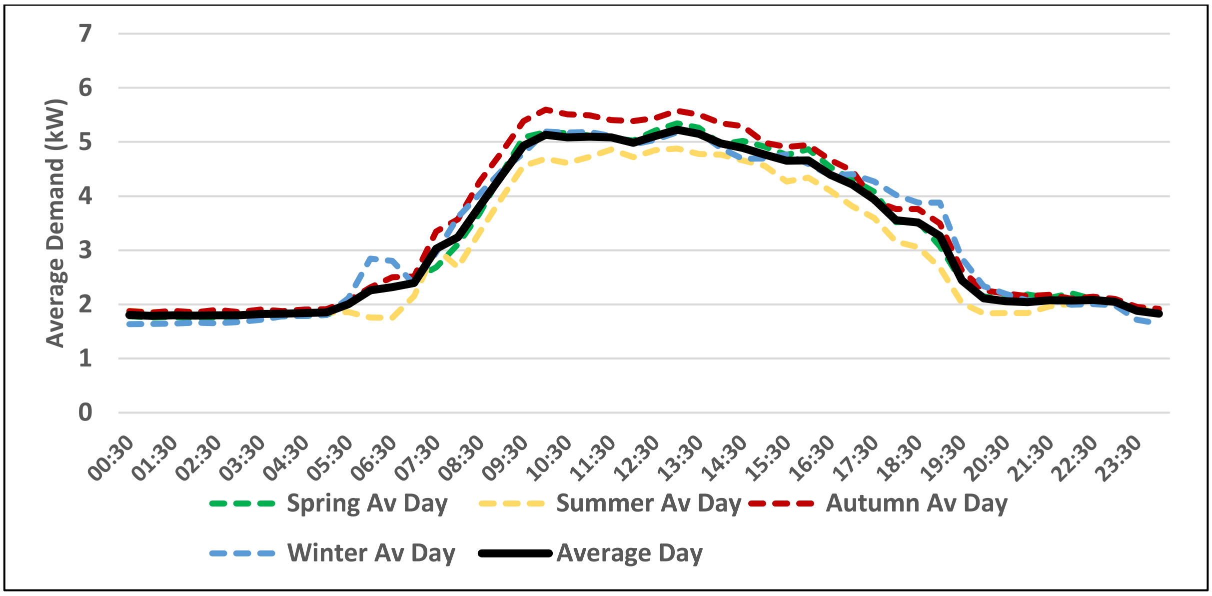

Figure 16: Resolven Office – Average Daily HH Demand Profile (with representative days within each season highlighted)

Appendix B.4.1: Comments

This office has a very similar demand profile to the Tŷ Cambria Office, but at approx. 10% of the average demand, peaking at 5.6 kW, compared to Tŷ Cambria's 60 kW peak demand (largely as this is a smaller office).

Whilst out of the scope of this assessment, with such low average peak demand, a similar recommendation to review the potential for roof-mounted solar PV would be the most sensible approach to supply renewable energy generation into this building. As a point of interest, 4–6 kW PV (a nominally standard roof-mounted PV system) is of similar size to a domestic roof-mounted system, so there are many example installations to draw from for cost comparison, as well as numerous products and installers available on the market to review for the next stage of feasibility. In addition to PV, there may also be the option to consider domestic-scale battery solutions, with many PV installers now offering PV and storage as a combined system solution. The ability to leverage extra financial benefits to provide a return on investment for the additional cost of a battery may be limited, depending on the electricity tariff applicable to the site and the amount of 'lost' PV generation that could be stored and used.

Appendix B.5: Laboratory Site – Llanelli Laboratory

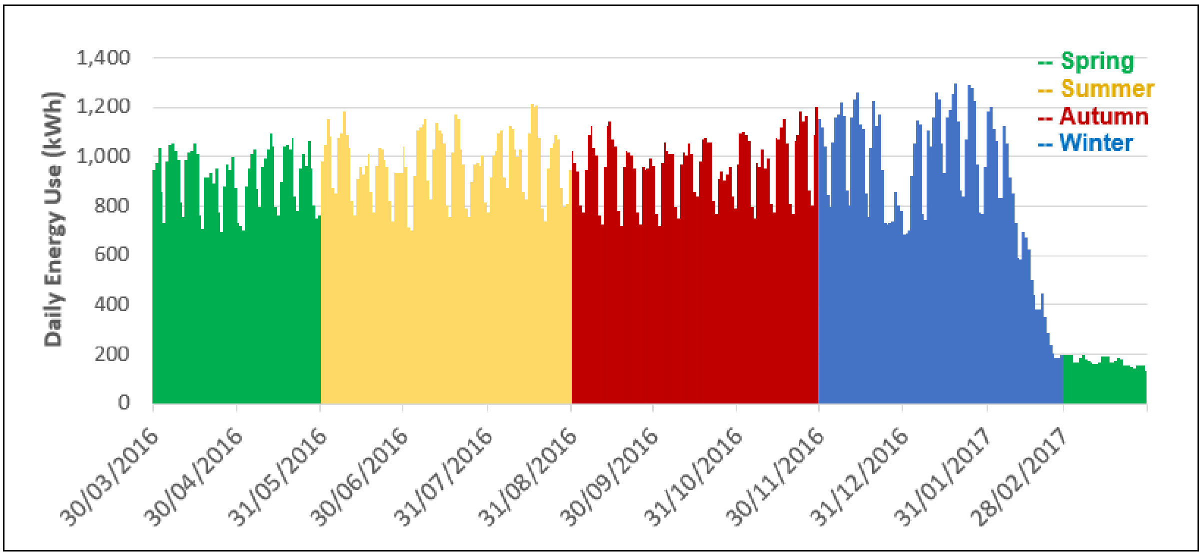

Figure 17: Llanelli Laboratory – Daily kWh (Mar 2016–Mar 2017)

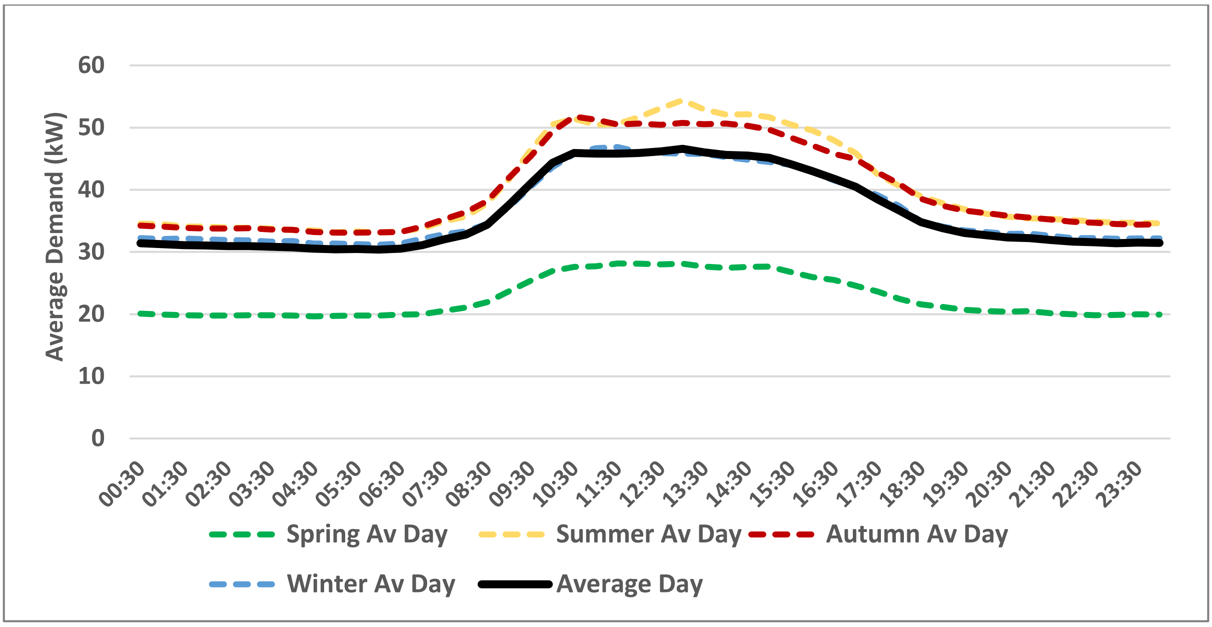

Figure 18: Llanelli Laboratory – Average Daily HH Demand Profile (with seasons highlighted)

Appendix B.5.1: Comments

This site has a similar daytime occupancy related demand profile but being a laboratory there is seemingly a higher baseload demand out of working hours than office sites.

To note, the Llanelli lab was relocated in February 2017 to Swansea University, explaining the drop in usage seen in Figure 17. It is assumed that the new lab operates in a similar manner in its new location and therefore the profile would remain consistent. Analysis of electricity consumption and profiling at the new location is advised to confirm this and an additional assessment of opportunities for self-supply should be conducted.

Appendix B.6: NRW monthly site usage analysis

In addition to the HH site data, the monthly consumption of some of NRW's sites was reviewed, based on meter readings.[182] Whilst this data does not enable daily usage profile analysis, to inform technology suitability assessment for these sites the following were produced:

- Monthly kWh consumption trend
- Summarised suitability for renewable energy technology
- Highlighted abnormal / exceptional usage months

Appendix B.6.1: Visitor Centres (three were assessed in total) – Coed y Brenin | Bwlch Nant yr Arian | Garwnant

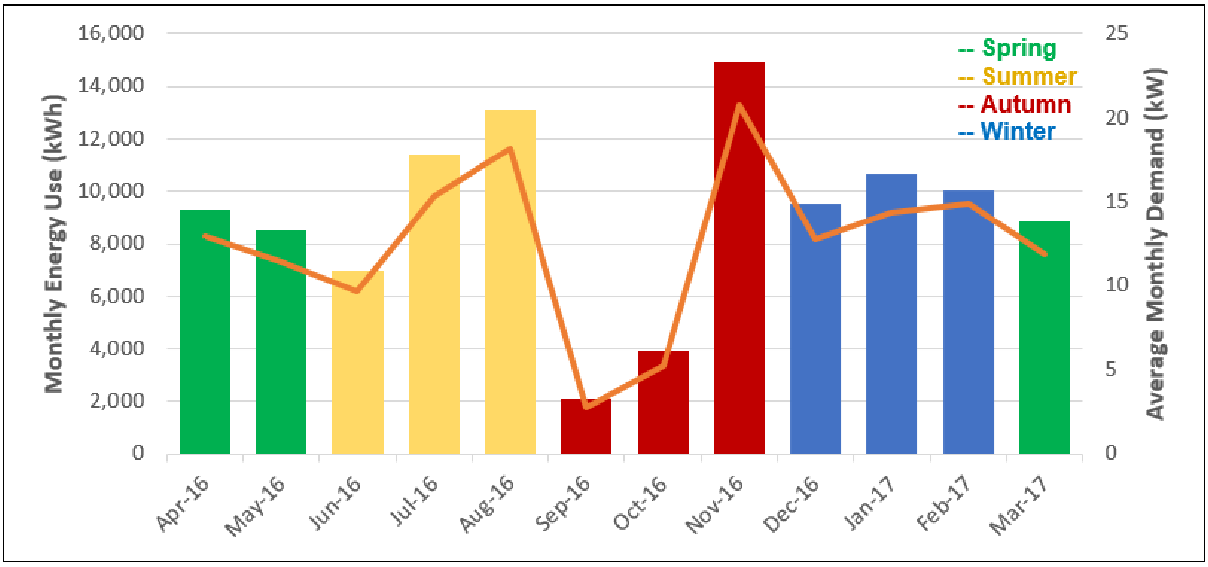

Figure 19: Coed y Brenin Visitor Centre – Monthly Energy and Demand Profile

[182] Although monthly billed cost figures were also provided by NRW for other sites, when these were reviewed they were found not to provide an accurate representative view of kWh consumption profiles, with standing charges, estimated meter readings and appearances of credit payments skewing annual usage profiles. As a result, only metered data is presented here.

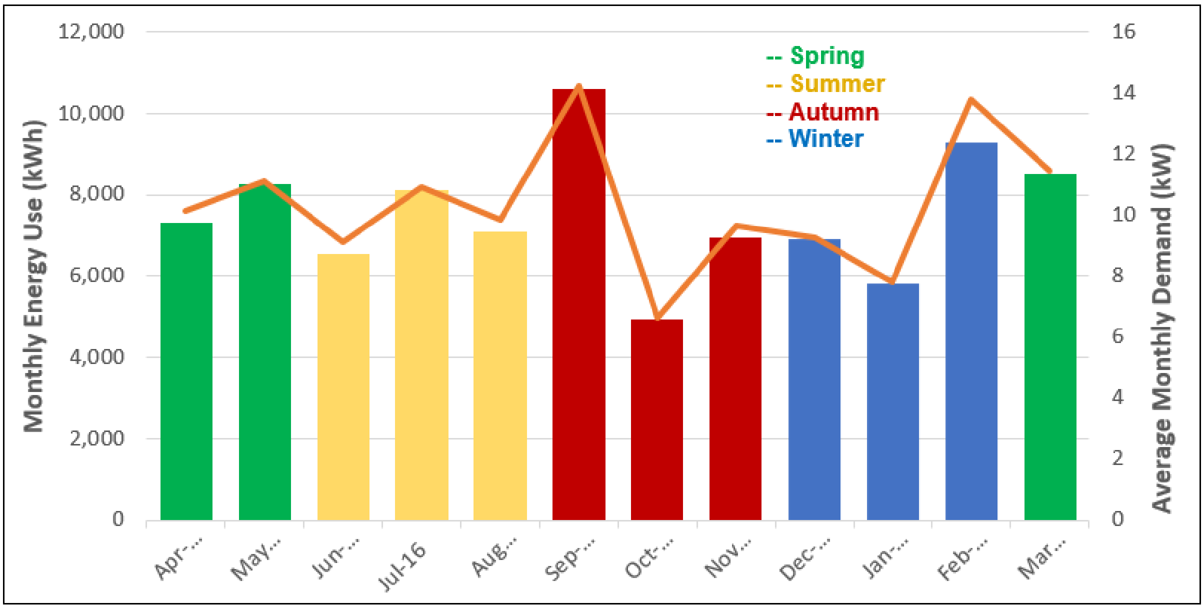

Figure 20: Bwlch Nant yr Arian Visitor Centre – Monthly Energy and Demand Profile

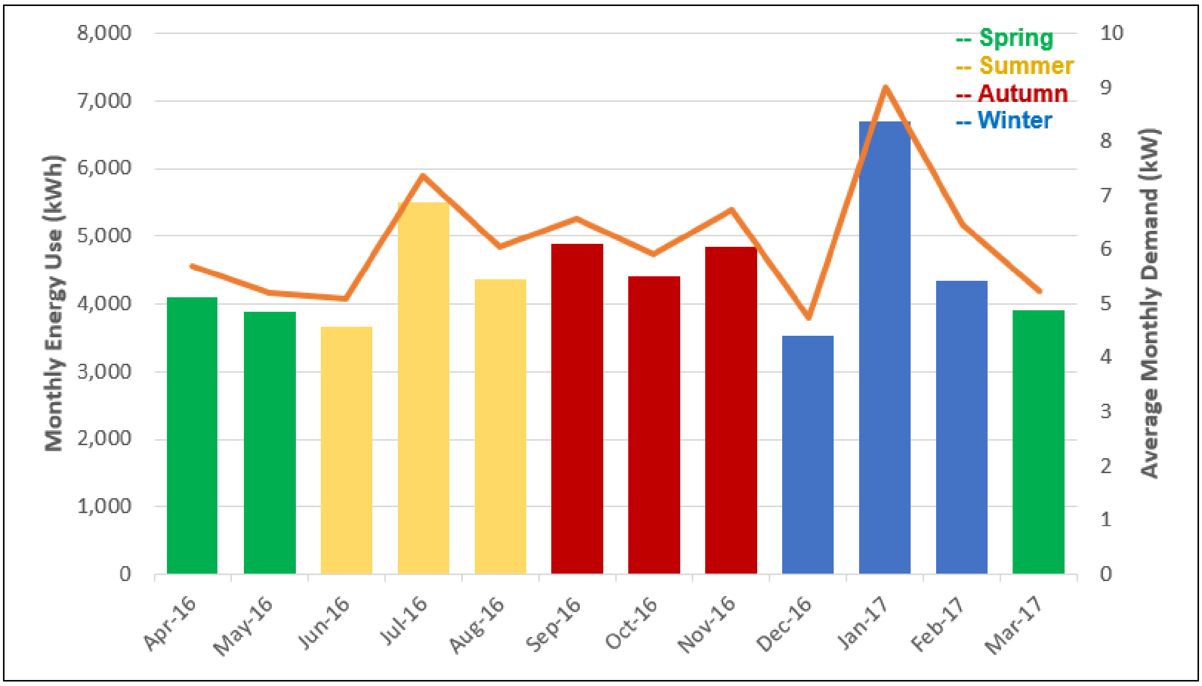

Figure 21: Garwnant – Monthly Energy and Demand Profile

Appendix B.6.2: Comments

Visitor centres will predominantly have building facilities (i.e. lighting, space heating and amenities) as the main loads. Across the three sites shown, there is a fairly flat, average demand of 8 to 12 kW across the seasons, showing similar scale consumption at each of the sites. There is no real correlation between the sites in terms of seasonal variation in consumption, with the most energy intensive months being different for all three sites. One anomaly seen is the significant reduction in monthly consumption at the Coed y Brenin site during September and October 2015, the reasons for which are unknown.

NRW's visitor centres, by their nature, might be assumed to have relatively high day time, occupancy driven electricity usage.[183] As a result, solar PV that generates in the daytime may be an appropriate generation match for onsite demand. Small-scale wind might also be considered suitable to supply baseload generation.

As per the self-supply assessment undertaken, it is noted that Coed y Brenin Visitor Centre already has an existing roof-mount solar array (estimated to be 8 kW). There is, however, the potential to deploy a further 5 kW of solar PV in land space available on the site (see 4.3.4.21 Summary of mitigation measures for ground-mounted self-supply installations).

In addition to this, there is also the potential for a 5 kW hydro turbine to be installed, based on a longlisted site opportunity 1.8 km away.

For Bwlch Nant yr Arian Visitor Centre, there is the potential for both small-scale ground-mount solar (10 kW) and small-scale wind (12 kW) to supply the site. With reasonable estimated wind speeds and autumn / winter peak usage months, this dual technology deployment could be a firm option to consider at this site (see 4.3.4.21).

Appendix B.7: Hatchery – Cynrig Salmon Hatchery

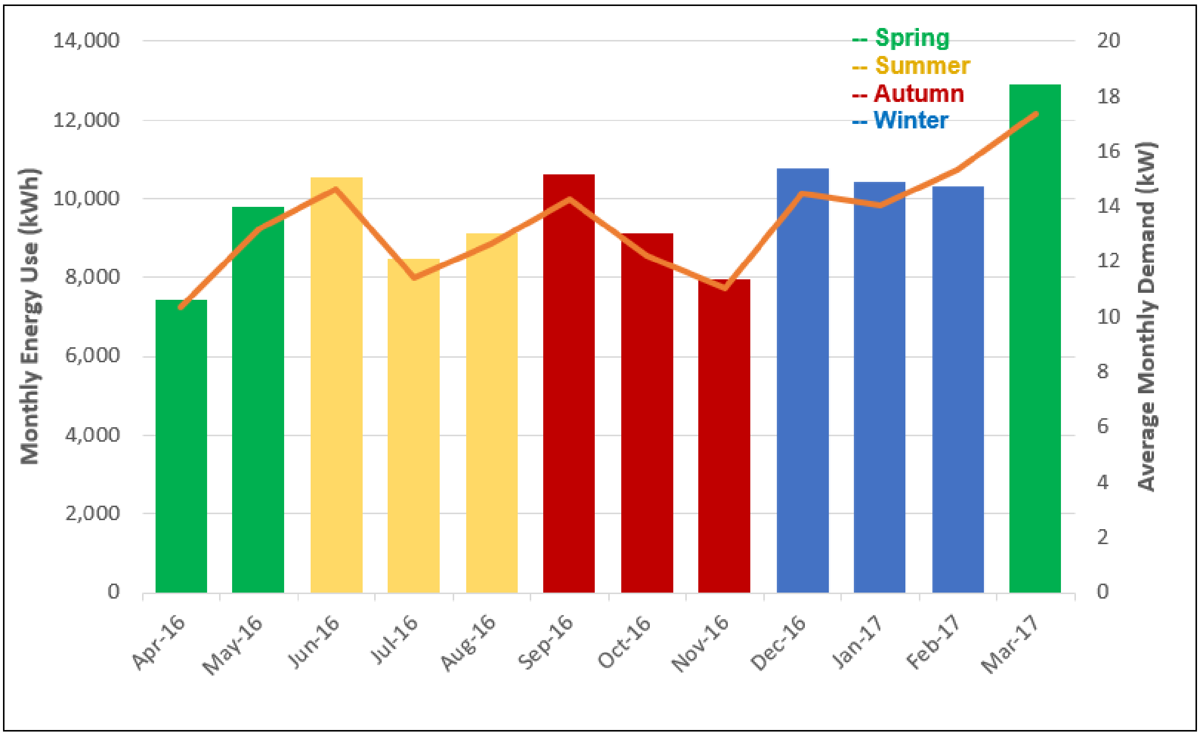

Figure 22: Cynrig Salmon Hatchery – Monthly Energy and Demand Profile

[183] Note: it is not possible to ascertain specific daily occupancy consumption profiles for matching specified generation opportunities, due to the monthly granularity of electricity use data here.

Appendix B.7.1: Comments

As a bespoke type of asset, the salmon hatchery will potentially have inter-site water pumping equipment, as well as temperature control plant on site. The scale of demand at this site shows a relatively steady 10–12 kW across the year, but with a spike in consumption in March – linked to on-site salmon activity.

If the location and nature of the operation of this type of asset means that it is located alongside water courses, there is a potential to consider on-site or adjacent small-scale hydro generation. Small-scale solar on any surplus land within the site compound or on roof spaces of buildings within the site would also be options to consider.

From the self-supply analysis undertaken, where visual inspection of GIS maps and satellite imaging was used to identify potential opportunities, there is potential for a small (10 kW) roof-mount solar array, and a nearby existing weir enables the potential for small, low-head (10 kW) hydro turbine (see 4.3.4.21).

8.3 Appendix C: Assessment of inter-annual variability in electricity use at NRW's pumping station assets

From the perspective of both data quality and the nature of the data as electricity billed costs, the following considerations should be noted:

- Billed electricity costs include non-consumption related elements (standing charges / fixed charges), so values are not wholly reflecting the consumption profile.

- Some monthly bill values were zero (predominantly in 2015), likely reflecting missing bills, and were estimated using the average of the months that did have values; this will however reduce accuracy of month-on-month profiling and introduce a further level of estimation of year-on-year comparisons.

- There are instances of monthly bills that are negative, which are reflecting credit payments related to overestimated usage / meter readings.

Appendix C.1: Pumping station billed cost analysis – graphs

With the aforementioned considerations as a basis, the bills for all pumping stations were totalled and compared year on year (see Figure 23 below).

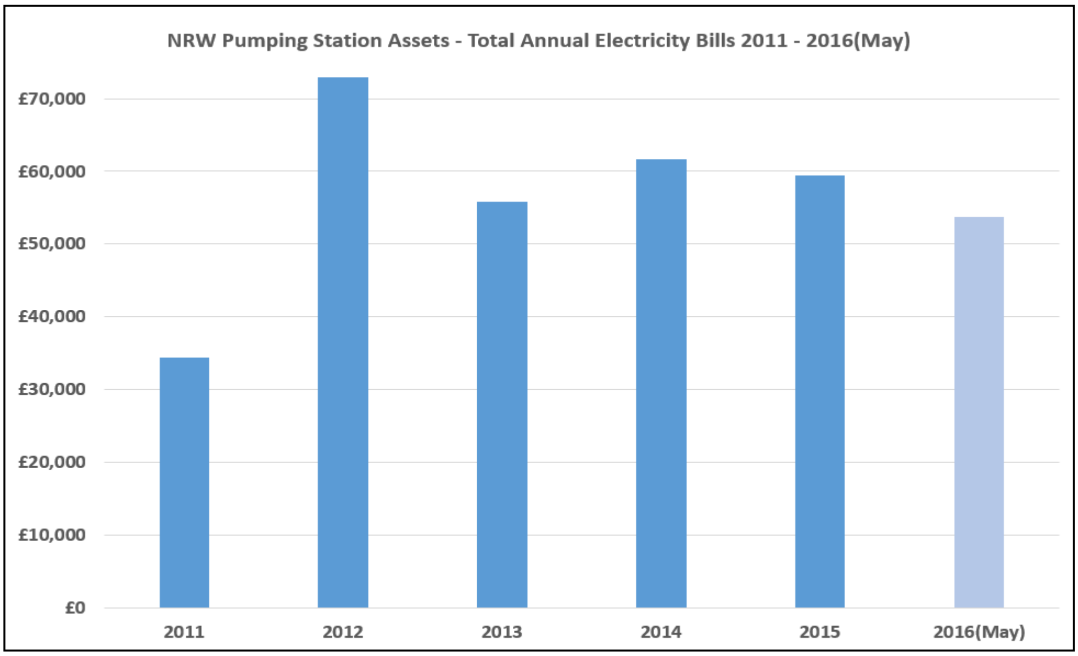

Figure 23: Annual billed cost for all pumping stations (2011-May 2016[184])

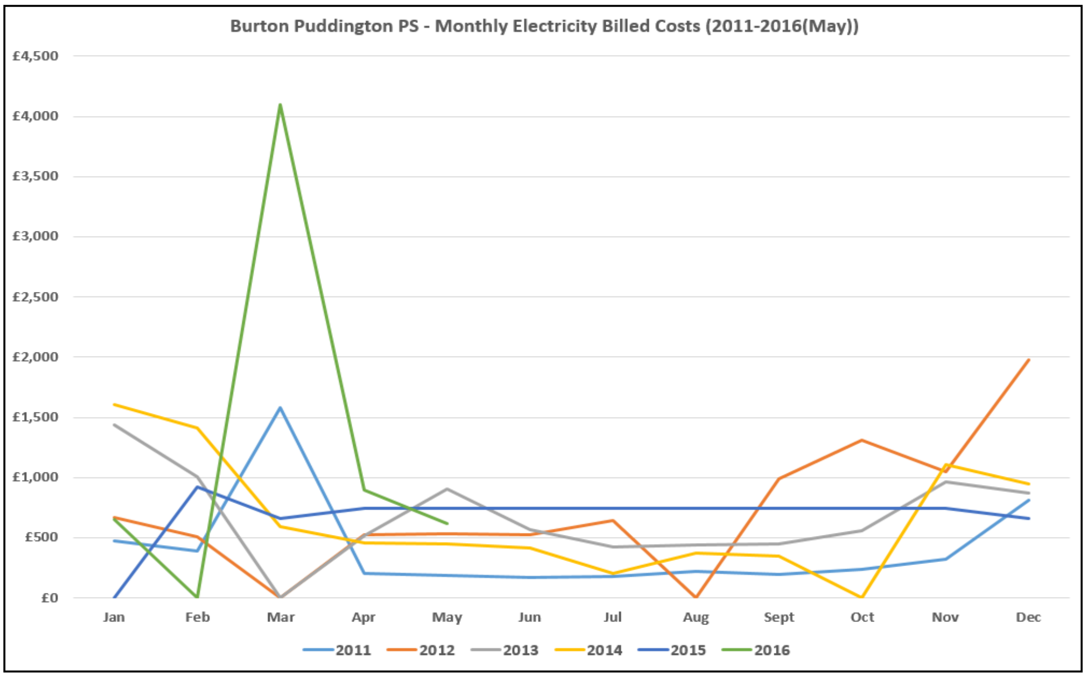

Figure 24: Burton Puddington PS monthly electricity bills (2011-2016)

[184] Electricity bills are for calendar years rather than financial years, i.e. '2011' is Jan–Dec 2011 and not Apr 2011–Mar 2012.

Appendix C.1.1: Comments

The data shown in Figure 23 suggests notable inter-annual variability in electricity costs / usage across all 22 pumping stations analysed. Figure 24 provides an example analysis of one of the pumping stations and shows that there can be a notable variance in electricity costs / usage within a given year (seasonal variation). This variability reflects the operation of sites as pumping stations and the link between energy consumption of the sites and water level conditions (and so pumping requirements) within and between years. This link is further evidenced when overlaying UK annual rainfall data against the annual pumping station electricity costs, see Figure 25 below.

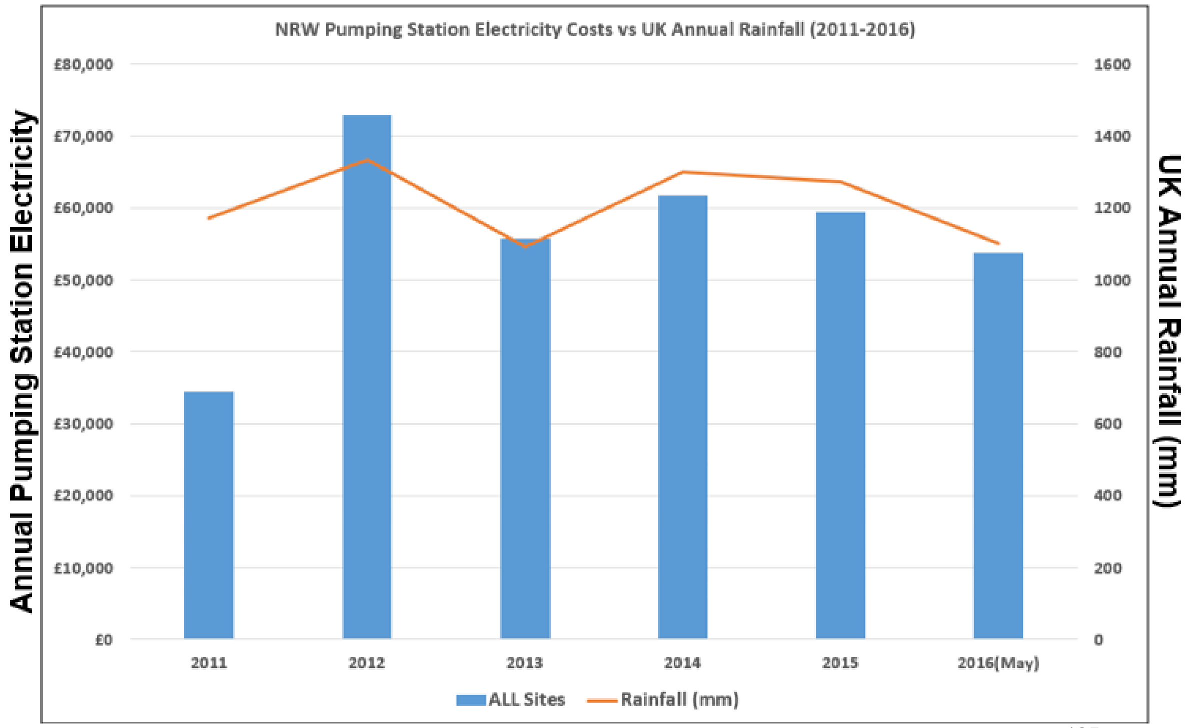

Figure 25: Pumping station annual electricity costs vs UK annual rainfall[185] (2011–2016)

With demand linked to rainfall and water levels, the most obvious potential generation technology match could be hydropower, given that hydro resource and land drainage / other water abstraction for pumping is well matched. However, when analysing the monthly profile of specific sites year-on-year, there is notable variation in billed costs within, as well as between, each of the years. This implies that more than one generation technology may be suitable to meet consumption at this site (i.e. wind or solar). Given the buildings present at pumping stations, this could mean there is also the potential for roof-mounted solar.

[185] UK annual rainfall values sourced from MET Office UK Climate Annual Summaries data, available online at https://www.metoffice.gov.uk/climate/uk/summaries/

An overarching recommendation would be to therefore to obtain more detailed kWh consumption data and review usage profiles in more detail to assess the generation technology that is best suited on a site-by-site basis.

8.4 Appendix D: Further detail on methodology to identify self-supply opportunities

The results from this method can be found in Section 4.3.4.

Appendix D.1: Self-supply site-finding assessment – ground-mounted solar PV

Step 1: Identify NRW assets with sufficient demand

Using the NRW electricity-consuming asset list, which included average electricity demand data provided by NRW, the first stage of the self-supply assessment identified properties with an average demand above 5 kW. Of the 327 assets listed, 20 sites remained once the 5 kW average demand requirement was applied and refinement by NRW (i.e. to exclude anomalies and disposed assets).

Step 2: Identify NRW assets with sufficient space for a solar array on-site or on nearby NRW-managed land within 500 m

The cost of cabling beyond the 500 m distance for this scale of project (5–15 kW) becomes economically infeasible. After this constraint was applied, six NRW assets (>5 kW demand) remained.

Step 3: Visual assessment of NRW-managed estate surrounding top consuming assets

The area of NRW-managed estate within 500 m, or directly associated with each of the six assets, was reviewed visually using satellite imagery to identify available space for a ground-mounted array. An area of approximately 100 m^2 is required to host a 10 kW array. The visual inspection looked for relatively flat ground with suitable orientation and no / minimal shading from nearby trees or buildings.[186] Five remaining self-supply opportunities for small-scale ground-mount solar were identified.

Step 4: Planning risks and considerations

Landscape, environmental designations and heritage constraints can restrict development of solar PV projects, therefore the designations set out in Table 65: Self-supply site-finding assessment – considerations applied for solar PV below were recorded at each of the remaining NRW electricity-consuming assets. These were

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186 For example, used for a rooftop solar assessment in the West Dorset Local Energy Plan (2011) https://www.dorsetforyou.gov.uk/media/174609/West-Dorset-Local-Energy-Plan/pdf/Final_West_Dorset_report_230311.pdf

not applied as hard constraints but recorded for consideration at a later point, due to much smaller scale solar PV self-supply opportunities.

Table 65: Self-supply site-finding assessment – considerations applied for solar PV

Planning risk considerations	Explanation	Source of methodology	Source of data
Designated landscapes were recorded: • National Parks • Areas of Outstanding Natural Beauty	Protecting designated landscapes	Regen industry experience	Lle Geo-Portal
The following environmental designations were considered: • Local Nature Reserves (LNR) • National Nature Reserves (NNR) • Ramsar sites • Scheduled Ancient Monuments (SAM) • Special Areas of Conservation (SAC) • Special Protection Areas (SPA) • Sites of Special Scientific Interest (SSSI)	To acknowledge any potential considerations for the protection of protected flora and fauna	Regen industry experience	Lle Geo-Portal

Appendix D.2: Self-supply site-finding assessment – wind

Step 1: Identify NRW assets with sufficient demand

Using the NRW electricity-consuming asset list, which included average electricity demand data provided by NRW, the first stage of the self-supply assessment identified properties with an average demand above 5 kW. Of the 327 assets listed, 20 sites remained once the 5 kW average demand requirement was applied and refinement by NRW (i.e. to exclude anomalies and disposed assets).

Step 2: Identify NRW assets with sufficient space for a small-scale wind turbine on-site or on nearby NRW-managed land within 500 m

The cost of cabling beyond the 500 m distance for this scale of project (<15 kW) becomes economically infeasible. After this constraint was applied, six NRW assets (>5 kW demand) remained.

Step 3: Visual assessment of NRW-managed estate surrounding top consuming assets

The area of NRW-managed estate within 500 m or directly associated with each of the six assets was reviewed visually using mapping and satellite imagery to identify available space for a small-scale turbine. An area of approximately 14.4 m^2 is required to host a 6 kW turbine.[187] The visual inspection looked for relatively flat, open ground with adequate space. The following constraint was also applied, as seen in Table 66: Self-supply site-finding assessment – constraints wind below. A remaining self-supply opportunity for small-scale wind was identified.

Table 66: Self-supply site-finding assessment – constraints wind

Constraint	Explanation	Source of methodology	Source of data
Areas with wind speeds below 5 m / s at 10 m excluded	Suitable wind speed for small-scale wind	Regen industry experience	NOABL 10 m

Step 4: Planning and additional considerations

Landscape, environmental designations and heritage constraints can restrict development of wind projects, therefore the designations and other considerations, set out in Table 67: Self-supply site-finding assessment – considerations wind below, were recorded at each of the remaining NRW electricity-consuming assets. These were not applied as hard constraints but recorded for consideration at a later point, due to the much smaller scale wind self-supply opportunities.

Table 67: Self-supply site-finding assessment – considerations wind

Constraint	Explanation	Source of methodology	Source of data
Areas with designated landscapes recorded: • National Parks • Areas of Outstanding Natural Beauty	Protecting designated landscapes	Regen industry experience and Welsh Government's Toolkit for Planners and specific guidance on this issue from NRW	Lle Geo-Portal
The following environmental designations and heritage were recorded: • Local Nature Reserves	To acknowledge any potential considerations for the protection of protected flora and fauna	Regen industry experience and Welsh Government's Toolkit for Planners and specific	Lle Geo-Portal

[187] Example foundation dimensions for a Kingspan KW6 turbine were used as an indicative model, more information available online at: http://www.naturalenergyuk.co.uk/kingspan-kw6/

Constraint	Explanation	Source of methodology	Source of data
• National Nature Reserves • Ramsar sites • Scheduled Ancient Monuments • Special Areas of Conservation • Special Protection Areas • Sites of Special Scientific Interest		guidance on this issue from NRW	
Impact of nearby trees or buildings on air turbulence	Air turbulence heavily impacts on turbine efficiency and financial viability of projects	Regen experience	Visual inspection of satellite imagery
Existing renewable energy installations, potential cumulative impact	As the aim is to reduce carbon emissions by generating energy on site, it is useful to know what contribution existing renewable energy installations are already making. Reviewing whether any existing turbines are visible from a potential site is important to understand whether there is any potential cumulative impact	Regen experience	• Visual inspection of satellite imagery[188] • Regen's existing projects list for Wales, based on national datasets (feed-in tariff installation report, Renewables Obligation Register and

[188] In particular, rooftop solar and larger onshore wind turbines can often be seen on satellite imagery.

Constraint	Explanation	Source of methodology	Source of data
			BEIS Renewable Energy Planning Database) • NRW assets above 5 kW and renewable energy installations dataset received from NRW
The topography local to the site and how this corresponds with average windspeed recorded in the NOABL database	NOABL windspeed is recorded for 1 km^2. Within each 1 km^2 there can be significant variation between speeds at a hilltop and speeds at a valley bottom. Visual inspection of the topography using contours from an OS map can enable an assessment of whether or not the NOABL windspeed is an accurate representation of the site's windspeed.	Regen experience	OS Terrain 50 contour map and Bing satellite mapping, 2017 DigitalGlobe

Appendix D.3: Self-supply site-finding assessment hydropower

For hydropower, a different approach was used to solar and wind, which is based on visual inspection of mapping and satellite imagery.

Step 1: In the first instance, the locations of top-consuming NRW assets were reviewed against sites longlisted through the method to identify wider renewable energy generation potential across the estate (see Appendix F: A method for identifying standalone renewable energy opportunities), to identify if any longlisted sites were within 1 km of a top consuming asset.[189] The potential connection route to the relevant asset was assessed and any issues recorded (e.g. difficult terrain, length of connection). No NRW assets were identified within 1 km of a longlisted opportunity.

Step 2: The site-finding approaches set out in the hydro sections in Appendix F: A method for identifying standalone renewable energy opportunities were repeated to identify opportunities for small-scale hydropower on the NRW-managed estate within 500 m of a top-consuming asset. Two key changes were made to the criteria used to search for standalone opportunities to make it relevant to small-scale opportunities:

- The required head figure of 30 m was dropped for high-head sites to reflect the different economic situation of self-supply.
- The required power of the opportunity was reduced from 25 to 5 kW for the same reason.

It should be noted that reducing the thresholds for head and power means that the approach of map-based searching becomes less accurate, the degree of certainty regarding these sites is lower, and therefore these opportunities should be validated with site visits as part of any future work, which may yield different power outputs to those outlined here. One remaining self-supply opportunity for small-scale hydro was identified.

Step 3: Key features of each potential small-scale opportunity were recorded in the opportunity list, such as the potential system scale and layout and any issues regarding bank / riverbed ownership.

[189] A larger distance (1 km) was used between potential medium scale hydro resource opportunities and top-consuming assets. This is because longer connections can be feasible, for instance using higher voltages. The nature of hydro-control systems means there is a degree of scope for site-specific equipment specification, allowing slightly longer distances to be used.

8.5 Appendix E: Self-supply opportunities – site maps

The following maps show the NRW operational assets (with demand over 5 kW) identified as having a potential opportunity for renewable energy as a means of self-supply, as set out in 4.3.4.21.

These maps do not show the specific location of the renewable energy opportunities, as adding specific project locations for each of the technology opportunities would not be appropriate without further assessment of on-the-ground conditions. Locating specific opportunities would be part of the next steps recommendation to complete site visits for each of the shortlisted opportunities. However, using satellite imagery, an indicative opportunity area has been highlighted to act as a reference for future site visits. Note that for self-supply hydro opportunities specifically, the water course and/or weir has been highlighted.

Figure 26: Bwlch Nant yr Arian Visitor Centre – solar (10 kW) or wind (12 kW) opportunity

Figure 27: Coed y Brenin Visitor Centre – additional solar (5 kW) and hydro opportunity

Figure 28: Cynrig Salmon Hatchery – hydro (10 kW) and solar (10 kW)

Figure 29: Deeside Area Office (Buckley) – solar (10 kW)

Figure 30: Gwydyr Uchaf Office – hydro (10 kW)

Figure 31: North Wales Conservancy (Clawdd Newydd, Ruthin) – solar (15 kW)

8.6 Appendix F: A method for identifying standalone renewable energy opportunities

The study commissioned by the Carbon Positive Project and carried out by Regen also set out a methodology for reviewing 'standalone opportunities' on the NRW-managed estate. The method would identify medium- to large-scale standalone renewable energy generation, which could be sited on land owned or managed by NRW (i.e. within its operational control).

Due to the medium- to large-scale of such opportunities, the electricity they would generate would be for export to the grid or via private wire to a third-party electricity user with sufficient demand. These sites would present an opportunity for the NRW-managed estate to make a contribution towards renewable energy generation in Wales and associated avoided carbon emissions.

Appendix F.1: Limitations of the study

For standalone sites, the method employed is based on a resource assessment approach, not a detailed site by site assessment. In order to estimate the potential, locations were identified that might be suitable for systems using criteria applied uniformly across the area. There is no guarantee that more detailed site searches would not bring forward potential sites outside of these areas, as specific site conditions may allow for constraints to be relaxed on a site-by-site basis. For example, a hydro system in an ancient woodland might be possible if a pipe was laid over ground or along existing access track features and if the specific woodland at an intake or outfall could accept some development without effects on the integrity of the woodland as a whole.

On the other hand, as a high-level pre-feasibility resource assessment, there are site-specific considerations for each technology that cannot be included at this stage. Additional considerations would need to be applied at the more detailed feasibility assessment stage, which may mean some of the opportunities identified are not feasible. Work required may include:

- Network system operator engagement to gather detail on site connections and subsequently complete grid application requests for specific sites.
- Landscape sensitivity assessments – carrying out assessments of landscape sensitivity at the next stage of site investigation to support any Strategic Environmental Assessment and/or Environmental Impact Assessment.
- Strategic Environmental Assessment (SEA).
- Environmental Impact Assessment (EIA).
- Assessment of accessibility to the site.
- Assessment of issues of cumulative impact.

Furthermore, in taking forward any opportunities, an initial next step should be assessing the ownership of land with resource areas highlighted and the impact that the type of ownership might have on the opportunities identified.

Appendix F.2: Standalone opportunities methodology – an overview

Appendix F.2.1: Resource assessment

A resource assessment approach was developed to assess the potential for standalone renewable generation on the NRW-managed estate. Renewable resource assessment, as defined by the Practice Guidance – Planning for Renewable and Low Carbon Energy – A Toolkit for Planners (referred to as the Welsh Government Toolkit for Planners hereafter)[190] [191] is a process of using GIS software to overlay geographic information as “constraint layers to identify specific locations where certain renewable energy technologies are more likely to be deliverable and viable”. This process is referred to as “constraints mapping”.

The outcome of this process is to identify the total area of land that is potentially suitable for development. This area can then be converted to a potential installed

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[190] Practice Guidance – Planning for Renewable and Low Carbon Energy – A Toolkit for Planners, Welsh Government, http://gov.wales/docs/desh/publications/151021renewable-energy-toolkit-en.pdf
[191] Regen’s previous experience includes commissioning AECOM to produce a toolkit for planners, for local authorities in the South West of England in 2010 (now defunct). This online resource is a clear precursor to the Welsh Government’s Toolkit, also produced by AECOM.

capacity and energy output. Constraints applied are dependent on the type and scale of technology being investigated, and also included some more detailed constraints work advised by NRW. The constraints considered included:

- Roads, railway lines, housing, electricity grid lines
- Windspeed, solar irradiance, head height and flow
- Agricultural land of grade 3a and above
- Infeasible land such as steep slopes
- National air traffic and its infrastructure
- Designated landscapes
- Environmental designations
- Strategic Search Areas (SSAs)
- Woodland, including scheduled ancient woodland

Further detail on resource assessments by technology is outlined below.

Appendix F.2.2: Solar resource assessment

For ground-mounted solar, Regen played a role of industry leader in developing planning guidance and later a resource assessment approach based on best practice for planning and the method used by solar developers to search for sites. In 2010, as the first wave of solar farms were built in the south west of England, Regen developed guidance entitled “Planning for solar parks in the south west of England”[192], which built on an approach taken by Cornwall Council. Regen’s guidance note was then developed further by the Building Research Establishment into “Planning guidance for the development of large scale ground mounted solar PV systems”.[193]

Regen’s resource assessment approach for this study draws on the best practice guidance set out in these documents, such as which grade of agricultural land is suitable, supplemented by further considerations developed through direct discussions with a broad spectrum of solar developers at our Solar Developers Forum. In particular, this established the criteria for distance from homes and distance to the grid. The approach used is broadly similar to that set out in the updated version of the Welsh Government’s Toolkit for Planners, with the addition of criteria used by solar developers (such as distance to the electricity network), which provides a greater level of detail, allowing more accurate results. Regen uses this methodology in our work for other private and public clients, such as North Somerset Council[194] and Merthyr Tydfil Council (to be published).

[192] http://regensw.s3.amazonaws.com/solar_parks_event_note_november_2010_cb7bd1d625965fdf.pdf
[193] https://www.bre.co.uk/filelibrary/pdf/other_pdfs/KN5524_Planning_Guidance_reduced.pdf
[194] Resource assessment for wind and solar in North Somerset and opportunities to support the wider sustainable energy sector, Regen SW (2014) https://www.n-somerset.gov.uk/wp-content/uploads/2015/11/Regen-SW-assessment-for-solar-and-wind-technologies-in-North-Somerset.pdf

Appendix F.2.3: Wind resource assessment

The resource assessment approach used in this study for wind is based on Regen's standard resource assessment methodology, which in turn is based on national guidance and has been further developed by Regen through its work with other public and private sector clients.[195] In particular, the method draws on best practice set out in SQW Energy's Renewable and Low-carbon Energy Capacity Methodology (2010)[196] (SQW Energy methodology hereafter) and the Welsh Government's Toolkit for Planners.[197] The methodology also refers to Welsh planning policy as set out in Technical Advice Note (TAN) 8: renewable energy.[198]

Neither the SQW Energy methodology nor the Welsh Government Toolkit includes a methodology for medium-scale wind assessment (e.g. 500 kW). The approach in this study has been developed by Regen drawing on work carried out in previous studies.

Appendix F.2.4: Hydropower assessment

For hydropower, a different approach is needed to assess the potential. Although various strategic level assessments have been undertaken on a national basis, there is not a standard approach which has been adopted, with each study using a tailored approach relevant to the particular objectives of the work.[199] Although assessments such as the BHA Assessment can be used as a starting point in understanding the potential hydropower resource, they do not constitute a reliable source of viable opportunities as it is difficult to identify hydropower opportunities by simply overlaying constraint layers (as used for solar and wind assessments). The Welsh Government's Toolkit for Planners advises local authorities looking to understand the hydropower resource within their authority to find out "whether any site or area-specific feasibility studies have been carried out" and advises local authorities to look to NRW, local hydropower companies and local energy agencies as sources of information on hydropower resource.

In Regen's experience, the most effective approach to identifying potentially suitable hydropower sites is for an appropriately qualified professional to scrutinise the

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[195] Regen's previous experience in this area includes contributing to the development of the SQW Energy methodology and piloted its use in 2010 by commissioning Wardell Armstrong to produce the Wind Resource Assessment for the South West Following SQW Energy methodology. Source: Regen Wind Resource Assessment for the South West Following SQW Energy Methodology (June 2010), available online at: https://www.regensw.co.uk/Handlers/Download.ashx?IDMF=acb0d288-ac3b-42f5-adda-627dbead2dc7

[196] Renewable and Low-carbon Energy Capacity Methodology (January 2010), available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/226175/renewable_and_low_carbon_energy_capacity_methodology_jan2010.pdf

[197] Practice guidance: Planning for renewable and low carbon energy – a toolkit for planners http://gov.wales/topics/planning/policy/guidanceandleaflets/toolkit-for-planners/?lang=en

[198] http://gov.wales/topics/planning/policy/tans/tan8/?lang=en

[199]A regularly cited study is the British Hydropower Associations 2010 England and Wales resource assessment ("BHA assessment") http://www.british-hydro.org/UK%20Hydro%20Resource/England%20and%20Wales%20Resource%20Study%20Oct%202010.pdf however this study was a reworking of an earlier study by Salford University ("Salford study") http://www.howardrudd.net/files/ETSU-SSH-4063-P1.pdf and did not include a new site search from first principles. The Salford report can be seen to have patchy coverage of small-scale high head sites based on the proportion of actual hydro schemes installed since 1989 which were originally identified in the 'Salford' study.

relevant catchment looking for potentially suitable sites. As a result, the hydropower assessment for this study was specifically developed based on the extensive experience and published work of the Project Team in the development of schemes of a similar scale.[200] The approach taken was to review sites visually from topographic and ownership maps. From this, river flow was estimated via measurement of catchment area, and head via mapping using 5 m contours. NRW's hydro guidance was then used as a method for identifying the potential abstraction volumes from the total river flow.

Appendix F.3: Longlisting

Areas remaining following the resource assessment process can then be longlisted and estimates of their potential installed capacity and the generation that might result can be developed.

Appendix F.3.1: Carbon reduction benefit

Under the UK government guidance for reporting greenhouse gas (GHG) emissions (in the form of BEIS' GHG reporting – conversion factors 2017[201]), carbon benefit has been accounted for differently, depending on the two types of opportunity identified. Accountable direct carbon reduction is only applicable to renewable energy volume that is generated and directly consumed at an NRW electricity-using asset (i.e. it is not exported to the grid). This is seen as 'Grid electricity – Generation' in Table 68: Grid electricity carbon conversion factors below.

For standalone opportunities that are exporting energy to the grid, and in discussion with NRW's Carbon Positive Team, carbon benefit of these opportunities as renewable energy being provided into the system should be captured as avoided carbon emissions. The organisation developing or facilitating the opportunity (i.e. building the renewable energy installation) cannot claim this carbon benefit against their own carbon footprint, as the carbon benefit is 'owned' / 'received' by the purchaser of the energy and cannot be counted twice. However, this approach recognises the contribution made to renewable energy generation by the organisation facilitating its generation. This is shown as 'Grid electricity – transmission and distribution' in Table 68 below.

The conversion factors used to calculate carbon benefits in the site opportunity lists are shown in Table 68 below.

The "generation only" factor can be used to calculate standalone generation that is exporting its energy to the network.

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[200] Key team member Chris Elliott – https://www.linkedin.com/in/chris-elliott/, https://www.amazon.co.uk/Planning-Installing-Micro-Hydro-Systems-Installers/dp/1844075389, https://www.eiseverywhere.com/ehome/index.php?eventid=47863&tabid=81789&cid=265091&speakerid=63388&&&&

[201] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2017

The “fully delivered” factor (Generation + Transmission and Distribution) can be used to calculate the self-supply generation that NRW can claim direct benefit.

Table 68: Grid electricity carbon conversion factors

Grid Electricity Component	$kgCO_2e/kWh$	Source
Grid electricity – generation	0.35156	BEIS GHG Conversion Factors (2017)
Grid electricity – transmission and distribution	0.03287	
Grid electricity – fully delivered	**0.38443**	

Appendix F.3.2: Financial business case

The financial business case can be assessed for each opportunity. Taking project capital costs and using the calculated annual generation, annual benefits from subsidy income, energy grid export or electricity-supply cost savings (where applicable) can be calculated. Both the costs and benefits associated with opportunities can vary depending on a number of factors, including (but not limited to):

- **Cost benchmark dependencies:** generation technology, capacity (kW) and proximity to the electricity network.
- **Benefit dependencies:** generation technology, capacity (kW), annual generation (driven by capacity factors) and locational factors.

A summary of the cost benefit analysis method is outlined in Table 69: Summary of cost benefit analysis method below.

Table 69: Summary of cost benefit analysis method

Site detail	Description
Project cost benchmark (£ / kW)	Referencing a lookup table of different project cost benchmark scales, depending on the kW / MW scale of the identified opportunity
Benchmark technology cost (£)	A resultant renewable technology project cost taking the MW capacity x identified project cost benchmark
Indicative connection cost (£)[202]	An estimated grid connection cost was provided, as a scaled percentage of the benchmark technology cost, referencing the relative identified distance to the network (11 kV {SPEN only}, 33 kV, 66 kV or 132 kV), based on the following ranges: **>1 km distance = 5% of technology project costs** **>500 m, <1 km distance = 4% of technology project costs** **<500 m distance = 3% of technology project costs**
Total project CapEx cost (£)	A sum of the technology project cost and indicative connection cost, as a total capital cost for the identified project opportunity
Project O&M OpEx cost (£ / year)	Referencing a lookup table, of different project O&M benchmarks, depending on the kW / MW scale of the identified opportunity

[202] Grid connection costs and scaling factors are indicative only. In reality, there are a range of complex factors, such as network constraints and terrain, that will affect connection costs. Therefore, connection costs should be considered further on a site-by-site basis as part of any future feasibility studies.

Site detail	Description
Subsidy income (£/yr)	Referencing the suggested capacity (MW) and a lookup table of FIT income band prices (p / kWh), the annual generation (kWh) is multiplied by the July–September 2018 FIT rate[203] to provide an annual subsidy FIT income
Export income (£/yr)	The annual generation is multiplied by an indicative export value of 5 p / kWh to give an annual export income
Total benefit (£/yr)	A sum of the subsidy income and export income, as a total annual benefit
Basic payback (years)	A payback expressed in number of years, calculated as: **Payback period (years) = total project CapEx (£) / (annual benefit (£) – annual O&M cost (£)**
Non-inflated net present value (NPV) (£)	Calculated non-inflated NPV – see Glossary for definition of NPV. Basic (non-inflated) NPV was calculated over 20 years[204] using: Upfront capital costs, fixed / flat annual benefits, a discount rate of 3.5% and MS Excel in-built NPV function
Inflated payback (years)	Calculated inflated payback expressed in number of years, using inflation values as outlined below: **FIT income & O&M cost indexation of RPI – 2.5%[205]** **Electricity price escalation – 3.5%[206]** Using Excel IF logic function, the year that the costs are outweighed by the accumulated (inflated) benefits is calculated as the inflated payback year
Inflated NPV (£)	Calculated inflated NPV MS Excel spreadsheet enclosed with this report for full (in-built) NPV calculation Inflation and discount rate values used outlined below: **Project duration (all techs) – 20 years** **Discount rate – 3.5%[207]** **FIT income & O&M cost indexation of RPI – 2.5%** **Electricity price escalation – 3.5%**
Annual avoided carbon emissions (tCO_2e)	Acknowledgement of the annual avoided carbon emissions, using the annual generation (kWh) and BEIS GHG conversion factor (2017): **Generation only – 0.35156 $kgCO_2e$ / kWh** **Carbon benefit (tCO_2e) = (Energy (kWh) x 0.35156) / 1,000**

The costs identified using this method should be considered as indicative estimates of technology deployment costs and have been based on referenced industry benchmarks. It should be noted that accurate actual costs for any project taken forward may be different, due to site conditions or other key factors (time of purchase, location, contract terms, on the ground complications etc.). Any future

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203 See latest Ofgem published FIT rates for more information
204 NPV duration is set at 20 years to reflect FIT subsidy length across all technologies for consistency of analysis. In reality, renewable energy project lifetimes can be longer, but beyond 20 years, further consideration would need to be given to capital re-investment and reconditioning of plant. As such Regen considered the use of a 20-year period to be appropriate for this assessment.
205 A nominal figure referencing UK government indexation targets, see January 2017 RPI value: https://www.ons.gov.uk/economy/inflationandpriceindices/bulletins/consumerpriceinflation/jan2017
206 Set at 3.5% to reflect electricity prices likely being 1% above RPI, based on discussion with NRW and for consistency with wider Carbon Positive Project methodology (e.g. on building energy efficiency measures).
207 See UK government (HM Treasury) Green Book supplementary guidance on discounting, available online at: https://www.gov.uk/government/publications/green-book-supplementary-guidance-discounting

feasibility studies should seek to refine the cost estimates and benefits to form a detailed business case. The benefits are also to be considered as indicative estimates, based on published forecast FIT subsidy rates, estimation of export income rates and electricity offset saving rates.

Appendix F.3.3: Network connection

Opportunities can also be assessed for the potential to connect to the network, predominantly by reviewing the proximity and generation headroom capacity from the 33 kV and 11 kV network in the SPEN licence area and the 33 kV network only in the WPD licence area.[208]

Due to the relative small-scale capacity of hydro generation, assessment for the potential to connect to the 11 kV network would be the primary focus for hydro sites where spatial data is available (i.e. opportunities in the SPEN licence area). For WPD's licence area, the 11 kV network connection potential was not known, due to lack of available spatial data on WPD's 11 kV network. For hydro sites under further consideration, 11 kV network connection potential would need to be identified by NRW raising enquiries with local WPD 11 kV network planners.

Appendix F.3.4: Additional considerations

A number of additional considerations can also be captured for identified opportunities at a pre-feasibility stage, some of which may present risks in the planning process for taking forward opportunities. These additional considerations vary depending on the technology type but include:

- Designated landscapes (and any required buffer zones)
- Environmental designations (and any required buffer zones)
- Heritage sites
- Scheduled ancient woodland

Appendix F.4: Shortlisting

Following the resource assessment and longlisting process, sites can be ranked and thereby shortlisted, based on a number of high-level screening metrics. NRW specialists informed the suggested methodology for shortlisting for NRW opportunities. Alongside this, further internal consultation, e.g. with NRW landscape specialists and the Energy Delivery Team, was used to refine the criteria that can be used to create a shortlist of opportunities for each technology.

As a result of this engagement, a set of site list screens / considerations / thresholds were developed and agreed, in order to facilitate the production of shortlists of

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[208] Spatial data for WPD area was only available at 33 kV network level.

opportunities for each of the technologies to guide future feasibility work. These screens were largely the same between technologies in principle, but had subtle differences dependent on the technology and scale of technology. Criteria included:

- Environmental and landscape impact considerations
- Hydro opportunities previously identified by NRW
- Distribution network connection viability
- Non-inflated payback[209]

[209] Both simple and discounted paybacks (using discount rates) can be captured and used. Following discussion with NRW, it was agreed that the screening should be based on non-inflated payback.

Data Archive Appendix

No new data outputs were produced as part of this report.

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