Defnydd Tir a Newid yn yr Hinsawdd

Adroddiad

i

Lywodraeth Cynulliad Cymru

Mawrth 2010

Land Use Climate Change

Report

to

Welsh Assembly Government

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A) Cyflwyniad

Sefydlwyd y Grŵp Defnydd Tir a Newid Hinsawdd ym mis Mawrth 2009 er mwyn dod o hyd i ffyrdd o wneud toriadau net sylweddol mewn allyriadau nwyon tŷ gwydr yn sgil defnydd tir, amaethyddiaeth a'r gadwyn fwyd. Cafodd y Grŵp, sydd wedi cyfarfod yn reolaidd yn y misoedd cyfamserol, ei sefydlu gan, ac mae'n adrodd i, Elin Jones, y Gweinidog dros Faterion Gwledig. Mae hefyd yn is-grŵp o Gomisiwn Cymru ar Newid yn yr Hinsawdd sy'n cael ei gadeirio gan Jane Davidson, y Gweinidog dros yr Amgylchedd, Cynaliadwyedd a Thai.

Yr oedd yn eglur o'r dechrau fod cryn her yn wynebu'r Grŵp. Yn wahanol i sectorau eraill ble ceir allyriadau carbon deuocsid (CO_2) o ganlyniad i ddefnyddio tanwyddau ffosil yn bennaf, y mae dau nwy arall, sef methan (CH_4) ac ocsid nitraidd (N_2O), yr un mor bwysig. Mae cysylltiad agos rhwng y nwyon hyn a systemau cynhyrchu amaethyddol. Cyfyd y cyntaf yn sgil eplesiad enterig ym mhob anifail sy'n cnoi cil a daw'r ail o weithgarwch microbau yn y pridd sy'n gysylltiedig â defnyddio nitrogen (N) yn wrtaith i gnydau. Yn achos N_2O, sefydlwyd bod yna berthynas linol agos rhwng cynnyrch cnydau a'r N sydd ar gael, boed hynny o N organig neu anorganig neu o godlysiau sy'n bachu N. Yn achos CH_4, yr hyn sydd gennym yw hen draddodiad o amaethu yn seiliedig ar dir pori ac anifeiliaid cnoi cil ar fryniau Cymru. Y mae'r nwyon hyn i'w cael yn yr atmosffer mewn crynodiadau llawer yn is na CO_2 ond y mae iddynt, yn ôl uned o bwysau, botensial llawer mwy o ran effeithio ar yr hinsawdd. Yn anffodus mae'r sylfaen wybodaeth yn llawer llai datblygedig ar gyfer y nwyon hyn nag ar gyfer CO_2 ei hun, yn enwedig dan yr amodau a geir yng Nghymru.

Er mwyn casglu'r wybodaeth a'r arweiniad gorau posib, aeth y Grŵp ati i gomisiynu nifer o adroddiadau arbenigol yn ogystal â derbyn tystiolaeth gan amrediad eang o sefydliadau. Carwn ddiolch i bawb a ddarparodd adroddiadau a sylwadau, a hoffwn gydnabod yn gyhoeddus iddynt fynd yr ail a'r drydedd filltir er mwyn ceisio darparu'r data mwyaf dibynadwy. Oherwydd y diffyg data a geir yn y maes hwn o gymharu ag eraill, un o'r canlyniadau yw fod yr adroddiad hwn, yn ogystal ag argymell camau y dylai Llywodraeth Cynulliad Cymru eu cymryd yn y dyfodol agos iawn, yn cynnwys hefyd argymhelliad y dylid mynd ati i ddwyn ynghyd ganlyniadau ymchwil a data er mwyn gwella ac egluro'r dulliau o amcangyfrif Stocrestr yr allyriadau ar gyfer Cymru, gan gydnabod yr angen am gysondeb o fewn adroddiadau Llywodraeth y Deyrnas Unedig (DU) ar gyfer Confensiwn Fframwaith y Cenhedloedd Unedig ar Newid yn yr Hinsawdd.

O gofio'r myrdd o gymhlethdodau ac elfennau ansicr sy'n perthyn i'r sefyllfa, mynegir y prif argymhellion yn nhermau gweithredoedd a fyddai o fudd sylweddol i Gymru wledig dan fwy neu lai pob sefyllfa ac sydd, gan fwyaf, yn debygol o redeg gyda'r graen o safbwynt bywyd gwledig ac amaethyddol. Dadl yr adroddiad yw y gellir dod o hyd i lwybr tuag at fwy o gynaliadwyedd a llawer llai o allyriadau nwyon tŷ gwydr net. Er hynny, fe fydd newidiadau cronnus a ragwelir, o ran newid ymddygiad unigolion a chymunedau, a newidiadau yn y fframwaith cymdeithasol ac economaidd sy'n sail i fywyd gwledig, yn golygu newidiadau sylweddol dros y 10-20 mlynedd nesaf.

Carwn ddiolch i'r Grŵp am eu hymroddiad a'u gwaith caled, a'u hagwedd gadarnhaol at y materion enbyd dan sylw. Atgyfnerthwyd gwaith y Grŵp gan gymorth a mewnbwn Dr Havard Prosser a Dewi Jones, aelodau o staff gwyddonol a thechnegol Llywodraeth Cynulliad Cymru. Pleser neilltuol yw cael cofnodi i'r adroddiad gael ei gymeradwyo'n unfrydol gan aelodau'r Grŵp, sy'n cynrychioli amrywiaeth mawr iawn o fuddiannau amgylcheddol a defnydd tir gwledig.

Er bod yr adroddiad yn un sy'n seiliedig ar dystiolaeth ac mor gynhwysfawr â phosib, mae'r Grŵp yn ymwybodol yr erys rhagor eto i'w wneud. Yn gyntaf, mae angen mynd ati i bennu cost yr argymhellion hyn a nodi dewisiadau polisi ac ymyriadau a fyddai'n hwyluso eu mabwysiadu. Yn ail, nid yw'r Grŵp wedi llwyddo i roi sylw llawn i "ymaddasu i hinsawdd" a fydd, mae'n debyg, yn dod yn fwyfwy pwysig tuag at ganol y ganrif ond y mae gofyn ei ystyried yn awr. Yn drydydd, nid aeth y Grŵp i'r afael chwaith â materion yn ymwneud â'r glannau, gan gynnwys llifogydd a physgodfeydd, na'r berthynas rhwng yr agenda newid yn yr hinsawdd a hamdden a thwristiaeth, gan gynnwys pysgota afonydd, sy'n bwysig i'r economi wledig.

Yn olaf, mae'n bwysig cofnodi, er bod yr adroddiad hwn yn canolbwyntio o raid ar y Stocrestrau Amaethyddol a Defnydd Tir, fe fyddai ymateb cynhwysfawr i'r her fyd-eang yn golygu cynnwys pawb: cynhyrchwyr a defnyddwyr, ffermwyr ac ymwelwyr achlysurol. Ym mhob penderfyniad unigol a wnawn, gallwn ddylanwadu ar y canlyniad, tra hefyd bod yn ddibynnol ar lywodraeth ar bob lefel i fynd i'r afael â'r materion sefydliadol, diwylliannol a rheoleiddiol sy'n angenrheidiol er mwyn hwyluso newid, megis troi at drydan carbon isel a thrafnidiaeth carbon isel.

Cyflwynir yr adroddiad hwn mewn dwy ran – y gyntaf, sy'n cynnwys y Cyflwyniad hwn a'r Crynodeb Gweithredol, Argymhellion, ac Ymgysylltu, sy'n hollol ddwyieithog. Mae'r ail ran, sy'n crynhoi y dystiolaeth gwyddonol ac yn cynnwys dadansoddiad eang o'r opsiynnau a senarios, yn uniaith.

Yr Athro Gareth Wyn Jones
Mawrth 2010

B) Crynodeb Gweithredol

Y mater

Cydnabyddir bod perygl newid niweidiol yn yr hinsawdd oherwydd gweithgarwch pobl, yn enwedig y carbon deuocsid (CO_2) a ryddhawyd wrth losgi tanwyddau ffosil dros y 150 mlynedd diwethaf, yn un o'r problemau rhyngwladol mwyaf difrifol – gweler adroddiadau'r Panel Rhynglywodraethol ar y Newid yn yr Hinsawdd (IPCC) ac amryfal Brotocolau a Datganiadau. Mae llywodraeth ar lefel Cymru, y DU a'r UE wedi ymateb drwy addo cadw at dargedau uchelgeisiol i dorri allyriadau, nid yn unig CO_2 ond yr holl nwyon tŷ gwydr yn ôl 80% erbyn canol y ganrif. Ymrwymodd Cymru i ostyngiad blynyddol o 3% o 2011 hefyd. Yng nghyd-destun defnydd tir, amaethyddiaeth, coedwigaeth a chynhyrchu bwyd, y nwyon tŷ gwydr eraill sy'n bwysig yw methan (CH_4) ac ocsid nitraidd (N_2O), sydd 21 gwaith a 310 gwaith yn fwy niweidiol na CO_2 ei hun, yn y drefn honno. Gan hynny, cofnodir y data ar ffurf ffigurau 'cyfwerth â CO_2' (CO_2e) sy'n rhoi cyfrif neilltuol am y ffactorau hyn ac yn cyfuno effaith y tri nwy o ran achosi newid yn yr hinsawdd.

Ymdriniaeth

Sefydlwyd y Grŵp Defnydd Tir a Newid Hinsawdd gan y Gweinidog dros Faterion Gwledig, Elin Jones, ym mis Mawrth 2009 ac y mae'n gweithredu hefyd fel is-grŵp o Gomisiwn Cymru ar y Newid yn yr Hinsawdd dan gadeiryddiaeth y Gweinidog dros yr Amgylchedd, Cynaliadwyedd a Thai, Jane Davidson. Swyddogaeth y Grŵp yw cynghori'r Gweinidog a'r Comisiwn ar ffyrdd o gyflwyno ymrwymiad polisi Llywodraeth Cynulliad Cymru i wneud toriadau sylweddol mewn allyriadau ol gynhyrchu amaethyddol, "defnydd tir, coedwigaeth a newid mewn defnydd tir" (LULUCF) a'r gadwyn fwyd o'r "cae i'r plât". Cadeirir y Grŵp gan yr Athro Gareth Wyn Jones a daw'r aelodau o blith cynrychiolwyr buddiannau ffermio a chefn gwlad, arbenigwyr academaidd a chynrychiolwyr asiantaethau'r llywodraeth. Fe'i cefnogir gan staff technegol a gwyddonol Llywodraeth Cynulliad Cymru. Ceisiodd y Grŵp seilio ei waith dadansoddi a'i argymhellion ar y data gwyddonol gorau a'r mwyaf cadarn, a chomisiynodd nifer o adroddiadau arbenigol i fwydo i'r trafodaethau. Cyflwynir rhestr o'r cyfraniadau hyn, aelodaeth lawn y Grŵp a'r Cylch Gorchwyl yn yr adroddiad llawn.

Penderfynodd y Grŵp ar ymdriniaeth ecosystem, gan ystyried mai'r her yw sicrhau cydbwysedd parhaus y gwasanaethau hyn (sicrwydd bwyd, dŵr, bioamrywiaeth, cyfleoedd hamdden ayb) mewn ffyrdd a fydd yn bodloni'r rhwymedigaethau nwyon tŷ gwydr. Ceisiodd y Grŵp sicrhau toriadau mewn nwyon tŷ gwydr mewn ffyrdd sy'n ddigon cadarn i fodloni unrhyw reidrwydd cyfredol, yn gymdeithasol, economaidd ac amgylcheddol, yn ogystal â chaniatáu ar gyfer eu haddasu yn y dyfodol. Fodd bynnag, ni roddir ystyriaeth fanwl i'r addasu hwn yn yr adroddiad. Cyfrifir allyriadau gan ddefnyddio "Stocrestr" yr IPCC y cytunir arni'n rhyngwladol. Ar y sail hon y mae Llywodraeth y DU yn adrodd ar allyriadau i Gonfensiwn Fframwaith y

Cenhedloedd Unedig ar Newid yn yr Hinsawdd, a sefydlwyd dan Brotocol Kyoto. Bydd allyriadau'r DU yn cael eu dadgyfuno yn ffigurau ar gyfer Cymru, Lloegr, yr Alban a Gogledd Iwerddon. Cynhyrchu amaethyddol a gweithgarwch defnydd tir sy'n esgor ar fwyafrif yr allyriadau yn y Stocrestr felly ystyriaethau o'r fath sy'n cael y sylw mwyaf yn yr adroddiad hwn. Ond penderfynodd y Grŵp, o'r dechrau, y dylid gosod y rhain yng nghyd-destun ehangach defnydd tir gwledig ac ymddygiad pobl, ac y dylid ystyried potensial Cymru wledig o ran ynni adnewyddadwy, gan mai allyriadau CO_2 yn gysylltiedig ag ynni yw'r prif bethau sy'n achosi newid yn yr hinsawdd. Amlygodd y Grŵp yr angen i ymwneud â ffermwyr, tirfeddianwyr a'r cyhoedd yn gyffredinol er mwyn nodi sefyllfaoedd ble bydd 'pawb yn ennill' megis arbedion costau a gweithredoedd cymunedol, a fyddai'n symbylu newid cadarnhaol. Credid y byddai dewisiadau ag iddynt elfennau rheoleiddiol er mwyn sicrhau newid yn debyg o arwain at faterion yn gysylltiedig â chydymffurfio a negyddiaeth ymysg y cyhoedd - yn fwy felly yn yr hinsawdd sydd ohoni o ran barn y cyhoedd.

Allyriadau Cymru

Mae'r dystiolaeth bresennol yn awgrymu bod gweithgarwch amaethyddol a newid mewn defnydd tir yn cyfrannu tuag 11% at gyfanswm allyriadau nwyon tŷ gwydr Cymru - neu ffigur ~net 5,200 cilo tunnell fetrig (kt) CO_2e. O hwn, mae oddeutu 45% ar ffurf CH_4 o anifeiliaid cnoi cil (o'u tail yn ogystal â'u hallyriadau enterig) gyda chyfraniad bron yn gyfwerth o N_2O, a ryddheir yn bennaf gan ficro-organebau mewn pridd fel rhan o'r gylchred nitrogen (N). Daw'r 10% sy'n weddill o danwydd a ddefnyddir mewn gweithgarwch amaethyddol. At hyn dylid adio'r allyriadau sy'n gysylltiedig â chynhyrchu a chludo gwrteithiau ac ychwanegion amaethyddol eraill, a chyda chludo, storio, prosesu a gwerthu bwyd. Nid yw'r allyriadau olaf hyn yn ymddangos ar y "Stocrestr amaethyddol" fel y cyfryw ond fe'u tadogir i sectorau eraill megis "ynni", yng Nghymru yn ogystal ag mewn mannau eraill.

Ni cheir asesiad cadarn ei sail ar gyfer y cydrannau hyn o ran Cymru yn unig, ond yn rhyngwladol amcangyfrifir bod y gadwyn amaeth-bwyd gyfan yn cyfrannu oddeutu 18-20% o gyfanswm yr allyriadau. Ar gyfer cymeriant yng Nghymru byddai hyn yn golygu ychwanegiad pellach o tua 3,000 kt CO_2e, gan wneud cyfanswm y sector tua *c*8,200-9,000 kt CO_2e. Dylid nodi y gellir tadogi'r allyriadau i'r cynhyrchydd cynradd, sef y ffermwr yn yr achos hwn, neu i'r defnyddiwr terfynol, sef y defnyddiwr bwyd yn yr achos hwnnw. Fodd bynnag, bydd allyriadau o'r gadwyn fwyd yn cael eu dosbarthu ymysg y sectorau diwydiannol, ynni a thrafnidiaeth fel cynhyrchwyr allyriadau perthnasol, yn ogystal ag i gynhyrchwyr tramor.

Wrth osod targed o 3% o ostyngiad, roedd Llywodraeth Cynulliad Cymru yn cydnabod bod y farchnad masnachu carbon o fewn Cynllun Masnachu Allyriadau yr UE yn dylanwadu'n gryf ar tua 50% o allyriadau Cymru – cafodd yr elfennau hyn eu hepgor o darged 3% Cymru. O ganlyniad, mae'r sectorau amaethyddiaeth a defnydd tir yn cyfrannu cyfran sylweddol uwch o'r allyriadau sy'n weddill dan awdurdod neu ddylanwad uniongyrchol Llywodraeth Cynulliad Cymru ac at gyflawni'r targed hwn.

Rhaid cydnabod nad yw'r dystiolaeth feintiol sy'n cefnogi peth o'r data gwaelodol a rhai o'r dewisiadau lliniarol yn dystiolaeth gadarn. Y mae pedair prif ffynhonnell ansicrwydd:

- dulliau'r IPCC o amcangyfrif allyriadau (e.e. ansicrwydd gwyddonol cynhenid fflycsau N_2O o godlysiau)
- amheuon ynghylch allosod data yn seiliedig ar y DU i Gymru, a phrinder data ymchwil sy'n berthnasol i amodau Cymru.
- tystiolaeth sâl am effeithiau rhai ymyriadau rheoli er mwyn lleihau allyriadau.
- i ba raddau y mae lleihad yn allyriadau Cymru yn arwain at ddadleoliad i wledydd eraill.

Y mae angen brys a diamwys am well casglu data (e.e. ar newid mewn defnydd tir a'r defnydd o wrtaith yng Nghymru) a gwell dealltwriaeth wyddonol. Yn ogystal, gyda'r un brys, mae angen ymchwil wedi'i thargedu o fewn Cymru, i fwydo i polisi yn y dyfodol ac er mwyn caniatáu i'r mentrau a ddatblygir yn yr adroddiad hwn gael eu hasesu, eu profi a'u monitro.

Yn y Stocrestr, tadogir allyriadau a suddiant yn ôl nwyon i'r prif is-sectorau amaethyddol a defnydd tir, ac mae'r fflycsau mwyaf yn cael eu crynhoi yn y tabl isod. (Rhoddir y ffigurau i ddau rif ystyrlon yn unig, oherwydd ansawdd y data.)

Tabl S1 - Crynodeb o brif ffynonellau a suddfannau nwyon tŷ gwydr (kt CO_2e) y tadogir I'r is-sectorau amaethyddiaeth a defnydd tir yn y Stocrestr

		Allyriadau blynyddol yn 2007
Prif ffynonellau amaethyddol a defnydd tir	Llaeth-eidion – CH_4	1,700
	Defaid-ŵyn – CH_4	940
	Priddoedd amaethyddol – N_2O	2,200
	Tir i dir dan gnwd – CO_2	1,100
	Tir i anheddiad – CO_2	690
Prif suddfannau	Tir i goedwigaeth - CO_2	1,400
	Tir i borfa - CO_2	640

Daw'r gwerthoedd ar gyfer newid mewn defnydd tir o allosod tueddiadau hanesyddol dros nifer o ddegawdau, nid o newidiadau diweddar disymwth.

Y mae'r data gynhwysfawr ar gyfer 2007, yn cynnyws yr holl gategorïau, nid yn unig y brif rai a ddangosir uchod, yn dangos suddiad cyfredol drwyddi draw net o 200 kt CO_2e yn yr is-sector "Defnydd Tir, Newid Mewn Defnyff Tir a Choedwigaeth" (LULUCF). Fodd bynnag, dengys rhagamcanion y bydd daliadau coedwigaeth, o fewn degawd, wedi dod yn ffynhonnell allyriadau blynyddol, yn hytrach na suddfan. Er bod angen i'r Stocrestr fynd ati i wella'r modd y modelir dulliau rheoli coedwigaeth presennol, mae'n debygol bod hefyd angen rhoi cychwyn ar dechnegau newydd o reoli coedwigaeth.

O ran amaethyddiaeth, ni chynhwysir costau ynni gwrteithiau N ond gallant fod yn agos at tua 500 kt CO_2e/flwyddyn ar gyfer Cymru, er nad yw'r ffigur hwn yn cydnabod y lefelau cymharol isel o daenu gwrtaith N yn y rhan fwyaf o Gymru o gymharu ag ardaloedd lle ceir amaethu mwy dwys.

Nid oedd yn bosib dadansoddi'r gadwyn fwyd yng Nghymru fel y cyfryw, oherwydd ei bod yn gymaint rhan o system archfarchnadoedd y DU. Ond, edrychwyd ar enghreifftiau o'r mathau o fwydydd a fwyteir yng Nghymru, ac aethpwyd ati wneud dadansoddiad cylch oes rhai prif nwyddau (cig oen, llaeth a chaws, tatws a mefus) er mwyn darganfod y prif ffynonellau allyriadau o fewn y cadwynau unigol a nodi cyfleoedd i dorri proffil allyriadau'r prif nwyddau. Mae amrywiaeth mawr yn yr allyriadau gros am bob kg neu am bob uned o gymeriant, gydag allyriadau CH_4 ar y fferm y mwyaf o ddigon yn achos y proffiliau mawr ar gyfer cig oen a llaeth/caws. Ar y llaw arall, yn yr allyriadau ar gyfer y proffil tatws, er bod ôl troed eithaf mawr ar gyfer Cymru oherwydd y cymeriant uchel, daw'r gyfran amlycaf o du CO_2 yn sgil cludiant oer, storio a choginio.

Gwelodd y Grŵp fod potensial ynni adnewyddadwy cynhyrchion, cymunedau ac ardaloedd gwledig yn arwyddocaol am ddau reswm, sef eu perthnasedd uniongyrchol i'r sectorau amaethyddol a choedwigaeth, ac yn ail oherwydd eu potensial fel ffordd i'w gosod yn erbyn allyriadau nwyon tŷ gwydr gwledig a chenedlaethol. Yn y dyfodol, mae'n bosib y bydd swyddogaeth ehangach gan ynni adnewyddadwy yn yr economi wledig ac y gall gynyddu pa mor abl fydd Cymru i wrthsefyll digwyddiadau annisgwyl yn y farchnad ynni ryngwladol.

Senarios ar gyfer lleihau allyriadau

Bu'r Grŵp yn ystyried pum senario, a byddai pob un yn adeiladu ar nifer o doriadau ar sail effeithlonrwydd fyddai'n fanteisiol; a manylir arnynt yn y prif adroddiad. Cyflwynir pob senario ar wahân, ond mewn gwirionedd maent yn gorgyffwrdd a gellir eu cyflwyno yn raddol dros gyfnod o amser. Gellir trosglwyddo elfennau o un i'r llall.

Senario 1

Mae hon yn seiliedig ar ffurf o "fusnes arferol" wedi'i haddasu, gyda gwelliannau technegol cynyddol yn trosglwyddo at ostyngiadau mewn allyriadau o rhwng 10-15% erbyn 2020. Mae'r gwelliannau hyn yn seiliedig ar set uniongyrchol o enillion effeithlonrwydd megis defnydd effeithlon o wrtaith N, a gwell hwsmonaeth da byw a allai, ac a ddylai, arwain at ostyngiadau manteisiol i bawb mewn allyriadau ar gyfer pob uned o gynnyrch marchnadwy. Ond, ar y cyfan, ni fydd parhau â'r systemau presennol a'r defnydd tir cyfredol yn arwain at gyflawni targedau Llywodraeth Cynulliad Cymru i leihau allyriadau. Mae'r Grŵp yn cydnabod, er y gallai darganfyddiadau gwyddonol newydd ddod i'r fei, y byddai'r rheiny'n hynod annhebygol o gael eu mabwysiadu yn ddigon eang er mwyn bodloni amserlen sy'n galw am newid erbyn 2020 neu hyd yn oed 2030. Felly, er mwyn cael y toriadau sylweddol sydd eu hangen mewn allyriadau, rhaid wynebu dewisiadau neu, fel sy'n hynod debygol, fe ddaw allyriadau CH_4 ac N_2O yn ganran gynyddol o'r cyfanswm cenedlaethol gydag effaith niweidiol ar lwyddiant poisi yn gyffredinol.

Senario 2

Senario a yrrir gan y farchnad yw hon. Fe'i seilir ar ehangu'r marchnadoedd masnachu carbon presennol i'r sector hwn ac i gynnwys yr holl nwyon tŷ gwydr perthnasol. Fel arall, gallai marchnad newydd ymddangos trwy gyflwyno dogni nwyon tŷ gwydr i unigolion, a fyddent wedyn yn gyfrifol am ddewis sut i ddefnyddio eu dyraniad. Wedyn byddai'n rhaid i ffermio yng Nghymru ymateb i'r marchnadoedd newydd hyn. Byddai'r lleihad mewn allyriadau a geid trwy'r senario hon yn cael eu gyrru'n gryf gan bris allyriadau yn y dyfodol.

Senario 3

Mae hon yn seiliedig ar orfodi toriadau mawr o tua 60-70% yn niferoedd yr anifeiliaid cnoi cil, fel y cynigiwyd gan Ganolfan Tyndall fel rhan o becyn o fesurau i weld lleihad o 6-9%/flwyddyn mewn cyfraddau allyriadau ar gyfer Cymru. Mae'r senario yn seiliedig ar ostyngiadau llym yn niferoedd anifeiliaid cnoi cil, gan eu bod yn brif gyfranwyr at allyriadau nwyon tŷ gwydr yn y sector defnydd tir, yn ogystal â bod yn ffynonellau cynnyrch llaeth a chig coch sy'n cael eu gweld yn niweidiol i iechyd y cyhoedd.

Senario 4

Dyma senario llai dwys, a fyddai'n seiliedig ar systemau ffermio cymysg eang, yn gwneud y mwyaf o effeithlonrwydd adnoddau trwy gynhyrchu porthiant ar y fferm, a defnyddio llai o wrtaith. Byddai'r lleihad yn y mewnbynnau yn cael ei gydbwyso gan lai o alw am gynnyrch anifeiliaid drwy gostyngiad yn y cymeriant, a llai o wastraff yn y gadwyn fwyd. Yn aml, gwelir perthynas rhwng systemau o'r fath a chadwyni bwyd lleol sydd wedi'u gwella'n sylweddol, a mwy o hunanddibyniaeth, ac fe'u hystyrir yn rhai sy'n gwella cynaliadwyedd amgylcheddol a chymdeithasol gydag amser.

Senario 5

Mae'r senario hon yn gysylltiedig â'r cynnig y dylai Cymru ymdrechu i gynnal ei photensial o ran cynhyrchu bwyd ond tra'n lleihau allyriadau. Byddai hyn yn golygu cyflwyno technolegau nad ydynt yn rhai cyffredin yng Nghymru, er eu bod yn gyffredin mewn mannau eraill, yn ogystal â chadw rhai systemau traddodiadol sef rhai ucheldir yn bennaf. Byddai angen ffyrdd, yn ddelfrydol yn seiliedig ar y farchnad, o reoli allyriadau anifeiliaid mewn systemau eang, ond yn y senario hon byddai Cymru yn ffynhonnell cynnyrch cig a llaeth o ansawdd uchel yn ogystal â rhagor o gnydau llysiau mewn byd ble mae prinder bwyd yn dechrau dod i'r amlwg. Ystyrir bod parhau i fasnachu bwyd (allforio yn ogystal â mewnforio) a masnachu mewn mwenbynnau eraill i'r gadwyn fwyd yn hanfodol i'r senario hon ond yn ddibynnol ar ddod o hyd i'r ffynhonnell nwyddau neu eitemau sydd â'r ôl troed carbon lleiaf.

Byddai nifer o'r senarios yn gwneud y pethau canlynol hefyd, er yn gwneud rhain i wahanol raddau a chyda gwahanol gymysgedd o adnoddau:

- mynd ati'n bwrpasol i fanteisio ar y potensial ynni adnewyddadwy gwledig ar gyfer trydan, gwres a bio-nwy.
- yn golygu cynlluniau sylweddol i blannu coetiroedd yn ogystal â gwell rheolaeth ar y coedwigoedd presennol.
- yn ceisio cyflwyno arallgyfeirio i'r economi wledig, ond mewn gwahanol ffyrdd.

Aseswyd pob senario yn erbyn y meini prawf canlynol:

- eu potensial i gyflwyno'r toriadau mawr sydd eu hangen yn brydlon er mwyn bodloni targedau lleihau allyriadau Cymru. Sef:
    - erbyn 2050 sicrhau toriad o 80% sy'n cyfateb i gyrraedd cyfanswm allyriadau sectoraidd blynyddol net o oddeutu 1,650 kt CO_2e o'r holl system fwyd, neu 1,040 kt CO_2e o'r allyriadau hynny a adroddir yn y Stocrestrau Amaethyddiaeth a LULUCF.
    - o leiaf ostyngiad o 3% mewn allyriadau o'r linell sylfaen, sef cyfanswm allyriadau cyfartalog Cymru yn 2006-2010, hynny yw 3% o tua 48,700 kt CO_2e, sy'n 1,461 kt CO_2e/flwyddyn. O hyn byddai angen I ryw 160-280 ktCO_2e ddod o'r sectorau mae'r adroddiad yma yn ymwneud a hwy. Yn ychwanegol mynegwyd dyhead yn adroddiad "Ffermio acv Amgylchedd Cynaliadwy: Camau Ymlaen at 2020" i weld Cymru wledig yn "garbon-niwtral" erbyn 2020.
- eu potensial o ran cyflwyno lleihad mewn allyriadau a adroddir yn Stocrestr yr IPCC.
- eu gallu i helpu i gyflwyno'r targedau ynni adnewyddadwy.
- eu gallu i gyflwyno gwell cynaliadwyedd yn economaidd, ddiwylliannol, gymdeithasol ac amgylcheddol ac i leihau risg.
- eu gallu i ddiogelu a chynnal yr holl amryfal wasanaethau ecosystem, heb fod yn niweidiol i opsiynau addasu y dyfodol.
- eu dichonoldeb economaidd a gwleidyddol.
- gan gredu bod cydweithio yn hanfodol er mwyn gweithredu polisi yn llwyddiannus, pa mor dderbyniol ydynt i'r gymuned wledig – yn enwedig tirfeddianwyr a rheolwyr tir.
- eu gallu i wrthsefyll effeithiau o ran sicrwydd bwyd, ynni a newid yn yr hinsawdd yn ôl y rhagolygon ar gyfer canol yr 21ain ganrif.
- eu gallu i wneud cyfraniad cadarnhaol tuag at y cyflenwadau bwyd ac ynni sydd ar gael yn fyd-eang, a chyfyngu ar y nwyon tŷ gwydr 'mewnol' a fewnforir gennym.

Dyma asesiad y Grŵp o'r gwahanol senarios:

- Senario 1 – ystyrid hon yn gam cyntaf rhesymegol y dylid ei weithredu, ond ni fyddai'n cyflawni'r gostyngiadau angenrheidiol er mwyn cyrraedd y targedau.
- Senario 2 – roedd yn anodd ei gwerthuso oherwydd nad oes gwybodaeth ddigonol am bris carbon y dyfodol, a fyddai y gyrrwr economaidd ar gyfer

lleihau allyriadau. At hynny, mae'r ffaith na ddaethpwyd i gonsenswS rhyngwladol yn Copenhagen yn cymylu'r mater.

- Senario 3 – nid ystyrid hon yn senario ymarferol, o gofio dibyniaeth amaethyddiaeth yng Nghymru ar systemau tir pori, manteision cymharol y newid yn yr hinsawdd i Gymru o ran cynhyrchu bwyd, y rhwystrau cymdeithasol ac economaidd a'r tebygolrwydd y dadleolir allyriadau i systemau cynhyrchu i rywle arall yn y byd.
- Senario 4 – roedd yma rai elfennau y dylid eu hasesu yn nhermau dichonoldeb a'u hymgorffori yn senario 5.
- Senario 5 (a rhai nodweddion o Senarios eraill) - y farn oedd mai dyma'r ffordd orau bosibl ymlaen er mwyn bod ar y llwybr cywir tuag at y targed lleihau allyriadau nwyon tŷ gwydr. Roedd y Grŵp yn cydnabod yr heriau mawr sy'n gysylltiedig ag arloesedd technolegol a'r buddsoddiad angenrheidiol, yn ogystal â'r angen i ystyried yr effeithiau ar yr holl wasanaethau ecosystem gan gynnwys bioamrywiaeth.

Y Senario a argymhellir gan y Grŵp

Mae'r senario a argymhellir (Senario 5) yn cynnwys pum prif elfen a nifer o elfennau ategol:

1. <u>Llaeth a chynnyrch eidion cysylltiol a threuliad anerobig (AD)</u>

   Byddai allyriadau CH_4 o dail a slyri o'r fuches laeth a'r cynhyrchu cig eidion sy'n gysylltiedig â hynny yn llai, yn gyntaf wrth i AD gael ei gyflwyno'n gyflym a chynhwysfawr. Dros gyfnod o amser, y cynllun fyddai datblygu system yn gyfan gwbl dan do heb bori ar dir sydd o safon uwch. Er mwyn ehangu faint o CH_4 a gesglir a faint o ynni a gynhyrchir, byddai'r bio-nwy o AD yn cael ei ategu gan dechnolegau sy'n cael eu datblygu a fyddai'n sgwrio'r CH_4 enterig o'r siediau. Byddai llai o allyriadau amonia oherwydd y sgwrio hefyd yn cynorthwyo i leihau dyddodiad N ac allyriadau N_2O o'r pridd - ffactor mawr, o bosib, ond heb ei ddiffinio'n briodol. Er mwyn lleihau allyriadau CO_2e perthynol, dylai'r AD gael ei ymgorffori hefyd yn rhan o reoli gwastraff bwyd a gwastraffau eraill. Gellid defnyddio'r bio-nwy a'r gwres a gynhyrchid gan yr anifeiliaid ar gyfer amryfal weithgareddau, megis gwahanol fathau o gyfarpar amaethyddol (e.e. tractorau bio-nwy) a garddwriaethol, neu weithgareddau masnachol eraill yn ôl y safle a'r cyfleoedd sydd ar gael. Byddai'r cynnyrch a dreulid yn cael ei ddefnyddio fel gwrtaith o ansawdd da gyda chyfraddau allyriadau N_2O is o bosib - mae hyn eto i'w brofi dan yr amodau a geir yng Nghymru. Byddai cyflwyno'r technolegau hyn yn creu gwaith ychwanegol yng Nghymru wledig. Gellid gwneud y gorau hefyd o ddefnydd N. O weithredu hyn yn llawn, gellid torri allyriadau'r sector tua 1,500 kt CO_2e gan gynnwys arbedion trwy ddefnyddio bio-nwy yn lle rhywfaint o'r tanwydd a ddefnyddir yn y sector amaethyddol.

2. <u>Rheoli ac ehangu coetiroedd.</u>

   Argymhellir ehangu coetiroedd dros gyfnod o 20 mlynedd o tua 100,000 ha o'r 284,000 ha a geir ar hyn o bryd. Coetir collddail fyddai'r coed ychwanegol yn bennaf ond gyda chyfran o rywogaethau conwydd ar gyfer defnydd terfynol a pharhad o ansawdd uchel. O ran tarddiad, coed wedi ymaddasu ar gyfer yr hinsawdd a ragfynegir fyddai'n cael eu defnyddio, a byddai'r plannu yn digwydd bron yn gyfan gwbl ar briddoedd ucheldir asid, gwael o ran ffrwythlondeb, gan gynnwys llethrau dan redyn. Byddai menter o'r fath yn creu suddfan sylweddol ychwanegol o 1,600 kt CO_2e o nwyon tŷ gwydr yn flynyddol erbyn 2040, gyda suddiad net o 1,200 kt CO_2e, a photensial pellach ar gyfer tanwydd coed - efallai 1.4 TWh/flwyddyn erbyn 2030-2040, i osod yn erbyn 350 kt CO_2e arall o danwyddau ffosil. Dylai cynaeafu cynhyrchion coed ddisodli defnyddiau uchel mewn ynni, megis dur a choncrit. Gallai nodweddion megis rhagor o gynefinoedd, cadwraeth harddwch naturiol, gwell rheolaeth ar adnoddau dŵr a llifogydd, a chreu gwaith a chyfleoedd hamddena newydd fod yn fuddion eraill. Yn ychwanegol, dylai Comisiwn Coedwigaeth Cymru gyflwyno cynlluniau i sicrhau nad yw'r daliadau cyhoeddus a phreifat presennol yn troi'n ffynhonnell flynyddol o nwyon tŷ gwydr ac y rheolir coedwigoedd Cymru er mwyn gwneud y mwyaf o'u gallu i leihau nwyon tŷ gwydr yn y tymor hir. Yn fyr, rhaid i goedwigoedd presennol ac estyniedig, boed yn eiddo cyhoeddus neu breifat, gael ei rheoli er mwyn darparu ffynhonnell gynaliadwy o goed tanwydd a phren ynghyd â gwasanaethau a chynhyrchion eraill, gan gynnwys bod yn suddfan garbon net yn y tymor hir.

3. <u>Gwella cynhyrchiant ar y fferm.</u>

   Mae'r elfen yma yn rhagweld cadw defaid a gwartheg pori eang ar yr ardaloedd ucheldir a thir canol – sef tir gradd 3 a gradd 4 yn bennaf – ond gyda gwelliannau yn yr hwsmonaeth. Gan gadw at y tueddiadau cyfredol, byddai cynnyrch cig oen yn cael ei gynnal tra byddai allyriadau'r sector defaid yn cael eu lleihau tua 20% (h.y. ~200 kt CO_2e). Gellid cyflawni hyn trwy gyfrwng ffactorau megis gwell canran wyna, a chynyddu hyd oes y mamogiaid fel na fyddai angen stoc bridio newydd mor aml. Byddai ystyriaethau tebyg yn perthyn i gynhyrchu cig eidion eang, er ei bod hi'n anos gwneud enillion o ran nwyon tŷ gwydr. Fodd bynnag, o ran lleihau'r allyriadau yn gyffredinol, mae'n hollbwysig nodi y byddai enillion nwyon tŷ gwydr, a wnaed trwy well hwsmonaeth ac effeithlonrwydd, yn cael eu tanseilio petai cynnydd yn niferoedd defaid neu wartheg.

4. <u>Ynni adnewyddadwy.</u>

   Yn ychwanegol at y bio-nwy a'r tanwydd coed a nodir uchod, y mae yng Nghymru wledig (y tybir ar gyfer yr ymarferiad hwn i fod â phoblogaeth o tua 0.8-1 miliwn) adnoddau ar gyfer cynhyrchu ynni adnewyddadwy trwy gynlluniau hydro graddfa fechan, gwynt, biomas pwrpasol, solar - gwres a ffotofoltaidd (PV) – a gwres yn tarddu o'r ddaear. Aseswyd yr adnoddau hyn a'u hamcangyfrif yn fras fel a ganlyn:

   - potensial pŵer hydro sylweddol o 0.3 TWh/flwyddyn o drydan o leiaf yn ucheldir Cymru.
   - ynni gwynt cymunedol neu bersonol o tua 1 TWh/flwyddyn o drydan.
   - mae potensial blynyddol gwres solar o dai unigol yn sylweddol ond ni ellir rhoi ffigur arno.

- biomas o reoli coetiroedd, lleiniau cysgodi, a chnydau biomas yn cynhyrchu 3 TWh/flwyddyn o ynni gwres; neu 1/3 o hyn ar ffurf trydan.
- echdynnu gwres o'r fuches odro yn cyfateb i 330 GWh/flwyddyn o wres, y gellid ei ddefnyddio mewn mentrau cnydau garddwriaethol wedi'u gwarchod.
- solar – PV o tua 0.03 TWh/flwyddyn o drydan.
- byddai rhywfaint o fio-nwy ychwanegol yn cael ei gynhyrchu trwy driniaeth AD ar wastraff bwyd.

Y mae cyfanswm yr adnodd hwn, er yn arwyddocaol - yn enwedig yn nhermau cynhyrchu ynni gwres - yn parhau'n gymedrol mewn perthynas â galw blynyddol Cymru o 125-130 TWh. Y mae'n bwysig nodi hefyd mai ffynonellau ysbeidiol yw'r rhan fwyaf o'r rhain, ond y bydd proffiliau blynyddol eu hallbynnau uchaf yn wahanol i'w gilydd. Dan y senario a argymhellir, gallai'r adnodd cyfan godi i fod rywle tua 3 TWh o drydan, a 3 TWh o wres bob blwyddyn. Byddai hyn yn cyfateb i leihad yn allyriadau nwyon tŷ gwydr Cymru o tua 1,500-2,000 kt CO_2e bob blwyddyn (~4%) - ar sail y cymysgedd cyfredol o ffynonellau ynni. Gellid trawsnewid rhan o'r adnodd gwres a bionwy yn drydan ar effeithlonrwydd o tua 30% - mwy mewn systemau gwres a phŵer ar y cyd.

Bydd enillion economaidd ar gyfalaf yn dibynnu ar y ffynhonnell a'r lleoliad. Yn ddiweddar, cyhoeddodd yr Adran Ynni a Newid Hinsawdd dariffau newydd ar gyfer Tariffau Bwydo i Mewn (FIT) yn cychwyn yn Ebrill 2010. Mae angen datrys materion yn ymwneud â'r gost a pha mor hwylus yw'r cysylltedd trwy Weithredwyr Rhwydwaith Dosbarthu. Mae'r Grŵp yn argymell yn gryf y dylid cynnal astudiaeth fanwl o'r materion hyn ar frys, ar y cyd â pholisi clir i wneud y mwyaf o botensial Cymru. Gallai'r tariffau FIT newydd fod yn atyniadol yn economaidd yn ogystal ag yn amgylcheddol, a darparu llif incwm ychwanegol ar gyfer rhannau o Gymru wledig.

5. <u>Newid yn y galw am fwyd, ffibr ac ynni – effeithlonrwydd, gwastraff a ffordd o fyw</u>

Mae'n eithaf posib fod yna gysylltiad pwysig rhwng annog micro-gynhyrchu ynni gwasgaredig a gwell rheolaeth ar ynni a gwastraff. Mae'r cynhyrchu gwasgaredig yn debygol o gynyddu cyfrifoldeb unigolion, teuluoedd a chymunedau ac felly gallai esgor ar gynnydd sylweddol o ran effeithlonrwydd ynni wrth i bobl geisio sicrhau'r enillion gorau posib o'u buddsoddiad. Gallai effaith o 50% ar effeithlonrwydd ynni mewn cartrefi arbed 4-5 TWh yn ychwanegol. Yn y cyd-destun hwn dylai ymgyrch Llywodraeth Cynulliad Cymru i sicrhau effeithlonrwydd wrth ddefnyddio ynni gynnwys gwneud safiad cadarnhaol wrth gyflwyno'r seilwaith ar gyfer bio-nwy dan wasgedd, cerbydau trydan (EV) a cherbydau EV 'plygio-i-mewn' gan y gallant wneud defnydd o danwyddau a gynhyrchir yn lleol.

Rhoddwyd pwyslais ar well effeithlonrwydd, llai o wastraff, a rheolaeth â gwell ffocws, o fewn yr is-sectorau amaethyddol a choedwigaeth. Mae casgliadau tebyg yn gymwys ledled y gadwyn fwyd ac yn ein rôl ni, bob un ohonom, fel defnyddwyr. Bydd gwastraff yn digwydd o ganlyniad i golledion yn dilyn cynaeafu, wrth brosesu, ac wrth manwerthu.

Amcangyfrifir bod gwastraff bwyd o gartrefi tua 25%. Mae rhywfaint ohono yn anorfod (e.e. crwyn tatws a phlisgyn wyau) a rhaid i unrhyw gadwyn fwyd fod ag elfen o fwyd dros ben rhag ofn y bydd problemau gyda chyflenwadau a bwyd yn difetha. Ond gellir lleihau llawer ar y gwastraff ac mae nifer o fentrau ar y gweill yng Nghymru i wella cyflenwadau lleol.

Mae i'r holl agenda diet/cyflenwadau bwyd oblygiadau enfawr o ran datblygu cynaliadwy ac o ran ôl troed ecolegol Cymru yn gyffredinol. Mae ymborth pobl wedi newid yn sylweddol, gan fynd ymhell y tu hwnt i ddarparu maeth a lefelau calorïau sylfaenol. Mae cydblethiad agos rhwng ein diet, ein ffyrdd o fyw a'r rheolaeth sydd gennym ar ein hamser personol. Sefydlwyd cysylltiad rhwng diet gormodol a gormod o fwyd braster-uchel gyda nifer sylweddol o farwolaethau cynnar y gellid eu lleihau petai dietau "iach" yn y DU yn cadw at ganllawiau maethyddol. Mae rhywfaint o'r baich iechyd hwn wedi'i gysylltu â bwyta cynhyrchion cig a llaeth. Serch hynny ceir tystiolaeth dda hefyd fod bwyta llai o gig na'r lefelau a argymhellir yn rhyngwladol yn gallu arwain at gymeriant elfennau hybrin hanfodol (e.e. haearn) a rhai fitaminau, sydd o dan lefelau a argymhellir. Yn fyd-eang, mae mwy o gynhyrchion cig a llaeth yn cael eu bwyta wrth i gyfoeth gynyddu, ond mewn gwledydd datblygedig y cyngor iechyd clir i'r cyhoedd yw lleihau faint a fwyteir ohonynt. Gellir sicrhau buddion i'r amgylchedd ac i iechyd trwy fwyta llai.

Mae'r Grŵp yn ystyried ei argymhellion yn gwbl gydnaws â galwadau am well dietau yng Nghymru a'r DU. Ar hyn o bryd, mae tua 95% o gig oen Cymru yn cael ei allforio. Os bydd gostyngiad yn y galw am gig oen yng Nghymru ei hun bydd angen dod o hyd i farchnadoedd bach ychwanegol yn lle hynny, ond mae'r rheiny'n debygol o fodoli yn sgil y datblygiadau a nodir uchod ac o fygythiadau i ardaloedd lled gras y byd. Gyda'i glawiad uchel a'r hinsawdd dymherus mae mantais gymharol gan Gymru o ran tyfu bwyd yn effeithlon o fewn systemau tir pori. Dylai'r cynigion ar gyfer ehangu'r cadwynau bwyd tymhorol lleol a chnydau tŷ gwydr a garddwriaethol ychwanegol ayb gyfrannu at wella diet yn ogystal ag ymwybyddiaeth y defnyddiwr.

Yn ychwanegol at y prif gydrannau, mae ymyriadau pwysig eraill yn cael eu hargymell neu eu rhagweld:

- rhagor o gynhyrchu cnydau garddwriaethol a thŷ gwydr yn rhannol er mwyn manteisio ar wres "gwastraff" ond hefyd i annog mwy o gadwynau bwyd lleol a thymhorol.
- cydnabod ein cyfrifoldebau byd-eang, gan ymdrechu i leihau faint o ddwysfwyd anifeiliaid a fewnforir yn ogystal â mewnbynnau eraill sydd ag ôl troed uchel o ran nwyon tŷ gwydr.
- byddai'n dilyn y ceid rhywfaint o arwynebedd âr ychwanegol, gan olygu cynnydd bach yn yr allyriadau nwyon tŷ gwydr yn y Stocrestr, ond gyda buddion eraill. Fe fydd yn bwysig monitro'r effaith net eang ar yr holl allyriadau yn ogystal â'r sefyllfa leol yng Nghymru; er enghraifft, mae'n bosib bod ôl troed llai gan fewnforion o ardaloedd sydd eisoes yn cynhyrchu grawn (e.e. East Anglia) na thrwy gynhyrchu o'r newydd yn lleol.

- technegau i ddiogelu a chynnal carbon yn y pridd mewn glaswelltiroedd trwy ffermio confensiynol ac organig.
- er mwyn cynnal y stociau carbon mewn mawn ucheldir ac iseldir, dylai fod yna gytundebau rheoli ar gyfer pob ardal o'r fath.

Un o'r materion mwyaf enbyd a nodwyd gan y Grŵp yw'r angen hanfodol am well data, ymchwil â ffocws pendant, a phrosiectau peilot. Gellir dosbarthu'r gofynion hyn fel a ganlyn:

- ymchwil i fodelu, profi a dilysu dichonoldeb technegol ac effeithiau'r systemau cynhyrchu esblygol.
- dadansoddiad trwyadl o gostau a buddion economaidd, amgylcheddol a chymdeithasol yr opsiynnau a argymhellir, hy "dull llinell gwaelodol driphlyg". Argymhellir y dylid mynd i'r afael â hyn ar unwaith.
- asesiad manwl o ddewisiadau polisi er mwyn nodi'r ffyrdd gorau o ysgogi newidiadau mewn arferion rheoli ac ymddygiad, er mwyn troi'r potensial technegol yn arfer. Mae profiad cyflwyno gwelliannau technegol ym myd ffermio yn dangos bod ymgymryd â dulliau newydd yn broses heriol oni bai y gyrrir y broses honno gan reoleiddio neu gymhellion sylweddol eraill.
- ehangu ymchwil ar wasanaethau ecosystem yng nghyd-destun y senario a argymhellir a rhagfynegiadau o ran newid yn yr hinsawdd, a rhoi prawf ar weithredoedd / ymyriadau posib eraill (ee fflycsau net yr holl nwyon tŷ gwydr mewn systemau organig). Fe fydd angen mynd ati hefyd i asesu'r effaith *net* eithaf, a sicrhau yr ystyrir dewisiadau polisi yn nhermau enillion cyffredinol. Fe fydd yn bwysig ceisio adnabod canlyniadau "anfwriadol" yn yr asesiad hwn.
- ymchwil i leihau'r ansicrwydd mawr wrth amcangyfrif allyriadau N_2O ynghyd â gwell casglu a chaffael data, fel y gellir cofnodi allyriadau Cymru yn fwy cywir o fewn y Stocrestr nwyon tŷ gwydr. Mae problem allyriadau N_2O yn bryder gwirioneddol.
- datblygu methodoleg Stocrestr sy'n fwy sensitif er mwyn olrhain polisïau a rhaglenni sy'n ceisio lleihau allyriadau.

Yn nhermau polisi a gweithredu mae yna amrywiaeth o faterion ynghylch rheoli gwastraff, tynnu dŵr a rheoli datblygu (cynllunio) y mae angen eu dadansoddi er mwyn dod o hyd i ffyrdd o hwyluso twf prosiectau micro-gynhyrchu adnewyddadwy. Mae angen dadansoddi mecanweithiau cefnogi yr UE a rhai cenedlaethol hefyd, a gweithredu er mwyn gostwng y rhwystrau presennol sy'n atal gweithredu prosiectau.

Casgliadau'r Grŵp

I grynhoi, fe allai'r senario a amlinellir uchod, erbyn 2040, petai'n cael ei gweithredu'n llawn, leihau allyriadau net y sector o 5,200 kt CO_2e i tua 2,000 kt CO_2e – byddai cyfran sylweddol o'r allyriad sydd ar ol ar ffurf N_2O. Un elfen hanfodol yn hyn o beth yw rheoli coetiroedd mwy er mwyn cael suddfan nwyon tŷ gwydr yn y tymor hir. Byddai'r senario yn cynnwys cynhyrchu tua 3 TWh o wres adnewyddadwy a 3 TWh o drydan adnewyddadwy hefyd. Byddai hyn yn gosod yn erbyn 1,500-2,000 kt pellach o allyriadau CO_2e bob blwyddyn - petai'n disodli'r cymysgedd ynni presennol a ddaw o'r ffynonellau ynni. Gellir cymharu hyn gyda'r amcangyfrif o 3,000 kt CO_2e yr asesir y dylid ei dadogi i'r sector fwyd. At hynny, dylai ynni adnewyddadwy gwasgaredig godi ymwybyddiaeth y cyhoedd ynghylch blaenoriaeth cynyddu effeithlonrwydd ynni a lleihau gwastraff. Drwodd a thro y mae'n cynnig y posibilrwydd o wneud toriadau o'r maint sydd eu hangen.

Gallai datblygiadau gwyddonol (ee mecanweithiau i leihau allyriadau N_2O, neu fridiau o anifeiliaid cnoi cil sydd ag allyriadau isel) ychwanegu enillion pellach ond ni ddylid tybio y bydd hyn yn digwydd. Fe fydd gallu'r sector i wneud ei gyfraniad llawn at y targed o ostyngiad blynyddol o 3% yn dibynnu ar ba gyfradd y mabwysiadir yr argymhellion a geir yn yr adroddiad hwn.

Byddai'r cynigion yn creu cynefin coetir ychwanegol, a allai yn ei dro wella rheolaeth ar lifogydd ac ansawdd dŵr. Byddai hyn yn gwarchod llawer ar gymeriad y tirwedd, a thrwy annog rhywfaint o dir âr ychwanegol (gan gynnwys tir na fyddai'n cael ei drin), byddai cynefinoedd tir ffermio ychwanegol yn cael eu creu, petai'r cyfan yn cael ei reoli'n ofalus. Mae angen astudio effaith amgylcheddol cynhyrchu porthiant heb bori, felly hefyd faterion perthynol hwsmonaeth ac iechyd anifeiliaid mewn systemau dan do. Fodd bynnag, dylai gwell rheolaeth ar slyri fod yn llesol i gyrsiau dŵr.

Dylai'r ymdriniaeth hon greu swyddi ychwanegol a chryfhau cymunedau, mentrau cymdeithasol a diwylliant Cymreig. Fe fydd angen mynd ati ar frys i ddatblygu sgiliau a'r sail adeiladu a gweithgynhyrchu er mwyn manteisio ar botensial micro-gynhyrchu, cynhyrchu cnydau garddwriaethol newydd a rhai tŷ gwydr (ar sail y ffynonellau gwres ychwanegol) a gwell cynhyrchion coedwigaeth.

I grynhoi, mae'r Grŵp o'r farn fod yr argymhellion yn disgrifio trywydd, yn seiliedig ar botensial technegol eithaf y systemau presennol, ond gan gydnabod y bydd technoleg a blaenoriaethau gwleidyddol ac economaidd yn rhwym o newid yn y 30 mlynedd nesaf. Erys sawl agwedd ar ymyrraeth polisi ac ariannu heb eu datrys ac mae angen rhagor o ddadansoddi manwl. Ond, erbyn 2040, gallai Cymru wledig gyflawni toriadau net mawr yn eu hallyriadau nwyon tŷ gwydr, sef toriadau o tua 70-80%, gyda mwy o gynaliadwyedd a chan adael Cymru yn fwy abl i wrthsefyll digwyddiadau annisgwyl rhyngwladol. Fodd bynnag, nid oes unrhyw ragolygon y gellir sicrhau niwtraliaeth nwyon tŷ gwydr erbyn 2020 trwy gyfrwng unrhyw senario, oherwydd y datblygiadau technegol sylweddol sy'n angenrheidiol mewn systemau ffermio. Fe fydd hi'n cymryd amser i ddulliau lleihau sy'n addawol ar hyn o bryd i symud o fod yn dreialon arbrofol at rai sy'n weithredol. At hynny, byddai rhaglen blannu coed a fyddai'n dechrau nawr yn cymryd rhwng 2-3 degawd cyn cyrraedd ei gallu llawn o ran amsugno carbon.

Ceisiodd y Grŵp gyflwyno ei asesiad gorau, gan fod yn gwbl ymwybodol o ddiffyg data hanfodol, barn gyhoeddus anghyson a blaenoriaethau sy'n cystadlu a'u gilydd. Ond, yn y pen draw, dadl y Grŵp yw y gellir nodi trywydd cadarnhaol i'w droedio, a bod symud ar hyd y trywydd hwn yn peri llai o risg na gwneud dim.

C Argymhellion

Gweithredoedd gan Lywodraeth Cynulliad Cymru

1 *Asesu Economaidd:* ychwanegu at yr adroddiad hwn trwy fynd ati ar fyrder i archwilio costau a buddion mabwysiadu (neu beidio â mabwysiadu) y cynigion hyn, gan fanylu ar eu cyfraniadau at yr economi wledig ac at dargedau trydan adnewyddadwy ac ynni gwres, yn ogystal ag o ran hyfywdra cymdeithasol a'r holl wasanaethau ecosystem.

2 *Ymwybyddiaeth a chynnwys y cyhoedd:* rhoi cychwyn ar ddeialog o bwys ledled Cymru wledig er mwyn gwella dealltwriaeth o faterion newid yn yr hinsawdd a dangos sut y gall pob unigolyn, cymuned a busnes gynorthwyo i ymateb i'r her fyd-eang, yn enwedig trwy newidiadau mewn ffordd o fyw er mwyn gwneud defnydd mwy effeithlon o adnoddau ac osgoi gwastraff. Un llwybr yw trwy gyfrwng Canolfan Datblygu Newid yn yr Hinsawdd Cyswllt Ffermio.

3. *Coedwigaeth:* mynd ati ar fyrder i ddatblygu cynlluniau manwl ar gyfer ehangu'r coetiroedd / coedwigaeth presennol o tua 100,000 ha dros yr 20 mlynedd nesaf trwy blannu amrywiaeth o goed collddail brodorol, sydd wedi ymaddasu'n dda i'r senario newid hinsawdd gymedrig, a chonwydd, yn ogystal â rhywfaint o adfywhad naturiol. Dylai'r rhain gael eu plannu ar briddoedd asidig ucheldir yn ogystal ag ar dir dan redyn, ond gan osgoi tir mawnog.

4. *Coedwigaeth:* sicrhau bod y daliadau presennol, yn rhai cyhoeddus - Comisiwn Coedwigaeth (FC) - a phreifat yn cael eu rheoli mewn modd sy'n gwneud y mwyaf o'u potensial i weithredu fel suddfannau nwyon tŷ gwydr yn ogystal â bod yn ffynhonnell gynaliadwy ar gyfer tanwydd coed a chynhyrchion coed eraill, sy'n ffurfio "suddfannau carbon" tymor hir a/neu y gellir eu defnyddio yn anuniongyrchol yn lle tanwyddau ffosil.

5. *Priddoedd / mawn:* sicrhau na chymerir unrhyw gamau a allai danseilio'r storfeydd carbon mewn mawnogydd ucheldir a chorsydd a gweunydd iseldir.

6. *Amaeth-amgylchedd:* sicrhau bod cyfarwyddebau Glastir yn gyson o ran yr angen i leihau allyriadau nwyon tŷ gwydr.

7. *Hwsmonaeth anifeiliaid:* rhoi cefnogaeth er mwyn i'r holl dail/slyri o'r fuches odro a systemau cig eidion/lloi perthynol gael ei brosesu trwy dreuliad anerobig (AD) a manteisio ar y potensial o ran bio-nwy.

8. *Hwsmonaeth anifeiliaid:* mynd ati gyda'r diwydiant llaeth ac eidion i archwilio'r posibilrwydd o fabwysiadu systemau heb bori er mwyn lleihau allyriadau methan (CH_4) ac ocsid nitraidd (N_2O) i'r eithaf, ac i fanteisio ar botensial bio-nwy dan wasgedd. Mae angen asesu effeithiau dim pori (cynaeafu porfa) ar fioamrywiaeth a gwasanaethau ecosystem eraill.

9. *Hwsmonaeth anifeiliaid / gwastraff bwyd:* hyrwyddo'r synergedd gorau rhwng AD slyri/tail a gwastraffau eraill (na ellir eu defnyddio'n fwy effeithlon) o'r gadwyn fwyd – gwastraffau o brosesu, dosbarthu a

defnyddwyr – trwy gydweithio â phroseswyr bwyd, adwerthwyr mawr ac awdurdodau lleol.

10. *Hwsmonaeth anifeiliaid:* annog gwell effeithlonrwydd o fewn y sectorau llaeth, eidion a defaid er mwyn lleihau allyriadau nwyon tŷ gwydr am bob uned o allbwn cynhyrchu a sicrhau toriadau yn yr allyriadau.

11. *Agronomeg*: annog gwneud y defnydd mwyaf effeithlon o nitrogen (N) trwy reolaeth yn ôl arferion gorau ar wrteithiau, tail a biosolidau.

12. *Agronomeg:* annog cynnydd yn y sector garddwriaeth / tŷ gwydr o ran manteisio ar ffynonellau gwres adnewyddadwy.

13. *Effeithlonrwydd y gadwyn fwyd:* defnyddio adnoddau'r Bartneriaeth Cynghori ar Fwyd a Diod a'r Grŵp Defnydd Tir a Newid Hinsawdd (LUCCG) i nodi a gweithredu gwelliannau wrth ddefnyddio adnoddau rhwng y ffermwr a'r defnyddiwr, trwy leihau gwastraff a defnydd ynni wrth brosesu ac yn y gadwyn ddosbarthu a thrwy addysgu'r defnyddiwr yn well.

14. *Ynni adnewyddadwy:* hyrwyddo holl elfennau potensial Cymru (wledig) o ran ynni adnewyddadwy mewn lleoliadau priodol a sicrhau bod unrhyw rwystrau o ran gweithredu a chyswllt â'r grid yn cael eu lleihau ar fyrder.

15. *Ynni adnewyddadwy:* hyrwyddo amrywiaeth o blannu coed er mwyn creu ffynhonnell ynni gwres adnewyddadwy yn gyfraniad sylweddol at ynni adnewyddadwy o'r sector gwledig.

16. *Ynni adnewyddadwy:* gweithio gyda diwydiant er mwyn sicrhau y gwneir defnydd o fio-nwy dan wasgedd mor fuan â phosib, a cherbydau a chyfarpar 'plygio-i-mewn'/hybrid yng Nghymru wledig a'r gadwyn fwyd.

17. *Gallu ymchwil:* gweithio gyda sefydliadau perthnasol a darparwyr ymchwil er mwyn sicrhau y gweithredir yr agenda ymchwil, ac y gellir cyflawni'r rhwymedigaethau a'r dyheadau mewn perthynas â newid yn yr hinsawdd a defnydd tir.

18. *Gallu llywodraethol:* sicrhau bod yno'r gallu, yr arbenigedd, y cyllid a'r dylanwad i gyflawni'r rhwymedigaethau a'r dyheadau mewn perthynas â newid yn yr hinsawdd a datblygu cynaliadwy, a'i fod yn datblgu ei bolisïau yn unol â gofynnion hinsawdd.

19. *Gallu llywodraethol:* sicrhau bod rheolau cynllunio yn cael eu llunio er mwyn hwyluso sefydlu systemau cynhyrchu ynni adnewyddadwy gwledig, yn amodol ar ddiogelu'r amgylchedd a pharch at adeiladau rhestredig.

20 *Cyfrifoldeb llywodraethol:* comisiynu adroddiad ar fecanweithiau yr ymaddasu i newid yn yr hinsawdd sy'n debygol o fod ei hangen yn y sector defnydd tir erbyn 2040 a thu hwnt.

Gwella'r Stocrestr

Cyfeirir yr argymhellion canlynol at Lywodraeth Cynulliad Cymru, ac at y Ganolfan Ecoleg a Hydroleg (CEH), sef y contractwyr presennol sy'n amcangyfrif allyriadau Stocrestr ar gyfer "defnydd tir, newid mewn defnydd tir a choedwigaeth” (LULUCF), ac at North Wyke Research (NW Research) sy’n gyfrifol am amcangyfrif allyriadau amaethyddol.

21 *Cyfuno amcangyfrifon:* CEH a NW Research i gyfuno eu dulliau a’u hamcangyfrifon yn fwy agos, er enghraifft ar allyriadau N_2O o briddoedd.

22 *Ystadegau newid mewn defnydd tir:* Llywodraeth Cynulliad Cymru a CEH i fireinio amcangyfrifon cyfredol ar gyfer newid mewn defnydd tir yng Nghymru trwy gyfuno canlyniadau model yr Arolwg Cefn Gwlad (CS) gydag ystadegau ar wir newid mewn defnydd tir er mwyn olrhain newid mewn defnydd tir gydag amser – gan ddefnyddio data ystadegau amaethyddol, data Stocrestr y Goedwig Genedlaethol a data am aneddiadau.

23 *Gwrthdroi newid mewn defnydd tir:* CEH i ddatblygu'r model ar newid mewn defnydd tir er mwyn gallu rhoi cyfrif am newidiadau o chwith ac asesu’r effeithiau net o safbwynt allyriadau.

24 *Ystadegau defnydd tir cylchdroi cnydau:* CEH i archwilio dosbarthu hyn yn fath o ddefnydd tir ar wahân, yn hytrach na chynnwys newidiadau aml rhwng gwahanol fathau o ddefnydd tir.

25 *Arferion rheoli o fewn categorïau defnydd tir:* CEH i asesu ffyrdd o gynnwys arferion amaeth-amgylchedd sy’n ceisio gwella’r mater organig mewn pridd, neu arloesi ym maes rheoli coedwigaeth, a’r defnydd o gynhyrchion coed wedi’u cynaeafu sy’n dod yn lle’r defnydd o danwyddau ffosil.

26 *Carbon mewn pridd:* CEH a’i is-gontractiwr Forest Research, i benderfynu ar y ffyrdd gorau o fodelu priddoedd mewn coedwigoedd o blith y modelau sydd ar gael ar hyn o bryd.

27. *Aneddiadau:* CEH i roi prawf ar ei dybiaethau cyfredol o ran newidiadau yn y carbon mewn pridd ar gyfer tir a drawsnewidir yn dir ar gyfer aneddiadau, ar sail gwella ei ddata am newidiadau yn y carbon mewn pridd.

28. *Rhagfynegi allyriadau:* CEH i sicrhau ei fod yn seilio ei ragamcanion ar gyfer allyriadau hyd at 2050 ar senarios polisi Llywodraeth Cynulliad Cymru ar gyfer newid mewn defnydd tir, a chymharu hynny â thueddiadau hanesyddol.

29 *Allyriadau amaethyddol:* Llywodraeth Cynulliad Cymru i gydweithio gydag Adran yr Amgylchedd, Bwyd a Materion Gwledig a Gweinyddiaethau Datganoledig eraill ar y prosiect ymchwil: “*Agriculture GHGI Enhancement*” er mwyn datblygu’r dulliau o olrhain allyriadau wrth i ddulliau newydd o reoli systemau ffermydd gael eu cyflwyno i leihau allyriadau - yn arbennig:

- datblygu amrediad cywirach o ffactorau allyrru ar gyfer CH_4 ac N_2O.
- datblygu ffactorau allyrru CH_4 ar gyfer amryfal systemau ffermio anifeiliaid cnoi cil, bridiau, dietau ac ychwanegion (ee effeithiau dietau ucheldir ar gyfer anifeiliaid cnoi cil).

- datblygu ffactorau allyrru N_2O ar gyfer amryw o gyflyrrau pridd a hinsawdd, mathau o briddoedd, mathau o gnydau a rheoli ffermydd/tir (ee systemau da byw ucheldir o gymharu â rhai iseldir).

30. *Defnydd gwrtaith:* Llywodraeth Cynulliad Cymru i gasglu ystadegau ar gyfer Cymru er mwyn rhoi amcangyfrif cywirach yn lle'r ystadegau a allosodir o rai ar gyfer y DU.

Ymchwil

Cyfeirir yr argymhellion canlynol at Lywodraeth Cynulliad Cymru, y rhai sy'n ariannu ymchwil a sefydliadau ymchwil:

31. *Dilysu astudiaethau arbrofol:* cynnal treialon graddfa-fawr ar ffermydd er mwyn profi pa mor dda y mae newid y diet yn lleihau allyriadau nwyon tŷ gwydr uniongyrchol ac anuniongyrchol, o anifeiliaid cnoi cil o gymharu â than amodau labordy.

32. *Swyddogaeth y rwmen:* ymchwilio rhagor i'r wyddoniaeth sylfaenol ar bwrpas y rwmen a'i addasu, yn enwedig er mwyn lleihau colled ynni o borthiant.

33. *Geneteg anifeiliaid:* ymchwilio rhagor i'r nodweddion sy'n lleihau allyriadau nwyon tŷ gwydr megis amrywiadau rhwng ac o fewn bridiau.

34. *Bwydydd anifeiliaid:* gwella dealltwriaeth o botensial gwahanol fwydydd anifeiliaid i gynhyrchu CH_4 a throsglwyddo'r wybodaeth hon i ffermwyr.

35. *Systemau ffermydd ucheldir:* asesu effeithiau amgylcheddau bryniau ac ucheldir ar allyriadau CH_4 - ble gall planhigion brodorol yn y diet newid yr eplesiad yn y rwmen gan leihau faint o CH_4 sy'n cael ei gynhyrchu.

36. *Allyriadau N_2O mewn priddoedd:* ymchwilio i'r ffactorau allweddol sy'n dylanwadu ar fflycsau cyfansoddion nitrogen mewn priddoedd, monitro fflycsau allyriadau dan amryw o amodau rheoli gan gynnwys systemau ffermio organig a rhai confensiynol, a nodi dewisiadau newydd ar gyfer lliniaru.

37. *Casglu CH_4 a systemau dan do*: ymchwilio i ddichonoldeb technegol cadw buches odro/eidion dan do gyda system gasglu CH_4 – gan roi ystyriaeth i iechyd a lles yr anifail, gofynion amgylchedd rheoledig, arbedion nwyon tŷ gwydr dros gylch oes, effeithlonrwydd adnoddau a thechnegau ymarferol casglu nwy.

38. *Cynnyrch ar ôl treuliad anerobig:* asesu ei werth fel gwrtaith a'r allyriadau N_2O wrth ei roi ar y tir.

39. *Da byw a gwasanaethau ecosystem*: datblygu dadansoddiad cliriach o werth (cadarnhaol a negyddol) da byw cnoi cil o ran cyflenwi gwasanaethau ecosystem – bwyd, ffibr, carbon mewn pridd, dŵr, bioamrywiaeth, a thirwedd.

40. *Dadansoddiad Cylch Oes (LCA):* datblygu'r ymagwedd a ddefnyddir wrth ddadansoddi effaith ymyriadau ar LCA o ran bwydydd eraill, er

mwyn llunio darlun llawnach o'r allyriadau nwyon tŷ gwydr ar sail diet, a'r ymyriadau a fydd yn arwain at leihau allyriadau.

41. *LCA:* datblygu dadansoddiad mwy soffistigedig o werth maethyddol gwahanol gynnyrch bwyd o gymharu â'u hallyriadau nwyon tŷ gwydr, yn hytrach nag asesu yn ôl uned o bwysau'r cynnyrch.

42. *Systemau Ffermio Organig:* cynnal dadansoddiad fflwcs cynhwysfawr ar gyfer systemau cynhyrchu organig a rhai confensiynol, er mwyn darganfod yr LCA yn gyffredinol ar gyfer cynhyrchion ffermydd Cymru.

43. .*Stociau carbon mewn priddoedd:* gwella'r amcangyfrifon o effaith symud o un defnydd tir at un arall (ee glaswelltir i goedwigaeth) o ran storio carbon yn y pridd, yn enwedig o ran y math o bridd, trwy gyfrwng arolygon caeau wedi'u targedu.

44. *Rheoli glaswelltir:* meintioli effeithiau gwahanol dwysterau pori a'r math o bori, ac effeithiau ailhadu tir pori yr iseldir (mecanwaith pwysig er mwyn gwella cynhyrchiant), ac effeithiau dulliau o drin y tir ar allyriadau nwyon tŷ gwydr.

45. *Rheoli glaswelltir:* bridio mathau newydd o borfa sy'n gwella storio carbon dan y ddaear.

46. *Dulliau trin y tir:* i asesu a yw'r ffaith fod mwy o ddefnydd organig yn y pridd oherwydd bod llai o drin ar y tir, yn cael ei osod yn erbyn y cynnydd mewn allyriadau N_2O, ac effaith draenio o ran lleihau allyriadau N_2O trwy gynnal amodau aerobig yn y pridd.

47. *Ail-wlychu mawn:* monitro fflwcsiau yr *holl* nwyon tŷ gwydr a'r colledion carbon wedi hydoddi ar yr un pryd yn yr un lleoliadau er mwyn pennu y potensial net o ran cynhesu byd-eang (hy pob mewnbwn ac allbwn sydd ei angen er mwyn cwblhau cyllideb nwyon tŷ gwydr llawn).

48. *Coedwigo:* asesu'r effeithiau ar stociau carbon yn y pridd mewn priddoedd organig gydol y cylch oes, gydag angen neilltuol i asesu dulliau newydd o reoli megis rheoli a chynaeafu coedwigaeth gorchudd parhaus.

49. *Modelu carbon mewn pridd:* datblygu'r model carbon mewn pridd, ECOSSE, ar gyfer dalgylchoedd cynrychioliadol gan ddefnyddio categorïau llystyfiant manylach a data creiddiol am bridd, ar y cyd â gwell amcangyfrifon ar gyfer cynnyrch cynradd net llystyfiant fel y gellir mynd ati'n annibynnol i roi prawf ar newidiadau yng nghyfraddau amsugno carbon y priddoedd. Yn y dyfodol dylid ehangu ECOSSE-2 gan lunio cyswllt rhwng y model hwnnw a model LCA fel y gellir cyfrifo'r gwerthoedd allyrru nwyon tŷ gwydr cyfan "o'r crud i'r bedd" (ee yn sgil cludiant, gwastraff ayb).

Ch) Ymgysylltu

Mae Cylch Gorchwyl y Grŵp yn cynnwys yr amcan hwn:

“Codi ymwybyddiaeth ymysg rhanddeiliaid ar bob lefel ynghylch effeithiau y newid yn yr hinsawdd mewn ardaloedd gwledig trwy gyfrwng rhwydweithiau gwybodaeth sydd eisoes yn bodoli a/neu rwydweithiau newydd; helpu i ddatblygu a hyrwyddo ymatebion priodol i newid yn yr hinsawdd a chyfrannu at weithredu strategaeth gyfathrebu am newid yn yr hinsawdd ar gyfer rheolwyr tir”.

Er mwyn i’r strategaeth a amlinellir yn y ddogfen hon lwyddo, rhaid iddi ddod i gael ei derbyn yn eang gan y cyhoedd; yn allweddol, wrth gwrs, rhaid iddi gael ei derbyn o fewn cymunedau ffermio, perchen tir a defnydd tir, ond hefyd yn fwy cyffredinol gan y diwydiant bwyd, y sector manwerthu a chennym ni oll fel defnyddwyr. Gellir tadogi allyriadau naill ai i’r cynhyrchydd neu i’r defnyddiwr terfynol – felly rydym oll yn gyfranogwyr, o safbwynt allyriadau nwyon tŷ gwydr o ddefnydd tir a’r gadwyn fwyd, ym mhob pryd a fwyteir gennym. Yn yr un modd, ar bob siwrnai a wneir gennym, ym mhob peth a brynwn, neu bob baddon neu gawod a gymerwn, rydym yn gwneud dewisiadau sy’n effeithio ar y newid yn yr hinsawdd. Y mae’r dewisiadau hyn, yn eu tro, yn bwydo’n ôl yn economaidd a chymdeithasol at gynhyrchwyr y nwyddau neu’r gwasanaethau; yn achos yr adroddiad hwn, maent yn dychwelyd drwy’r gadwyn fwyd a chadwynau eraill at yr economi wledig.

Priodolir yr argymhellion ar gyfer lliniaru nwyon tŷ gwydr gan gydnabod y pethau canlynol:

- y bydd gyrwyr uniongyrchol, ac eithrio’r newid lleol yn yr hinsawdd fel y cyfryw, yn hynod ddylanwadol am y degawd nesaf o leiaf - yn enwedig costau ynni.
- fe fydd y gyrwyr hyn, yn ffodus, yn arwain at gamau gweithredu ac ymyriadau (ee mwy o ynni adnewyddadwy mewndarddol, ehangu coetiroedd, gwell rheolaeth ar dail a slyri a gwastraff) sy’n fuddiol i’r agenda ehangach ar liniaru’r newid yn yr hinsawdd.
- cyfyngir ar bwerau gorfodi pob llywodraeth (oni bai y derbynnir ar goedd ei bod yn gyfnod o ryfel) mewn cymdeithas ddemocratig rydd.
- mae pwerau Llywodraeth Cynulliad Cymru yn fwy cyfyngedig na rhai llywodraeth y DU, er y gallai hyn newid dros y cyfnod dan sylw yn yr adroddiad hwn.
- gallai diwygio o du Polisi Amaethyddol Cyffredin yr UE weithredu fel gyrrwr pellach y tu hwnt i’r cynllun Glastir cyfredol i ariannu mesurau lliniarol.
- ni all Cymru a’r Cymry eu gosod eu hunain ar wahân i fygythiadau byd-eang a dylent chwarae rhan gadarnhaol, er rhan gymharol fechan, o ran ymateb i’r heriau byd-eang hyn trwy gyfrannu at gynhyrchu bwyd a pheidio â dadleoli allyriadau i wledydd eraill.
- tra bo newid yn yr hinsawdd yn fygythiad enfawr ac o bosib yn fygythiad dinistriol i nifer o gymunedau (ee ynysoedd isel yng nghefnfor y Pasiffig, delta afon Nîl a nifer o ranbarthau cras), yng Nghymru wledig y mae’n

cynnig cymaint o gyfle ag o fygythiad, gan y gall ffyrdd newydd o feddwl a gweithredu gyfuno mesurau lliniaru ac ymaddasu ac esgor ar gyfleoedd economaidd newydd a chyfleoedd newydd o ran ennill bywoliaeth.

Er mwyn gwireddu'r potensial hwn, rhaid i ddinasyddion, sefydliadau a llywodraeth gydweithio.

O fewn y DU, mae'r cyhoedd rywfaint yn llai parod i dderbyn yr achos gwyddonol dros newid buan a niweidiol yn yr hinsawdd, o ganlyniad yn rhannol i'r "wasgfa gredyd", amheuaeth ynghylch newid hinsawdd, diffyg arweiniad gwleidyddol cryf a dim cytundeb yn y trafodaethau yn Copenhagen. Mae'r amheuaeth yn waeth byth yn sgil nifer fechan o wallau ym 4^{ydd} adroddiad y Panel Rhynglywodraethol ar y Newid yn yr Hinsawdd, ond yn fwy arwyddocaol efallai, yn sgil dau haf gwael a dau aeaf cymharol oer (er mai prin y gellir eu cymharu â'r gaeafau oer ar ganol yr 20^{fed} ganrif). Mae anwadalrwydd yn y tywydd wedi cyfuno â thueddiadau hinsoddol tymor hir, felly bydd unrhyw haf gwael yn cael ei ystyried yn dystiolaeth o blaid y rhai sy'n "ymwrthod" â syniad newid hinsawdd, a phob trychineb o ran hinsawdd (e.e. y gwres mawr yn Ewrop yn 2003 neu amryfal gorwyntoedd neu stormydd) yn cael eu cyflwyno fel prawf digamsyniol bod trychineb ar ddod. Y mae'r Grŵp Defnydd Tir a Newid Hinsawdd (LUCCG) hwn wedi'i argyhoeddi fod y dadansoddiad gwyddonol sylfaenol yn gywir ac y bydd y nwyon tŷ gwydr sy'n cronni yn achosi newid yn yr hinsawdd yn fyd-eang, ond y mae'r Grŵp yn cydnabod hefyd fod llawer o'r manylion yn parhau'n aneglur o ran sut y bydd y newid hwn i'w deimlo yng Nghymru a thu hwnt. Nid yw hyn yn golygu bod llai o angen gweithredu ar fyrder, gan fod y bygythiad byd-eang mor fawr a'r amser sydd ei angen i wneud y newid enfawr gofynnol mor hir. Y mae synnwyr cyffredin a phwyll cyffredin, fel ei gilydd, yn dweud y dylid gweithredu ar fyrder.

Mater o bryder yw nodi fod rhai yn gwrthwynebu ar y sail y bydd grymoedd y farchnad yn datrys y problemau i gyd, er gwaethaf tystiolaeth helaeth o du trafferthion y banciau buddsoddi na ddigwydd hynny. Hefyd, er bod Adroddiad Stern* yn dadlau i'r gwrthwyneb, y mae rhai'n parhau o'r farn ei bod yn rhatach a mwy cost effeithiol canolbwyntio ar ymaddasu i'r newid yn yr hinsawdd, a'i bod yn well mynd ati i'n gwneud ein hunain yn fwy abl i'w wrthsefyll trwy gyfrwng buddsoddiadau eraill (e.e. darparu dŵr glân, gostwng tlodi byd-eang, gwell gofal iechyd).

Mae'r ffactorau gwleidyddol a seicolegol hyn yn pwysleisio'r angen am ymwneud â'r cyhoedd yn gadarnhaol a phwyllog ar bob lefel ac ym mhob ffordd.

Mae gan yr LUCCG swyddogaeth benodol o ymgysylltu â'r gymuned wledig ac mae disgwyl y bydd yn gweithio gyda Llywodraeth Cynulliad Cymru,

* N Stern: The Economics of Climate Change: the Stern Review. Cambridge University Press 2007

Comisiwn Cymru ar y Newid yn yr Hinsawdd a nifer o gyrff eraill i greu trafodaeth genedlaethol wybodus. Yn arbennig, fe fydd rhaglen weithredu yn rhan o'r Strategaeth ar y Newid yn yr Hinsawdd gyda chryn bwyslais ar gyfathrebu. Cydnabyddir yn eang na fydd atebion technegol ynddynt eu hunain yn arwain at ddigon o leihad mewn allyriadau, ac y bydd gofyn i bob sector o gymdeithas newid ymddygiad er mwyn cyflawni'r amcanion. Bydd angen i gyrff a sefydliadau edrych ar eu harferion a'u hymddygiad hefyd, a chwalu'r rhwystrau at lai o allyriadau.

Mae'r LUCCG yn awgrymu'r camau penodol canlynol:

- cyhoeddi fersiwn byr dwyieithog, gyda darluniau, o'r adroddiad hwn i'w ddosbarthu'n eang mewn cymunedau gwledig ac i ffermwyr a thirfeddianwyr (gellid ystyried paratoi fersiwn ar gyfer y cyhoedd yn gyffredinol hefyd).
- trefnu cyfres o gyfarfodydd rhanbarthol gyda sefydliadau ffermwyr er mwyn esbonio casgliadau ac argymhellion yr adroddiad hwn.
- cyfres o gyfarfodydd rhanbarthol gyda sefydliadau megis Merched y Wawr, Sefydliad y Merched, grwpiau masnachol ayb.
- hybu'r brand "Helpu Cymru i Leihau ei Hôl Troed Carbon" er mwyn dangos yr ôl troed wrth gynhyrchu bwyd.
- gweithio gyda'r Panel Cynghori ar Fwyd a Diod ynghylch lleihau gwastraff yn y sectorau prosesu, dosbarthu a gwerthu bwyd.
- fideo byr a/neu gyflwyniad PowerPoint.
- adroddiad yn ôl gan Lywodraeth Cynulliad Cymru i'r LUCCG ar y cynnydd o ran yr argymhellion ymchwil.
- ymgynghori â chynhyrchwyr teledu er mwyn sefydlu prosiect i adnabod a gwobrwyo cymunedau gwledig yng Nghymru sydd fwyaf llwyddiannus o ran lleihau eu hôl troed nwyon tŷ gwydr.
- annog ffermwyr i ddadansoddi eu hôl troed carbon - gan ddefnyddio, yn ddelfrydol, dull cyffredin.
- annog micro-gynhyrchu gwasgaredig fel buddsoddiad personol – fe fydd hyn yn gwneud mwy nag unrhyw beth i hyrwyddo effeithlonrwydd ynni.
- dylid cymeryd camau o wella 'r wybodaeth o ymarfer gorau mewn llefydd eraill ar dir mawr Ewrop (ee dirprwyaeth ar y cyd o ffermwyr a cynllunwyr i ymweld â sefydliad treulio anaerobig).

Section 1

A) Introduction

The Land Use and Climate Change Group was established in March 2009 to find ways to make major net cuts in greenhouse gas emissions for land use, agriculture and the food chain. The group, which has met regularly in intervening months, was set up by and reports to Elin Jones, Minister of Rural Affairs. It is also a sub-group of the Climate Change Commission for Wales, which is chaired by Jane Davidson, Minister for Environment, Sustainability and Housing.

It was clear from the outset that the Group faced a formidable challenge. Unlike other sectors where carbon dioxide (CO_2) emissions from fossil fuel use dominate, two other gases, methane (CH_4) and nitrous oxide (N_2O), are equally important. Both these gases are intimately linked with agricultural production systems. The former arises from enteric fermentation in all ruminant animals and the latter from soil microbial activity associated with nitrogen (N) fertilisation of crops. In the latter case it is well established that there is a close linear relationship between crop yield and N availability, be that from organic or inorganic N or from nitrogen-fixing legumes. In the former we are dealing with a long established tradition of pastural, ruminant-based agriculture on the Welsh hills. These gases are present in the atmosphere in much lower concentrations than CO_2 but have, per unit weight, a much greater climate forcing potential. Unfortunately the information base for these gases is less developed than for CO_2 itself, especially in Welsh conditions.

In order to get the best possible information and guidance, the Group commissioned a number of expert reports as well as taking evidence from a wide range of organisations. I would like to thank all those who provided reports and comments and would wish to acknowledge, publicly, that they went the second and third mile to try and provide the most reliable data. One consequence of the relative data poverty is that this report, as well as making recommendation for Welsh Assembly Government actions in the immediate future, also recommends research and data collation in order to improve and clarify the methods for estimating the emissions Inventory for Wales, recognising the need for consistency with the reports of the UK Government to the UN Framework Convention on Climate Change.

Given the myriad complexities and uncertainties, the main recommendations are couched in terms of actions which would have substantial benefits to rural Wales under virtually all conditions and which are, for the most part, likely to run with the grain of rural and agricultural life. The report contends that a path to greater sustainability and greatly reduced net greenhouse gas (GHG) emissions can be identified. Nonetheless, the cumulative changes envisaged in both individual and community behaviour and in social and economic framework underpinning rural life will be substantial over the next 10-20 years.

I would like to thank the Group for their dedication and hard work and their positive attitude to the formidable issues being addressed. The Group's work has been enormously strengthened by the assistance and inputs of Dr.

Havard Prosser and Dewi Jones, members of the scientific and technical staff of the Welsh Assembly Government. It is a particular pleasure to record that the report has been endorsed unanimously by members of the Group, representing a very wide range of environmental and rural land use interests.

Although the report is as comprehensive and evidence-based as possible, the Group is conscious that much more remains to be done. In the first place, work is required to cost out these recommendations and to identify policy options and interventions that will facilitate their adoption. Secondly, the Group has not comprehensively addressed “climate adaptation” which will, in all likelihood, become of increasing importance towards mid-century but must be considered now. Thirdly, the Group has not addressed either coastal issues, including flooding and fisheries, or the relation of the climate change agenda to recreation and tourism, including river fishing, which are important in the rural economy.

Finally it is important to record that, although this report is focussed *per force* on the Agricultural and Land Use Inventories, a comprehensive response to the global challenge involves everyone: producers and consumers, farmers and casual visitors. In all our individual decisions we can influence the outcome, while also being dependent on government at all levels to address the institutional, cultural and regulatory issues required to facilitate change, such as the adoption of low-carbon electricity and low-carbon transport.

This report is presented in 2 sections – the first, comprising this Introduction and the Executive Summary, Recommendations, and Engagement, is fully bilingual. The second section, which summarises the scientific evidence and contains a more extensive analysis of the options and scenarios, is monolingual.

Professor Gareth Wyn Jones
March 2010

B) Executive summary

The issue

The risk of damaging climate change, driven by human activity especially carbon dioxide (CO_2) released by fossil fuel burning over the last 150 years, is recognised as one of the most pressing international problems - see Intergovernmental Panel on Climate Change (IPCC) reports and various Protocols and Declarations. Government at the Wales, UK and EU levels have responded by pledging ambitious targets to cut emissions not only of CO_2 but of all greenhouse gases (GHGs) by 80% by mid-century. Wales has also committed to an annual 3% reduction from 2011. In the context of land use, agriculture, forestry and food production, the other important GHGs are methane (CH_4) and nitrous oxide (N_2O), respectively 21 fold and 310 fold more damaging than CO_2 itself. Data are therefore recorded as CO_2 equivalents (CO_2e) which specifically take these factors into account and integrate the global climate forcing impact of all three gases.

Approach

The Land Use Climate Change Group was established by the Minister for Rural Affairs, Elin Jones, in March 2009 and it also serves as a sub-group of the Climate Change Commission for Wales chaired by the Minister for Environment, Sustainability and Housing, Jane Davidson. The Group's role is to advise the Minister and the Commission on ways to deliver the Welsh Assembly Government policy commitment to making major cuts in emissions from agricultural production, "land use, forestry and land use change" (LULUCF) and the food chain from "field to plate". The Group is chaired by Professor Gareth Wyn Jones with membership drawn from representatives of farming and countryside interests, academic specialists and representatives of government agencies. It is supported by technical and scientific staff of the Welsh Assembly Government. The Group sought to base its analyses and recommendations on the best and most robust scientific data and commissioned a number of expert reports to inform its discussions. A list of these inputs, full Group membership and Terms of Reference are presented in the full report.

The Group adopted an ecosystem approach, seeing the challenge as being to balance continuity of these services (food security, water, biodiversity, recreational opportunity *etc*) in ways that meet GHG obligations. The Group has sought GHG cuts in ways that are sufficiently robust to meet current social, economic and environmental imperatives as well as to allow future adaptation. However, detailed consideration is not given to adaptation in the report. Emissions are calculated using the internationally agreed "Inventory" from the IPPC. On this basis, they are reported to the UN Framework Convention on Climate Change, established under the Kyoto Protocol, by the UK Government. UK emissions are disaggregated to Wales, England, Scotland and Northern Ireland. Agricultural production and land use activities produce the major part of the Inventory emissions so such considerations have dominated this report. But the Group determined, at the outset, to place these in the broader context of rural land use and human behaviour and to consider the renewable energy potential of rural Wales, given that energy-related CO_2 emissions are the main drivers of climate change. The Group highlighted the need to engage with farmers, landowners and the public generally to identify win-win situations such as cost-savings and community actions, which would motivate positive change. Regulatory options for change were considered likely to lead to compliance issues and public negativity – the more so in the current climate of public opinion.

Wales' emissions

Existing evidence suggests that agricultural operations and land use changes contribute around 11% to Wales' total GHG emissions - or a ~net 5,200 kt CO_2e. Of this, about 45% is in the form of CH_4 from ruminant animals (both their enteric emissions and manure) with an approximately equivalent contribution from N_2O, mainly released by soil micro-organisms as part of the nitrogen (N) cycle. The remaining 10% comes from fuel used in agricultural operations. To this should be added the emissions associated with the production and transport of fertilisers and other agricultural additives and with the transport, storage, processing and retailing of food. These latter emissions do not appear in the "agricultural Inventory" *per se* but are attributed to other sectors such as "energy", both in Wales and elsewhere.

There is no well-founded assessment of these components for Wales alone but internationally it is estimated that the whole agri-food chain contributes about 18-20% of total emissions. For consumption in Wales this would compute to about a further 3,000 kt CO_2e, bringing the sector total to *c*8,200-9,000 kt CO_2e. It should be noted that emissions could be assigned to the primary producer, in this case the farmer, or to the end user, that is the food consumer. However, emissions from the food chain are distributed amongst the industrial, energy and transport sectors as producers of relevant emissions as well as to overseas producers.

In setting the 3% reduction target, the Welsh Assembly Government recognised that about 50% of Wales' emissions are strongly influenced by the carbon trading market within the EU Emission Trading Scheme. These elements were excluded from the Wales 3% target. Consequently, the agriculture and land use sectors contribute a significantly larger proportion of the remaining emissions under the authority or direct influence of the Welsh Assembly Government and to the achievement of this target.

It must be recognised that the quantitative evidence supporting some of the underlying data and mitigation options is not robust. There are four main sources of uncertainty:

- the IPCC methods for estimating emissions (e.g. intrinsic scientific uncertainty of N_2O fluxes from legumes)

- suspect extrapolation of UK-based data to Wales and a paucity of research data relevant to Welsh conditions.
- poor evidence of the effects of some management interventions for emission reductions.
- the extent to which Wales' emission reduction lead to displacement to other countries.

There is an unambiguous and urgent need for improved data collection (e.g. for land use change and for fertiliser use in Wales) and a better scientific understanding. In addition there is an equally urgent need for targeted research within Wales, both to inform future policy and to allow the initiatives developed in this report to be assessed, tested and monitored.

In the Inventory, emissions and sequestration are attributed by gas to the major agricultural and land use sub-sectors. The major fluxes are summarised in the table below. (The numbers are quoted to two significant figures only, because of the quality of the data).

Table S1 - Summary of the major GHG sources and sinks (kt CO_2e) attributed to agricultural and land use sub-sectors in the Inventory

		Annual values in 2007
Major agricultural and land use sources	Dairy-beef – CH_4	1,700
	Sheep-lamb – CH_4	940
	Agricultural soils – N_2O	2,200
	Land to cropland – CO_2	1,100
	Land to settlement – CO_2	690
Major sinks	Land to forest - CO_2	1,400
	Land to grass - CO_2	640

The land use change values are derived from extrapolations of historic trends extending over many decades, not abrupt recent changes.

The complete 2007 data, covering all the categories, not just the major ones shown above, indicate a current net overall sink of 200 kt CO_2e in the "Land Use, Land Use Change and Forestry" (LULUCF) sub-sector. However, projections show that within a decade, forest holdings will become an annual emissions source, not a sink. Although current forest management methods need to be better modeled by the Inventory methods, it is likely that new forest management techniques will also need to be initiated.

For agriculture, energy costs of N fertilisers are not included but may approach about 500 kt CO_2e/year for Wales, although this figure does not recognise the rather low level of N fertiliser application in most of Wales compared with regions of more intensive agriculture.

It was not possible to analyse the Welsh food chain *per se,* because of its tight integration into the UK supermarket system. But, as examples of the types of foods consumed in Wales, life cycle analysis of specific commodities (lamb meat, milk and cheese, potatoes and strawberries) has been undertaken in order to determine the major emission sources within the individual chains and to identify opportunities to cut commodity emission profiles. These vary widely in gross emissions per kg or per unit of consumption with the large lamb and milk/cheese profiles being dominated by on-farm CH_4 emissions. On the other hand, the emissions from the potato profile, although showing a significant Welsh footprint because of the high consumption, are dominated by CO_2 from chilled transport, storage and cooking.

The Group found the renewable energy potential of rural products, communities and areas to be significant, both because of their direct relevance to the agricultural and forest sectors and because of their potential as offsets for rural and national GHG emissions. In the future, renewable energy may have a wider role in the rural economy as well as increasing Wales' resilience to shocks in the international energy market.

Scenarios for emission reduction

The Group considered five scenarios, each of which would build on a number of win-win efficiency-based cuts detailed in the main report. While each scenario is presented separately, in reality they overlap and could be phased over time. Elements could be transferred from one to another.

Scenario 1

This is based on a modified form of "business as usual" with incremental technical improvements delivering emission reductions in the range of 10-15% by 2020. The improvements are based on an immediate set of efficiency gains such as the efficient use of N fertiliser, and improved livestock husbandry which can and should lead to win-win decreases in emissions per unit of marketable product. But overall, the continuation of existing systems and land use patterns will not lead to the achievement of Welsh Assembly Government targets for emission reductions. The Group recognises that while scientific breakthroughs may be made, they would be highly unlikely to be adopted on a sufficient scale to meet a 2020 or even 2030 timescale. Therefore, to achieve the required major emission cuts, choices must be faced or, with high probability, CH_4 and N_2O emissions will become an increasing percentage of the national total and have a detrimental effect on overall policy achievement.

Scenario 2

This is a market-driven scenario. It is based on the extension of existing carbon trading markets to this sector and to cover all relevant GHGs. Alternatively, a new market could emerge from the issuing of GHG rations to individuals who would then be responsible for choosing how to use their allocation. Welsh farming would then have to respond to these new markets. The emissions reduction achieved from this scenario would be strongly driven by the future price of emissions.

Scenario 3

This is based on major imposed cuts of around 60-70% in ruminant animal numbers, as has been proposed by the Tyndall Centre as part of a package of measures to achieve emission reduction rates of 6-9%/year for Wales. The scenario is based on the drastic reductions in ruminant animal numbers, as they are the major contributors to GHG emissions in the land use sector, as well as sources of dairy and red meat products which are seen as being damaging to public health.

Scenario 4

This is a lower intensity scenario, which would be based on extensive mixed farming systems, maximising resource efficiency from on-farm production of feedstuffs, and a reduction of inputs of fertiliser. The reduction of inputs would be balanced by reduced demand for animal products through a reduction in consumption, and reduction of waste in the food chain. Such systems are often associated with greatly enhanced local food chains, greater self-reliance, and are seen as increasing environmental and social sustainability over time.

Scenario 5

This scenario is predicated on the proposition that Wales should endeavour to maintain its food production potential while cutting emissions. It would require rolling out of technologies that, although common elsewhere, are not widespread in Wales, as well as retaining some, mainly upland, traditional systems. Mechanisms, preferably market-based, for curbing animal emissions on extensive systems would be required, but the scenario would see Wales as a source of high quality meat and dairy products as well as more vegetable crops in a world of incipient food shortages. Continued trading in food (both export and import) and in other inputs into the food chain is seen as essential to this scenario but predicated on sourcing of the lowest carbon footprint commodity or item.

Several of the scenarios, although to different degrees and with different resource mixes, would also:

- seek to purposefully exploit the rural renewable energy potential for electricity, heat and bio-gas.
- involve major woodland planting as well as better management of existing woodlands.
- seek to diversify the rural economy, although in different ways.

The scenarios were assessed against the following criteria:

- their potential for the timely delivery of the large cuts required to meet Wales' reduction targets. These are:
    - by 2050 an 80% cut: equivalent to reaching total net annual sectoral emissions of about 1,650 kt CO_2e from the whole food system, or 1,040 kt CO_2e from those emissions reported in the Agriculture and LULUCF Inventories.

  - at least an annual 3% decrement in emissions from the baseline of Wales' average total emissions in 2006-2010, that is 3% of about 48,700 kt CO_2e, which is 1,461 kt CO_2e/year. Of this some 160-280 kt CO_2e would need to come from the sectors covered in this report. In addition there was an aspiration in “Sustainable Farming and Environment: Action towards 2020” report to achieve a “carbon-neutral” rural Wales by 2020.
- their potential to deliver emission reductions recorded by the IPCC Inventory.
- their capacity to help deliver the renewable energy targets.
- their capacity to deliver enhanced economic, cultural, social and environmental sustainability and to reduce risk.
- their ability to protect and maintain the whole range of eco-system services, without being detrimental to future adaptation options.
- their economic and political feasibility.
- believing co-operation to be essential to successful policy implementation, their acceptability to the rural community - especially land owners and managers.
- their ability to increase resilience in the face of the food security, energy and climate change impacts forecast for the mid 21st century.
- their capacity to make a positive contribution to global food and energy availability and limit our imports of embedded GHGs.

The Group assessed the scenarios as follows:

- Scenario 1 was considered to be a logical first step that should be implemented, but it would not achieve the reductions required to meet targets.
- Scenario 2 was difficult to evaluate due to inadequate information on the future price of carbon, which would act as the economic driver for emissions reduction. Moreover, the issue is clouded by the absence of an international consensus at Copenhagen.
- Scenario 3 was not considered to be practical, given the dependence of Welsh agriculture on pastural systems, the comparative climate change advantages of Wales for food production, the social and economic barriers and the likelihood of displacing emissions to production systems elsewhere in the world.
- Scenario 4 contained some elements that should be assessed in terms of feasibility and incorporated into scenario 5.
- Scenario 5 (plus some features of other Scenarios) was viewed as being the optimum way forward to achieve the required direction of travel for target GHG emission reduction. The Group recognised the major challenges associated with technological innovation and the investment required and the need to consider impacts on all ecosystem services including biodiversity.

The Group's recommended scenario

The recommended scenario (Scenario 5) contains five major, and a number of ancillary, elements:

1. Dairy and associated beef production and anaerobic digestion (AD).

   CH_4 emissions from manure and slurry produced by the dairy herd and related beef production would be minimised, firstly by the rapid and comprehensive introduction of AD. Over time the plan would be for a fully housed, zero-grazed system on the higher grades of land. To expand CH_4 capture and energy production, the AD biogas would be supplemented by emerging technologies to scrub the enteric CH_4 from the sheds. Reduction of ammonia emissions by scrubbing would also assist in reducing N deposition and N_2O emissions from soil – this remains a possibly large, but ill-defined, factor. To decrease attendant CO_2e emissions, the AD should also be incorporated into food and other waste management. The biogas and animal heat produced could be used for activities such as various types of agricultural machinery (e.g. biogas tractors) and horticultural or other commercial activities according to site and opportunity. The digestate would be used as a high quality fertiliser with possibly lower N_2O emission rates - yet to be proven under Welsh conditions. Rolling out of these technologies would create additional work in rural Wales. N use would also be optimised. Full implementation could cut sectoral emissions by about 1,500 kt CO_2e including savings from use of the biogas to replace some of the fuel used in the agriculture sector.

2. Woodland management and expansion.

   An expansion of woodland over 20 years by about 100,000 ha from the current 284,000 ha is recommended. The additional woodland would be mainly deciduous but with a proportion of conifer species for high quality, enduring end uses. Tree provenances adapted to the projected climate would be used and planting would take place almost entirely on low-fertility, acid upland soils, including bracken-dominated slopes. This initiative would create an additional major GHG sink of 1,600 kt CO_2e annually by 2040, with a net sink of 1,200 kt CO_2e, and an additional fuel wood potential - perhaps 1.4 TWh/year by 2030-2040, off-setting emissions of a further 350 kt CO_2e of fossil fuels. Harvested wood products should substitute for high energy materials such as steel and concrete. Other benefits could be additional habitat, conservation of natural beauty, better water-resource management and flood control, and creation of new work and recreational opportunities. Additionally, Forestry Commission Wales should bring forward plans to ensure that the current public and private holdings do not become an annual GHG source and that Wales' forests are managed to optimise their long-term GHG abatement capacity. In short, the existing and expanded forest, public and private alike, must be managed to provide a sustainable source of fuel-wood and timber alongside other services and products, including the long-term net carbon sink.

3. On farm productivity improvement.

   This element envisages the retention of extensive pastural sheep and cattle on the middle and upland areas - mainly grade 3 and grade 4 land - but with improvements in husbandry. Following the current trends, lamb meat production would be maintained while reducing sheep sector emissions by about 20% (i.e. ~200 kt CO_2e). This could be achieved by factors such as better lambing percentage, and increasing ewe lifespans so reducing replacement rates. Similar consideration would apply to extensive beef production although GHG gains are harder to make. However, for overall emission reductions, it is imperative to note that the GHG gains, made by improved husbandry and efficiency, would be undermined by increases in ewe or cattle numbers.

4. Renewable energy.

   In addition to the biogas and wood fuel noted above, rural Wales (assumed for this exercise to have a population of about 0.8-1 million) has resources for renewable energy generation from small-scale hydro, wind, dedicated biomass, solar - heat and photovoltaic (PV) - and ground-source heat. These resources have been assessed and broadly estimated as follows:

   - a significant hydro power potential of at least 0.3 TWh/year of electricity in upland Wales.
   - community or personal wind energy of about 1 TWh/year of electricity.
   - the annual solar heat potential of individual homes is substantial but not quantifiable.
   - biomass from woodland management, shelter belts, and biomass crops generating 3 TWh/year of heat energy; or 1/3 of this as electricity.
   - heat extraction from the dairy herd equivalent to 330 GWh/year of heat, which could be used in horticultural protected cropping enterprises.
   - solar – PV generation of about 0.03 TWh/year of electricity.
   - some additional biogas would be generated by waste food AD treatment.

   This total resource, although significant particularly in terms of heat energy production, is still modest in relation to Wales' annual energy demand of 125-130 TWh. It is also important to note that most of these sources are intermittent but that their maximal outputs will have different annual profiles. The total resource could rise under the recommended scenario to be of the order of 3 TWh of electricity, and 3 TWh of heat annually. This would equate to a decrease in Wales' GHG emissions of about 1,500-2,000 kt CO_2e annually (~4%) – based on the current mix of energy sources. Part of the heat and biogas resource could be converted to electricity at about 30% efficiency - more in combined heat and power systems.

   The economic returns on capital will depend on source and location. The Department of Energy and Climate Change has recently announced new Feed in Tariffs (FITs) starting in April 2010. Issues relating to the cost and ease of connectivity though the Distribution Network Operators need to be resolved. The Group strongly recommends an urgent detailed study of these issues combined with a clear policy to maximise Wales' potential. The new FITs could prove economically as well as environmentally attractive and provide an additional income stream for parts of rural Wales.

5. <u>Changing demand for food, fibre and energy - efficiency, waste and lifestyle</u>

There may well be an important link between encouraging dispersed energy micro-generation and improved energy and waste management. The dispersed generation is likely to increase individual, family and community responsibility and thus could lever significant increases in energy efficiency by those seeking to maximise returns on their own investment. A 50% impact in household energy efficiency would save an extra 4-5 TWh. In this context the Welsh Assembly Government's drive for energy use efficiency should entail a positive stance in rolling out the infrastructure for compressed biogas, electric vehicles (EVs) and plug-in EVs as they can utilise locally generated fuels.

Increased efficiency, less waste and better-focussed management have been emphasised in the agricultural and forest sub-sectors. Similar conclusions apply throughout the food chain and in our individual roles as consumers. Waste occurs from post-harvest losses, processing, and retailing. Food waste is estimated at about 25% from households. Some (e.g. potato peelings and egg shells) is inevitable and any food chain must have some element of redundancy against supply problems and spoilage. But waste can be much reduced and a number of initiatives are taking place in Wales to enhance local supplies.

The whole diet/food supply agenda has huge implications for sustainable development and to Wales' overall ecological footprint. Human diets have changed significantly, reaching well beyond the provision of minimal nutrient and calorie levels. Our diets are intertwined with our lifestyles and our personal time management. Dietary excess and too much processed high fat food is linked with a substantial number of premature deaths that could be diminished if, in the UK, "healthy" diets met nutritional guidelines. Some of this health burden has been linked with the consumption of meat and dairy products. However there is also good evidence that a reduction in meat consumption below that internationally recommended can lead to intake of essential trace elements (e.g. iron) and some vitamins at below recommended levels. Globally, the consumption of meat and dairy products is rising with increasing wealth, but in developed countries the clear public health advice is to reduce consumption. Both environmental and health benefits may be achieved by reducing consumption.

The Group considers that its recommendations are entirely compatible with calls for improved diets in Wales and the UK. Some 95% of Welsh lamb is currently exported. A reduction in home demand will require Wales to locate small additional replacement markets, but these are likely to arise from the developments noted above and from threats to the world's semi-arid ranges. Given its high rainfall and temperate climate Wales has a comparative advantage in growing food efficiently within pastural systems. The proposals for expanding local seasonal food chains and additional horticultural and greenhouse crops *etc* should improve both diet and consumer awareness.

In addition to the main components, other important interventions are recommended or anticipated:

- increased horticultural and greenhouse crop production in part exploiting "waste" heat but also to encourage more local and seasonal food chains.
- recognising our global responsibilities, making efforts to minimise imported animal feed concentrates and other inputs carrying a high GHG footprint.
- some additional arable area would follow, slightly increasing GHG emissions in the Inventory but having other benefits. It will be important to monitor the broad net impact on all emissions as well as the local Welsh situation; for instance imports from existing grain producing areas (e.g. East Anglia) may have a lower footprint than new local production.
- techniques to protect and maintain soil carbon in grasslands through conventional and organic farming.
- in order to maintain carbon stocks in upland and lowland peats, all such areas should be subject to management agreements.

One of the most pressing issues recognised by the Group is a critical need for better data, focussed research and pilot projects. These requirements may be classified as:

- research to model, test and verify the technical feasibility and impacts of the evolving production systems.
- rigorous analysis of the economic, environmental and social costs and benefits of these recommended options, i.e. a "triple bottom line approach". It is recommended that this is undertaken immediately
- detailed assessment of policy options to identify the best ways of motivating changes to management practice and behaviour to convert the technical potential into practice. Experience of technical improvement in farming indicates that achieving high uptake of new methods is challenging unless driven by regulation or other significant incentives.
- expanded research on eco-system services within the context of the recommended scenario and climate change projections and test other possible actions / interventions (e.g. net fluxes of all GHGs in organic systems). It will also be necessary to assess the ultimate *net* impact, and to ensure that policy options are considered in terms of overall gains. It will be important to seek to identify "unintended" consequences in these assessments.
- research to reduce the large uncertainties in the estimates of N_2O emissions combined with improved data collection and acquisition to allow more accurate records of Wales' emissions within the GHG Inventory. The problem of N_2O emissions is of real concern.
- development of a more sensitive Inventory methodology to track policies and programmes to reduce emissions.

In terms of policy and implementation there is a range of issues on regulation of waste, water abstraction and development control (planning) which needs to be analysed to find ways to facilitate growth of renewable micro-generation projects. EU and national support mechanisms also require analysis and action to reduce current barriers to implementing projects.

The Group's conclusions

To summarise, the scenario outlined above could, by 2040, if fully implemented, reduce net sectoral emissions from 5,200 kt CO_2e to around 2,000 kt CO_2e – a significant proportion of the remaining emissions would be as N_2O. One critical element in this is the management of enlarged woodlands to achieve a long-term GHG sink. The scenario would also include generation of about 3 TWh of renewable heat and 3 TWh of renewable electricity. This would offset a further 1,500-2,000 kt of CO_2e emissions annually – if replacing the current energy mix of energy sources. This can be compared with the estimated 3,000 kt CO_2e which is assessed to be attributable to the food sector. In addition, dispersed renewable energy should increase public awareness about the priority for increasing energy efficiency and reducing waste. Overall it offers the possibility of cuts of the order required.

Scientific advances (e.g. mechanisms to decrease N_2O emissions, or low emission breeds of ruminants) could add further gains but this should not be assumed. The ability of the sector to make its full contribution to the annual 3% reduction target will depend on the rate with which the recommendations in this report are adopted.

The proposals would create additional woodland habitat, which in turn could improve flood control and water quality. They would preserve much of the character of the landscape and, by encouraging some additional arable (including minimum- or no-tillageor tillage) land, create additional farmland habitats if managed sympathetically. The environmental impact of zero-grazed forage production requires study as do attendant issues of animal husbandry and health in housed systems. However, better slurry management should be beneficial to watercourses.

This approach should create additional jobs and strengthen communities, social enterprises and Welsh culture. There will be an urgent need to develop skills and the construction and manufacturing base to exploit the potential of micro-generation, new horticulture and glasshouse production (based on the additional heat sources) and enhanced forest products.

In summary, the Group considers that, the recommendations set out a direction of travel, based on the maximum technical potential of existing systems, but recognising technology and political and economic priorities will undoubtedly change in the next 30 years. Many aspects of policy intervention and funding are unresolved and require further detailed analysis. But by 2040, rural Wales could achieve major net GHG emission cuts of the order of 70-

80%, with increased sustainability and improved Welsh resilience to international shocks. However, there is no prospect of achieving GHG neutrality by 2020 in any scenario because of the substantial technical development that is required for farming systems. Current promising reduction methods will take time to move from experimental trials to implementation. In addition, a tree planting programme starting now will take 2-3 decades before reaching maximum carbon sequestering capacity.

The Group has sought to present its best assessment, being fully aware of the lack of crucial data, a stuttering public opinion and competing priorities. But, in the last analysis, it contends that a positive direction of travel can be identified and that embarking down this road is lower risk than the risk of inaction.

C) Recommendations

Actions by Welsh Assembly Government

1. *Economic Assessment:* to supplement this report by undertaking urgently an examination of the costs and benefits of adopting (or not adopting) these proposals, detailing their contributions to the rural economy and to renewable electricity and heat energy targets as well as to social viability and all ecosystem services.
2. *Public awareness and involvement:* to institute a major dialogue throughout rural Wales to improve understanding of climate change issues and to show how every individual, community and business can assist in responding to the global challenge, especially by lifestyle changes to increase resource-use efficiency and avoid waste. One avenue is through the Farming Connect Climate Change Development Centre.
3. *Forestry:* to develop urgently detailed plans with a view to expanding current woodland / forest cover by about 100,000 ha over the next 20 years by planting a range of native deciduous trees, that are well adapted to the mean climate change scenario, and conifers, together with some natural regeneration. These should be grown on both acid upland soils and bracken land, but avoiding peats.
4. *Forestry:* to ensure that the current public - Forestry Commission (FC) - and private forest holdings are managed to optimise their greenhouse gas (GHG) sink potentials as well as providing a sustainable source of fuel-wood and other timber products that form long term "carbon sinks" and/or substituting for fossil fuels.
5. *Soils / peat:* to ensure that no steps are taken which might undermine the carbon stores in upland peats and lowland fens and mires.
6. *Agri-environment:* to ensure that Glastir prescriptions are consistent with the needs to reduce GHG emissions.
7. *Animal husbandry:* to provide support for all manure/slurry from the dairy herd and attendant beef/veal systems to be processed through anaerobic digestion (AD) and to exploit the biogas potential.
8. *Animal husbandry:* to explore with the dairy and beef industry the adoption of zero-grazed systems to minimise methane (CH_4) and nitrous oxide (N_2O) emissions and to exploit the compressed biogas potential. The impacts of zero-grazing on biodiversity and other ecosystem services need to be assessed.
9. *Animal husbandry / food waste:* to promote the maximum synergy between AD of slurry/manure and other wastes (that can't be utilised more efficiently) from the food chain – process, distribution and consumer wastes - through co-operation with food processors, major retailers and local authorities.

10. *Animal husbandry:* to encourage increased efficiency within dairy, beef and sheep sectors to decrease GHG emission per unit of productive output and to ensure cuts in emissions.
11. *Agronomy*: to encourage maximising nitrogen (N) use efficiency through best practice management of fertilisers, manures and biosolids.
12. *Agronomy:* to encourage an increase in the horticultural / glasshouse sector taking advantage of renewable heat sources.
13. *Food chain efficiency:* to harness the resources of the Food and Drink Advisory Partnership and the Land Use Climate Change Group (LUCCG) to identify and implement resource efficiency improvements between farmer and consumer, through reduction of waste and energy use in the processing and distribution chain and via better consumer education.
14. *Renewable energy:* to promote all elements of the renewable energy potential of (rural) Wales in appropriate locations and to ensure the obstructions to uptake and grid connectivity are minimised with all speed.
15. *Renewable energy:* to promote a range of woodland (biomass) planting to create a source of renewable heat energy as a significant contribution to renewable energy from the rural sector.
16. *Renewable energy:* to work with industry to ensure as rapid as possible take-up of compressed biogas (CBG) and electric plug-in/hybrid vehicles and machinery in rural Wales and the food chain.
17. *Research capacity:* to work with relevant organisations and research providers to ensure that the research agenda is implemented, and allows it to fulfil its obligations and aspirations in relation to climate change and land use.
18. *Governmental capacity:* to ensure it has the capacity, expertise, finance and influence to fulfil its obligations and aspirations in relation to climate change and sustainable development and that it "climate-proofs" its policies.
19. *Governmental capacity:* to ensure that planning regulations are designed to facilitate installation of rural renewable energy generation, subject to essential environmental protection and respect for listed buildings.
20. *Governmental responsibility:* to commission a report on climate adaptation mechanisms likely to be required in the land use sector by and beyond 2040.

Inventory improvement

The following recommendations are directed to the Welsh Assembly Government, the Centre for Ecology and Hydrology (CEH) - the current contractors for estimating Inventory emissions for "land use, land use change and forestry" (LULUCF) - and North Wyke Research (NW Research), which is responsible for estimating agriculture emissions.

21. *Integration of estimates:* CEH and NW Research to integrate their methods and estimates more closely, for example on N_2O emissions from soils.

22. *Land use change statistics:* Welsh Assembly Government and CEH to refine current estimates of land use change in Wales by integrating the outputs of the Countryside Survey (CS) model with actual land use change statistics in order to track land use changes over time – using agricultural statistics data, National Forest Inventory data and settlement data.

23. *Land use change reversal:* CEH to develop the land use change model so that it is able to take account of reverse transitions and is able to assess net impacts for emissions.

24. *Crop rotation land use statistics:* CEH to investigate classifying as a separate land use type instead of the inclusion of frequent transitions between land uses.

25. *Management practices within land use categories:* CEH to assess ways to include agri-environment practices aimed at increasing soil organic matter, or innovations in forest management, and the use of harvested wood products that substitute for fossil fuel use.

26. *Soil carbon:* CEH and its sub-contractor Forest Research to resolve the best ways for modeling forest soils from the models currently available.

27. *Settlements:* CEH to test its current assumptions for soil carbon changes for land converted to settlement, on the basis of improving its data on soil carbon changes.

28. *Emission projections:* CEH to ensure that it bases its emission projections out to 2050 on Welsh Assembly Government policy scenarios for land use change, and compares with historical trends.

29. *Agricultural emissions:* Welsh Assembly Government to collaborate with the Department for Environment, Food and Rural Affairs and other Devolved Administrations on the research project: “Agriculture GHGI Enhancement” to develop the methods for tracking emissions as new methods for managing farm systems are introduced to reduce emissions – in particular:
    - developing a more accurate range of emission factors for CH_4 and N_2O.
    - developing CH_4 emission factors for a range of ruminant farming systems, breeds, diets and additives (e.g. effects of upland diets for ruminants).
    - developing N_2O emission factors for range of climatic and soil conditions, soil type, crop type, and farm/land management (e.g. upland vs lowland livestock systems).

30. *Fertiliser use:* Welsh Assembly Government to collect statistics for Wales to provide a more accurate estimate to replace extrapolated statistics from UK.

Research

The following recommendations are directed to Welsh Assembly Government, research funders and research organisations:

31. *Validating experimental studies:* to carry out large-scale trials on farms to test how well dietary manipulation reduces both direct and indirect GHG emissions from ruminants compared with laboratory conditions.

32. *Rumen function:* to research further the basic science on rumen function and modification, in particular to decrease loss of feed energy.

33. *Animal genetics:* to research further the varying traits for reducing GHG emissions between and within breeds.

34. *Animal feeds:* to improve the understanding of potential CH_4 production from differentf feeds and transfer of this knowledge to the farmer.

35. *Upland farming systems:* to assess the effects of hill and upland environments on CH_4 emissions where indigenous plants in the diet may alter rumen fermentation to reduce the amount of CH_4 that is produced.

36. *N_2O emissions in soils:* to research the key factors that influence the fluxes of N compounds in soils and to monitor emission fluxes under a variety of management conditions including organic and conventional farming systems and identify new mitigation options.

37. *CH_4 capture and housed systems:* to research the technical feasibility of a housed dairy/beef herd with a CH_4 capture system – taking account of animal health and welfare, controlled environment requirements, lifecycle GHG savings, resource efficiency and practical gas capture techniques.

38. *AD digestate:* to assess the fertiliser value and the N_2O emissions from its application to land.

39. *Livestock and ecosystem services:* to develop a clearer analysis of the value (positive or negative) of ruminant livestock for delivery of ecosystem services – food, fibre, soil carbon, water, biodiversity, and landscape.

40. *Life Cycle Analysis (LCA):* to develop the approach of analysing the effect of interventions on LCA by extending to other foods including processed foods, so as to build up a picture of the GHG emissions on a whole diet basis, and to identify the interventions that will lead to emission reduction.

41. *LCA:* to develop a more sophisticated analysis of the nutritional value of different foodstuffs relative to their GHG emissions, instead of assessing by unit weight of product.

42. *Organic Farming Systems:* to undertake comprehensive GHG flux analysis of organic and conventional production systems to determine overall LCAs for Welsh farm products.

43. *Soil carbon stocks:* improve estimates of the impact of moving from one land use to another (e.g. grassland to forestry) on soil carbon storage, particularly in relation to soil type, by a targeted field survey approach.

44. *Grassland management:* to quantify the effects of grazing intensity and type, and re-seeding of lowland pastures (an important mechanism to improve productivity), and the impacts of tillage methods on GHG emissions.

45. *Grassland management:* to breed new grass varieties that enhance carbon storage below ground.

46. *Tillage methods:* to assess whether the increase in soil organic matter from reduced tillage is offset by the increase in N_2O emissions, and the effect of drainage in reducing N_2O emissions by maintaining aerobic conditions in the soil.

47. *Peat re-wetting:* to monitor the fluxes of *all* GHGs and dissolved-carbon losses simultaneously in the same locations so that the net global warming potential can be determined (i.e. all the inputs and outputs required to complete a full GHG budget).

48. *Afforestation:* to assess the effects on soil carbon stocks in organic soils throughout the life cycle, with a particular need to assess newer forest management methods such as continuous cover management and harvesting.

49. *Soil carbon modeling:* to develop the soil carbon model, ECOSSE, for representative catchments using finer vegetation categories and underpinning soil data, coupled with better estimates for vegetation net primary production to allow independent testing of changes in soil carbon sequestration rates. Future expansion of ECOSSE-2 should link the model with an LCA model that allows the whole "cradle to grave" GHG emission values to be calculated (e.g. from transport, waste *etc*).

D) Engagement

The Group's Terms of Reference include the objective of:
"Raising awareness among stakeholders at all levels about the impacts of climate change in rural areas through existing and/or new knowledge networks; help develop and promote appropriate responses to climate change and contribute to the implementation of a climate change communications strategy for land managers".

For the strategy outlined in this document to succeed it must enjoy widespread public acceptance; critically of course within the farming, land owning and land use communities but also more generally in the food industry, retail sector and with all of us as consumers. Emissions can be attributed to either to the producer or the end-user - so we are all participants in greenhouse gas (GHG) emissions from land use and the food chain in every meal we eat. Similarly, in every journey or purchase we make, or bath or shower we take, we are making climate change choices. These choices, in turn, feed back economically and socially onto the producers of the goods or services; in the case of this report through the food and other chains into the rural economy.

The GHG mitigation recommendations are predicated on a recognition that:

- direct drivers other than local climate change *per se* will be highly influential for at least the next decade - especially energy costs.
- these drivers, fortunately, lead to actions and interventions (e.g. more endogenous renewable energy, expanded woodlands, better manure and slurry and waste management) which are beneficial to the wider climate change mitigation agenda.
- the enforcement powers of all governments (short of a public acceptance of a war footing) are limited in a free democratic society.
- the powers of the Welsh Assembly Government are more constrained than hoise of the UK government, although this may change over the period considered in this report.
- EU Common Agricultural Policy reform may act as a further driver beyond the current Glastir scheme to fund mitigation measures.
- Wales and Welsh people cannot isolate themselves from global threats and should play a positive, albeit a relatively small, role in responding to these global challenges by contributing to food production and not displacing emissions to other countries.
- while climate change is a huge and potentially devastating threat to many communities (e.g. low lying Pacific Islands, the Nile delta and many arid regions), in rural Wales it is as much an opportunity as a threat as new ways of thinking and operating can combine mitigation and adaptation and open up new economic opportunities and livelihood opportunities.

For this potential to be achieved, citizens, organisations and government must work together.

Within the UK, public acceptance of the scientific case for incipient and damaging global climate change has waned somewhat in the face of the impacts of the “credit crunch”, climate change scepticism and the lack of strong political leadership and agreement from the Copenhagen talks. The scepticism has been exacerbated by a small number of errors in the Intergovernmental Panel on Climate Change 4th report, but perhaps more significantly by two poor summers and two relatively cold winters (although scarcely comparable to those of the mid-20th century). Seasonal and annual weather fluctuations have been conflated with long-term climate trends, so any poor summer is taken as evidence for the “nay-sayers” and every meteorological catastrophe (e.g. the 2003 European heat wave and various hurricanes and storms) is trumpeted as proof of long-term climate disaster. This Land Use Climate Change Group (LUCCG) has been convinced of the validity of the fundamental scientific analysis that global climate forcing will result from the accumulation of GHGs, but recognises that many of the details of how this will play out in Wales or elsewhere remain unclear. This does not in any way diminish the need for urgent action as the global threat is so large and the time required to make the huge scale of change so long. Both common sense and common prudence dictate urgent action.

Worryingly, some object on the ideological grounds that market forces will solve all problems despite ample evidence (e.g. from the trouble of the investment banks) that this is not the case. In addition, although the Stern Report* argued otherwise, there is still a view that it is cheaper and more cost effective to focus on adapting to climate change, and it is better to raise our resilience by other investments (e.g. providing clean water, reducing global poverty, better health care).

These political and psychological factors reinforce the need for a positive measured engagement with the public at all levels and in all ways.

The LUCCG has a specific role in engaging with the rural community and expects to work with Welsh Assembly Government, the Climate Change Commission for Wales and many other bodies to create an informed national debate. In particular the Climate Change Strategy will have an action programme with a strong communications component. It is widely recognised that technical fixes themselves are not going to deliver the scale of emission reduction required, and it will require all sectors of society to change behaviour to achieve the objectives. Organisations and institutions will also need to look at their cultures and behaviours, and unblock the channels to delivering emissions reduction.

The LUCCG suggests the following specific actions:

- publication of a short illustrated bilingual version of this report for wide circulation in rural communities and to farmers and land owners (a version for the general public could also be considered).

* N Stern: The Economics of Climate Change: the Stern Review. Cambridge University Press 2007

- a series of regional meetings arranged with farmers' organisations to explain the findings and recommendations in this report.
- a series of regional meetings with organisations such as Merched y Wawr, Women's Institute, trade groups *etc*.
- promote the "Help Wales reduce its Carbon Footprint" brand to show the footprint of food production.
- work with the Food and Drink Advisory Panel on reduction of waste in the food processing, distribution and retail sectors.
- a short video and/or power point presentation.
- a regular report back from Welsh Assembly Government to the LUCCG, or its successor, on progress with the research recommendations.
- consultation with TV producers to establish a project to identify and reward communities in rural Wales who are most successful in reducing their GHG footprints.
- farmers to be encouraged to analyse their carbon footprint, ideally to a common methodology.
- encourage dispersed micro-generation as a personal investment - this will do more than anything to promote energy efficiency.
- steps should be taken to improve knowledge of best practice elsewhere on mainland Europe (e.g. a joint deputation of farmers and planners to visit well established AD installations).

Section 2

Abbreviations used in the report

AD	anaerobic digestion
BBNP	Brecon Beacons National Park
BP	before present
CBG	compressed bio-gas
CCW	Countryside Council for Wales
CEH	Centre for Ecology and Hydrology
CHP	combined heat and power
CO_2e	carbon dioxide equivalents
CS	Countryside Survey
DECC	Department for Energy and Climate Change
EV	electric vehicle
FC	Forestry Commission
FIT	Feed in Tariff
FR	Forest Reseach
gha	global hectares
GHG	greenhouse gas
GHGI	Greenhouse Gas Inventory
GWP	global warming potential
IPCC	Intergovernmental Panel on Climate Change
LCA	life cycle analysis
LUa	livestock unit years
LUCCG	Land Use Climate Change Group
LULUCF	Land Use, Land Use Change and Forestry
N	Nitrogen
NMVOC	non-methane volatile organic carbon
NP	National Park
odt	oven dried tonnes
ppm	parts per million
PSA	pressure swing adsorption
PV	Photovoltaic
VOC	volatile organic carbon

Units and conversions

Energy is expressed in terms of Watt hours (Wh) apart from the energy in food which is expressed in Calories.

t = tonnes

ha = hectares

l = litres

^{o}C = degrees Centigrade

m = metres

Prefixes and multiplication factors

Multiplication factor	Abbreviation	Prefix	Term	Symbol
1,000,000,000,000	10^{12}	Tera	trillion	T
1,000,000,000	10^{9}	Giga	billion	G
1,000,000	10^{6}	Mega	million	M
1,000	10^{3}	kilo	thousand	k

Chemical formulae of compounds

CH_4	Methane
CO_2	Carbon Dioxide
N_2O	Nitrous Oxide
NOx	Oxides of Nitrogen
SOx	Oxides of Sulphur

LUCCG members

Chair

Professor Gareth Wyn Jones, National Trust / Bangor University

Members

Peter Davies, Commissioner, Sustainable Development Commission

Professor Gareth Edwards-Jones, Bangor University

Professor Bridget Emmett, Natural Environment Research Council Centre for Ecology and Hydrology

Mike Howe, Head of Conservation, Pembrokeshire Coast National Park (NP), Representing Welsh NPs

Professor D L Jones, Bangor University

Bernard Llewellyn, NFU Cymru

Craig Mitchell, Welsh Local Government Association

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1. Context

1.1 General situation

It is recognised that drastic cuts must be made in global human-generated emissions of greenhouse gases (GHGs), as they increase the capacity of the Earth to retain the Sun's radiant energy, thus gradually increasing the mean global temperature and forcing other changes in the Earth's oceanic, terrestrial and atmospheric circulatory systems. Compelling scientific evidence (see Box 1 below) shows that the atmospheric GHG concentrations are rising steeply and are already leading to significant changes in the Earth's climate. The Intergovernmental Panel on Climate Change (IPCC)[1] has concluded from an analysis of the scientific evidence that, with a *very high confidence,* the globally-averaged net effect of human activities since 1750 has been one of warming. Global and regional climate patterns can also, of course, be influenced by a number of other human activities (e.g. oxides of sulphur (SO_x) emissions), and by natural events (e.g. volcanic eruptions and planetry and solar cycles), but this recognition does not diminish the basic proposition.

This report focuses on three of the GHGs which are significant in the context of Wales' land use and food chain:

- Carbon dioxide (CO_2) - mainly produced by the burning of the fossil fuels that have catalyzed the development of the global economy during the last 150 years, and also by major global and local land use changes.
- Methane (CH_4) – generated by a number of sources including microbial anaerobic fermentation in ruminants, biomass burning, wetlands, landfill sites and coal mines.
- Nitrous oxide (N_2O) - a product of microbial metabolism usually in soils, and there are also emissions from the chemical industry and combustion sources.

Relative to the impacts on radiant energy capture by CO_2 (calculated on a 100-year time frame), CH_4 has a Global Warming Potential (GWP) approximately 21-25 times greater on a unit weight basis while N_2O is 298-310 times more effective as a GHG. In calculating emissions relative to reduction targets set in the UN Framework Convention on Climate Change, the agreed GWP for CH_4 is 21, and for N_2O is 310 compared with CO_2. These values were adopted on the basis of IPCC recommendations.

The atmospheric concentrations of CH_4 (approximately 1.7 parts per million (ppm)) and N_2O (0.3 ppm) are much lower than CO_2 (386 ppm). Nevertheless, although most public attention is focused on CO_2 because of its link to, and our dependence on, local and global energy supplies from fossil fuels, these other gases are highly significant. Their concentrations in the atmosphere are also at historically high levels. The true potential global-forcing impact of

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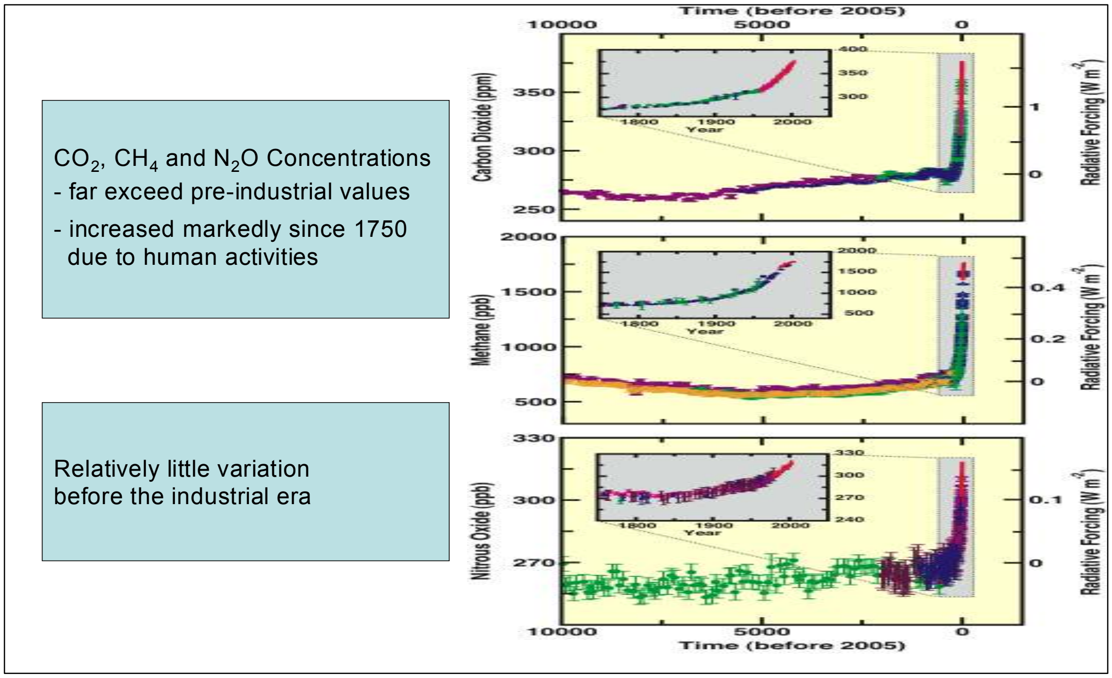
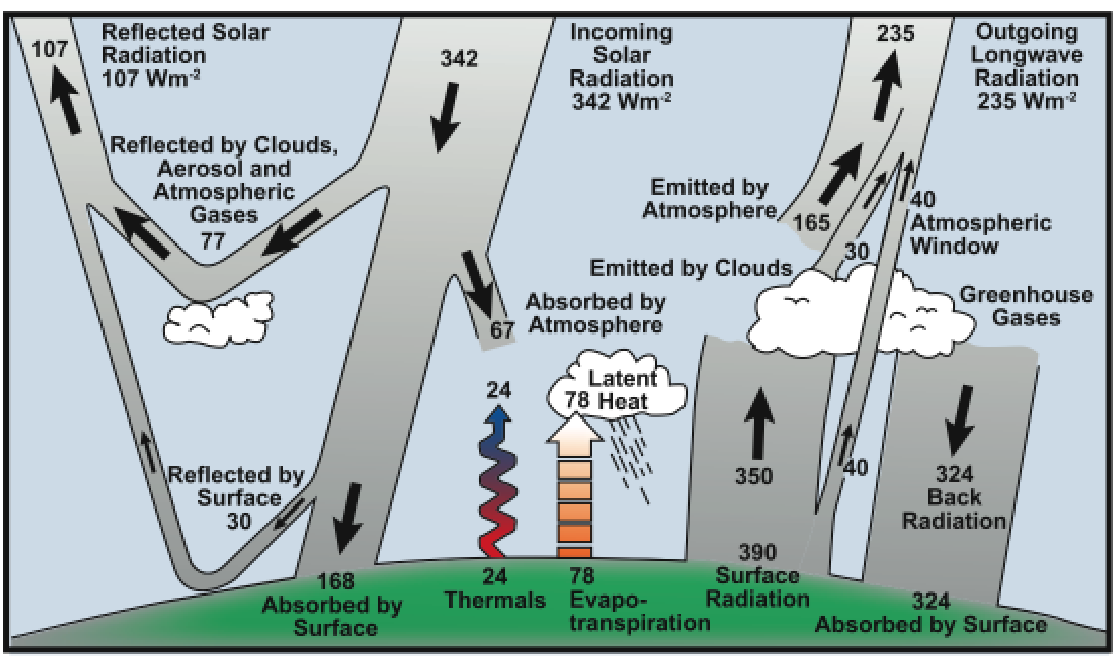
[1] IPPC Fourth Assessment Report Climate Change 2007: Synthesis Report

Box 1 Human and natural drivers of climate change

a) Historic trends in GHG concentrations in the atmosphere



b) Global heat fluxes (W/m^2)



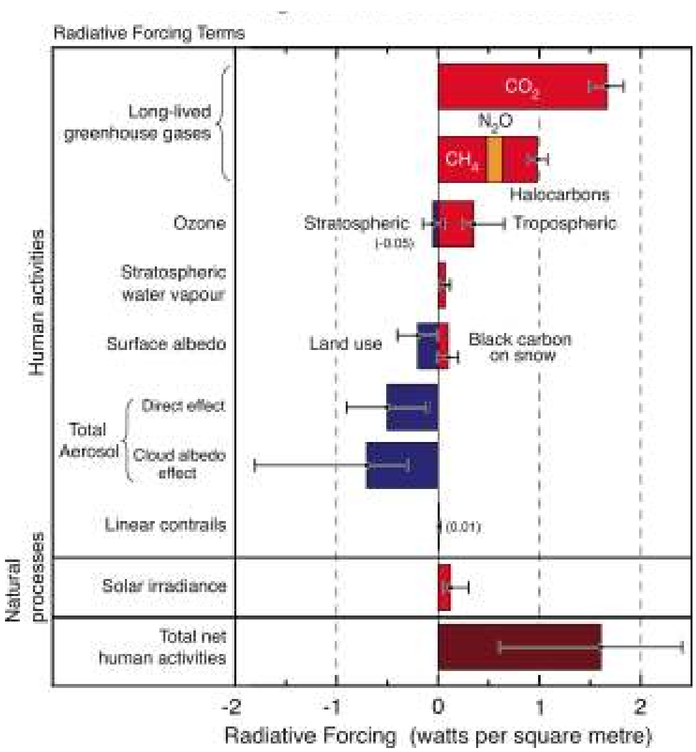
c) Projections of future changes in climate

Projected globally averaged surface warming at the end of the 21st century for different model cases. Individual scenarios are described in the IPCC 4th assessment reports.

Case	**Temperature Change (^oC at 2090-2099 relative to 1980-1999)**	
	Best estimate	**Likely range**
Constant year 2000 concentations	0.6	0.3 – 0.9
B1 scenario	1.8	1.1 – 2.9
A1T scenario	2.4	1.4 – 3.8
B2 scenario	2.4	1.4 – 3.8
A1B scenario	2.8	1.7 – 4.4
A2 scenario	3.4	2.0 – 5.4
A1F1 scenario	4.0	2.4 – 6.4

Reference: IPCC 4th Assessment Report 2007.
http://www.ipcc.ch/publications_and_data/ar4/syr/en/spm.html

d) Radiative forcing of climate between 1750 and 2005



Reference: IPCC 4th Assessment Report 2007.
http://www.ipcc.ch/publications_and_data/ar4/syr/en/spm.html

GHGs is the integrated impacts of all relevant gases including the three noted above. In this report data are expressed as CO_2 "equivalents" (CO_2e), thereby including the impacts of all gases[2].

The probable social and economic, as well as environmental, consequences of climate change to the welfare and habitability of vast tracts of this planet have resulted in both the EU and UK committing to 80% cuts in total GHG emissions by 2050 from 1990 levels. In Wales our Welsh Assembly Government, as well as being party to the international consensus, is also committed to annual incremental cuts of 3% in GHG emissions from 2011 onwards (calculated from a 2006 - 2010 averaged baseline). Clearly such an annual cut would, over 30 years, achieve the international and UK targets; equally, delays in instituting cuts will mean that annual incremental decreases (decrements) of greater than 3% will be needed, with a potential for greater economic and social disruption.

Box 1 records the global data for mean atmospheric levels in CO_2, CH_4 and N_2O for the last decades showing the rapid rises in these gases and outlines the main global consequences of climate change.

1.2 Economic and policy context

Other factors inform this report. There is growing evidence that oil availability will not keep pace with expanding demands and that peak easily-extracted energy (i.e. cheap oil) will soon be (possibly has been) reached. Further, oil, gas and even coal reserves which account for >80% of Wales' energy use, are finite and most oil and gas reserves occur in somewhat unstable countries. The oil price spike of 2008 may be a harbinger of the future while base-line oil prices have already increased in a decade by 3-4 fold. Secondly a number of countries, including the UK, are challenged to meet electricity demand within the next 10-15 years as existing generating capacity is phased out, partly to meet the "climate change agenda" and partly because of increasing obsolescence. Time is required to bring on new sources.

There is no prospect of continuing to rely on fossil fuels to drive the world or the Welsh economies, recognising also the dependence of agricultural production on fossil energy for fuel and especially for nitrogen (N) fertilisers.

The EU has set a target that by 2020, 20% of Europe's energy will come from renewable sources[3]. In the UK, the Department for Energy and Climate Change (DECC) has set a UK target for over 30% of the UK's electricity, 12% of heat and 10% of road transport fuel requirements coming from "renewables" by 2020[4]. Electricity currently supplies about 23 TWh of Wales' total annual energy demand of 129 TWh, but only about 1.6 TWh of this

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[2] Emissions of greenhouse gases are also commonly expressed as 'Carbon Equivalents' which are 0.273 x CO_2e (1 unit of carbon is equivalent to 3.67 units of CO_2)
[3] http://ec.europa.eu/environment/climat/climate_action.htm
[4] The UK Low Carbon Transition Plan. UK DECC – July 2009

comes from renewable sources – excluding pumped storage schemes[5]. The EU and UK targets therefore equate to about 25 TWh of renewable energy and 6 TWh of renewable low-carbon electricity in Wales. The EU and UK governments are promoting the production of CO_2-efficient electric vehicles (EVs), plug-in-EV and various other hybrid vehicles to decrease the growing CO_2 and NO_x emissions from transport. This will, of necessity, increase electricity demand. The same can be said for electrifying the railways. If the full environmental benefits of such technological innovations are to accrue, the demand must be met from low-carbon or carbon-free sources of electricity. There is an expectation that the new investment required to meet this demand and to fulfil the renewable energy target will result in electricity becoming increasingly expensive.

Clearly there is therefore a compelling environmental and economic case for curbing demand and achieving significant increases in energy use efficiency in all aspects of our lives.

For the inhabitants of rural Wales, with a high dependence on personal vehicular transport, these issues interplay and overlap with potentially positive or negative consequences. Agricultural production has a heavy indirect, as well as direct, dependence on energy costs (e.g. the price of fertiliser is highly correlated with that of oil). Distribution and travel costs are especially onerous in rural areas and for associated small, low volume businesses. For these reasons, and because dispersed electricity and heat generation are possible ecosystem services, sources of income and carbon off-sets (for CO_2, CH_4 and N_2O emissions from agricultural land use), this report considers aspects of dispersed micro-generation of electricity and heat.

It is highly possible that in Wales these pragmatic, economic arguments about the cost and availability of energy will be more influential in relation to public behaviour and individual choices in the next decade than any personal responses to "climate change" *per se.*

1.3 Climate change scenarios / challenges

The principle of the GHG effect is well understood scientifically. The Earth's climate is driven by the energy from the Sun, mainly in the form of visible light. About 30% is immediately scattered back into space, but most of the remaining 70% that is absorbed passes down through the atmosphere to warm the Earth's surface. Earth must retransmit most of this energy back into space in the form of infrared radiation. Being much cooler than the Sun, the Earth does not emit energy as visible light but instead emits infrared, or thermal radiation. GHGs in the atmosphere block some of the infrared radiation from escaping directly from the surface to space. Physics shows that the blanketing effect of the 'natural' pre-industrial global atmosphere, mainly due to water vapour and CO_2, has allowed a mean planetary temperature of

[5] Wales' CO_2 and other GHG Emissions Base Year 2006. Carbon Trust in Wales in association with the Welsh Assembly Government

about +15^{0}C compared with a calculated –18^{0}C in the absence of such an atmospheric blanket (*cf* surface temperatures on the Moon). As a result, historic levels of GHG have allowed life on our planet to evolve. The modern problems arise from human activity, primarily fossil fuel burning, changing these balances.

The data showing anthropogenic climate change, derived from a number of sources, are summarised in the reports of the IPCC. Their findings are based on a range of global climatic records and supplemented by signals of previous climates from over several hundred thousand years (e.g. ice and sediment cores). Recent records of global and regional temperatures (especially in polar regions), measurements of rates of melting of glacier and ice sheets and rates of sea level rise all support the basic theory. A rigorous examination has excluded other possible explanations (e.g. changes in the intensity of the Sun's radiation).

These climatic records have been used to validate models used for predicting future climate change. Global climate projections are highly complex with some atmospheric anthropogenic factors (e.g. additional CO_2) causing warming, and others (e.g. SO_x and dust/organic particulates), cooling (see Figures b) and d) in Box 1). Projections are, of course, dependent on assumptions made for global, regional and national attempts (e.g. Kyoto Protocol, EU Directives and UK carbon Budgets) to curb and hopefully reverse the increasing rates of emission of the major GHGs (e.g. atmospheric CO_2 is currently increasing by about 1.5 ppm per year) and damaging changes in land use (e.g. tropical forest destruction). Other potentially confounding effects include changes in the Sun's radiation, and other global cycles including the changes in the Earth's orbit (the Malenkovich cycles, which might currently be anticipated to cause global cooling). Nevertheless, the overall trends are, by now, clear at a better than 90% confidence level. Figure c) in Box 1 records the global consensus, median projections.

Especially troubling is the strong possibility of positive feedback reactions that could trigger rapid and essentially irreversible climatic shifts from one state to another (e.g. the risks of massive release of CH_4 from the warming of Arctic tundra). Hence, there is a widely held view (confirmed in Copenhagen) that global GHG levels should not exceed 450 ppm CO_2e, which is roughly equated to a 2^{o}C rise in mean global temperature.

Anderson and Bowes have estimated that the global cumulative emissions budget to 2050 necessary to maintain the temperature increase below 2^{o}C is 858 Gt CO_2e[6] which would imply a UK share of 17.6 Gt and 880-1,050 Mt for Wales[7]. Whether this can be achieved must be open to serious doubt, but it is imperative to do everything possible, including examining our individual and collective lifestyles, to limit the possibility of catastrophic changes.

[6] K Anderson and A Bowes PHIL Trans R Soc 366, 3863-3882 2008. Reframing the climate change challenge in light of post-2000 emission trends

[7] http://www.naseg.co.uk/events/presentations/2007/8_nov2007.html

For comparison, total emissions of all GHGs in Wales for 2007 are estimated at 46.8 Mt CO_2e of which CO_2 itself contributes about 39 Mt[8]. Thus at this rate, our 'quota' can be expected to be completely exhausted in about 20 years. Even so, this almost certainly underestimates Wales' full foot print with our dependence on "carbon" that is embedded in our imports and expended in aviation *etc*.

While exact global projections are difficult (despite the unambiguous trends), precise extrapolations at a local level for small land areas, such as Wales or regions within Wales, are problematic.

The central estimates of change for the 2050s for Wales based on median estimates of global increases in GHGs are:

- average annual temperatures projected to increase by 2.3°C.
- in summer, daily maximum temperatures projected to increase by 3.4°C.
- in winter, daily minimum temperatures projected to increase by 2.5°C.
- overall the total annual average rainfall projected to remain much the same, but rainfall projected to increase in winter on average by 14% and decrease in summer by 16%.
- sea levels around Wales projected to rise by approximately 20cm[9].

These suggest:

- that the physical impacts on Wales will be less severe that on some areas (e.g. the Mediterranean basin, the Arctic, major deltas, low lying islands *etc*).
- occurrence of modest impacts on seasonal weather patterns with warmer, possibly somewhat drier summers but wetter, temperate winters,
- increases in extreme events including severe storms and periodic droughts, and
- possible flooding from the third bullet point above and from increases in sea level and storm surges *etc*.

Some experts would predict greater changes, particularly in relation to sea level rise.

It is also worth noting that north-western Europe is uniquely warmed by the Gulf Stream. Wales shares a latitude, but not a climate, with Labrador, southern Hudson's Bay and the Aleutian Islands. In the medium term, paradoxically, global warming and Arctic ice melt pose a small but significant threat to this good fortune.

It is probable, however, that over the next two or three decades indirect social and economic impacts and the effects of governmental commitments to mitigate international crises will be greater than any direct climatic effects.

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8 http://www.airquality.co.uk/reports/cat07/0909231418_DA_GHGI_report_2007_maintext_Issue_1.pdf

9 http://ukclimateprojections.defra.gov.uk/content/view/2157/528/

Prof John Beddington, Chief Scientist to the UK government, has postulated a "perfect storm" in which global population growth and a growing middle class, concomitant food demand, depletion of over-exploited water resources, climate change and an energy (cost as well as availability) crisis combine to affect global and regional food supplies, human migratory patterns and international and internal conflicts and unrest.

Wales and its inhabitants will not be insulated from such as a storm.

1.4 Environmental (ecosystem) services

Our land, including the coasts and inshore waters that come under the formal authority of the Welsh Assembly Government, provides us with a wide range of essential eco-systems goods and services such as food, drinking water, recreational opportunities and related physical and psychological health benefits, flood alleviation, timber for building and fuel, biodiversity and wildlife and, of course, natural beauty. In addition, our ecosystems are critical to soil conservation and nutrient cycling, to fresh and inshore water quality and to air quality. Land use has been historically, and remains, an important source of renewable energy, not only traditional fuel wood, but also locations for hydro, wind, photo-thermal, photo-voltaic, biomass and bio-fermentation power systems. These services are also important to the Welsh economy generally, to rural Wales specifically and to adjacent areas of England.

Alongside the "provisioning services" of land using activities, food, wool, timber and more recently biofuels, the management of land supports the supply of "regulation" ecosystems services, which include climate regulation, water purity, surface flows and ground water recharge, and absorption of waste products. All of these regulation services come into the categories described by economists as either "externalities" (an impact, which can be a benefit or a cost, on someone other than those directly involved in an exchange) or public goods (because nobody can be excluded from benefiting from it with little or no incentive for private producers). In both cases, such ecosystem services are poorly captured by existing markets. Society, as a whole, could nevertheless benefit if the public sector used tax revenues to purchase them. The effect of such new incentives could then help to change the structure of land management, to make better use of our growing understanding of systems-wide synergies in agriculture and forestry.

The problem is that, while a good case can be made for more ecosystem services output, it is by no means clear how much more should be encouraged. Estimates of benefits, in terms of what we have to give up to get them, must be attempted and that usually means making some simplifying assumptions to assess an appropriate measure of their price. On a global scale, Robert Costanza and colleagues[10] have estimated the mean total value of renewable ecosystem services as US$33 trillion; distributed across different biomes, total *annual* values for all services per unit area ranged from $92/ha

[10] Robert Costanza *et al.*, "The value of the world's ecosystem services and natural capital", *Nature*, vol. 387, May 15 1997, pp. 253–260.

for cropland, $232/ha for grassland and $302/ha for boreal forest. While it would not be meaningful to apply such general estimates to Welsh land use (especially as more recent estimates of potential damage from climate change would increase the shadow price of GHGs and they also neglect cultural and recreational land use values), the figures give some indication of the relative orders of magnitude involved.

Over recent years there has been an increasing recognition of the role of the natural environment in contributing to economic development and our well-being as individuals. Environmental assets provide benefits that enhance economic performance, offer new opportunities for investment and employment, and improve living standards and quality of life.

Ecosystem services are defined as services provided by the natural environment that benefit people. The Millenium Ecosystem Assessment has classified ecosystems into 4 categories. Details of these are summarised in Table 1.1.

The challenge is to balance these vital services in ways that allow substantial progress in meeting the GHG emission targets, and to identify short- to medium-term policy options that can be implemented at an individual, community and regional level through improved management, investment options and interventions. These must be sufficiently robust to meet the current critical climate change imperatives, whilst not prejudicing our capacity for future adaptation. We must also seek to maintain and hopefully enhance social, economic and broader environmental sustainability.

In the context of this report the following ecosystem services are particularly relevant:

Food

This can be considered from two complementary perspectives. Agriculture and consequential food production make a significant contribution to the economy and social fabric of rural Wales. Also all inhabitants of Wales require food, only part of which is “home” produced. Much comes from other parts of the UK and some from abroad. It is important to recognise that the marketing and food chains are highly integrated within the UK. Wales exports a large proportion of its lamb, beef, milk and milk products. The UK imports approximately 35% of its food from outside its borders.

The population of Wales is *c*2.95 million in an area of 20,700 km^2 (~2.1 million ha) - i.e.140 persons per km^2 (*cf* England at 380). Of this area some 1.64 million ha is farmed, and about 76% of the farmed area is regarded in agricultural terms as disadvantaged (recognised by the EU as “Less Favoured Area”). 86% is grassland and only about 6% is currently arable. Most of the rest – 286,000 ha - is woodland (roughly divided into 56% coniferous plantation and 44% deciduous)[11].

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11 http://www.forestry.gov.uk/website/forstats2009.nsf/LUContents/BF32BD6C9B18DD3680257360004FE23E

Table 1.1 - Millenium Ecosystem Assessment categories of ecosystem services and examples

Category	Examples of ecosystem services provided
Provisioning services (i.e. products obtained from ecosystems)	• Food e.g. crops, fruit, fish • Fibre and fuel (e.g. timber, wool) • Biochemicals, natural medicines and pharmaceuticals • Genetic resources: genes and genetic information used for animal and plant breeding and biotechnology • Ornamental resources (e.g. shells, flowers)
Regulating services (i.e. benefits obtained from regulation of ecosystem processes)	• Air quality maintenance: ecosystems contribute chemicals to and extract chemicals from the atmosphere • Climate regulation (e.g. land cover can affect local temperature and precipitation, globally ecosystems affect GHG sequestration and emissions) • Water regulation: ecosystems affect (for example the timing and magnitude of runoff, flooding *etc*) • Erosion control: vegetative cover plays an important role in soil retention and prevention of land/asset erosion • Water purification/detoxification: ecosystems can be a source of water impurities but can also help to filter out/decompose organic waste • Storm protection
Cultural services (i.e. non material benefits that people obtain through spiritual enrichment, cognitive development, recreation *etc*)	• Spiritual and religious value: many religions attach spiritual and religious values to ecosystems • Inspiration for art, folklore, architecture *etc* • Social relations: ecosystems affect the types of social relations that are established (e.g. fishing societies) • Aesthetic values: many people find beauty in various aspects of ecosystems • Cultural heritage values: many societies place high value of the maintenance of important landscapes or species • Recreation and ecotourism: people often choose where to spend their leisure time based on the landscape *etc*
Supporting services (necessary for the production of all other ecosystem services)	• Soil formation and retention • Nutrient cycling • Primary production • Water cycling • Production of atmospheric oxygen • Provision of habitat

The farming system is largely pastural with a national flock of 4.2 million breeding sheep (plus their lambs) - down from 5.5 million in 1996. In 2008 there were 573,000 cattle aged >2 years, with more dairy than beef numbers. There is only a small representation of the arable, horticultural, and pig and poultry sectors[12].

[12] http://wales.gov.uk/docs/statistics/2009/090625farmfacts09en.pdf

Table 1.2 - Welsh Primary Output by Sector in 2006

	Output (t unless noted otherwise)	Embedded water (m^3)	Farmgate value (£ million)
Milk	1,550 $\times 10^6$ l	1.7 x 10^9	266.7 *
Meat:			
beef and veal	45,000	69.7 x 10^3	196.8
lamb and mutton	83,000	127 x 10^3	194.8
pig meat	1,500	2.80 x 10^6	3.3
Poultry	46,000	8.59 x 10^7	47.4
Wool	8.8 million kg		4.6
Grains:			
Wheat	100,000	4.51 x 10^7	7.7
Barley	96,000	6.50 x 10^7	
Oats	22,000	1.44 x 10^7	
Potatoes	64,000	4.81 x 10^6	8.1
Eggs	400 million	3.52 x 10^7	21.4

* **Note:** (includes milk and milk products)

Sources

- Chapagain, A.K. and Hoekstra, A.Y. (2004) 'Water footprints of nations' available at: http://www.waterfootprint.org/?page=files/Publications
- Statistics for Wales (2009) 'Aggregate Agricultural Output and Income 2008' available at: http://wales.gov.uk/docs/statistics/2009/090224sdr232009en.pdf?lang=en

In Table 1.2 the embedded water involved in this primary production and the farm gate values are recorded. These figures do not include the retail value or the energy and water used in the processing, distribution and marketing.

From a Welsh food consumption perspective, the energy provided to individuals, assuming an average of intake of over 3,000 calories/person/day, equates to about ~3.4 kWh/person/day (or >3 TWh of food energy for Wales per year). However the energy involved in producing, packing, distribution, storage and waste of that diet will be at least ten times this figure; perhaps some 30 TWh/year for Wales (*cf* Wales total energy use of 129 TWh). In a healthy diet the direct energy inputs might be subdivided into 1.5 kWh (1290 calories) directly from vegetables (including potatoes and grains), 0.7 kWh (600 calories) from dairy products, 0.2 kWh (170 calories) from eggs and 0.5 kWh (430 calories) from meat[13].

Wood/Timber

Wood, alongside food, is the other key provisioning ecosystem service from land management in Wales. In 2008, just over half (51%) of Wales' 284,000 ha of woodland was under active management. This includes the 106,000 ha of Welsh Assembly Government owned woodlands managed by Forestry Commission (FC) Wales. A further 40,000 ha have an approved management plan under the Better Woodlands for Wales grant scheme. The annual timber harvest varies between 0.9 and 1.2 million m^3, primarily due to

[13] David J C MacKay Sustainable energy without the hot air

market conditions affecting the willingness of private woodland owners to market their timber. However on average, the current softwood timber resource in Wales is almost optimally harvested with 86% of forecast volume achieved over the 6-year period - 2002-2008. The picture for the active management of the hardwood resource is not nearly as positive with estimates that in 2000, the average annual increment was 400,000 m^3 but the actual harvest was 32,000 m^3 (8%).

The forest sector in Wales is an important component of the land management economy, especially in rural areas. The Office for National Statistics quantified the Gross Value Added from the domestic forestry sector at £429 million in 2004. However, as with food provision, Wales is not self-sufficient in wood fibre. More than 75% of our needs as a country are imported, and with an increasing trend to large-scale energy production from woody biomass, imports seem set to increase.

One of the challenges for Welsh forestry currently is the paradox of strong consumer demand for wood products, set against a domestic resource that is currently under-managed. There are many apparent reasons for this ‘disconnect’ and current Welsh forestry policy has already prioritised outcomes that aim to make progress in this area.

Welsh forestry has a number of contributions to make towards helping Wales reduce its GHG emissions:

- reduction of direct operational emissions through technical efficiency measures and alternative fuels
- carbon fixation in soil and woody biomass via sequestration to create a ‘sink’
- fossil fuel substitution by “harvested wood products”. This substitution is either direct for fossil fuels via wood fuel or indirect via material substitution where solid timber is used to replace materials that have high GHG emissions during their manufacture. In addition, the carbon “pool” in these solid timber products is relevant as well.

In addition to being sources of timber, pulp and wood-fuel, woodlands are important contributors to biodiversity, water quality, watershed management and natural beauty.

Landscape/Natural Beauty

Because of the dominance of pastural agriculture - a hilly (sometimes mountainous) topography, high rainfall and large areas of relatively infertile moorland soils - much of Wales has retained a high level of biological and geological interest and a very varied and beautiful landscape. Similar claims can be made for much of the coast line - especially perhaps from the Mumbles to the Great Orme - much of which is designated as National Park (NP) or Area of Outstanding Natural Beauty. This, somewhat paradoxically, despite a long history of mostly small-scale mining and quarrying which dates back to the Bronze Age. Nevertheless much of our landscape and biodiversity is a product of human activity and of historic land management by farmers and foresters. As a result, very large areas of Wales, although bearing the footprints of long human habitation, enjoy some designated or protected status either for their landscape or biodiversity value. This is illustrated in Fig 1.

Biodiversity

Wales contains relatively few unique species or habitats. Even the iconic refuge species *Lloydia serotina* (Snowdon Lilly), is quite common elsewhere (e.g. in parts of the Rockies and the Carpathians). Much of the visual impact and ecological interest lies in the mosaic of habitats - patchwork of fields and small woodlands with dramatic changes over short distances - as well as the relative tranquility. The conservation system is predicated on the identification and long term retention of specific “interests” (e.g. Sites of Special Scientific Interest). This system was devised prior to our understanding of the likely impacts of climate change and may need to be adapted. Conserving biodiversity in the face of climate change makes it even more crucial that other pressures on the natural environment are limited. New concepts, such as the development of migratory corridors, are required. Similarly the fabric of the landscape can be anticipated to change over the next 50 years, as discussed later.

Tourism/recreation

Tourism and recreation are important contributors to the rural economy and to rural employment. These are significant and dependent on the natural beauty of the countryside and coast. Also, within the last two decades an increasing synergy has emerged between local production of high quality foods, including sea-food, greatly improved food outlets and restaurants catering partly for the tourist trade.

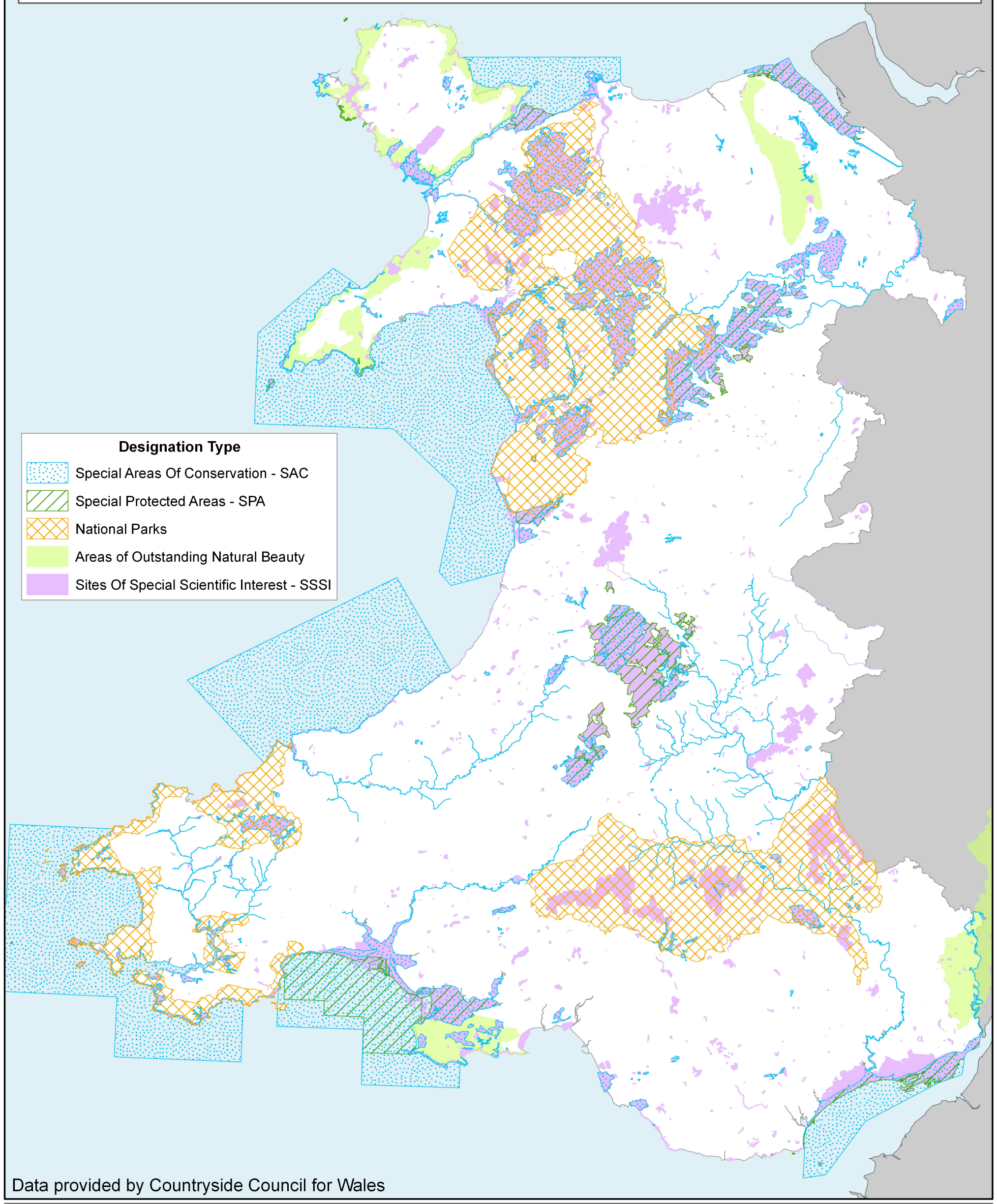
Soils, water, flood control and other services

Soils are a major component of the natural environment, linked inextricably to the landscape. For example, there are shallow mountain soils, derived from hard parent material in extreme climatic conditions, which contrast with the deep fertile loamy red soils of the Welsh borders, derived from soft sandstone.

Soils, along with light, air and water, are essential for plant growth, which underpins our food and fibre production. Also soil is an extremely important biological habitat and gene reserve, with great biotechnological and pharmaceutical potential. Below-ground biodiversity is vast. More than half the world’s species live in the soil. One gram of soil supports approximately 10,000 protozoa, 10 million bacteria and 5 km of fungal mycelium.

Soils deliver many environmental services, such as retaining and releasing clean water within our river catchments, and buffering, filtering, transforming and storing contaminants. Over 90% of our drinking water flows through or over the soil. The importance of soil carbon and its role in the global carbon cycle has become increasingly apparent. Welsh soils hold about 16 times more carbon than the atmosphere above Wales.

Fig 1 - Distribution Of Selected Designation Categories Across Wales



The importance of soil is recognised by the proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil. In Wales a Soil Action Plan is being finalised by the Welsh Assembly Government.

2. Historical and social perspective

As the last Ice Age drew to a close around 12,000 years ago the land that is now Wales was devoid of wildlife, developed soil and people. By around 8300 BP (before present) the country had become free of ice and was being gradually populated by plants and animals including humans; the latter most probably moving up the Atlantic coast from modern Iberia. By around 7,500 BP the land was heavily forested, except over *c*750 m and the coastal dunes and estuaries. A climatic climax with higher than current temperatures was reached some 5,500 years ago followed by a slow but irregular decline interspersed with cooler and warmer periods, exemplified by a medieval warm period and the 'Little Ice Age' of the late 18th and early 19th century. The cooler wetter period about 4,000 BP saw the creation of the upland blanket and bog peats which now contain a very large but potentially vulnerable carbon store (*c*400 Mt of carbon which would emit 1,500 Mt CO_2 if lost) in Wales).

The retreat of the ice also saw major changes in sea level and the inundation of places such as Cardigan Bay and Traeth Lafan possibly recalled in the folk myths typified by 'Cantref Gwaelod'.

Early forest clearance in Wales was probably bought about by the small semi-pastural / hunter-gatherer population. But for thousands of years the population remained low and their environmental impact limited. Even as late as the Anglo-Norman conquest, around 1300 AD, the population of Wales is estimated at only around 300,000. Moreover the cataclysm of the Black Death and major civic strife saw it fall back to perhaps 200,000, not re-attaining 300,000 until the late Tudor period (*cf* 3.75 million in England). Even by 1770 the population was only about 0.5 million, but by 1851 the more reliable census data put the number at 1.16 million, reaching 2.5 million by the First World War (not far short of the current 2.95 million). The dramatic 19th century leap was of course driven by the industrial revolution in which Wales played a pivotal role.

The industrial revolution was accompanied by a parallel agrarian revolution with major changes in land use to meet the demands of the expanding urban centres: extensive deforestation for fuel and building (including the merchant and navy fleets) and major migration from rural Wales into the towns. Data suggest sheep and cattle numbers plateaued at 3-4 million total sheep and lambs between from 1870 and the early 1950s. Sheep numbers were exceptionally high in the 1990s. Similarly cattle and calf numbers, after decades of relative stability, peaked around 1970. In each case farmers were responding to the UK or EU support on offer. The influence of support systems is clearly illustrated in the recent decline in sheep numbers with the withdrawal of headage payments. The coming of the tractor and farm mechanisation saw horse numbers decline from 180,000 at the end of the Great War to less than 50,000 today. Within a dominantly pastural countryside, the records from 1860 show a steady decline in arable cropping interrupted by two peaks: a very sharp spike during the 1914-18 war and a broader peak from 1939 through to the early 1950s. There was a parallel decline in forest cover, but since the Wars predominantly coniferous afforestation has partially reversed this trend. See Box 2 for data on historic changes.

The last century has seen a large decline in the numbers employed in agriculture, also in the numbers of farmers and holdings and in agriculture's contribution to the wealth of Wales (including rural Wales). Rural as well as individual farm incomes have diversified although historically, mining and agricultural smallholdings have been inter-wined in Wales.

There has been a fundamental change in farming economies over the past 50 years. These economies were dominated by primary production, including agricultural, forest and mineral products, but particularly in upland areas, there has been a shift to the service sectors with such as provision of tourism and leisure activities. Rural communities have become more diverse because of out-migration by young people, combined with increasing numbers of 'amenity migrants' who are higher income earners and retirees, making lifestyle decisions to buy rural property. Farms have diversified their businesses, with members of the family working off-farm or engaged in contracting on other farms.

Small and medium sized family farms continue to survive through considerable "tenacity and flexibility to endure". Adaptation and retrenchment take place rather than determined disengagement from agriculture. Adaptation often takes the form of reduced labour input and the sale of some property assets, especially among older occupiers. This has been exacerbated succession issues where children are increasingly less likely to succeed. Sale of land has led to expansion of farm units, but they are often fragmented.

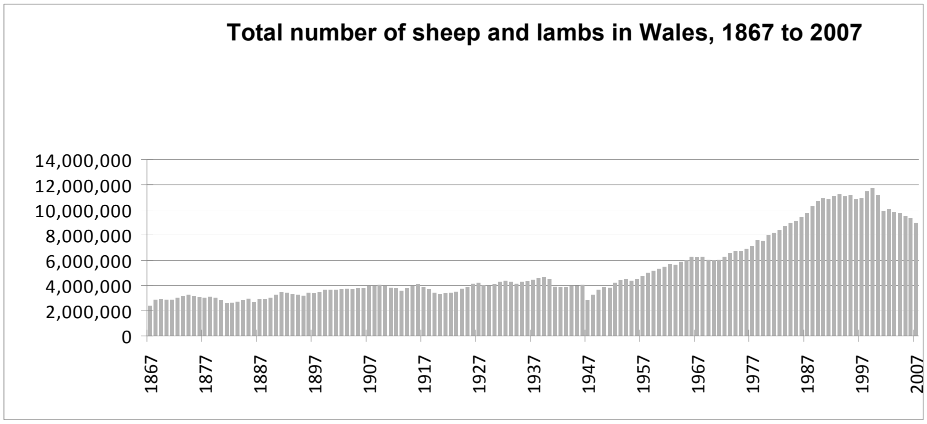
In response to these changes, in 2009 the Assembly Government published proposals to revise planning guidance in Technical Advice Note 6 to facilitate the diversification of the rural economy as a way to provide local employment opportunities, increase local economic prosperity and minimise the need to travel for employment. [14]

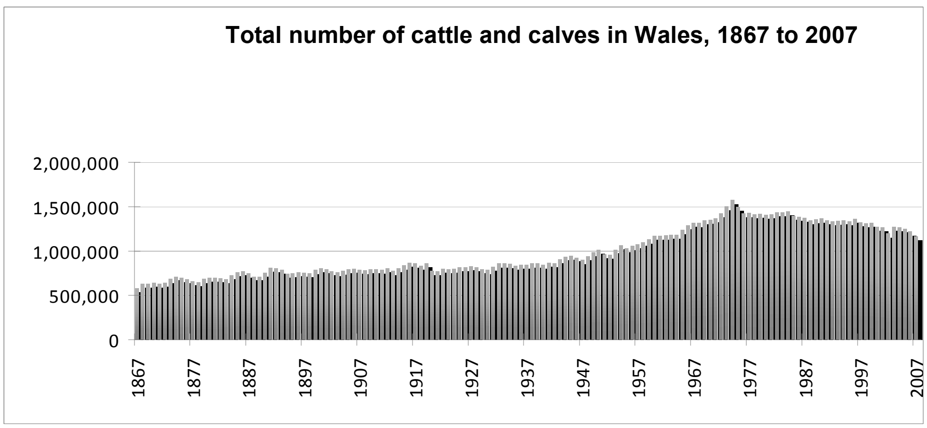
This highlights several points:

- Over the last 10,000 years neither climate nor land cover (nor indeed sea level and shoreline) have been constant. Humans and wildlife have adapted, sometimes by migration (accompanied by cultural and technological innovation), sometimes by changes in lifestyle. However, the migratory option is highly constrained in a heavily populated world with large and increasing expectations.

[14] Draft Technical Advice Note 6 Planning for sustainable rural communities – Welsh Assembly Government. July 2009

Box 2 - Historic changes in animal numbers and arable land





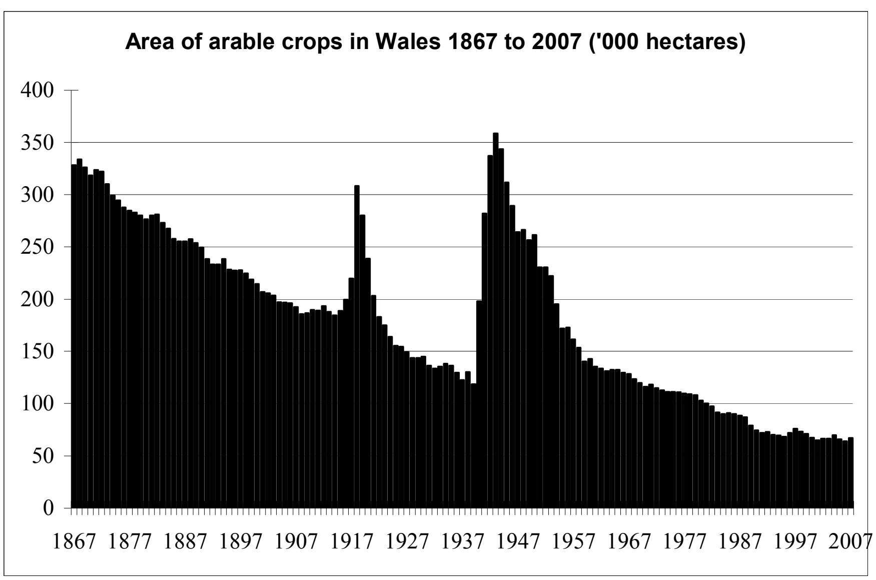
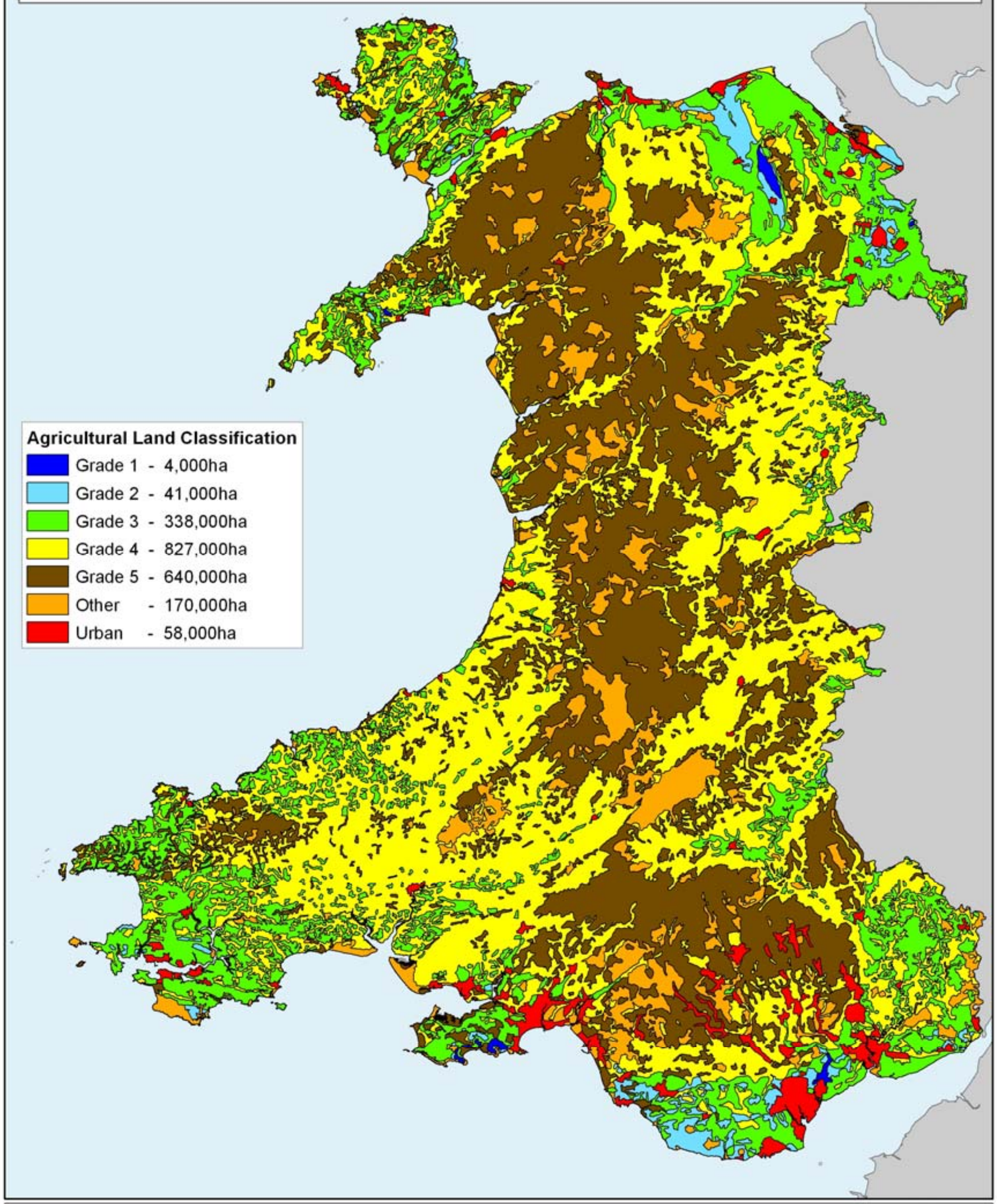


Fig 2 - Provisional Agricultural Land Classification of Wales



Cartography by SEED

Llywodraeth Cynulliad Cymru
Welsh Assembly Government

- Wales' land cover and land use have experienced significant changes, emphasising the flexibility and adaptability of rural people and farming systems. From a historic perspective current forest cover is low.
- Even taking into account changing agronomic practices and the demands of mechanisation, both the historic land use figures and the Agricultural Land Classification (Map 2) suggest a significant potential for increased arable production.
- The large spike in sheep numbers in the late 1990s was the product of headage intervention, not reflecting best land use, animal husbandry practices or long term economic sustainability.

The data show how rapidly farmers and attendant land use practices respond to policy and financial signals.

Previous evidence implied that the climate change challenge, combined with other physical and economic pressures (e.g. mass extinction of biodiversity, over-use of limited water supplies in many countries, reduced availability of cheap energy) threaten (cheap) food supplies and potentially may precipitate for economic dislocation and social strife. All this is in a growing world and UK population.

Consequently given the relatively fortunate geographic position of Wales and our human and natural resource base, a positive response to these challenges is essential. Humankind has a greater technical capacity and an understanding of planetary cycles, dynamics and issues which will help to inform our responses.

3. Current contributions of land use and related sectors to GHG emissions (including from farm inputs, through the food chain, to cooked food on the plate)

Globally, GHG emissions from human activity are in excess of 34 Gt of CO_2e/year (*cf* the “natural” terrestrial and oceanic cycles of over 700 Gt). Given a growing world population of over 6 billion, this amounts to about 5.5 t of CO_2e/head. Wales' annual per person emissions (i.e. the emissions which originate in Wales from industry, power generation *etc* and land use) are estimated at 15.6 t CO_2e (2007 data) - approximately three times the global mean, which is itself the cause of international concerns. An 80% cut, assuming no population growth, would bring this figure to 3.1 t CO_2e / person by 2050. Clearly a more realistic estimate of the global population at about 9 billion would imply a figure nearer 2 t CO_2e / person.

Part of Wales’ embedded CO_2e (as well as water) is in materials exported from Wales. Conversely Wales also imports embedded CO_2e and water in food, consumer durables and other imported material. To date the most comprehensive method of assessing this consumption footprint has been the ecological footprint which is an indicator of our total environmental burden on the planet. It represents the area of land needed to provide raw materials, energy and food, and to absorb pollution and waste created. Wales’ 2003 ecological footprint is 5.16 global hectares (gha) per person – but the biological land actually available on a global level is 1.8 gha per person. This means that if everyone lived the same way as a person in Wales, we would require 2.8 planets to provide the resources that this would imply[15].

The GHG Inventory (GHGI) for Wales (2007) estimates the total annual Wales emissions to be 46.8 Mt CO_2e, to which the agricultural and land use sector contributes a net ~5.2 Mt CO_2e, or 11% of the total. This estimate omits both GHGs from the food chain beyond the farm gate and GHGs / energy embedded in imported fertilisers and other farm inputs. About 18% of UK GHG emissions are related to food production and consumptions[16] Extrapolating from this data to Wales, it may be assumed that land use in Wales plus the whole food production and consumption chain generates about 8.2-9 Mt CO_2e /year. In terms of *production* this is attributable to the Welsh agricultural sector. However, in *consumption* terms, these emissions are a component of the food consumption carbon-footprint of all Welsh people as well as the emissions embedded in food exported from Wales and consumed elsewhere. A demand-based perspective must necessarily require an engagement with both consumers and the supermarkets (which dominate the food retailing business) and consequently with the urban population.

Of the ~8-9 Mt CO_2e related to production, as noted above, all three main GHGs are involved and contribute as below:

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[15] Wales’Ecological Footprint – Scenarios to 2020. E Dawkins, A Paul, J Barrett, J Minx, K Scott. Stockolm Environment Institute 2008

[16] Cabinet Office Strategy Unit. Food Matters – Towards a Strategy for the 21st Century. July 2008

- 2.72 Mt CO_2e is as CH_4 (60% of total Welsh emissions of CH_4) mainly from enteric ruminant fermentation but also from stored manure and anaerobic organic soil decomposition.
- 2.83 Mt CO_2e is as N_2O (82% of total Welsh N_2O emissions) from microbial action in soils and manures including leaching of N fertiliser (27%), synthetic inorganic fertiliser application (19%), manure used as fertiliser (8%), ploughing in crop residues (1%) and cultivation of legumes (<0.1%).
- the remainder is CO_2 comprising 0.48 Mt CO_2e as direct emissions from on-farm combustion of fuel, aerobic microbial decay and release, and aerobic metabolism of soil organic matter (includes electricity use on farm - approx. 0.11 Mt). To this must be added CO_2 embedded in imported fertilisers. For the UK, annual fertiliser consumption of 900,000 tonnes causes emission of about 6Mt CO_2e - equivalent to about 1% of UK emissions[17]. On a pro rata basis this would contribute around 0.47Mt CO_2e to Wales emissions on a consumption basis. Emissions from energy used in the rest of the food chain would contribute perhaps - 3 Mt CO_2e, noting the need to clearly attribute emissions to either the production sector (food as an ecosystems service) or to consumption.

In later sections these individual gas emissions are allocated to activities within the farming system or to categories of land use change.

Box 3 shows the methods used to calculate the emission inventory.

[17] How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050. WWF(UK) and Food Climate Research Network 2010

Box 3 - Inventory methods for estimating emissions

UK emission inventories are prepared to internationally agreed guidelines prepared by the IPCC. These guidelines are used to ensure that emission estimates are consistently reported internationally for compliance with the Kyoto Protocol.

Within the UK, annual emission estimates are also made for Wales and other constituent countries. Methods are published in "UK Greenhouse Gas Inventory 1990 to 2007" – AEA April 2009, and are summarized below for the agriculture and land use sectors.

Agriculture

The agriculture Inventory is prepared by North Wyke Research, and is based on estimates of emissions from the major UK sources:

- Enteric fermentation (CH_4)
- Manure management (CH_4 and N_2O)
- Agricultural soils (N_2O)

The main drivers are animal numbers, crop areas, crop production, and fertiliser / manure use.

<u>CH_4</u>

Emissions are calculated from the equation A x EF
where: A = Activity data (animal numbers, fertiliser use, etc)
EF = Emission Factor / unit source
Activity data are obtained from statistical surveys. Examples of emission coefficients are presented below:

Table B3.1 – CH_4 Inventory emission coefficients (kg CH_4/head/year)

	Enteric Fermentation	Manure
Dairy cattle	105	25.8
Beef cattle	48	2.74
Other cattle > 1 year	48	6
Other cattle < 1 year	32.8	2.96
Sheep	8	0.19
Lambs < 1 year	1.6	0.076

For example for 100 dairy cows the annual emissions in CO_2e are
130.8 x 21x100 = 275 t CO_2e

Emission factors for dairy cattle take account of average weights, milk production rates and average milk fat contents. Emission factors for beef cattle take account of average weight, grazing time, gross energy intake and daily weight gain.

N_2O emission coefficients – manure management

Direct emissions from manure during storage and treatment depend on the amount of N compounds in the manure, the duration of storage and type of waste handling system. Coefficients for emissions during manure management are expressed as a proportion of N excreted. The correction for losses as ammonia and NO_x comes into the N_2O emissions from soils category. Here, the amounts of manure N and fertiliser N applied to soils are adjusted to account for volatilisation (20% for organic manures, 10% for fertilisers). N excretion rates for different animal types are used to estimate total amounts, and emissions are calculated from the fraction of the total manure managed by each handling system, using the following emission factors:

Table B3.2 – Inventory emission factors (kg N_2O/kg N excreted) for various waste handling systems

Waste handling system	Emission factor
Liquid system	0.0016
Daily spread	0 *
Solid storage	0.031
Pasture - Grazing	0.031

*** Note:** data on handling systems come from reviews by research organisations. None are specifically for Wales. Emissions from land spreading of manures on soil are estimated under “Agricultural Soils” (see below).

Agricultural soils – N_2O

The following sources are included in the methodology for estimating direct N_2O emissions from managed soils, with Emission Factors.

Table B3.3 – Sources of N_2O emissions from agricultural soils and their emission factors

Source[i]	Emission Factor
Artificial fertilisers	0.0125 kg N/kg N applied[ii]
Organic N applied as fertiliser e.g. animal manure, compost, sewage sludge	0.0125 kg N/kg N applied
Biological N fixation	0.0125 kg N/kg N fixed by crop
N in crop residues (above-ground and below-ground)	0.0125 kg N/kg N applied
Drainage / management of organic soils (histosols)	12.6 kg N_2O/ha/year[iii]
Atmospheric deposition of volatilised N oxides and ammonia from fertilisers and manures	0.0157 kg N_2O/kg N

Notes: (i) Quantities of fertilisers applied are based on British Survey of Fertiliser Practice.
(ii) 0.0125 kg N/kg N applied is equal to 0.0196 kg N_2O /kg N applied.
(iii) Where soil carbon is lost through oxidation as a result of land use or management change, this loss will be accompanied by a simultaneous mineralisation of N, an additional source available for conversion to N_2O.

Emissions from urine and dung N deposited by grazing animals are estimated under manure management systems. Estimates of N applied take account of volatilised N on application and during manure storage. Corrections are not made for leaching and run-off (i.e. the amount of N applied is not adjusted to account for this), but an estimate of the proportion of N being lost via that route is made and an estimate of subsequent indirect emissions from that source.

Land use, land change and forestry

The Inventory is prepared by CEH, and is based on estimates of emissions from the changes in carbon quantities in soils and biomass when the use of specific land areas is changed (e.g. arable land changing to forest). In addition, for forest land use remaining as forest land, the C-Flow model is used to estimate changes in carbon content of soil and biomass to provide an estimate of CO2 emissions and sinks.

But for other land uses which have remained unchanged for many decades and where soil carbon levels have reached equilibrium, the net CO2 emissions from soils and biomass are assumed to be zero because the overall system is hypothetically in equilibrium - except “liming” see below.

Changes in soil carbon take many years to reach equilibrium. Carbon losses are assumed to occur over 50-150 years, while carbon gains are assumed to occur over 100-300 years. Emissions and removals for any one year include estimates of the continuing loss or uptake of carbon as a result of land use change in previous years.

Carbon stock changes, resulting in net CO_2 emissions / removals, for each land use category are estimated for:

- living biomass (gains and losses)
- dead organic matter (net change)
- soils (net change in mineral and organic soils)

Emissions of GHGs from the following land use activities are included:

- N fertilisation of Forest Land
- Liming of Cropland and Grassland - CO_2
- Biomass burning of Forest Land - CO_2, CH_4, N_2O

Activity data come from a range of sources.

Land use

For forestry, estimates of carbon stock changes are based on a dynamic growth model (C-Flow) and annual afforestation data from FC. Estimates of carbon gains and losses for conifers are based on Sitka Spruce yield classes 12 and 14, and broadleaves are based on beech parameters. Data come from FC yield tables and other experimental data.

For other land uses, GHG emissions from liming come from statistics on mineral extraction, and fertiliser practice. The emissions from wetlands are not estimated specifically, nor are estimates from other land management practices considered, for example grassland and arable management techniques.

Land use changes

Estimates of carbon stock changes when converting from one land use to another are based on a model which in turn is based on soil and biomass carbon densities for different land uses and types of soils, and land use change trends from CS data. Emission estimates depend on the changes between initial and final land use, and the rate of conversion. The average changes in Equilibrium Soil Carbon densities to 1 metre depth for land use changes are summarised below.

Table B3.4 - Weighted average change in equilibrium soil carbon density (t carbon/ha) in Wales*

	FROM	Forestland	Grassland	Cropland	Settlements
TO	Forestland	0	23	57	114
	Grassland	-18	0	36	101
	Cropland	-53	-38	0	48
	Settlements	-110	-95	-73	0

*** Note:** Based on National Soil Resources Institute. soil carbon data for Wales and scientific literature. Rate of change depends on time to reach equilibrium between the initial and final land use.

Biomass carbon changes other than for forestry are estimated in the same way as for soil carbon changes. The weighted average change in equilibrium biomass carbon density to 1 metre depth is summarised in the following table.

Table B3.5 - Weighted average change in equilibrium biomass carbon density (kg carbon/m^2) in Wales

	FROM	Forestland	Grassland	Cropland	Settlements
TO	Forestland				
	Grassland		0	0.07	-0.08
	Cropland		-0.07	0	-0.13
	Settlements		0.08	0.13	0

Estimates of emissions from conversion to settlements are based on soil carbon stock changes, assuming half the soil carbon is lost immediately, and the remaining carbon is lost over 50-150 years. Change in areas of settlements is based on analysis of Ordnance Survey data in England, but this analysis is not done in Wales.

Land use change data for Wales are estimated from GB matrices from Monitoring Landscape Change data in 1947 and 1980, in combination with CS in 1984, 1990 and 1998. There was poor coverage for Wales, with 64 one-km squares surveyed in 1998, and 46 in 1990. The annual land use changes are based on the CS in 1990 and 1998. The matrix for Wales is below, with aggregation of main habitat types monitored in the CS.

Table B3.6 - Annual change in land use area (ha) in Wales 1990-1999

	FROM	Forestland	Grassland	Cropland	Settlements
TO	Forestland		2,400	200	200
	Grassland	1,500	0	5,500	600
	Cropland	0	8,000		0
	Settlements	100	1,800	200	

Biomass burning after forest conversion to grassland (deforestation) is estimated from felling-licence data from FC (1990-2002) and IPCC default emission factors.

Other activities

Changes in stocks of carbon in harvested wood products (HWP) from forest management are based on annual forest planting rates and the C-Flow model which assumes intermediate thinning and then clear-felling and replanting at 57 or 59 years for conifers and 92 years for broadleaves. 95% of the living biomass carbon stock is assumed to transfer to the HWP pool, and 5% is lost immediately on harvesting. Residence times (time to 95% carbon loss) for HWP are assumed to be:

Thinnings	5 years
Conifer wood products	59 years
Broadleaves wood products	92 years

4. Approach of the Group

The Land Use Climate Change Group (LUCCG) has adopted a number of working guidelines:

- the report records the short-term (2010 –2015) mitigation options and focuses on possible medium-term (2015 – 2025) scenarios and related interventions.
- the report identifies, where possible, “win-win” options which will allow farmers and others to cut emissions while maintaining or improving economic viability.
- the report seeks to balance and maximise eco-system services from rural Wales, including the capacity to adapt to future change in climate and demand patterns beyond 2020 – 25; recognising the possible trends in water availability and demands within Wales and southern Britain and trends in international food and energy availability and costs.
- the Group recognised that our response to the challenge of climate change must engage with and motivate the farming and rural community despite public scepticism.
- the Group also recognised that proposed solutions to rural GHG emissions must be compatible with other eco-system services (as varied as flood control, food production and biodiversity conservation) or they would not be acceptable.
- the Group recognised significant gaps in our knowledge and a number of scientific uncertainties even with emission data. These are noted and research and pilot projects are recommended to fill these gaps.
- the Group recognised the vital importance of maintaining the current carbon store in Wales' soils and peats in the face of projected climate changes.
- the Group recognised the importance that Wales makes a positive contribution to global problems including food and energy availability and limiting our imports of embedded emissions.
- this report does not address possible cropping / land use patterns beyond 2025; except that the forestry recommendations clearly have implications beyond this time frame.
- the Group recognised a number of factors outside the formal terms of reference which will clearly have major impacts on rural land use / food chain emissions. These include policy on renewable energy, waste, land use and transport technologies.
- the Group also recognises that recommendations must take into account median climate change projections, seek to increase resilience and anticipate, if possible, future adaptation, including landscape permeability, water conservation *etc*.
- while recognising their importance, this report does not address coastal / inshore fishing issues.

- the current report does not address in any detail adaptation mechanisms, however the Group recognises that this is an urgent priority for future work.

5. Activity sectors

In order to address land use related GHG emissions of CO_2, CH_4 and N_2O and, where appropriate, off-setting carbon sequestration or low-carbon energy generation (electric and/or heat), the Group considered four activity areas. These are addressed in some detail in the next four chapters. The impacts of the three gases - CO_2, CH_4 and N_2O - are considered in each chapter.

Table 5.1 gives a general breakdown of the GHG emissions currently attributed to Wales. The rigour of the individual entries varies but all represent the best estimates currently available.

Table 5.1 - GHG emissions (kt CO_2e) by agricultural sector in Wales in 2007

Sector		Source	CO_2	CH_4	N_2O	Totals	
Livestock	Dairy	Ruminant metabolism		520		516	
		Manure (liquid/solid)		130	95	220	**740**
	Beef	Ruminant metabolism		830		828	
		Manure		80	60	140	**970**
	Sheep	Ruminant metabolism		920		920	
		Manure		22		22	**940**
	Horses	Digestive metabolism		17		17	
		Manure		1		1	**18**
	Poultry	Manure		12			**12**
						Total Livestock	**2,680**
Engines / Transport			500	1	55		550
Agronomy / Feed / Crop Production					2190		2190
		Totals	**500**	**2530**	**2400**		**5420**

Notes: i) figures do not add exactly because of rounding errors
ii) N_2O emission from dairy and beef have been allocated according to the ratio of manure CH_4 emissions.

The allocations to activity sectors within agriculture arefnot precise but nevertheless allow the main sectoral activities responsible for the emissions to be identified and prioritised. A number of points arise:

- in the agricultural sector, as defined above, CO_2 emissions *per se* are a relatively minor component and are derived from the use of conventional electricity and fossil fuel [diesel, petrol] to run agricultural machinery and vehicles (i.e. excluding the rest of the food chain).
- in the dairy/beef sectors (which in practice overlap), CH_4 emissions from ruminant metabolism and from manure handling dominate.
- in the sheep sector the main source is CH_4 from the animal itself as there is less accumulation of manure.
- a major contribution is the release of N_2O from soils by microbes especially under N-rich and water-logged / wet conditions. No data exists to allocate this to the farm production sectors but, as it is a function of high to excessive N fertiliser application on improved land, it might be

reasonable to consider that this is mainly attributable to the arable sector and short leys in intensive dairying. It is a factor in both manure and inorganic N application and therefore is an issue in both conventional and organic systems.

- by comparison, GHG emissions from the other animal sectors are small reflecting, largely, the low numbers in Wales of animals that produce small amounts of enteric CH_4 - horses, poultry and pigs. This is advantageous in terms of emissions, but in the case of pigs and poultry they lack a rumen to utilize pasture (grass, herbs) including low quality herbage. Consequently their dietary profile has historically overlapped more with the human diet. This clear distinction has been eroded by the practice of feeding cereal and other concentrates (sometimes imported) to ruminants to increase yields.
- not included in Table 5.1 is the energy cost of applied fertilisers and other inputs. As noted in Chapter 3, extrapolating emission figures for UK fertiliser use would indicate that the emissions from manufacturing and importing fertiliser for use in Wales are about 470 kt CO_2 e, although anecdotal evidence indicates that fertiliser use in Wales is below the UK average.
- since 1990 (i.e. Kyoto Protocol period), agricultural emissions have decreased by about 19%, mainly due to a decline in animal numbers following the withdrawal of headage payments.

Table 5.2 below summarises the Inventory data on GHG fluxes attributable to land use changes. It should be noted that some data are derived from pro-rata extrapolation from UK wide data (e.g. converted to settlement), as Wales data are unavailable. These are subject to considerable error.

Table 5.2 - GHG fluxes (kt CO_2 e) by land use / land use change in Wales in 2007 (where "+" = emission and "-" = storing).

	CO_2	CH_4	N_2O	Total
Biomass burning (grass / moors / brush)	30	3	~0.2	33
Liming of grassland and cropland	44			44
Land to forest	-1,430			-1,430
Land to grass	-640			-640
Land to (urban) settlement	690			690
Land converted to cropland	1,050			1,050
Cropland remaining cropland	-11			11
Harvested wood products	68			68
			TOTAL	**-175**

Notes: figures do not add exactly because of rounding errors

It is important to recognise that there are substantial uncertainties and errors in estimated emissions entered into the Inventory. Table 5.3 gives error estimates for the total UK agricultural GHGI estimates (in Mt CO_2e for 2007) and associated 95% confidence intervals[18].

Table 5.3 – UK error estimates for GHG emissions (Mt CO_2e)

Gas / source	2007 total	95% confidence interval
N_2O – soils	23,300	±252%
N_2O+CH_4 – manure management	4,500	±30%
CH_4 – enteric fermentation	15,400	±20%

In addition, the current Inventory for understandable reasons is designed to be applicable internationally and so does not record the impacts of many management interventions. As will be discussed later the LUCCG considers it important to move Wales to a more comprehensive recording system, which potentially would allow the sector to benefit from improved management practices.

[18] S Choudrie, J Jackson, J Watterson, T Murrells, N Passant, A Thomson L Cardenas, D Mobbs, G Thistethwaite. UK Greenhouse Gas Inventory 1990-2006. DEFRA

6. Actions within livestock systems

6.1 Introduction

The main GHGs produced by livestock systems in Wales are CH_4 from enteric fermentation in ruminants, CH_4 and N_2O from manures and slurry and N_2O from urine patches, manure and fertilisers on soils. Table 6.1 summarises the main sources of emissions. A small amount of CO_2 can be attributed to energy use on farm, from farm machinery, electricity use, water heating and milk cooling. Emissions from pig and poultry sectors in Wales are relatively small.

Table 6.1 - Wales' emissions (kt CO_2e) Inventory – agriculture and land use 2007

		CO_2	**CH_4**	**N_2O**	**Total**
Agricultural engines *etc*		498	1	55	554
Enteric	Dairy		516		
	Other cattle		828		
	Sheep		922		
	Horses		17		
	Others		2		
Manures	Dairy cattle		127		
	Other cattle		79		
	Sheep/goats/deer		22		
	Horses		1		
	Poultry		12		
	Pigs		4		
Manure systems	Liquid			5	
	Solid			112	
	Other			35	
Agricultural soils	Fertiliser application			400	
	Manure application			230	
	Grazing – direct depositions			700	
	Crop residues			20	
	Biological fixation by arable legume crops			0	
	Improved grassland – clover			30	
	Histosols (cultivated organic soils)			10	
	Indirect from leached N compounds			630	
	Indirect from atmospheric deposition of N from agriculture			160	
	Sub-total			2,187	
Totals		498	2,533	2,394	5,424

Note: these are the numbers reported in the Inventory rounded to the decimal point. Totals subject to rounding errors.

It is important to recognize that the estimates of emissions for the Inventory are based mainly on animal numbers, manure management systems and amounts of N deposited on soils from fertiliser, manure and animals. With revised Inventory reporting methods, technical efficiency options could lead to lower reported emissions. DEFRA and Devolved Administrations will be funding new projects (AC0114, AC0115 and AC0116) from March 2010 to derive the required emission factors for the UK.

There are significant uncertainties in the use of emission factors for N_2O. The lack of data on emissions from legume-based crops for building fertility leads to perverse consequences in comparing these systems with fertiliser and manure-based systems. The uniformity of emission factors for determining emissions may be an over-simplification, and raises policy issues in that any "inventory of savings" will be inaccurate. It is important that the Inventory is improved so that it does not perversely discriminate between farming systems and incorporates better data to drive models of N_2O loss from farms with a range of systems and climates.

For ruminants, a major focus is to reduce CH_4 emissions by improving technical efficiency. A key condition for the current Inventory reporting is that options that lead to emission reductions through technical efficiency need to do so via a reduction of animal numbers for a given level of overall production.

One option being advocated by some is that the quantity of animal products consumed should be reduced, and this would therefore lead to a reduction of animal numbers and a reduction of emissions. At an economic and social level this would have impacts on Wales' agriculture, and the analysis of this option is presented as a scenario in Chapter 10. This chapter restricts itself to technical options for reducing emissions, based on the assumption of maintaining the current levels of production. The following sections cover the mitigation options that are expected to count in the current Inventory and ones that may count when the Inventory is developed further.

6.2 Short-term interventions which count in the Inventory

CH_4 emissions are a by-product from anaerobic ruminant digestion and represent a significant loss of energy. For dairy cows, the conversion rates for feed carbon and N into useful products (meat and milk) are poor, at approximately 20-25% over the whole animal lifetime. Nutrition strategies that increase the animal performance can reduce the proportion of the energy required for maintenance over the animal's lifetime and so reduce CH_4 emissions per unit output. Improved nutrition can mean that animals reach target weights more quickly, and reproduce at younger ages. But this may also have an impact in increasing disease incidence and reducing longevity, particularly in dairy cows.

The main methods for emission reduction that are counted in current Inventory reporting methods are based on:

- increasing productivity per dairy cow.

- increasing fertility to reduce number of followers required (both these first two options are based on improving production traits through genetic improvement).
- improving the health of animals to increase longevity, reduce turnover rate (thereby reducing the number of followers required), and ensure that animals are producing as efficiently as possible.
- engineering solutions based on AD.
- more efficient manure and fertiliser management.

These options are described below for the different types of livestock.

Increased technical efficiency - Dairy

The key aims are to increase the efficiency of a cow in producing milk, based on keeping GHG emissions constant or smaller, while increasing production per cow. Methods of doing this are described below:

- Raising lactation yield - CH_4 generation does not increase much with yield, i.e. the more milk produced per cow, the less CH_4 per litre. Higher yields are generally achieved by higher inputs of concentrate feeds, because the higher starch/sugar level and fine particle size of these feeds replace the high fibre forage feeds associated with higher CH_4 output. However, pushing milk yields too high can have a detrimental effect on herd health and fertility and work against lifetime efficiency.
- Improving cow longevity - which has a limited effect on lifetime efficiency. For example, currently the average number of lactation's per cow is 3.44 (*cf* 4.76 thirty years ago). In the past, selection for milk yield traits has been achieved with little regard for those traits associated with fertility and other longevity factors. There is also a link with herd health, with higher yielding cows more likely to be culled for foot problems or mastitis. Opportunistic losses associated with poor cow health can be large: a sick cow is not an efficiently productive cow. Milk yield is reduced as a result of lameness, mastitis and other disorders although she is still consuming food and excreting CH_4 and N.
- Improving dairy cow fertility - through genetic selection or nutrition, while maintaining yield. This can improve longevity and decrease the replacement rate.
- Calving heifers at 2 instead of 2½ or 3 years - will reduce lifetime emissions and recoup the investment through faster growth and development.
- Changing to organic systems - reduces the emissions associated with inputs as no synthetic fertilisers are used in organic systems. The current Inventory assessment for N_2O emissions would show lower emissions from replacing artificial fertilisers by legume crops which fix N. The use of organic systems would also reduce emissions because of lower stocking rates.

  However, in results of Life Cycle Analysis (LCA) for organic systems, CH_4, when expressed per litre output becomes more important. In all systems, conventional or organic, high or low yield, the most significant impact on GHG emission per unit output is technical efficiency. In a literature review undertaken by Garnett[19], five research papers have calculated GHG emissions of between 640-1,510 g CO_2e/l milk. The calculations involved are not consistent and the researchers were comparing different dairy systems. This would explain the relatively large range. In another LCA review based on European dairy production, 5 studies which compared conventional and organic systems showed similar emissions – averaging 1.090 kg CO_2e/l for conventional systems and 1.120 kg CO_2e/l for organic systems[20]. Generally, organic systems were found to have higher GHG emissions per litre due to the CH_4 emissions being comparable but allocated to lower production rates. But there is no consistent approach to estimating emissions for production of artificial fertiliser or imported feeds, nor for accurately estimating GHG emissions from soils and biomass in organic and conventional systems.

Increased technical efficiency – Beef & Sheep

For improving technical efficiency, emission reduction is again driven by a reduction in total livestock numbers while producing better yield. Methods of doing this are:

- Increasing meat yield - from a breeding animal over the same lifetime and/or attaining the same yield from its progeny in a shorter lifetime – using optimum husbandry. Selecting for traits such as higher fertility or increased longevity of ewes / suckler cows, would results in fewer replacement breeding beef cows or ewes being needed, thereby reducing livestock numbers in total.
- Selective breeding for efficiency – as animals can be selected on the basis of digestive efficiency, productivity, and resistance to disease. The use of artificial insemination (AI) and embryo transfer (ET) in sheep and beef work will speed up the rate of genetic improvement.

Engineering solutions

- On-farm anaerobic digestion (AD) - of manures and slurries has the greatest technical potential to reduce CH_4 emissions from manure storage and spreading. AD converts organic matter into biogas composed of CH_4, CO_2 and hydrogen. Biogas can be used for heating and/or electricity production, and therefore substitutes for fossil fuels. The residual liquor can be used a liquid fertiliser, and the residual fibrous material as a soil conditioner. These products substitute for artificial fertiliser – reducing the energy input to agriculture.

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[19] Garnett.T. November. 2007. MEAT AND DAIRY PRODUCTION & CONSUMPTION. Exploring the livestock sector's contribution to the UK's greenhouse gas emissions and assessing what less greenhouse gas intensive systems of production and consumption might look like. Working paper produced a part of the work of the Food Climate Research Network. Centre for Environmental Strategy. University of Surrey.

[20] J-V Dourmad, C Rigolot, H van derWerf. Emissions of greenhouse gas, developing management and animal farm systems to assist mitigation. British Society of Animal Science Conference - Livestock and Global Climate Change May 2008

- Biogas - can be used as produced for cooking and heating. Following removal of the corrosive impurity, hydrogen sulphide, biogas can be used in boilers and internal combustion engines.

  Currently the UK Inventory methods would track the emission reductions from the substitution of fossil fuels by biogas, but *not* the reduction of CH_4 emissions from manure and slurry systems as a result of the AD process.

The UK CH_4 recovery potential has been estimated to be 28% of the theoretical quantity in a conventional system because of the difficulties of collecting manure from pasture land[21]. The most obvious source of CH_4 is dairy manure since much of this is already available from housed systems. Manure from housed beef cattle would also be readily available. The technical potential for collection from dairy cattle was estimated to be 29.1% and 6.8% from other cattle excluding calves. So the resulting technical potential for AD to reduce CH_4 emissions is 42 kt CO_2e/year. Additional GHG emission savings would come from reduction of N_2O emissions from manure systems, although that is difficult to quantify.

As well as the high costs of installation of AD equipment, barriers to expansion of AD[22] are:

- the lack of understanding of the technique and its impacts among planning authorities, regulators and general public.
- status of digestate as a waste, which is subject to waste management controls.
- complexity and costs of the process for obtaining access to the national grid via Distribution Network Operators. CLA has reported costs of up to £25,000 for connecting a 750 kW plant.

Manure and Fertiliser Management

40% of Wales' agricultural emissions are from N_2O emissions, mainly from soils as a result of direct deposits of manure and urine from grazing animals, and application of manures and fertilisers. Reduction of N_2O emissions focuses on efficient use of N fertilisers and manure to reduce the amounts of unused N in the soil. ADAS reviewed mitigation options including those for N_2O reduction in May 2009[23]. It concluded that four main approaches had a robust scientific evidence base and could be implemented now. They are:

- do not exceed crop N requirements - 5% reduction, but poor information on whether excess N is applied, and over what area.
- make full allowance for manure N supply - 5% reduction, but rate of implementation is uncertain.
- spread manure at appropriate times/conditions - 2-10% reduction, but in practice the scope to improve timing of applications is limited. Extent of implementation is difficult to predict.

[21] P Mistry, T Misselbrook. Assessment of methane management and recovery options for livestock manures and slurries. Defra Report Ed 05180 (2005)

[22] DEFRA Workshop – Increasing the uptake of anaerobic digestion – Exeter. September 2007

[23] Analysis of Policy Instruments for reducing Greenhouse Gas Emissions from Agriculture, Forestry and Land Management Project Report RMP/5142 to DEFRA May 2009

- increase livestock diet efficiency - 6% reduction of direct emissions and 5-6% reduction in nitrate leaching from livestock manures.

These approaches would only be tracked by current Inventory reporting methods if they result in farmers reducing their application of fertilisers.

Other options considered for reducing N_2O emissions, where the evidence base is poor are:

- use of nitrification inhibitors – tested and used in New Zealand grazing paddocks which are generally free draining and have a long growing seasons, whereas UK soils particularly in parts in Wales are predominantly heavy textured with a shorter growing season. The principle of the technique has not been tested fully in the UK.
- use of crop varieties with improved N use efficiency – high potential but requires more research.
- controlled release fertilisers – an expensive approach
- use of biological fixation to provide N inputs – evidence of whether leguminous crops reduce emissions is weak.
- use of reduced/zero tillage - only generally applicable to clay/medium soils in arable production. Uses less energy and can increase short-term soil carbon, but may result in higher N_2O emissions due to anaerobic soil conditions. Overall net GHG balance is uncertain.
- change from solid manure to slurry systems - straw systems may have higher N_2O emissions from storage and land application – as much as 15% compared with slurry systems. Results are variable.
- take stock off wet ground - to reduce compaction and anaerobic conditions – difficult to assess extent of mitigation per unit area, and extent of area.

6.3 Interventions which do not count in the current Inventory

This section covers methods of increasing technical efficiency for ruminants which would not be tracked by the current Inventory method in the UK. The types of intervention which would not be recorded include:

- use of feed additives - to reduce rumen hydrogen production.
- reducing the fibre content of feed - to increase digestibility and reduce CH_4 production, for example using grain and concentrate to replace forage. Supplying less energy as forage and more as concentrates reduces CH_4 production as a result of lower hydrogen production in the rumen. Higher grain levels in the diet will decrease production of acetic acid and CH_4, but this may have a detrimental effect on cow health and welfare (e.g. laminitis). Feeding pelleted or ground forage or even reducing chop length of silage will also reduce CH_4. Forages containing starch, maize and arable silage, will also reduce CH_4 emissions compared to grass silage. Other approaches are to use higher digestibility cereals, and ryegrasses with higher water-soluble carbohydrate content.
- more accurate feeding of ruminants - could reduce CH_4 emission per unit output but could also lead to more efficient use of dietary N. Optimising N

inputs in feedstuffs can reduce N output and improve milk output. Limiting protein (N) in the diet to the animal requirement can reduce N in waste. Feeding a diet balanced in energy and protein will increase the efficiency of N use. Feeding for high yields also requires protein sources that are less degraded in the rumen and this will also decrease N excretion.

- developing animal genomics - on the basis of the important genetic variations among and within breeds of all main livestock species that affect the GHG production per unit food produced[24]. The genetic improvement that has been achieved over the last 20 years has resulted in a substantial reduction in emissions per unit product. The cumulative effects equate to improvements of around 0.8% (of current levels) per year of selection for dairy cattle. In each case, genetic improvement in all of the traits has helped but the greatest reductions have been achieved through the improvements in feed conversion ratios.

6.4 Longer term options to the 2020s

The main mitigation strategies that are being researched are:

- use of diet supplements - to limit CH_4 formation by reducing the production of hydrogen, inhibiting methanogenesis, and directing hydrogen into alternative products or sinks. These supplements include saponins, tannins, garlic and rhubarb extracts[25]. Fats and oils reduce CH_4 emissions because they are toxic to methanogens. Organic acids have also been used because they act as sinks for hydrogen which would otherwise form CH_4. Use of ionophores which are anti-microbial compounds can also reduce CH_4, but these compounds may not be used for dietary additives under EU regulations.
- plant breeding for reduced GHG emissions – for example, new varieties of forage, grass, and legumes that reduce enteric CH_4 production by improving amino acid profile, reducing rumen protein degradation and improving fibre digestibility. Breeding of grass varieties with high sugar levels alters the way that bacteria in the stomachs' of the animals break down plant material into waste gas. There is also potential to breed plants that express nitrification inhibitors that reduce the nitrification of manure and mineral fertilisers to NH_4 and NO_3.
- instrumental methods - to ensure practical delivery of the correct diet which minimises CH_4 formation.
- developments in animal genomics - based on direct selection for CH_4 emission reduction and to improve animal health and robustness characteristics instead of production traits. This includes ensuring diversity of genetic resources by retaining breeds which are best adapted to low input systems and able to maintain existing landscape management for the range of ecosystem services.

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[24] DEFRA Project AC0204 A study of the scope for the application of research in animal genomics and breeding to reduce nitrogen and methane emissions from livestock based food chains. April 2008

[25] J Newbold, S Lopez, N Nelson, H Omed, R Wallace, A Moss. Br. Journal of Nutrition 94, 27-35, 2005

- increasing the use of sexed semen - to obtain the required replacement rate for the dairy herd. This would enable only the cows of highest genetic merit to breed dairy heifer replacements and avoid having to produce pure-bred male calves that are not ideal for high value beef production.
- changing the breed make up of the Welsh dairy herd - to breeds which are a less extreme dairy type. Such breeds yield less milk but produce calves that can finish as beef animals. If the current trend in dairy cow breeding continues such that pure dairy-bred male calves are not used for beef, and if beef consumption is maintained, beef production from suckler cows would have to increase. The suckler system of beef production is not as efficient in terms of GHG emissions compared with calves from dairy cows that are effectively a by-product of milk production.
- using cloning techniques - to increase the number of female animals with desirable characteristics (e.g. low residual feed intake / low CH_4 emission). Although this may offer more rapid breeding progress, public acceptance of this method is uncertain.
- genetic manipulation (GM) - to create livestock with lower GHG emissions. Again public resistance may be an issue.
- improving animal output by use of hormones - this science is well established but currently banned within the EU. In beef animals, hormonal implants which include naturally occurring hormones (e.g. oestradiol 17β, testosterone, progesterone) or artificial analogues (e.g. trenbolone, zeranol) can increase growth rate by improved feed efficiency.
- development of a vaccination technique - for methanogenic microbes to reduce their influence within the rumen and thereby reduce CH_4 production. Further development work is needed to determine which organisms to immunise against, whether the rumen would adjust with other microbes undertaking methanogenesis and the longer-term effects on animal health. There are possible problems with public perception of vaccination against organisms that do not cause disease.
- development of fully housed dairy systems - with zero grazing and capture of enteric CH_4 emissions from livestock. CH_4 could be captured by pressure swing adsorption (PSA) from livestock maintained in carefully designed buildings. PSA is used to purify CH_4 from landfill gas and potentially from coal seam gas[26]. The energy required to power ventilation and PSA extraction equipment would need to be compared with the reduced emissions / energy created from CH_4 capture. Dragosits *et al*[27] estimated that fully housed intensive dairy compared with conventional intensive systems would also reduce emissions of N_2O.

[26] S Cavenati, C A Grande, A E Rodrigues, Pressured layer swing adsorption for methane recovery from methane/carbon dioxide/nitrogen streams. Adsorption 11 549-554 2005

[27] U Dragosits, D Chadwick, A del Prado, D Schofield, J Mills, L Crompton, J Newbold. Implications of farm-scale methane mitigation measures for national methane emissions. In Land Management in a Changing Environment. SAC and SEPA. http://nora.nerc.ac.uk/2643/

6.5 Importance of grazing animals for habitats

It is important to recognise that grazing livestock have a range of benefits for ecosystems. This is potentially significant in the context of a trend to reduce livestock numbers to curtail emissions. One of these benefits is habitat management. For example, Countryside Council for Wales (CCW) has estimated the level of grazing needed in upland habitats to avoid problems of both over- and under-grazing in the main habitat types. By estimating the area of such habitats, it is possible to give an estimate of the numbers of livestock needed to maintain biodiversity. Using the CCW Phase 1 survey data, CCW has estimated the areas of relevant habitats and sub-habitats in the uplands (i.e. those occurring above the upper level of enclosure across the entire Welsh landscape, excluding rock dominated land and woodland) categorised into three simplified groupings: grasslands, heathlands and mires. The aggregate areas of each are:

	ha
Grasslands	157,300
Heathlands	79,100
Mires	68,800

Based on seasonal minimum and maximum grazing rates, it is possible to describe an appropriate level of stocking in minimum and maximum terms, *but doing so is only truly meaningful if set within a prescribed period (season) for grazing to occur.* Outwith those periods the "safest" assumption is that grazing levels would be zero or close to it. A crude estimate from the data suggests that stocking levels - expressed in livestock unit years (LUa) - for the Welsh uplands need to be:

		LUa
Grasslands	=	15,730 - 47,190
Heaths	=	2,965 - 15,820
Mires	=	1,720 - 3,784
All uplands habitats	=	20,415 - 66,794

This takes no account of the relative merits of sheep versus cattle. However, as the vast majority of the land covered in the analysis receives grazing overwhelmingly dominated by sheep, the figures can be roughly converted into the equivalent of 0.12 million sheep (ewes and followers) at the minimum, to 0.4 million sheep at the maximum. A key issue is that the way agriculture statistics data are collected does not permit us to know what the current or historic *actual* stocking levels have been on these habitats; we only know that the condition of many areas suggests grazing is not at or within these beneficial ranges.

6.6 Emissions reduction potential

Impacts on GHG emissions of suggested changes in livestock systems in the short- to medium-term have been based on typical farm types using data from the Farm Business Survey. It is essential to emphasise that the estimates of emission savings are the *maximum technical potentials*, and unless otherwise stated, assume 100% take-up of the option.

Dairy

Potential emission reductions of CH_4 are estimated to be:

- reducing age at calving – based on calving at 2 years instead of 2½ years - **potential saving of 50 kt CO_2e/year.**
- increasing milk yield per cow - from 6,519 l/cow to 7,558 l/cow - **potential saving of 106 kt CO_2e/year.**
- AD on dairy farms – **potential saving of 37 kt CO_2e/year.**

An option that would not be tracked by the Inventory is:

- accurate feeding in the dairy sector - may achieve a 1/6th reduction **– potential saving of 86 kt CO_2e/year.**

Beef

- production efficiency may reduce CH_4 emissions in total by around 10% in Wales.[28] Based on the Inventory for 2007, - **potential saving of 83 kt CO_2e/year.**
- AD on beef farms – **potential saving of 5 kt CO_2e/year.**

Sheep

The following options have been analysed:

- Reduction in replacement rate - of the Welsh ewe flock through a variety of nutritional, management and breeding techniques would lead to a reduction of 0.42 million head per year if current production levels of lamb are maintained. This is equivalent to 8.5% of the total sheep units in Wales (2007) - **potential saving of 78 kt CO_2e/year.**
- Improving lambing percentage - in the Wales national flock by 10% would lead to a potential saving of 8-10% of the total sheep CH_4 emissions in Wales - **potential saving of 73.0-91.0 kt CO_2e/year.**

Soils

Based on 80% uptake of options – using the experience of Catchment Sensitive Farming pilot schemes – the possible emissions reduction is estimated to be:

- Do not exceed crop N requirements 5% reduction
- Make full allowance for Manure N supply 5% reduction

[28] Market Mechanism for Reducing GHG Emissions from Agriculture, Forestry and Land Management. Defra NERA Economic Consulting September 2007

- Spread Slurry at appropriate times 2-10% reduction

  - **potential saving of (net emission reduction) 97 kt CO_2e/year**

This excludes reduction of CH_4 and N_2O emissions from manures and manure storage/handling systems from reduction of manure quantities.

6.7 Knowledge gaps and constraints

These are summarised as follows:

- Large scale trials on farms to test how well dietary manipulation reduces both direct and indirect GHG emissions from ruminants compared with laboratory conditions. A key issue is the development of new methods to monitor CH_4 and N_2O emissions *in vivo* under farm conditions.
- Further research is needed on the basic science of rumen function and modification, in particular to decrease loss of feed energy.
- Programmes to reduce GHG emissions using animal genetics need further development.
- Need to improve the understanding of potential CH_4 production of feeds and transfer of this knowledge to the farmer.
- Obtain CH_4 emission data from animals in hill and upland environments where the indigenous plants consumed may alter rumen fermentation to reduce the amount of CH_4 that is produced.
- Improvement to LCA of systems including the fluxes of N compounds in soils. Knowledge of the effects of emission reduction options for N_2O from soils is uncertain. Monitoring of emission fluxes is required under a variety of management conditions.
- Better information on the sheep breeds in Wales to assess the true "livestock units"
- Evaluation of existing AD operations in other countries to assist in designing exemplar projects within Farming Connect demonstration farms, or to be promoted with other partners for treating a range of biodegradable wastes. Exemplar projects are important to improve understanding and credibility of the AD process.
- Need to assess the fertiliser value of AD digestate and the emissions from its application to land.

7. Actions to minimise loss of current soil carbon and enhance sinks in soils and biomass

7.1 Introduction

In this section a wide range of mitigation measures for GHG emissions are considered with a lifetime of up to 50 years. A more detailed review – see Appendix 1 - includes the whole range of options that have been addressed.

There have been few studies of CO_2 fluxes from soils but changes in soil carbon levels have been used widely to estimate such fluxes. There are even fewer studies for N_2O and CH_4. The existing reported data are hugely variable and have been derived from both field experiments and modeled data. Many of these, however, have not been Wales - or even UK - based. Gaseous emissions from land are subject to large variations both spatially (i.e. within a single field as well as in the landscape) and temporally. This variability is particularly apparent for N_2O. Furthermore, emissions from certain land uses have just not been measured, especially in Wales (e.g. under different grassland management regimes).

Taking these statements together, it therefore remains difficult to derive robust "annual average" values for GHG emissions (e.g. a forest may be a carbon sink in a dry year and a carbon source in a following colder year, but remain a carbon sink over the full rotation period). This is an important factor if we consider that an agri-environment scheme typically has a life span of 10 years, whereas a change of land use from arable to woodland requires a time span of 100 years for soil carbon to achieve optimum levels - although most change in ecosystem carbon storage tends to happen in the first 25 years. Therefore the data presented must be accepted as having a wide variation and dependent on the permanence of the option to deliver the full GHG reduction reported.

To address this issue, literature values were collated for all intervention measures and the midpoint of the range reported was applied to the land cover / soil type combinations present in Wales - except where Welsh studies indicated different values should be used. The potential for different land use change strategies to mitigate against GHG over a 50 year timescale (i.e. 2010-2060) if all were initiated in Year 1 was evaluated. The effects of different levels of farmer uptake were also assessed. Although most scientists are agreed on the most appropriate GHG mitigation options, they disagree on the magnitude of the response, the timescale in which it can happen, the area of land available to implement the option, and the socio-economic potential for adoption. Some abatement options operate predominantly on one GHG (e.g. more efficient use of N fertiliser to reduce N_2O losses), others on several (e.g. planting trees to reduce CO_2, N_2O and CH_4) whilst others involve trade-offs (e.g. ditch blocking in wetlands to capture CO_2 but increasing CH_4).

It is important to recognise that, although increasing soil carbon can have substantial benefits to the structure and productivity of soils, there is poor evidence about the linkage between many land management activities and changes in soil carbon and net GHG emissions – taking account of CO_2, N_2O and CH_4. Photosynthetic processes which fix CO_2 in the soil and biomass on a permanent basis are key to reducing the concentrations of the gases in the atmosphere. Protection of soil carbon stocks already accumulated should remain a priority. Also, it is important to recognise that there is a limit to the soil carbon storage that is possible after any land use or management change. This is because a new equilibrium is reached - so called 'saturation'. It is important that options to enhance carbon storage are "permanent" if the full benefits are to be achieved, so that carbon stored is not subsequently released back into the atmosphere. An additional consideration is the possibility of displacement where benefits achieved in one area are offset elsewhere (e.g. manure being concentrated in one field to enhance soil carbon stock thus creating hotspots of soil carbon rather than increasing soil carbon overall).

Finally, it is clear that that the potential trade-offs and co-benefits of land management options for GHG emissions reductions and other requirements from the land need to be quantified objectively, together with full LCA to ensure the desired outcome on GHGs across sectors can be achieved.

7.2 GHG flows and carbon stocks

For Wales in 2007, land use change to forestry and grassland sequestered *c*2,084 kt CO_2e, and conversion of land to cropland and settlements led to emissions of 1,875 kt CO_2e. In total, land use change led to a net sink of 199 kt CO_2e. On present trends, by 2020 the emission rate (source) will be greater than the sink rate because current Welsh forests are becoming mature with reducing rates of growth and carbon uptake. The major components of these sinks and sources are in Table 7.1.

An important factor determining sinks and sources is the high soil organic content of Welsh soils, mainly associated with permanent grassland and the uplands. The most accurate estimate of the carbon stock of Welsh soils is obtained by aggregating comparable data derived from Bradley *et al*[29] and Smith *et al*[30]. The Welsh soil carbon stock is estimated to be 409 Mt carbon or 1,499 Mt CO_2e. However, estimates of soil carbon reserves are heavily reliant on the quality of soil maps (degree of ground truthing, map scale, classification type) and on algorithms describing carbon density in soil[31]. Consequently, estimates of national soil carbon storage from different mapping approaches give a range of 340-530 Mt carbon (1,246-1,943 Mt

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[29] Bradley RI, Milne R, Bell J, Lilly A, Jordan C, and Higgins A (2005) A soil carbon and land use database for the United Kingdom. Soil use and Management 21, 363-369

[30] Smith P et al. (2007) ECOSSE - Estimating carbon in organic soils sequestration and emissions. Climate Change and Air Division, Scottish Executive, Edinburgh

[31] Frogbrook ZL, Bell J, Bradley RI, Evans C, Lark RM, Reynolds B, Smith P, Towers W (2009) Quantifying terrestrial carbon stocks: examining the spatial variation in two upland areas in the UK and a comparison to mapped estimates of soil carbon. Soil Use and Management 25: 320-332.

CO_2e) and a mean of 436 ± 27 Mt carbon (1,598 ± 99 Mt CO_2e) estimated from 7 different datasets / national soil maps[32].

Table 7.1 - Emissions and removals (kt CO_2e) of GHG by LULUCF in 2007[33]

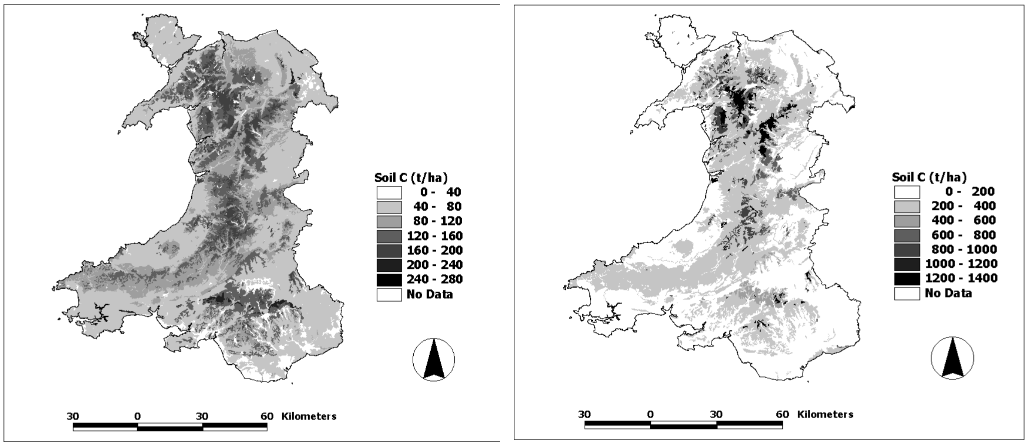
	Annual GHG emissions			
	CO_2	**CH_4**	**N_2O**	**Total**
Forest – biomass burning	19	2	0.2	21
Grass – biomass burning	6	0.5	0.05	6
Settlement – biomass burning	4	0.4	0.04	4.4
Grass – liming	37			
Cropland – Liming	7			
Land to settlement	688			
Land to cropland	1,053			
Harvested wood products	68			
Total emissions				**1,885**
Land to forest	-1,430			
Land to grass	-643			
Cropland remaining cropland	-11			
Forest remaining forest	0 (pre-1920 forest / woodland)			
Grassland remaining grassland	0			
Settlement remaining settlement	0			
Total Sink				**-2,084**
Net Total				**-199**

These quantities are based on changes in biomass and soil carbon levels. The “C-Flow” model, used for land use changes, does not provide emission estimates for CH_4 and N_2O. As noted the estimates do not cover land use changes only in a specific year, but include emissions in that specific year from historic land use changes.

Approximately half of the total soil carbon stock is located within an area of 492,721 ha or 23.4% of the land surface of Wales, predominantly in upland areas and/or areas of permanent grassland. The remaining 76.6% of Wales is covered primarily by mineral soils with a lower carbon content (see Fig 7.3).

[32] Ibn Malik A (2006) Terrestrial carbon in Wales. PhD thesis, Bangor University.
[33] Thomson AM (2008) Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry. Annual Report, July 2008, DEFRA Contract GA01088, Centre for Ecology and Hydrology, Edinburgh, UK.

Fig 3 - Distribution of soil carbon in Wales (the left hand panel represents the amount of carbon stored from a depth of 0-15 cm and the right hand panel from a depth of 0-100 cm)



It is also important to recognise the carbon stock in forestry and woodland. Based on the average UK forest carbon stock of approximately 200 t CO_2e/ha[34], the 285,000 ha of forest in Wales has a stock of 57 Mt CO_2e in trees. In addition, there is typically significantly more carbon stored in forest soils than in the trees themselves. In total, the forest soil carbon stock of Wales is probably around 169 Mt CO_2e, comprising 116 Mt CO_2e under conifers, (about 738 t CO_2e/ha), and 53 Mt CO_2e under broadleaves (about 414 t CO_2e/ha); (upscaled from Biosoil plots[35], UK Assessment, 2009). Due to the age structure of the current Welsh woodland resource, most woodland is well past its maximal annual sequestration rate and due to the harvesting of wood products for a range of other benefits, the size of the sink is declining over time. The C-Flow model used to estimate the current GHGI contains assumptions which introduce uncertainty over the rate of this reduction and how much of the current "business as usual" management is exacerbating or ameliorating the overall trend.

Assessment of mitigation options was done for three main soil types, namely mineral soils, organo-mineral soils, and organic (peat) soils. Soil type is paramount when considering impacts of agricultural operations and land use change, as different soils react differently to the same operation. So a certain operation undertaken on organic soils may reduce emissions while the same operation on mineral soils results in increased emissions. The land cover types were defined using the Centre for Ecology and Hydrology Land Cover Map (LCM) 2000 and mapped onto soil types using the "NATMAP" vector soils data. A summary of the classes and soil type distribution within each land use type is provided in Table 7.2. In this report, it was decided to use the Countryside Survey (CS) as the basis of scenarios for land use change,

[34] BROADMEADOW, M and MATTHEWS, R (2003). *Forests, carbon and cliomate change: the UK contribution.* Forestry Commission Information Note 48. Forestry Commission, Edinburgh

[35] www.forestresearch.gov.uk/biosoil

because the GHGI is currently based on the CS, and it is updated at regular intervals.

Table 7.2 - Soil type versus land use ('000 ha) relationships in Wales

Land cover classes	Land cover type	Area of land cover types by soil type		
		Mineral	Organo-mineral	Peat
Cropland	Arable cereals	17.3	0.3	0
Cropland	Arable horticulture	80.0	2.7	0.1
	Total cropland	**97.3**	**3.0**	**0.1**
Improved grassland	Improved	728.4	32.4	2.2
Semi-natural grassland	Setaside	1.8	0	0
Semi-natural grassland	Neutral	66.7	60.1	4.2
Semi-natural grassland	Calcareous	136.3	7.4	0.6
Semi-natural grassland	Acid	158.5	126.8	31.2
	Total grassland	**1,091.7**	**226.7**	**38.2**
Fen, marsh and swamp		0.5	0.7	0.4
Bog		0.4	3.1	2.1
Saltmarsh		4.1	0	0
	Total wetland	**5.0**	**4.7**	**2.5**
Broadleaved forest		149.2	8.7	0.5
Coniferous forest		77.2	54.2	10.6
	Total forest	**226.4**	**63.0**	**11.1**
Urban	Suburban (built up areas, gardens)	60.4	6.3	0.4
Urban	Continuous urban	15.2	1.1	0.1
	Total urban	**75.6**	**7.4**	**0.5**
Grand total of areas represented (out of total area of - approx 2.1 million ha)		**1,496.0**	**304.8**	**52.4**

Notes: (i) Based on CEH LCM 2000 - 25 m data and NATMAP vector soils data (i.e. essentially land use cover versus soil type based on 1998 data)
(ii) No LCM class 43 (arable non-rotational) mapped in Wales
(iii) No classification for man-made soils into mineral, organic, peat
(iv) Results only based on areas where data for both land cover & soils
(v) It is likely that the above numbers should be considered to two significant figures only.

7.3 Key emission and loss processes

Carbon is largely lost from soil as CO_2 as a result of the natural breakdown of soil organic matter by soil micro-organisms[36]. The rate of soil carbon loss is maximal in warm, relatively moist and aerobic conditions. This process is also exacerbated by physical disturbance (e.g. ploughing), which breaks up soil aggregates - enhancing oxygenation and allows microbial access to physically protected carbon. CH_4 is produced when organic materials decompose in

[36] Paul EA, Clark FE (1996) Soil Microbiology and Biochemistry, Academic Press, San Diego.

oxygen-deprived anaerobic conditions, such as permanently waterlogged soils. N_2O is also generated when soil micro-organisms run out of oxygen (e.g. in very wet or compacted soils) and occurs when there is a lot of available nitrate (where available N exceeds plant requirements). It is also exacerbated after addition of N rich organic wastes to wet soils.

The exchanges of carbon between the land and atmosphere are dominated by the emission and plant fixation of inorganic carbon (*c*43.3 Mt CO_2e/year as Net Primary Productivity (NPP) in Wales). Emissions include both CO_2 through respiration and non methane volatile organic carbon (NMVOC) which is a precursor of ozone in the lower atmosphere (troposphere) and contributes 3-7% to the greenhouse effect*. As forests release more NMVOC's than grassland, it is likely that total NMVOC emissions from Wales are at the lower end of the emission range.

* Although there is uncertainty in the figures, particularly for grazed grasslands, current estimates for global NMVOC loss rates to the atmosphere range from 0.18 - 1.8 Mt CO_2e/year, which equates to a loss of 0.1-1.0% of total vegetation carbon each year representing c 0.5-4% of the net carbon fixed by plants in photosynthesis

In reviewing actions to reduce emissions, estimates of soil carbon loss have been based on assuming that all loss is as CO_2 emitted to the atmosphere. However, carbon can also be lost from soil as dissolved organic carbon, particulate organic carbon and dissolved inorganic carbon either from surface erosion, runoff or leaching[37].

Increasing the soil carbon content can only occur either by increasing carbon input, decreasing carbon output or by a combination of the two through improved management. Agricultural management systems and forestry operations can strongly influence soil processes such as carbon sequestration and erosion. Examples include drainage of and cultivation of waterlogged organic soils, leading to aeration, increased microbial decay and an associated increase in CO_2 emissions, but decreases in N_2O emissions. Intensive arable use of mineral soils can enhance N_2O emissions due to the increased rate of de-nitrification associated with excess fertiliser applications, yet it is known that N is an important driver for fixing more carbon in soils. This emphasises the need to look at all GHG fluxes, and not focus solely on soil carbon. A major gap in our information is an accurate account for all GHG fluxes to and from soils. For soil carbon specifically, two monitoring programmes have reported on changes in topsoil carbon (i) for England and Wales[38] and (ii) all of GB plus individual countries including Wales.[39] In

[37] Worrall F, Guilbert, T, Besien T (2007) The flux of carbon from rivers: the case for flux from England and Wales. Biogeochemistry 86: 63-75.
[38] Bellamy PH, Loveland PJ, Bradley RI, et al. (2005) Carbon losses from all soils across England and Wales 1978-2003. Nature 437: 245-248.
[39] Carey, P.D., Wallis, S., Chamberlain, P.M., Cooper, A., Emmett, B.A., Maskell, L.C., McCann, T., Murphy, J., Norton, L.R., Reynolds, B., Scott, W.A., Simpson, I.C., Smart, S.M., Ullyett, J.M. 2008. Countryside Survey: UK Results from 2007. NERC/Centre for Ecology & Hydrology, 105pp. (CEH Project Number: C03259).

addition several EU studies reviewed by Schils et al[40]. Generally a decline in topsoil carbon for arable soils is reported, with increases in woodland soils but no consistent trend reported for grassland and semi-natural soils.

For this sector it is important to recognise that there are significant feedback mechanisms, whereby climate change can exacerbate emissions from soils. There is conflicting evidence about the trend in soil carbon levels in Wales. However, the complex direct and indirect feedback loops that can occur also mean that it is difficult to predict how climate change will ultimately affect soil GHG emissions[41]. This report has therefore not taken account of projected changes in climate and atmospheric CO_2. Currently, the potential positive or negative impacts of climate change on soil carbon are not included in Inventory calculations.

7.4 Inventory issues - land use change options

Box 3 explained how the GHGI for land use is estimated. In reviewing options for reducing emissions, it is important to recognise that the estimates are based on a dynamic model to predict year-on-year changes in carbon storage/loss associated with land use change. In some cases the models are relatively complex (e.g. C-Flow for forest growth) and involve elements of product use, whilst others rely on less sophisticated algorithms (e.g. arable to grassland). In addition, as it is not spatially explicit, there is no accounting for within land use management changes (e.g. re-seed of grassland to grassland) which may induce a considerable reduction in soil carbon storage. Similarly, Land Use, Land Use Change and Forestry (LULUCF) does not take account of policy instruments (e.g. agri-environment schemes) which may have significant changes in a land use (e.g. reduction in grazing) and resultant changes in GHG emissions. In addition, the C-Flow model does not take account of CH_4 and N_2O emissions, and impacts of deposition of N compounds. Other anomalies are that grassland and pre-1920 woodland are assumed to be neither a source or sink for carbon.

It is also important to recognise that the land use change data for the Inventory estimates are derived from modelled changes based on the CS. For example, land use change data for the 2007 Inventory was based on predicted changes from the CS in 1998. Results of the Survey in 2007 were not available. Actual land use change data are not used, and it was clear in considering the land use statistics that there appeared to significant differences, for example, in the rate of afforestation. For Wales, there are significant weaknesses in this approach since the CS in 1998 only covered 56 one-km squares out of over 20,000 km squares, and is therefore not a

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[40] Schils R, Kuikman P, Liski J, van Oijen M, Smith P, Webb J, Alm J, Somogyi Z, van den Akker J, Billett M, Emmett B, Evans C, Lindner M, Palosuo T, Bellamy P, Alm J, Jandl R, and Hiederer R(2008) Review of existing information on the interrelations between soil and climate change

[41] Smith P, Fang CM, Dawson JJC et al. (2008) Impact of global warming on soil organic carbon. Advances in Agronomy 97: 1-43.

statistically representative sample. CS in 2007 covered 112 one-km squares in Wales, providing an improved, but still limited, baseline for tracking future land use change. Robust and reliable data on land use change could and should be collated for Wales, provided that this can be integrated with CS data.

7.5 Short-term interventions which count in the Inventory

This sub-section restricts itself to options that were considered to be feasible, with good evidence of overall technical potential to reduce emissions. The mitigation potential of these options is summarised in Table 7.3.

For arable croplands which only represent a small area of Wales (5.4% of the total land area based on CS), at least 97% are associated with mineral soils. Potential effective management options for croplands include:

- improved fertiliser management: more efficient use of N-based fertilisers, which are responsible for a large proportion of the GHG emissions from croplands (arising from fertiliser production, application, and direct N_2O emissions post-application)[42]. In GHG terms, N fertilisers have conflicting effects because they increase plant growth and therefore result in greater carbon inputs into the soil and replenishment of the soil organic matter pool. However, it is likely that this will be more than offset by the CO_2 emissions involved in fertiliser production and subsequent N_2O emissions when applied to the soil. This option is also discussed in Chapter 6.
- conversion: this is the permanent conversion of croplands to an alternative land use. All land uses other than urban store more carbon both above and below ground relative to cropland, so in all cases this would lead to a reduction in GHG emissions. However, conversion to grassland or forestry would have an inevitable negative impact on food production and potentially increase imports of embedded GHGs in food and fodder.
- greater application of organic residues to land: this depends on incorporating biological material produced from photosynthetic processes which take CO_2 out of the air and lock the carbon compounds permanently in soil (i.e. >50 years). Application of compost, digestate and recycled paper-processing waste potentially offers GHG emission savings through the diversion of materials from landfill sites which are in themselves major sources of CH_4 emissions. Also due to the nutrient delivery associated with applying green waste compost a reduction in synthetic fertilisers is achieved. However, evidence suggests that these only represent transient stores of carbon in soil unless continually replenished.

Improved grasslands represent a large area of Wales (41% of the total land area). Of this, CS indicates that at least 96% is associated with mineral soils and 4% with organo-mineral soils. In many respects, improved grasslands are difficult to manage in terms of climate change mitigation as there is a

[42] Hillier J, Hawes C, Squire G et al (2009) The carbon footprints of food crop production. International Journal of Agricultural Sustainability 7: 107-118.

fundamental lack of knowledge (or inconsistent results) about many of the potential mitigation options. In addition, mathematical models describing carbon and N cycling in these ecosystems are relatively poor in this context. It should also be noted, that our knowledge of GHG emissions from these sites in Wales is relatively poor with only a few having been studied in detail.

For livestock systems there are a number of proposed management options to reduce GHG emissions from grasslands in Wales. These have been reviewed in Chapter 6.

Unimproved grasslands (i.e. those not receiving fertilisers, lime *etc*) represent a relatively large area of Wales (32% of the total land area and 43% of all grasslands). Of this, 61% is associated with mineral soils, 33% with organo-mineral soils and 6% with peat soils. It should be noted, however, that our knowledge of GHG emissions from these sites in Wales is relatively poor with only a few having been studied in detail. Consequently, the evidence presented here is subject to known and unknown uncertainty.

Afforestation is achievable in a managed or unmanaged way on all types of land use. However, there are clear issues with respect to soil type. Where possible, organic, peaty soils should be avoided as trees can dry out these naturally wet soils leading to a stimulation of soil organic matter loss through enhanced microbial action. There is also evidence to suggest that planting trees can stimulate the mining and loss of subsoil carbon in organo-mineral soils, although this can be offset by the increased sequestration of carbon in the above-ground biomass. Low sequestration figures in early years are due to the young trees not being at their maximal growth rates, along with modest soil carbon emissions at establishment. This is accentuated in unmanaged systems thus there are significantly lower total GHG reductions for unmanaged forests after 10 and 30 years (Table 7.3).

It should be acknowledged that forestry may induce a loss of soil carbon, at least in the short term. These emissions are quickly abated (in less than 3 years) on loam and gley soils. Moreover, there may be further scope to improve best practice in soil management to reduce the early years' emissions even further. This will be especially important on organo-mineral soils and natural regeneration could potentially eliminate any emissions associated with tree establishment techniques.

Conversely, an expansion of arable land by conversion from grassland on mineral soils will lead to a modest release of CO_2. This is discussed later in Chapter 10 in relation to the various scenarios being advocated.

Work from Forest Research (FR) suggests the forest sequestration rates may be double those reported here or those from the C-Flow model. These estimates are derived from the FR Forest Management Cycle Carbon Calculator – "CSORT". This wide range in estimates is likely to be a consequence of variability and uncertainty associated with soil types, thinning and harvesting practices, substitution issues and other underlying assumptions in the estimates. Irrespective of this, forestry is clearly one of the strongest candidates for reducing emissions. It is clear that the planting of woodlands and forests could be a win-win option. However, any new planting should take place as soon as possible because maximal mitigation does not occur instantly. The current afforestation rate in Wales is about 750 ha/year from CS estimates, although Forestry Facts and Figures suggests a lower annual rate of about 500 ha/year. A 10% afforestation of cropland plus grassland areas proposed here could hypothetically deliver an expansion of 150,000 ha, but will require significant economic incentives to deliver. This is in line with recent recognition at a UK level that woodland creation options have the most potential to contribute to the longer-term 2050 targets*, if action is taken soon.* Such a scenario would have a number of other benefits in terms of new habitat creation, biodiversity flood management and recreational opportunities.

Table 7.3 - Estimated theoretical GHG emission reduction potential (t CO_2e/ha/year). Values represent the sum of all GHGs (CO_2, CH_4 and N_2O) expressed as CO_2e per year.

Land use type	Intervention	GHG emission mid-point (Wales) (t CO_2 e/ha/year)	GHG emission range (Literature) (t CO_2 e/ha/year)	Potential annual GHG reduction – Year 10 kt CO_2e/yr	Potential annual GHG reduction – Year 30 kt CO_2e/yr
Cropland	Fertiliser management	1	0.02 - 1.42	2	0
Cropland	Convert to grassland	3	0 - 6.40	30	3
Cropland	Organic residues	3	0.37 - 5.50	14	3
Improved grassland	Fertiliser management	0.7	0.29 - 1.10	16	3
Improved grassland	Organic residues	2.9	0.37 - 5.50	112	22
Cropland & grasslands	Afforestation – managed	5.8	4.50 - 7.20	1,810	3,622
Total*	**All**	**16.4**	**10.05 - 31.52**	**763**	**1,389**

*** Note:** based on literature values, the midpoint adopted for Wales plus potential rates for Wales land area (kt CO_2e/year) at Year '10' and '30' assuming 10% uptake rates by farmers from Year 1. Total assumes 10% uptake with 50% of land converted to managed forests and 50% to unmanaged forests.

As well as climate change mitigation from new woodlands, forestry is best examined in net abatement terms rather than through separate sink and source analysis, due to the ability of wood products to substitute for fossil fuels and to act as a carbon stock in their own right. Consequently, there is an urgent need to better model the abatement achieved by the current Welsh woodland resource, overlaid with the figures from any new afforestation programme. A possible objective for Wales as a whole is that a new programme of 100,000 ha of woodland creation is achieved over a 20-30 year period. This might contribute 2.0-3.0 Mt CO_2/year from 2050-2100 - compared with the existing business as usual prediction of forests being a source of emissions.

The cumulative and long-term carbon abatement potential is illustrated for programmes of 50,000, 100,000 and 150,000 ha that have been modeled. These are shown in Table 7.4 and differ from those estimates in Table 7.3 because of the use of different models with different assumptions. Table 7.3 is based on the C-Flow model, and Table 7.4 on the FR CARBINE model.

Table 7.4 - Annual abatement (kt CO_2e) impacts from 10, 20 and 30-year tree planting programmes at 5,000 ha/year averaged for decadal periods based on FR CARBINE model

	Broadleaves Unmanaged – Gley Soil			Mixed Continuous Cover Woodland – Loam Soil			Total		
Planting programme (ha/year)	**2,500**			**2,500**			**5,000**		
Length of programme (years)	**10**	**20**	**30**	**10**	**20**	**30**	**10**	**20**	**30**
Total woodland creation (ha)	**25,000**	**50,000**	**75,000**	**25,000**	**50,000**	**75,000**	**50,000**	**100,000**	**150,000**
2010-2019	7	7	7	23	23	23	30	30	30
2020-2029	206	211	211	289	310	310	495	522	522
2030-2039	460	666	672	424	713	734	884	1379	1406
2040-2049	424	884	1090	381	805	1094	805	1689	2184
2050-2059	337	761	1221	335	717	1141	673	1477	2362
2060-2069	250	588	1011	297	632	1013	547	1220	2025
2070-2079	180	430	768	146	443	778	326	873	1546
2080-2089	131	311	561	152	298	595	283	609	1157
2090-2099	99	230	410	193	345	491	292	575	901
2100-2109	76	176	306	192	384	537	268	560	843

These planting programmes assume a woodland creation rate of 5,000 ha/year for 10, 20 and 30 years respectively. An additional 100,000 ha of new woodland would take Wales' woodland area to 385,000 ha, a 35% increase on the current level, achieving a woodland cover of about 19%. A 10-year programme to achieve 50,000 ha contributes an annual maximal abatement figure of 0.884 Mt CO_2e between 2030 and 2039. The 20-year programme to achieve 100,000 ha peaks at 1.689 Mt CO_2e between 2040 and 2049. The 30-year programme to achieve 150,000 ha peaks at 2.362 Mt CO_2e between 2050 and 2059. The figures in Tables 7.3 and 7.4 indicate the scale of sequestration possible, but are not comparable because of different assumptions in the models. In addition Table 7.4 assumes a phasing of woodland expansion.

A woodland expansion option is scaleable and could be implemented in a number of ways. This might be achieved for example at a farm level by establishing 5 ha of woodland on each of the 20,000 farm holdings or by a more targeted approach on poorer farm soils or through a programme of larger woodland plantings, or indeed, a combination of all three.

Some native woodland creation occurs by natural processes on less intensively utilised farmland. While natural woodland creation by this route is slow, it also avoids the up-front carbon emissions associated with intervention to plant trees.

Woodland creation currently attracts planting grants of £1,700/ha for “Quality Mixture” and £1,800/ha for Native Woodland. These are based upon “Standard Costs” of £4,086/ha and £4,149/ha respectively. Uptake of these grants is low and current levels of woodland creation maybe below 500 ha. Higher grant levels may be achieved through paying a higher percentage rate through the Rural Development Programme. However, the reality is that achieving woodland creation programmes anywhere close to the size suggested in this report will require innovative new delivery mechanisms. Some of these may be further developments of current approaches, whilst others will need to be genuine new models. For example, there may also be a possibility of additional funding through voluntary carbon finance - the “additionality” of individual projects will be crucial to this. The FC is developing a Code of Good Practice to facilitate this.

7.6 Interventions which do not count in the Inventory

The current LULUCF Inventory approach would not capture the following changes because the Inventory does not consider the impacts of land management practices:

- reduced grazing: current evidence on grazing intensity in the Welsh uplands suggests that reduced grazing results in either no change in soil carbon or a slight increase in carbon sequestration and depends on the initial grazing intensity. There are two studies which suggest that light grazing may be optimal for soil carbon stocks[43] and one study which identified no change between different grazing intensities[44]. This variability will depend on the initial grazing intensity and existing magnitude of the soil carbon store with respect to the potential maximum potential for soil carbon storage. Effects of grazing intensity on N_2O production are limited as emission rates from unimproved pastures are low[45]. Effects of reduced grazing on habitats is considered in Chapter 6 as are the effects of changes in animal numbers on CH_4 emissions. These will be additive to

[43] Bardgett et al., 2002; D. Jones Pers. Comm

[44] Emmett, BA, Griffiths B, Williams, D and Williams B. (2007) Interactions between grazing and nitrogen deposition at Pwllperian. In: UKREATE 2007. Terrestrial Umbrella: Effects of Eutrophication and Acidification on Terrestrial Ecosystems. CEH Contract report. Contract Number CPEA 18. July 2007.

[45] Curtis CJ, Emmett BA, Reynolds B and Shilland J (2006) How important is N_2O production in removing atmospherically deposited nitrogen from UK moorland catchments? Soil Biology & Biochemistry, 38, 2081-2091.

those reported here if there is no increase in animals elsewhere to compensate.

- agro-forestry and hedgerows: planting trees and expanding hedgerows within upland grassland environments has some potential to store carbon in the long term and many other benefits for water, soil and biodiversity. However, this should only be done on mineral or organo-mineral soils.
- re-wetting peats: restoration of peats by raising the water table and re-wetting, for example by blocking drainage ditches (often referred to as 'grips'), can restore the function of the peat as a net sink of CO_2 and a semi-permanent carbon store. The evidence-base concerning GHG gas emissions and carbon storage in peat in total after re-wetting, however, is poor as there are too few studies, and those that exist are of low quality. In particular there is a major need to determine the long-term rates of CH_4 flux from both virgin, drained and rewetted peats in Wales. There is a greater amount of evidence on the effect of draining peat; however, the quality of most of these studies is similarly poor. The available evidence to date is consistent with this intervention mitigating climate change, at least to some degree, but better evidence is urgently needed.
- increase rotation length of forests: increasing rotation length from the current default of 59 years may provide a simple way of increasing carbon storage[46]. This arises as essentially there is low decay associated with forestry products. There is also potentially another benefit – that of reduced soil carbon losses as a result of soil disturbance associated with the extraction process resulting in decomposition of organic matter and erosion. But delaying felling in many Welsh conifer plantations may increase the risk of wind-throw with all the resulting soil disturbance and potential higher decay associated with sub-optimally harvested wood products. A far better option in the medium-term is to manage a higher proportion of Welsh forests without clearfelling, ideally maintaining carbon stocks, reducing site impacts and maintaining a wood product flow.
- site management: one potential option is to encourage minimum site preparation practices in Welsh forests. The disruption of the soil and removal of carbon inputs, post-harvest leads to a decline in soil carbon stocks. It should also be noted that site preparation can also lead to losses of soil carbon (estimated to be up to 30%)[47], which may or may not be recovered over the subsequent decades of forest growth. The move to continuous-cover forestry is perceived to have a small but positive impact on climate change mitigation, although the evidence is not definitive.

It is important not to discount these interventions since they contribute to maintaining soil carbon stocks and also have other benefits for the environment.

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[46] Cannell MGR, Milne R (1995) Carbon pools and sequestration in forest ecosystems in Britain. Forestry 68: 361-378.

[47] J Morison, R Matthews M Perks T Randle E Vanguelova M White and S Yamulki. The carbon and GHG balance of UK Forests: a review. Forestry Commission 2009

7.7 Longer-term options to the 2020s

Apart from the longer-term benefits of afforestation, the following methods hold promise for reducing emissions:

- biochar addition to land: biochar (charcoal) is produced from the pyrolysis of organic materials. If buried in soil it can act as a long-term soil carbon store (>500 years). Although Biochar could be produced on farm, the volumes of biomass available are probably insufficient to meet demand. Therefore, it has been suggested that Biochar could be produced from large volume waste materials (e.g. green waste, biosolids, forest residues) and subsequently ploughed into agricultural fields. Typical application rates of Biochar to arable fields are in the range 8-35 t/ha. After a few years of Biochar amendment this would effectively double the amount of carbon stored in soil organic matter in the topsoil. Before adoption, however, full LCA is required to quantify emissions associated with Biochar production, transport and application, together with implications for soil and water quality and long-term food production. The best methods of incorporation of Biochar into grassland have not been identified. It is likely that a one-off application could occur during reseeding where the Biochar could be incorporated into the topsoil.
- improvements in agronomy: development of genetic breeding technologies including the selection for N-use efficient cultivars (reducing the application rate of N fertilisers), and selection for deeper rooting crops that can sequester carbon deeper in the soil profile. Reduction of fertiliser application would be tracked by the Inventory, but not increases in soil carbon levels.

7.8 Overall analysis

It is clear that the main opportunity to reduce GHG emissions is through a tree planting programme – requiring at least a 10-fold increase in the current planting rates. This would have a maximal effect in the first 30 years but reaches quasi-saturation after 50 years. A tree-planting programme at the required scale starting now would make a substantial contribution to meeting the 3% annual reduction target in the next 30-40 years. After this point other mitigation measures would need to be devised if the targets are to be met.

Information pertaining to the impact of changing grassland management regime on GHG emissions remains scant with very few holistic studies undertaken in Wales or indeed globally. There is therefore a need to improve the knowledge base from a Wales-centric perspective; however, this must be done robustly. Research areas that urgently need attention include:

- GHG budgets: there is a need for integrated studies covering all 3 key GHGs taking account of losses to water as well as to air. Few studies have actually been undertaken in Wales. Instead, values used to predict the impact of land use change in Wales are derived from non-UK studies - these are often incomplete. There is therefore a need to validate current estimates in a Welsh context or at least assess the level of uncertainty.

- Inventory improvement: current estimates of land use change in Wales need significant refinement as they lack detail and fail to capture functional landscape details. Methods of improving the LULUCF Inventory need to be progressed, with particular concern to use actual land use change statistics to track land use change with time – for example, using agriculture statistics data, National Forest Inventory data and CCW Phases 1 and 2 data. One of the challenges is to provide land use data that can be integrated with the overall CS data and land use change model. In addition, the Inventory needs to be developed to be able to track changes in land use management as well as land use change. The assumptions about soil carbon loss from conversion to settlements needs better evidence. For Wales, trends in urban development need to be collated to provide better input-data.
- soil carbon stocks: although estimates of total soil carbon stores in Welsh soils (and vegetation) have been made, the impact of shifting from one land use to another (e.g. grassland to forestry) on soil carbon storage has great uncertainty, particularly in relation to soil type. Implicitly, the rate of change in soil carbon as a result of land use change has even greater uncertainty. Too many studies have emphasised the *potential* for carbon sequestration not the *likely* sequestration rates. Estimates of soil carbon stocks under different land uses are also limited by sampling schemes that only survey topsoil (0-15 cm) or by assuming that soil carbon content under different land uses indicate changes in sequestration rates. We recommend that a targeted field survey approach, which explicitly addresses these problems, is used to rectify this deficiency. Also the development of the next generation of soils maps focussing on integration of soil parameters of functional importance.
- land management: as noted earlier, the effects of land management practices and changes on emissions are far from being quantified; in particular, the effects of land use changes on combined emissions in soils and biomass:
  - for grassland, further research is required to quantify the effects of grazing intensity and type. Also re-seeding of lowland pastures is an important mechanism to improve productivity and reduce weeds but the impact on GHG emissions remains unknown. Work needs to investigate the potential for optimizing this practice (time of year, plough depth, minimum-till potential *etc*). The potential to create new grass varieties that enhance carbon storage below ground is also worthy of study.
  - research is also required on organic farm systems, due to the conflicting conclusions reached by recent studies. In particular little is known about N_2O emissions from legume crops.
  - with respect to peat rewetting ("grip blocking"), there is a particular need for studies to address the flux of *all* GHGs and dissolved-carbon losses simultaneously in the same locations so that the net GWP can be determined (i.e. all inputs and outputs required to complete a budget). Future large-scale schemes for re-wetting of peat should ensure that these measurements are put in place urgently to ascertain whether this management intervention is having the planned net

benefit for climate change mitigation. We recommend that an integrated experimental approach is used to address this at the catchment level.

- although tilled land only accounts for a small proportion of Wales, it is likely that changes in management regime will occur in the near and distant future as both technology and knowledge improves. In particular, the use of no-till regimes is of interest as there have been conflicting reports about the relative merits of adopting it in a management strategy[48]. The main uncertainty surrounds whether the increase in soil organic matter from reduced tillage is offset by the increase in N_2O emissions. In addition drainage may be an important factor in reducing N_2O emissions by maintaining aerobic conditions in the soil.
- afforestation increases carbon storage in vegetation, but its impact on soil carbon stocks is less certain in organic soils. Further studies are required to assess impacts through the life cycle, and in particular to assess new forest management methods such as continuous cover.

- ECOSSE: Ecosse-2 provides the best mathematical model currently available to predict the impact of land use change on climate change mitigation[49]. Its current use is limited by the poor quality of soil and land use data at the correct spatial scales. We recommend that Ecosse is run for representative catchments using finer vegetation categories (split semi-natural vegetation categories) and obtained from different sources (e.g. Integrated Administration and Control System-IACS, CS). Similarly the underpinning soil data should be used from contrasting sources (e.g. NRSI, CS, catchment-specific *etc*). The model also requires better estimates for vegetation net primary production to allow independent testing of changes in soil carbon sequestration rates. Greater knowledge of carbon losses during forest harvesting is also needed. Future expansion of Ecosse-2 should be to link the model with an LCA model that allows the whole 'cradle to grave' GHG emission values to be calculated (e.g. from transport, waste *etc*).
- Volatile Organic Carbon (VOC) losses: emissions of VOC's from vegetation represent a small but important carbon loss pathway and are of similar magnitude as those for carbon leaching into freshwaters. There are almost no values available for the UK, and of those, few relate to the impact of land use change on emissions. We recommend that an experimental approach is used to address this and that it should focus on grasslands where there is greatest uncertainty.

[48] Bhogal A, Chamber B, Whitmore AP, Powlson DS. The effects of reduced tillage practices and organic material additions on the carbon content of arable soils. DEFRA report SP0561. 2007

[49] Smith P et al. (2007) ECOSSE - Estimating carbon in organic soils sequestration and emissions. Climate Change and Air Division, Scottish Executive, Edinburgh

8. Food chain reduction options

8.1 Introduction

Food is a vital global ecosystem service. In Wales home-grown food makes a minor contribution to our diet while most arises from food traded within the UK mainly through the dominant supermarket chains. The UK supplies 84% of its requirements for dairy and egg products, 80% of meat and meat products, but only about 19% of fruit and vegetables[50]. Where food comes from outside of the UK, it is again supplied via the supermarkets. Wales' food exports, mainly milk/cheese and beef and lamb meat, are however, also important to farm incomes and the rural economy. The dependence on imports is a consequence, in part, of the preponderance of pastural animal-based systems in Wales. As noted, Wales has currently a limited arable/horticultural sector, but this competes with the dominance and international reach of the supermarket chains, to provide for the changing consumer expectations of a wide range of foods from across the globe throughout the year. Numerous Welsh Assembly Government initiatives attempt to promote a more localised food chain but the umbilical link to the international market place remains a pervasive feature[51]

Work on the GHG footprint of specific food commodities suggests that, for certain foods, farming itself may not be necessarily the major source of GHG emissions from the food supply chain. But overall as part of the UK food-chain, agriculture emits 50% of the GHG emissions with food manufacture, UK transport and retail emissions being around 26% and catering and home food preparation leading to the remainder[52]. Assuming these figures can be applied in Wales, based on the annual agriculture emissions of 5,200 kt CO_2e, the food processing and distribution emissions amount to another 2,600 CO_2e.

Several areas in the chain may be responsible for significant emissions and offer opportunities for reductions. Studies of Wales' ecological footprint show that food accounts for 20% of the ecological footprint mainly from the supply chain[53]. For example, changes to the way food is processed, efficiencies in transport, reduced/amended packaging, reduced process and consumer waste and alternative cooking methods, all offer potential gains. Moreover it is not axiomatic that local foods are always more GHG-friendly than imported food. The LUCCG commissioned work (the "LCA study") – see Appendix 1 - to identify GHG efficiencies in Welsh food supply chains, and consequently in the embedded carbon (CO_2e) in some Welsh food exports, focussing in the first instance on lamb meat, milk and cheese, potatoes and strawberries; the latter as a proxy for a range of soft fruits. The Group recognises the need for

[50] UK Food Security Assessment Detailed Analysis. DEFRA August 2009

[51] Farming, Food & Countryside – Building a Secure Future – Welsh Assembly Government

[52] Scoping studies to identify opportunities for improving resource use efficiency and for reducing waste through the food production chain AEA. For DEFRA February 2007

[53] Wales' Ecological Footprint – Scenarios to 2020. E Dawkins, A Paul, J Barrett, J Minx K Scott. Stockolm Environment Institute 2008

more extensive studies, especially on processed / pre-prepared meals, which are important in the diet (but the time and resources available did not permit more work to be undertaken).

Table 8.1 - Food commodity GHG emissions from LCA study

	Standardised carbon footprint (kg CO_2e/ kg product)	Consumption (kg/person/year)	Total Welsh footprint (kt CO_2e/year)	Food calories / kg
Lamb meat	32.0	2.9	271	2,500
Cheese	12.5	4.6	171	3,833
Liquid milk	1.7	26.2	131	615
Strawberries	1.3	2.6	10	302
Potatoes	1.0	26.0	79	1,000

The carbon footprint of cheese is more than 7 times that of milk although both share much of their life cycle and a footprint dominated by on farm emissions, as each 1 kg of cheese takes about 10 kg of milk. Despite their relatively low per-kg footprint, potatoes make a contribution (79 kt CO_2e per year) to the estimated annual Welsh food footprint, but of course also make an important calorific contribution. 70% of the carbon footprint of fresh potatoes comes from the electricity used in long-term storage and cooking. Lamb at 271 t CO_2e is the greatest carbon footprint contributor, but again with a high calorific value.

It should be recognised that the calorific, nutritional and health impacts of the commodities also vary widely and both current and 'best practice' portions of the food items vary widely. The nutritional and health impacts are very complex and will be discussed very briefly later.

8.2 Short-term reduction potential and options

8.2.1 General situation

The commissioned study showed a considerable scope for GHG emission reduction in all five food items. The modeled interventions gave rise to GHG reductions respectively of 32% for lamb, 55% for milk, 42% for cheese, 45% for strawberries and 136% for fresh potatoes: the large figure for potatoes arises from AD and the use of the biogas for road transport for deliveries. In total the interventions amount to some 342 kt CO_2e emission reduction per year; with the possibility of Welsh potatoes production and consumption becoming a net carbon sink when grown on mineral soils. It should be noted that many of the recommendations are generic and relevant to food items not specifically discussed here. But this is not necessarily true for food processing options.

8.2.2 Individual footprints

- <u>lamb:</u> footprint dominated (>90%) by on-farm emissions; mostly N_2O from soils (28%) and CH_4 from enteric fermentation (39%).
- <u>milk and cheese:</u> dominated by on-farm emissions, again of N_2O from soils, CH_4 from enteric fermentation, and indirect inputs (concentrate feed, agro-chemicals / fertilizers and bedding).
- <u>strawberries:</u> 95% of emissions are associated with on-farm emissions but in this case due to production, packaging and storage on-site, with 62% arising from indirect inputs (irrigation, agro-chemicals and overseas plant stock sourcing).
- <u>potatoes:</u> electricity-related emissions contribute 71%, due partly to chilled transport and storage within which total home food preparation itself contributes about 20%.

8.2.3 Implementation options

The generic recommendations from the LCA study are:

- all electricity used at any stage of the lifecycle should be generated from renewable sources. In the next Chapter, the capacity of farms and rural Wales generally to meet energy requirements from local renewable resources is addressed.
- all diesel fuel used at any stage (primarily on-farm use and freight transport) should be exchanged for compressed bio-gas (CBG) generated from AD of liquid manure or food waste. In fuel LCA analysis, this fuel is generated from within the carbon cycle and replaces a fuel, which makes a net input to the carbon cycle (i.e. diesel or petrol) and therefore has a negative carbon footprint.
- all refrigerants (in abattoirs, chilled transport, retail, home-storage) should be replaced with ammonia or another low-footprint refrigerant. In this Report the GHG implications of emission from the use of refrigerants are not considered.
- any manure handled on-farm (in the case of the mixed farm studies, much of this will be cattle manure) is anaerobically digested. The bio-gas generated should maybe be converted to CBG or used to generate electricity. In the current study it has been assumed that CH_4 is burned off (i.e. converting CH_4 to CO_2 so decreasing 21 fold the GWP of the emissions) but this does not maximise resource use.
- this is based on all oil-based packaging plastics is replaced by degradable bio-film.
- maximal short-term gains are assumed in transport efficiency (e.g. "Safe and Efficient Driving"[54] training for drivers, transport co-ordination, route planning could achieve up to a 22% reduction in fuel consumption).
- a medium-term move to EVs or hydrogen fuel vehicles, which if coupled to local renewable sourcing will contribute to carbon neutrality.

[54] www.safed.org.uk

- consumer transport by cars and diesel buses to retailers is replaced by lower carbon transport options e.g. walking or use of EVs recharged by renewable electricity.

The specific recommendations from LCA study are:

- for beef / milk / lamb:
  - farm management: spring calving to use spring grass and reduce concentrate feed use.
  - improved flock management.
  - reduce use of imported concentrates when these contribute to environmental degradation e.g. tropical forest destruction or over-fishing.
  - increase lambing percentage from 120%, and achieve better kill-out percentages.
  - milk bottles from x50 re-usable, recyclable, high density polyethylene.
  - slaughter waste products (material not fit for rendering or human consumption) minimised. This waste is commonly incinerated, but could be anaerobically digested to provide CBG. For example the annual amount of animal and mixed biodegradable waste arisings in UK from processing of meat and meat products is 816,000 t[55] and the annual total from all food processing is 1,030,000 t.
- for strawberries:
  - packaging plastic in punnets and lids replaced with degradable plastic bio-film.
- for potatoes
  - home preparation: potatoes are cooked in a conventional oven shared with other meal components (e.g. baked or roasted while meat is roasted), or in a micro–wave oven. Table 8.2 shows the energy and emissions from cooking potatoes using different methods.

Table 8.2 - Comparison of emissions from electricity use between four different cooking methods for potatoes[56]

Cooking method	kWh / kg potato	kg CO_2e / kg potato
Boiled on stove	0.83	0.45
Roasted with meat in oven	0.17	0.09
Baked in oven	0.23	0.12
Baked in micro wave	0.27	0.15

8.2.4 Research data needs and priorities

- the current research considered a limited range of commodities but excludes processed and pre-package foods that form a significant part of the Welsh diet. The GHG footprint of these materials needs to be

[55] Mass balance of the UK Poultry Industry. Biffaward. www,biffaward.org
[56] The Food Refrigeration and Processing Engineering Research Centre – www.frperc.bristol.ac.uk

addressed - both in relation to local companies and the mass-produced items on supermarket shelves.

- the GHG impact of additional land allocated to allotments does not appear to have been assessed, although, in relation to public health and awareness of food quality, it seems entirely desirable.
- little is known, collectively, about current energy and water usage and waste production in the food production chain. There is a dearth of real data with which to map resource flows with any confidence. This sets a challenge to identify areas within the food production chain where resource use efficiency might be cost-effectively improved.
- work is required on ways to strengthen, shorten and make more seasonal the food chains, both from the viewpoint of reducing emissions but also increasing resilience of the food supply chain.
- consumer choice seems determined largely by time and money pressures although local and national allegiances play a part. Research on behavioural and social aspects is required to inform decisions to favour food commodities with low embedded GHGs.
- it is important to compare GHG emissions not only per unit product but also by their nutritional value (e.g. meat has a much higher calorific value than milk or soft fruit).

8.2.5 Summary

Three interventions would have major short- to medium-term impacts on the GHG efficiency of the food chain:

- the reduction in CH_4 emissions by the comprehensive adoption of AD to improve manure and food waste management - both process and consumer waste. This AD process can also lead to CBG and/or electricity production offsetting fossil fuel energy as well as providing an effective residual fertiliser, which appears to release less N_2O. Although there are important regulatory issues to unravel, in many parts of Wales urgent consideration should be given to creating facilities to digest anaerobically a range of food wastes, animal residues and slurry to generate biogas or electricity and so minimise atmospheric CH_4 emissions.
- the generation and use of renewable energy not only from AD but other renewable resources for the food-chain processing and distribution.
- energy efficiency measures within the farming, processing and distribution sectors to reduce energy demand.

Other important interventions are:

- improvements in livestock management to increase production per unit GHG released e.g. better lambing percentage, spring calving (see Chapter 6).
- less and fully biodegradable packaging to replace fossil fuel derived plastics.

8.3 Medium-term options

Waste reduction

Ways to change consumer behaviour are required to reduce the large amount of food that is wasted. Studies of Wales' ecological footprint indicate that reduction of food waste by 1/6th could reduce the footprint by 7.2% by 2020. Waste Resource Action Programme (WRAP) estimates that 8.3 million t of food waste is thrown away annually by households in the UK[57] , of which 5.3 million t is considered avoidable. As an overview, the amount of food (including liquid and solid foods but excluding drink) wasted per year is 25% of that purchased (by weight). For food and drink, the 8.3 million t per year of waste represents 22% of purchases (again, by weight). Nearly 40% of the total food waste is fruit and vegetables. WRAP estimates that the avoidable waste equates to 20 Mt CO_2 e. On a population basis, for Wales this avoidable waste is equivalent to 1 Mt CO_2e.

In addition to the consumer waste, it is important to reduce wastage in post-harvest storage, and throughout the processing and distribution chain. The extent of this wastage is unclear.

This issue is discussed further in Chapter 11.

The role of local marketing and shortened food chains

Currently, as far as can be ascertained, only a small fraction of Wales' food is grown locally. Issues such as seasonality, embodied energy in the production of the commodity and food miles do not loom large in the choice of mainstream consumers. However when major, dramatic international events such as crop failures force global climate change onto the public consciousness, this situation may change. It must be recognised that food miles are only part of the GHG footprint, and that it is more important to encourage a greater focus on not eating foods out of season.

Nonetheless, international food costs and supply scenarios have changed significantly in the last decade. Expectations of a continuing gradual reduction in world commodity price have been replaced by fears of major increases in staple food prices - a consequence of increasing water shortages, higher energy costs, population growth and, of course, climate change. This has made it important that we understand and track the resilience and exposure to threats and challenges within the food system[58].

Lifestyle

Human diets have changed significantly, well beyond the provision of minimal (or excessive) nutrient and calorie levels. Food and how it is prepared and eaten has a strong cultural component. It interacts with life style to shape our physical and mental health. In this sense, health has some elements of being an ecosystem service as well as the more apparent components of recreation and relaxation. For example the report on Wales' Ecological Footprint –

[57] WRAP Household Food and Drink Waste in the UK. November 2009
[58] UK Food Security Assessment. Detailed Analysis. DEFRA August 2009

Scenarios to 2020 (see ref 15) identifies eating out and expenditure on catering as having the largest impact on the ecological footprint of food.

<u>Diet</u>

What we eat has a major impact on our health. *Food Matters*[59] concluded that 70,000 premature deaths could be avoided if, in the UK, diets met nutritional guidelines. Diet-related ill health costs the NHS an estimated £8 billion a year and obesity alone is estimated to cost the wider economy £15.8 billion. The Foresight[60] programme suggests that this figure would rise to £50 billion by 2050. Some of this health burden has been linked with the consumption of meat and dairy products. Globally the consumption of these products is rising with increasing wealth, but in developed countries, the public health advice is to reduce consumption. In the case of Wales' dependence on pastoral agriculture, this presents a significant point for argument. Both environmental and health benefits may be achieved by reducing consumption, but the social and economic impacts would be significant.

<u>Several issues arise:</u>

- given that Wales' climate change scenarios are relatively benign, do we have a responsibility to continue to emphasise food production provided this can be achieved while meeting our climate change targets? *The Group's response was that Wales did carry this responsibility.*
- in the event of major disruption of the international food supply chain and/or very large price rises, can Wales (or perhaps more accurately the regions of Wales) make a larger contribution to home food needs while again meeting our climate change obligations, which, in such an international crisis, would in all likelihood become more onerous? *The potentials and drawbacks of greater self-sufficiency are discussed later.*

It must also be noted that these questions and indeed the whole diet/food supply agenda have huge implications for sustainable development and to Wales' overall ecological footprint. A key question is where does the balance lie between environmental and health benefits, and social and economic impacts from change of lifestyle and diet. A response to these questions is offered in Chapter 11.

[59] Food Matters: Towards a Strategy for the 21st Century, Cabinet Office July 2008
[60] www.foresight.gov.uk

9. Renewable energy potential on farms and in rural communities

9.1 Introduction

This section addresses the renewable energy resources of rural Wales, their integration within low GHG emission farming systems, their possible financial contribution to the rural economy and to instigating and motivating community action. Additionally some consideration is given to their possible role in carbon off-set systems or carbon trading both to help move to a zero-carbon agriculture post 2020 and to incentivise the farming community. Constraints on the exploitation of this potential are identified and initiatives are recommended.

This report does not discuss larger scale installations (i.e. greater than about 250 kW). However, it is vital to note that, where large commercial installations are envisaged, their impact on total GHG emissions is assessed rigorously. For example, safeguards are essential to ensure that the embedded carbon and net GHG emissions from Wales' upland peat are not compromised during upland wind farm development.

Rural Wales has substantial renewable energy resources, compared with the urban areas where most of the population lives. The opportunities for biogas from AD have been reviewed in Chapter 6. As well as biogas, other resources include wind, solar, bioenergy (biomass) and hydro-electricity. The challenge is to link energy supply and demand most efficiently. Although the rural sector has the potential to generate renewable energy, the electricity networks to transmit the power to the main markets in conurbations are weak. In addition, for renewable heat sources, markets need to be near to supply to minimise energy losses from transport. Biomass has the potential to make a significant contribution to renewable heat, but its use for generating electricity can lead to the loss of 2/3rds of the energy. The Group recommends that there is clear information from the DNOs on the network constraints, and investment to address these constraints where significant generation opportunities exist.

Apart from the technical aspects uptake will depend on the financial incentives, including the schemes for Feed in Tariffs (FIT) and Renewable Obligation Certifications for electricity and heat.

It must be recognised that apart from the benefits of generating renewable energy, the operators of these facilities gain greater sensitivity to the use of energy, and community renewable schemes have opportunities to leverage substantial energy efficiency benefits. Welsh Assembly Government is keen to support community renewable schemes.

The Group notes that some hydro-electricity is being produced from Wales' existing reservoirs but the output appears very patchy. The LUCCG recommends early and urgent consideration of the currently untapped potential of existing facilities e.g. hydro-electrical energy potential of the numerous large water supply reservoirs and dams throughout Wales (such as those in the Taff valley between Storey Arms and Cefn Coed y Cymer).

In assessing the potential of renewables it is essential to take account of the overall efficiency including the embedded energy in the devices. Several studies have been carried out of the LCA of renewables [61]. The emissions for a range of feedstocks for generating electricity, heat and Combined Heat and Power (CHP) are compared with emissions for grid electricity in Table 9.1. On-shore wind is most efficient in emission terms for electricity generation, and biomass is efficient for heat generation and CHP.

Table 9.1 - GHG balance of renewable generation (kg CO_2e/kWh)

Feedstock	GHG emissions / kWh		
	Heat	**Electricity**	**CHP**
Grid electric	0.58	0.58	0.58
Oil	0.44		
LPG	0.36		
Natural Gas	0.30		
Straw	0.06	0.23	0.18
SRC Wood chip	0.02	0.07	0.04
Forest wood chip	0.02	0.07	0.04
Solar water	0.22		
Solar PV		0.18	
Wind on-shore		0.007	

9.2 Short-term options

Data presented in the sections on livestock production and the food chain demonstrate the importance of AD and the availability of low-carbon transportation and machinery to making major reductions in GHG emissions. GHG efficient management of agricultural waste, especially on dairy enterprises by AD can be combined with heat and electricity generation. These offer major opportunities and advantages if the capital outlay is not excessive. The subsequent use of bio-gas (CH_4) as a fuel will reduce the other GHG emissions from the animal/milk production sectors of the food chain (as the conversion of CH_4 to CO_2 lowers the GWP of the emissions 21 fold). Also AD digestate is a useful organic fertiliser with possibly a lower N_2O release. A detailed appraisal of the AD potential related to animal numbers and reducing GHG emissions is given in Chapter 6.

Chapter 7 (on land use) highlights the importance of afforestation to create an enlarged sink for the sequestration of CO_2 with a significant off-set potential. Both the existing and any additional woodlands planted offer a renewable source of fuel wood for space heating. This could support a number of

[61] Review of Greenhouse gas life cycle emissions, air pollution impacts and economics of biomass production and consumption in Scotland - Scottish Executive - Environment and Rural Affairs Department - 2006.

community and individual heating schemes providing a secure heating source as well as off-setting GHG emissions from the use of fossil fuels.

Other renewable energy sources include:

- biomass – wood thinnings and special crops (e.g. Miscanthus and short rotation coppice)
- ground and air source heat pumping - taking advantage of the thermal properties of the subsoil/shallow rock below about 1 m or greater depth, which have as a result of the incident annual average solar radiation a fairly constant temperature of about $12C^0$.
- solar water heating and photovoltaic (PV) electricity – parts of coastal Wales enjoy sunshine hours similar to southern England and have a good solar energy potential.
- small scale wind power - many parts of upland and coastal Wales have relatively high and consistent wind suggesting that community wind power schemes could make a contribution in suitable areas.
- small scale hydroelectricity - farm and community small-scale hydro was not uncommon a century ago and is being revisited with new technology (some low-head systems are becoming available) to take advantage of Wales' high rainfall and topography. While median climate change scenarios predict somewhat drier summers, winter rainfall is expected to increase.

The Group does not anticipate that Wales has a significant potential for arable bio-diesel crops (e.g. oil seed rape *etc*) for three reasons: a) the limited areas of productive arable soils will be required for conventional food and fodder production in any scenario envisaged; b) the conversion of addition grassland to arable leads to a loss of soil carbon, and; c) the net GHG emission reduction accruing from the production and use of such bio-fuels to replace diesel and petrol in temperate climates seems small.

With regard to carbon trading or other methods of valuing or trading GHG offsets, to date such schemes are only being applied to large industrial emissions within the EU and by individual companies to improve their public profile (e.g. tree planting in tropical areas by airline companies). In time such concepts may become applicable in rural Wales.

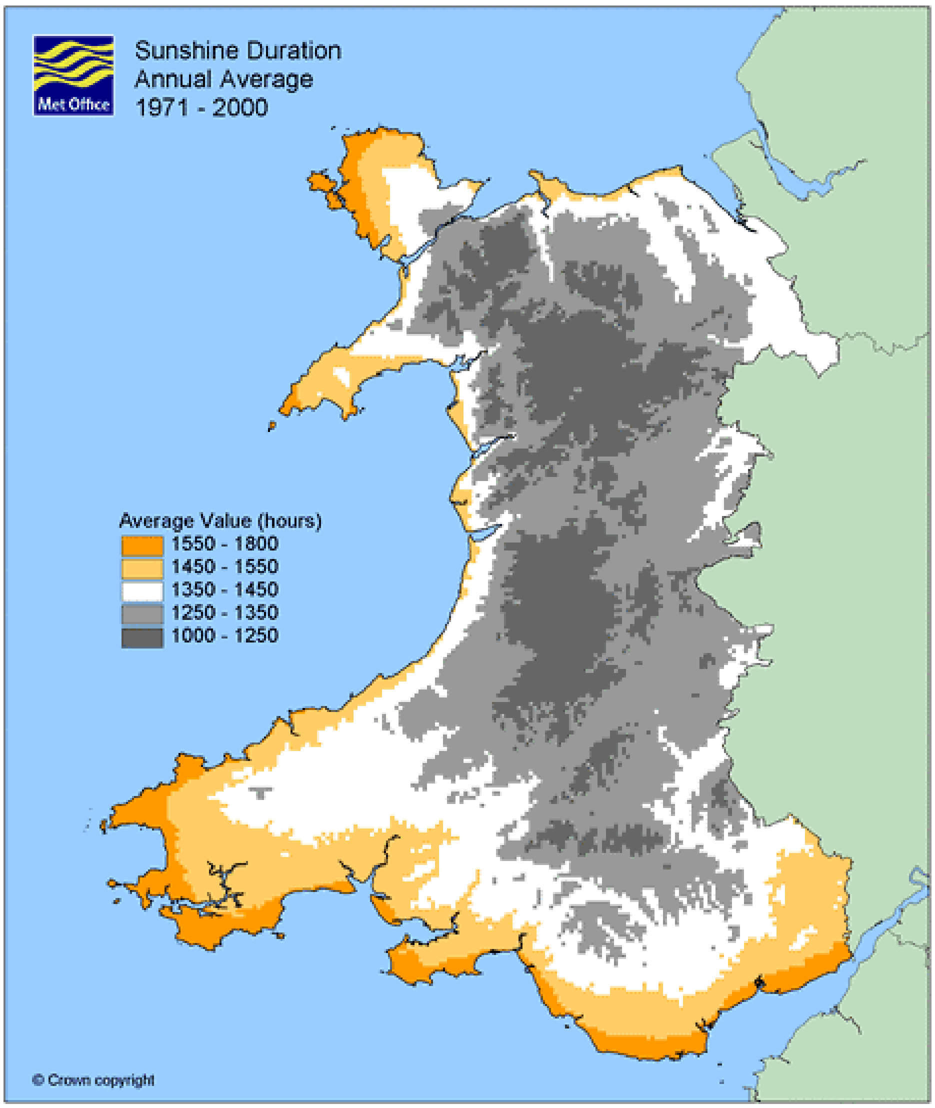
9.3 Examples of installations

It is not possible in this report to give a comprehensive assessment of the small-scale renewable energy potential of all of rural Wales or of specific areas therein. Clearly the renewable source base varies with physical geography (e.g. fuel wood, hydro and wind in the upland areas; solar, wind and biomass in lowland areas). Each holding and community must be encouraged to assess and exploit its own potential.

Solar heat and PV arrays

Areas of rural Wales have exploitable levels of annual solar radiation which make both solar thermal water heating and PV installations potential investments. Fig 4 shows the annual average sunshine hours in Wales. Areas such as coastal Pembrokeshire and western Anglesey have 1,450-1,800 hours / year of sunshine, which compares well with that of the south coast of England - 1,700 hours / year[62]. Exploiting this resource requires an area of pitched, un-shaded house or shed roof facing between south east and south west. Mackay[62] states that in the UK, solar hot water panels produce about 1.3 kWh per m^2 and that 2.5 m^2 of panel would provide an average house with much of its hot water.

Fig 4



[62] D MacKay Sustainable Energy – without the hot air. www.withouthotair.com

Turning to solar PV systems, these are more expensive to install but it is reasonable to estimate that Wales could support many thousands in both urban and rural areas. Assuming at least 10,000 PV installations with a nominal capacity of at least 3.1 kW per installation, this should generate perhaps 10,000 x 3,000 kWh per year equivalent to 30 GWh. Based on a feed tariff of 36.5 p per kWh this would be worth over £10 million to Wales annually. In Box 4 an example is presented of the return on capital investment of a scheme generating 2,500 kWh based on current prices. A total output of 30 GWh is equivalent to reducing emissions by 13 kt CO_2e.

A significant development is the planned large-scale demonstration of solar cells on steel roofing and cladding by Corus and Dyesol at the Corus site at Shotton. The solar cells are based on dye-impregnated coatings. If successful, this approach could be used on large areas of roofing on farm buildings to generate power.

There would be a further substantial financial benefit to farms and rural communities if they could run their EVs and/or some agricultural machinery; as well as provide space heating from their own fuels (e.g. bio-gas or electricity); so both reducing fuel costs, increasing energy use efficiency and sparing fossil fuel-derived GHG emissions. Mackay[62] quotes an electric car as using 15 to 20 kWh per 100 km compared with a conventional petrol car, which uses 5 times this energy input and, of course, emits GHGs.

Hydro electric schemes

The England and Wales Hydropower Resource Assessment report (April 2009) summarises the existing Welsh potential as 26,800 to 63,000 kW basing the assessment on the 1989 ETSU[63] report. But the 2009 report notes that this may be a significant underestimate given:

- that the Welsh report of 1980 returned a figure three times the ETSU study.
- a SEEDA[64] low-head resource study in south-east England based on modern low-head technology doubled that region’s practical potential, and
- the report claims a general consensus that the ETSU study missed many viable locations. The 2009 study included no fieldwork and, for example, recorded no viable sites in the southern part of Plumlumon or Hiraethog, Migneint or Berwyn.

Consequently it seems reasonable to estimate Wales' micro-hydro generating potential as being in excess of 100,000 kW (100 MW). The study quotes a load factor of 37%, *cf* 28% for onshore wind, although the Abercraf installation in the Brecon Beacons NP (BBNP) does find a load factor of 95%. To a first approximation, a potential of 100,000 kW is probably realisable, generating some 0.3 TWh annually. In the BBNP, officials estimate a potential capacity of 2-3 MW with a 70 % load factor yielding up to 13 GWh / year, applying stringent environment criteria to the installations. This estimate does not address any unrealised hydro electric generating potential of many of existing large dams throughout Wales.

[63] Energy Technology Support Unit
[64] South East England Development Agency – www.seeda.co.uk

Bioenergy

- Wood - the estimated current annual sustainable woody resource, suitable for wood fuel purposes, from the public forest is 400,000–450,000 oven dried tonnes (odt)/year[65]. However, subtracting existing markets, primarily the chipboard and pulp markets, then an estimate of 150,000 odt remains. FC Wales estimates that a further 90,000 odt could realistically be recovered for biomass purposes from privately owned woodlands in Wales. Therefore a current total sustainable annual resource of about 240,000 odt is available from Wales with no disruption to existing markets. However it is unclear how much of this is already used for heating.

  This current resource can supply:

  - Domestic Firewood market - this historic market remains unquantified but anecdotal evidence suggests an increasing popularity of wood burning stoves. There are a number of more well established businesses trading high quality product - several thousand tonnes a year- at prices in excess of £100/t for seasoned logs but much of the supply chain remains informal. This market offers important opportunities for rural business diversification, high prices for good quality material, and local fuel security. A key action to promote the market may be to adopt a HETAS[66] firewood standard.
  - Commercial heat market - an estimated 35 MW of installed wood chip and pellet heating systems have been installed in Wales since 2002 consuming approximately 35,000 t of fresh wood chip and about 1,000 t of wood pellets per annum. These systems are saving approximately 31 kt CO_2e/year. Typical delivered wood chip prices are equivalent to £80/t for chipped seasoned wood and wood pellets fetch approximately £175/t for bulk delivery and £210/t for bagged material.

- Bio-mass plantings - Scenarios can be developed for enlarged future energy production from bioenergy sources. Here we present examples for energy generation and emission saving options based on growing an additional 50,000 ha by 2020 – about 8% of the land considered suitable for biomass crops. Actual planting would depend on the future support for

[65] Woodfuel Resource In Britain, H. Mckay December 2003 and in-house FC Wales, 2007
[66] www.hetas.co.uk

Box 4 - Investment appraisal of PV installation

Assumptions:

- investment costs - £18,000 (£15,500 with grant aid).
- minimum lifetime of investment - 20 years.
- annual generation - 2,500 kWh.
- price paid per unit generated (FIT rate) - 36.5 pence/kWh.
- savings from home generation - 9.4 pence/kWh.
- real annual interest rate - 4.19% (commercial re-mortgage fixed interest rate for 20 year loan of 6.59% less annual inflation rate of 2.4%).

Net present value (NPV) of investment (i.e. investment cost less grant aid and discounted stream of future electricity bill savings and FIT payments)

Electricity price change (%) in real terms	NPV (£)
0	-178.92
2	465.99
5	1,774.46

Hence, if electricity prices remain constant in real terms, the cost is greater than the benefit to the investing household. But with annual rises of 2% or more in the real price of electricity, the investment in PV begins provide a return.

The actual return on investment - the internal rate of return (IRR) - can be calculated as that interest rate which just produces a zero NPV. If the IRR is greater than the cost of the funds used to make the investment, then it will be profitable. Given that historic interest rates have been below 5% in real terms since 1993 (and sometimes considerably lower), a greater than 2% annual increase in the real price of electricity will make a long-lived investment of this duration profitable.

IRR on investment (discount rate at which the NPV is zero)

Electricity price change (%) in real terms	IRR (%)
0	4.06
2	4.53
5	5.39

In some areas of Wales, better sunshine levels would produce a higher annual electricity output from a similar PV installation. For such locations, the NPV of the investment is enhanced - positive at £2885.29 at level future real electricity prices, £3,659.19 with a 2% real term increase in future electricity prices and £5,229.35 with a 5% increase. The respective IRRs are 6.22%, 6.70% and 7.57%.

BOX 5 - Abercraf micro-hydro installation in the BBNP

The scheme:

- head - 80m
- pipe diameter - 150 mm
- flow rate - 25 l/s-(max)
- turbine capacity - 12.7 kW
- phase: - Triple
- annual MWh - 72.3
- system cost - £23,500 including grant of £3,500 from BBNP
- unit price: £72 per MWh
- double ROC price - £96 MWh
- annual revenue - £12,146
- payback time - 2 years

Generally the system will work at about 95% capacity for the year as it is spring fed from a very reliable source that is not affected by rainfall variations. Over the last three years the 11 other new micro hydro schemes in the Brecon Beacons have seen that the summer has been more productive than spring and autumn.

Total installation cost was £23,500 (and included a £3,500 grant from the BBNP Authority). The scheme did not qualify for any of the 'accredited' grant schemes as it was designed and constructed by local people as part of a broader – "The Green Valleys" - Project. Opting to not go down the accredited route enables the Scheme to built and engineer components itself locally at much lower cost. The system is currently receiving 7.2p / unit for export (this will likely go down considerably on the next contract) and qualifies for double ROCs at about 10p / unit.

This system is installed on 3-phase electricity but similar sized schemes on single phase have been accepted by Western Power. For this system grid connection cost about £1,000.

biomass planting and future fossil fuel energy costs, and prices for alternative food products from the land that could be converted to biomass growing:

- Coppice willow scenario - based on use of Grade 3 and 4 land below 300 m, a yield of around 12 odt/ha/year would be expected. For 50,000 ha, annual production would be 60,000 odt. This would provide heat output of 2.6 TWh/year, saving emissions of about 830 kt CO_2e/year, or electricity output of 0.9 TWh, saving 300 kt CO_2e/year.
- Energy Grasses scenario (based on miscanthus) - miscanthus grows less well at higher altitude and may be restricted to land below 300 m. Yields of around 12 odt/ha/year are expected. For 50,000 ha, the heat output would be 2.6 TWh/year saving emissions of about 830 kt CO_2e/year, or electricity output would be 0.9 TWh/year saving 310 kt CO_2e/year.
- Wood - the scenario based on an additional 50,000 ha for energy illustrates the energy potential. This has the heat output of up to 0.7 TWh/year, saving emissions of 180 kt CO_2e/year while electricity output would be up to 0.25 TWh/year saving 76 kt CO_2e /year. These figures are lower than for willow short rotation coppice and Miscanthus, but may represent the lower intensity of management of woodland in Wales.

The overall extent of impact on biodiversity and soil carbon will depend on previous land use and mitigation measures. Environmental Impact Assessment regulations and use of the ECOSSE guidelines on managing soils provide mechanisms to maintain soil carbon levels and prevent a net loss of carbon from crops.

9.4 Summary

The Welsh Assembly Government Low Carbon Energy statement (annex 3) summarises the estimated potentials of various renewables recalling that Wales' total annual energy demand is about 129 TWh of which about 23 TWh is as electricity.

Clearly both urban and rural Wales have a renewable energy potential. Some resources are essentially rural while others (e.g. solar heating and solar PV) are equally applicable. In the case of solar the major practical resource may lie in urban areas as the great majority of the Welsh built-environment and hence suitable roofs are found in these areas. From this limited perspective, it is fortunate that the great bulk of Wales' population lives in the sunnier coastal belts. Heat pumps may be used in many places - urban as well as rural – provided heat extraction areas do not overlap.

The data in this report, while making no claim to being comprehensive, suggest:

BOX 6 - Ceredigion County Council wood chip boiler

Ceredigion County Council at Penmorfa, Aberaeron has installed a 550 kw wood chip boiler to heat a complex comprising offices, a school, an elderly person's home and sheltered housing. The three buildings have a total floor area of 6,608 m^2 with heat demand of about 1,250 MWh annually to provide heating and hot water. The total project cost for the purpose-built boiler house, fuel store and biomass heating system was £585,000, partly funded by a WEBS grant of £212,000. The system is fuelled by 285 t of seasoned, locally supplied wood chips at approximately £75/t. Estimates of annual savings against oil are £36,000-48,000 providing a payback after grant of between 14-26 years and an annual carbon saving of 373 t of CO_2e.

The savings

Previous heat source	Electric and oil
Previous annual fuel consumption and cost	1.2 MWh from oil would be: £36,000 @ 30p/l, or £48,000 @ 40p/l
Woodfuel costs	£21,375
Annual saving over oil	approx £14,625 @ 30p/l approx £26,625 @ 40p/l
Payback (over oil use) in crude terms on capital cost of £595,000 (less £212,000 grant) leaving £383,000	26 years @ 30p/l 14 years @ 40p/l

- a significant micro-hydro power potential of at least 0.3 TWh of electricity in upland Wales.
- this report has not sought to quantify community or personal wind energy but this could amount to 1 TWh electricity (internal WAG assessment). This could be based on installing about 400MW of wind turbines. For example this could be achieved by each of the *c*20,000 farm holdings in Wales installing 20kW of turbines. The solar heat potential on individual homes is substantial but not quantifiable.
- biomass, such a short rotation coppice willow, on the land above 300 m or miscanthus at lower altitudes could generate about 2-3 TWh as heat or 1/3 of this as electricity.
- 250,000 dairy cattle at 36 kWh/day themselves generate 330 GWh of heat which could be used in horticultural greenhouse enterprises *etc.*
- in relation to PVs, some locations could produce a viable economic return on the basis of their incident irradiance and the recently published rates for FIT. These could be equally in towns and in rural areas.

Compared with the total problem the potential contribution of our small-scale rural micro renewables is relatively small – maybe about 3 TWh per year of electricity and a similar amount as heat. In terms of emissions savings this would total about 1,500-2,000 kt CO_2e.

However the argument for government support has other facets. The energy efficiency/saving potential in households is about a third i.e. in Welsh terms perhaps around 9 TWh annually out of 27 TWh. A major question is: not just how much energy would micro-generation produce, but also what would be its potential impact on energy efficiency behaviour change?

There would be some 20,000+ generators conscious of their personal investment with a desire to maximise their returns and behave accordingly. This may impact directly on 20,000 families but would be a spur to their friends and neighbours and engage a large percentage of Wales' population. Community based schemes could be even more effective. It could therefore have an "energy saving multiplier" - particularly given the close nature of Welsh society. This would be equivalent to 4-5 TWh. Therefore, one possibility is that an investment in connectivity *etc* to produce 3 TWh of electricity and perhaps 3 TWh of heat, could actually leverage as much as a further 4-5 TWh of energy saving - equivalent to a major power station.

A further multiplier can be expected when EVs come on the market as it will be very financially advantageous to run cars on cheap home generated electricity instead of petrol/diesel, which is likely to become more expensive. Currently Wales' energy consumption for all transport is about 28 TWh, and cars, light goods vehicles and motor bikes emit around 70% of total transport emissions in Wales. Significant emission savings would occur if the personal electricity generation was sufficient for domestic use and personal transport. A 10% uptake for cars, light goods vehicles and motor bikes would save about 500 kt CO_2e in annual emissions. Some of these points apply equally in towns and in the countryside and may be more applicable to influencing behaviour in the major population centres.

However, as noted above, the major renewable resources e.g. hydro, biomass, bio-gas and even wind are located in rural areas. Hence the LUCCG considers that there is a strong case for government to invest to overcome the DNO connectivity constraints, which are greater in areas of low energy density than in towns. A second set of arguments revolve around strengthening the economy of rural Wales, diversifying and increasing Wales' resilience against global shocks *etc*. These are considered in the next chapter.

DECC has recently announced the new range of FITs for renewable electricity and heat.

Table 9.2 - Range of tariff levels for electricity financial incentives (pence/kWh)[67]

	Power Ratings of installations	Year 1: 1.04.10-31.03.11	Year 2: 1.04.11-31.02.12	Year 3: 1.04.12-31.03.12	Tariff Lifetime (years)
AD	≤500 kW - >500 kW	9.0 - 11.5	9.0 - 11.5	9.0 - 11.5	20
Hydro	≤15 kW – 5 MW	4.5 - 19.9	4.5 - 19.9	4.5 - 19.9	20
Micro CHP pilot*	≤2 kW*	10*	10*	10*	10*
PV	≤4 kW – 5 MW	29.3 - 41.3	29.3 - 41.3	26.8 - 37.8	25
Wind	≤1.5 kW – 5 MW	4.5 - 34.5	4.5 - 34.5	4.5 - 32.6	20
Existing microgenerators transferred from the RO		9.0	9.0	9.0	to 2027
Tariffs are set for different power ratings, defined by DECC					

* **Note:** this tariff is available only for 30,000 micro CHP installations. A review will take place when 12,000 units have been installed.

Table 9.3 - Range of tariff levels for renewable heat incentives (pence/kWh)

Technology	Scale	Tariffs	Tariff lifetime (years)
Solid biomass	0 kW – 500 kW and above	1.6 - 9.0	15
Biodiesel	up to 45 kW	6.5	15
Biogas on-site combustion	0 - 200 kW	5.5	10
Ground source heat pumps	0 kW - 350 kW and above	1.5 - 7.0	20 - 23
Air source heat pumps	0 - 350kW	2.0 - 7.5	18 - 20
Solar thermal	0 - 100kW	17 - 18	20
Biomethane injection	All scales	4	15
Tariffs are set for small, medium and large installations defined by DECC			

[67] http://www.decc.gov.uk/en/contents/cms/news/pn10_010/pn10_010.aspx

10. Scenarios for emissions reduction

10.1 Introduction

In the immediate future the modest gains, outlined in chapters 6 and 7, from efficiency gains in the animal sectors (CH_4 emissions) and in N use (N_2O emissions) must be achieved. But these do not offer an adequate response if agricultural land use and food production are to play their part in reducing emissions and meeting the objective, reaffirmed at Copenhagen, of not allowing the mean global temperature to rise more than 2^0C compared with pre-industrial levels. Nor do such modest gains meet the clear policy commitments and ambitions of Welsh Assembly Government, UK Government, and the European Union.

Many sectors argue for entitlement to special treatment in relation to GHG emissions. In the case of food production, the drive for emissions reduction must be placed in the context of the continuing growth in the global population, increasing demand in developing countries for greater contribution to their diet from animal products, increasing use of land for energy crops, and direct climate change impacts on food production including trends in current water use. These all point to pressures to raise the production and productivity of farming systems, locally and internationally, in order to meet the projected demands and avoid shortages. From both an international as well as Welsh perspective the need is to meet these challenges and make major GHG emission cuts.

This section outlines and assesses five possible scenarios for a Wales land use strategy and their potential to meet the above challenge.

In comparing the possible scenarios, it is important to recall that Wales' current annual net CO_2e emissions in the whole land use and food chain sector are estimated at about 5,200 kt (5,400 kt from agriculture and a sink of 200 kt from land use). An additional *c*3,000 kt comes from emissions linked to energy use in the transport (food distribution *etc*), electricity generation (food preparation, storage *etc*) and manufacturing (agro-chemicals/fertiliser production) sectors.

These emissions are partly in Wales and appear in the Inventory, but others are apportioned to other countries. Nonetheless, as climate change is a global issue, responsibility lies with the user as well as the producer.

10.2 Possible scenarios

The five scenarios cover the range of possibilities. They are not necessarily mutually exclusive but represent different visions of how the problem could be approached. However each share some attributes and depend on interventions in other sectors. The agricultural and food economy and its GHG emissions would benefit from increased availability of low carbon electricity and from a new generation of low carbon vehicles being developed by major motor manufactures. Secondly all individuals, communities, companies and agencies must work to minimise waste and inefficiency; be it food waste or loss of heat or electricity. These generic issues are considered in the next chapter. In all cases a priority must be to minimise the loss of upland peat cover as its erosion/oxidation could negate all attempts to reduce Wales' GHG footprint.

All scenarios are predicated on the adoption of the efficiency interventions outlined in chapters 6, 7 and 8, which will make an immediate but modest contribution to GHG reductions. It should be noted that scenario 1 and, to an extent, scenario 2 differ from the other three. The first one involves an additional response based on current and emerging knowledge but it would be likely to require the sector to plead that it is indeed a "special case". The second scenario would incorporate the first while awaiting agreed international interventions in the marketplace. The last three involve clearly targeted policies but, of course, could also comprise actions and interventions within the first two scenarios.

The five scenarios can be characterised as:

<u>Incremental Improvement (Scenario 1)</u>

This scenario is a continuation of recommendations for immediate action as outlined in chapters 5-8 (i.e. incremental reduction of emissions based on improvements of livestock management and manure/fertiliser management). It is a modified "business as usual" scenario with the encouragement of "low carbon" innovations, delivered by a variety of advice and funding mechanisms. As noted, these are also relevant to the other scenarios. However in this scenario the argument would need to be put and widely accepted that agriculture/land use and human food production is, indeed, a special case as it would become the major source of Wales' GHG emissions when 80-90% cuts in overall emissions have been achieved in other sectors.

<u>Market Driven Scenario (Scenario 2)</u>

This is based on changes being driven by a free market in goods and services including food. The level and type of food production would be determined by the market and by the possible introduction of an international carbon-trading market or carbon taxes applied to the agriculture and LULUCF sectors as well as by consumer demand or by climate change itself.

<u>Low Animal - Low Emissions (Scenario 3)</u>

This envisages a radical reduction of ruminant animal-based systems, with consequential huge cuts in farm animal numbers. It would be accompanied by a switch from animal products to neo-vegan or vegetarian diets by most people and their companion animals; although some white meat eating could continue. Dairy products would have to be replaced by plant-based substitutes.

<u>Lower Production – Lower emissions (Scenario 4)</u>

This envisages a major move to improve resource efficiency through the food chain, balancing low intensity mixed agricultural systems with decreased demand through reduction of waste and a healthy diet based on reduced intake of animal products. Animal numbers would decline on the lower more intensively farmed areas but there would not necessarily be a major thrust toward a vegan or vegetarian diet.

Optimum Services - Minimum Emissions (Scenario 5)

This is a more interventionist scenario with a collective agreement in Wales to use a combination of methods to optimise production of food and other eco-system services compatible with minimising net GHG emissions. This would be delivered by a combination of market, advisory and support mechanisms.

These scenarios were assessed by the Group against a number of criteria:

- their potential for timely delivery of the large cuts required to meet Wales' reduction targets. These are:
  - by 2050 at least an 80% cut equivalent to reaching total net annual sectoral emissions of about 1,650 kt CO_2e from the whole food system, or 1,040 kt CO_2e from those emissions reported in Agriculture and LULUCF Inventories
  - at least an annual 3% decrement in emissions from the baseline of Wales' average total emissions in 2006-2010. In addition there was an aspiration in “Sustainable Farming and Environment: Action towards 2020” report to achieve a “carbon-neutral” rural Wales by 2020.
- their potential to deliver the emissions reductions recorded by the IPCC Inventory.
- their capacity to help deliver the renewable energy targets.
- their capacity to deliver enhanced economic, cultural, social and environmental sustainability.
- their ability to protect and maintain the whole range of eco-system services.
- their economic and political feasibility.
- their acceptability to the rural community, especially land owners and managers believing their cooperation to be essential to successful policy implementation.
- their ability to increase resilience in relation to food security and climate change impacts as forecast by the mid 21st century.
- their capacity to make a positive contribution to global food and energy availability and limit our imports of embedded GHGs.
- their capacity to utilize Wales' comparative advantage of ample rainfall and long growing season.

The Group analysed the scenarios by criteria and formed the following conclusions:

- Scenario 1 was considered to be a logical first step that should be implemented, but it would not achieve the reductions required to meet targets

- It was difficult to evaluate Scenario 2 due to inadequate information on future price of carbon which would act as an economic driver for emissions reduction
- Scenario 3 was not considered to be practical, given the dependence of Welsh agriculture on pastural systems, the comparative climate change advantages of Wales for food production, the social and economic barriers and the likelihood of displacing emissions to imported food.
- Scenario 4 contained some elements that should be assessed in terms of feasibility and incorporated into scenario 5.
- Scenario 5 (plus some features of other scenarios) was viewed as being the optimum way forward to achieve the required direction of travel for target GHG emission reduction. The Group recognised the major challenges associated with technological innovation and investment required for this scenario.

10.3 Detail of the scenarios

10.3.1 Incremental improvement (Scenario 1)

A continuation of current policies is envisaged with a major effort by Rural Development Plan mechanisms such as Farming Connect and Glastir, combined with support from the Farming Unions, to encourage good practice (e.g. better controlled and timed N application rates, better animal husbandry as described in Chapter 6). Animal numbers would be defined by market demand, the new post-2013 Common Agricultural Policy and the value of the £/euro exchange rate. Annual tree planting of about 750 ha/year by the FC would continue, and be increased to some extent. As technological innovations come on stream from agricultural or other research, their adoption would be encouraged. For example, over time lower CH_4 -emitting animals may be bred, and grazed on lower emission pasture species. Some farms would adopt AD for commercial or water pollution control reasons.

On the basis of the expert evidence presented to LUCCG[68] the overall decline in agricultural emissions might be of the order of 15-20% by 2025. In the longer term other reductions might occur from:

- animals with genetically modified rumen flora in which CH_4 production is disengaged from other rumen functions, and/or
- modification of / inoculation against rumen functions, and/or
- special diets, feeds or supplements.
- technologies to decrease N_2O emissions from pasture.

Farms individually would take advantage of micro-generated electricity FITs and of vehicles powered by electricity and/or CBG; but additional support from the Welsh Assembly Government would be limited.

[68] The Frank Arden Lecture 2008 – Options for Greenhouse Gas mitigation in UK farming – Chris Pollock

Other eco-system services would be managed as planned within Glastir.

In this scenario it is unlikely that net cuts of greater than 50% can be achieved by 2030-40. Consequently, if other policy and technical interventions focused on renewable energy and low CO_2 technologies are successful, the LULUCF emissions will become an increasing percentage of Wales' total emissions. At present these emissions contribute 11% (as narrowly defined) and about 18-20% (as broadly considered) to Wales' total. But the 11% is a significantly larger proportion of the *c*50% of Wales' emissions over which the Welsh Assembly Government has direct influence/authority. CH_4 and N_2O might become some 50% of Wales' residual emissions by 2040-50.The inertia and lags implicit in this scenario also make it difficult to see how the Welsh Assembly Government policy objectives on emission reduction can be met, unless other sectors achieve even greater than 3% reduction rates.

The implications of this scenario would be:

- farm incomes and output would be determined by the next CAP reform.
- the system would be highly sensitive to changes in oil prices and possible international shortages.
- marketing and branding would be dependent on local initiatives.
- pastural farming could come under increasing pressure from an "anti-red meat lobby" which might argue that emission reductions must come from greatly reducing meat consumption. Meat consumption may arrive at a situation not unlike tobacco smoking or fox hunting.
- farmers would feel free to maximise their economic returns which could, in turn, lead to great ruminant animal numbers and more GHG emissions.
- the Welsh dependence on the international market would be increased with possibly initially cheap food but a greater sensitivity to global disturbances and price fluctuations (e.g. external changes in costs of fertiliser and imported concentrates or food availability).
- it is likely to be accompanied by farm amalgamation and a continuation in the slow changes in the social and economic fabric of rural Wales.
- there would likely be little incentive to diversify Welsh agricultural production systems.
- Welsh Assembly Government GHG targets would not be met; farming would come under increasing pressure as the sector could be viewed as responsible for contributing to the failure of Welsh Assembly Government policy.

10.3.2 Market driven (Scenario 2)

In the case of Welsh agriculture the basic rationale for this scenario would be a desire to minimise regulations and red tape and to exploit what could be perceived to be new opportunities arising from the combination of a relatively benign climate change scenario for Wales and much worse scenarios for Mediterranean Europe and other global food producers. Possible changes in Gulf Stream flows, in sea level, water and energy supplies, resulting in "global perfect storms" *etc* are largely discounted.

This scenario is predicated on the hypothesis that market-based systems with an attendant carbon tax are the most efficient and least distorting. It would assume the withdrawal of or decline in EU agricultural subsidies and support mechanisms, possibly as the farm support system focuses more on Eastern Europe. It would be compatible with international or European agreements on “cap and trade” carbon trading. These could be extended to all GHG gases, which would then have a tradeable “carbon off-set” value. In this scenario the farming system would be responsive to the international commodity markets. Farm amalgamation would most likely accelerate and any decrease in GHG emissions would arise either from fulfilling niche green markets for low GHG goods i.e. consumer choice or from carbon trading (e.g. major companies might seek to buy to areas in Wales for tree planting to offset their industrial emissions).

The implications of this scenario would be:

- in some ways this could be seen as a more extreme version of Scenario 1 and many of the features apply.
- while, over decades, it might lead to major reductions in GHG emission, the timing of such changes cannot be predicted.
- some protective measures would have to be established to protect the upland peats and bogs, possibly by strengthening of the EU Habitats Directive.

10.3.3 Low animal -low emissions (Scenario 3)

In recent months a number of organisations or individuals have argued that the climate change outlook is so serious, especially the need to limit the global mean increase of temperature to less than 2^0C, that a drastic and rapid decrease in domestic ruminants is required to reduce the significant emissions of CH_4 (e.g. Sustainable Development Commission Report on Sustainable Healthy Diets[69]). These single out red meat and dairy products as being both environmentally damaging and unhealthy components of human diet.

Up to a 70% cut in animal numbers (mainly sheep, cattle) is advocated in some cases. It is argued widely that public health would benefit from a major decline in the consumption of red meat and dairy products. In the event of a large decrease in ruminants, the public diet would have to change drastically, perhaps characterised as a move to a near-vegan diet but with some white meat (pig and poultry) and fish - despite stock issues. There may be only a limited scope for a conventional vegetarian diet as milk, cheese, butter and yoghurt would also be drastically cut (in chapter 6 of this report the interdependence of the dairy and beef sectors is outlined). This would improve human health in the developed countries currently suffering from a high incidence of heart disease, diabetes and obesity. Internationally a large cut in feed-lot, grain-fed ruminant numbers would release grain and other potential food supplies to the poorer developing world as a large proportion of

[69] Sustainable Development Commission – Setting the Table. December 2009

grain is used as animal feed at low conversion rate. This analysis would not apply to grass-fed, pastural or extensive systems world-wide or indeed in Wales.

The direct impact of a 70% cut in cattle and sheep numbers would be a decrease in emissions of about 2,000 kt CO_2e/year i.e. a major cut in CH_4 and N_2O emissions from the animals and their manure as proposed in work by the Tyndall Centre on options to make 6 or 9% annual reductions in emission. Its effect on N_2O emissions from agronomy and crop production is difficult to assess as a decline in fodder production might be offset by an increased requirement for local grains, vegetables, fruits and nuts, vegetable-derived milk and other dairy product substitutes, and probably white meat - poultry and pigs. These latter animals require a non-ruminant diet, which overlaps and competes more with the human diet than do pastural ruminants, but have higher feed conversion ratios. It is reasonable to assume that in the event of this policy being adopted, the country would ban meat imports as the substitution of Welsh/UK products with imports does nothing to curb global emissions and would be a deceit. It would be important to take account of the GHG emissions related to land use change for growing imported vegetarian foods such as soya, palm oil, nuts *etc*.

A cut of 2000 kt CO_2e per year represents a cut of 38% of the agricultural/land use sector and about 24% of the whole sector taking an integrated approach covering all inputs.

The implications of this scenario would be:

- internationally, extensive rural depopulation/social disruption would ensue as the inhabitants of large expanses of this planet have been for thousands of years and remain dependent, wholly or partly, on pastural systems i.e. most mountainous and arid/semi-arid regions. Perhaps a billion people displaced into over-crowded towns.
- it is not apparent how such a policy could be applied only in Wales or, indeed, the UK.
- it is not clear how such a policy could be enacted with Wales/UK remaining within the European Union.
- the population would need to accept the dietary restrictions that would require a system similar to wartime rationing. But if this were to materialise, government would have to impose red meat and dairy product import bans as it would be unacceptable to use other countries' carbon footprints to support our consumption i.e. it would be unacceptable to displace emissions from the UK to other countries.
- it is not clear how in a land-owning, free democratic society, such a policy could be imposed.
- it is highly questionable if such a scenario is compatible with the principles of sustainability as it would cause grave damage to the economic and social life and culture as well as having potentially damaging biodiversity consequences.

- aspects of human nutrition in the UK could be improved by a drastic cut in dairy and red meat consumption but it must also be recognised that a vegan diet and/or diets without dairy products offer serious challenges in relation to calcium, iron and micro-nutrient availability.
- some grazing animals would be required to avoid loss of habitat management for biodiversity.
- the release of grazing land would allow a huge increase in forestry which would create a major carbon sink (above and below ground) and provide Wales with a major off-set potential, probably beyond 2050 as this scenario would favour natural regeneration.
- the food production potential from grasslands and a range of agricultural wastes would be lost in a time of predicted food shortages. This report seeks to differentiate sharply between the ability of animals to convert herbage, and wastes into usable products and the practice of feeding grains, which otherwise could be used directly by humans, to animals.
- currently less than 10% of Wales' food is home produced (only in relation to fresh milk is the Welsh home market important) and 95% of Welsh lamb exported. The latter trade would decline and the former would need to increase unless dependence on food imports is to increase.
- the scenario fails to address the critical issue of N_2O emissions and would likely increase dependence on inorganic N fertilisation. There would be loss of animal organic matter as a fertiliser and energy source.
- in all likelihood this scenario is compatible with increased renewable electricity/energy production (except from bio-gas) and could lead to a near carbon/GHG neutral rural Wales in perhaps 30-40 years but at a very high social and economic cost.
- this scenario would create social unrest and political alienation in Wales. In all probability it would distract from, and delay the, effective measures at government and individual levels to combat climate change.
- in the longer term the impact is ambiguous. The “wilding” of marginal land will generate additional “unmanaged” biomass. Undoubtedly the large unused biomass accumulation would attract feral animals - goats, horses and deer. Thus over time, unless regularly and severely culled, animal numbers, including a high proportion of ruminants (deer and goats), would rise and partly reverse the decline in GHG emissions.

10.3.4 Lower production - lower emissions (Scenario 4)

This scenario is intermediate between Scenarios 3 and 5, with the emphasis on maximising resource productivity. It would be based on an extensive mixed farming system based on maximising resource efficiency from on-farm production of feedstuffs, and reduction of inputs of fertilizer. This reduction of inputs would be balanced by reduced demand for animal products through a reduction in consumption of animal products, and reduction of waste in the food chain. Such systems are often associated with greatly-enhanced local food chains, greater self reliance, and increased environmental and social sustainability over time.

The main aspects of the scenario would be:

- reduction of inputs and associated emissions from fertilisers, imported feedstuffs and oil-based products.
- adoption of mixed farming based on cereals, maize silage, legumes to reduce imported feedstuffs, with possible greater use of cereals and and protein from other parts of UK that grow fruit/vegetables.
- increased local food production - by on-farm fruit/vegetable growing, expanded horticulture sector and allotments.
- greater vulnerability to losses from pests, weeds and diseases, and hence lower technical efficiency.
- increased kill-out percentage of animals by using more of the animal.
- reduction of consumption of animal products, with potential for a more healthy diet where backed by public health campaigns.
- reduction of overall food demand by public health campaigns, which would have the benefit of reducing obesity and other diseases; a centralist approach would be to adopt the wartime rationing system.
- reduction of food waste by food processors, distributors and retailers.
- reduction of post-consumer waste by better education on purchasing of food.

The implications of this scenario would be:

- yields would be reduced per ha. Biological N fixation (primarily by *Rhizobium* species) and recycling through green manures, composts and animal manure represent important ways in which reliance on synthetic N can be reduced and N losses to water and non-agricultural ecosystems minimised. However, the off-take of N in crops for human consumption, limited recycling of human waste to agriculture and leaching to water mean that substantial inputs of N derived from chemically synthesised ammonia or urea are essential to the maintenance of current yields.
- yields may also be reduced in situations where available phosphate levels are low. It is possible to recycle phosphorus by treating animal bones with sulphuric acid. However, loss to water and adsorption in soil mean that the supply of phosphorus in agricultural systems needs to be continuously replenished; mined rock phosphate represents the only substantial supply.
- production levels of the major Welsh products – red meat and dairy products - would reduce, and there would be less international/UK trade of these commodities.
- there would be pressure to maintain current production levels but this would imply an expansion in production areas. This could in turn have negative impacts for biodiversity and on CO2e emissions from the conversion of grassland to arable as well as other environmental assets.
- livestock numbers would reduce because of less intensive systems and the need for more arable land for feed crops.

- maintenance of farm incomes would require a premium on the products, greater government support and/or diversification of farm businesses.
- food waste reduction amounting to 25% of purchased food production, which would reduce waste to landfills.
- reduction of obesity would be a major health benefit but there would be no way to avoid imports of food from other parts of the UK or abroad. Success would depend critically on successful public health campaigns.
- Wales would be in a poorer position to respond to the drivers of chronic food insecurity – increasing population, increasing per capita incomes leading to growing demand for livestock products (meat and dairy), increasing water and land scarcity, and adverse impacts of climate change in major global food producing areas. Food insecurity leads to greater fluctuation in food prices, and greater global insecurity.
- food insecurity is also driven by the slowing international increases in agricultural productivity that would be reinforced by a switch to this scenario in Wales.

10.3.5 Optimum services - minimum emissions (Scenario 5)

This scenario is more interventionist and is based on the concept of a co-ordinated effort to minimise emissions while maintaining both animal and dairy production. It would also generate a number of other ecosystem goods and services and should increase the economic resilience of rural communities. Potential win-win options are identified, and reasonable economic returns on private or community/public investments may be achievable. While this scenario is framed to meet the climate change obligations of the Welsh and UK Governments, it contains a set of viable rural development proposals to help maintain the rural economy in the face of probable increases in energy costs and an uncertain food supply, whilst creating extra resources for a range of industries including tourism and forest products. This scenario is explored in greater detail as:

- it offers net cuts compatible with Welsh Assembly Government and international policy objectives and, potentially, a net zero-GHG rural Wales by about 2040 when GHG sinks from woodland maximise. Also, it is only attainable with the renewables offsetting other GHG emissions.
- it appears consistent with the sustainable development principles of the Government of Wales Act.
- it could provide great social and economic resilience.

It would be based on five pillars and a dual strategy for a more intensively-farmed lowland and an extensive hill/upland system retaining many of the current characteristics:

- minimising GHG emissions from the dairy and associated beef sector by the rapid introduction of AD followed by a move to a housed, zero grazing system, which in time would include CH_4 scrubbing to both avoid emissions and capture the energy potential of animal CH_4; the latter development is predicated on the required research and pilots being carried out and showing the system to be sustainable and that animal welfare is protected. Techniques for CH_4 capture have been developed for both landfill and coal mining and could be applied to agriculture.[70]

- a major increase in woodland cover - almost exclusively on upland acid grassland and bracken land with no planting allowed on the peats - to generate a significant long term carbon sink above and below ground.
- this carbon sink would off-set extensive, high quality beef and sheep production with the total flock and herd size established by the above GHG off-set potential and critically by the efficiency of the husbandry.
- a major effort to maximise the micro- and meso-renewable electricity and heat potential of farming, forestry and rural communities through Wales so that the whole food chain can become as GHG neutral as possible. Micro-generation would also be seen as potentially producing economic returns to landowners, farmers and communities.

In addition to these major pillars the scenario would seek greater product diversification, secure other ecosystem services and improved local and seasonal food supply chains and outlets.

This scenario contains two potentially contentious proposals:

- emissions from the total extensive breeding ewe flock and cattle herd i.e. in addition to pillar 1, would have to be contained to prevent additional GHG emissions.
- in pillar 1 the dairy herd and its beef dependants would evolve into a zero-grazed, housed herd so that all CH_4 emissions could be trapped and if possible, used.

However overall animal production would remain constant and could potentially increase if, *provably and transparently*, other GHG emissions (e.g. N_2O) from the sector can be demonstrated to be curtailed within the terms of the Inventory and/or equally unambiguous evidence emerges of lower CH_4 emitting animals. Farm incomes could either remain steady, or increase with the additional rural outputs that are identified.

It must be emphasised that a major recommendation of this report is that in relation to the second bullet point above the necessary research and pilot schemes be established without delay and international best practice interrogated to inform Welsh farmers.

Agricultural change is often presented as a choice between unsustainable intensification of agriculture and extensive systems with fewer negative impacts. It is relevant to note that the Royal Society report "Reaping the benefits: science and the sustainable intensification of global agriculture" concludes that "*we must aim for sustainable intensification - the production of more food on a sustainable basis with minimal use of additional land. Here,*

[70] Absorption 11 527-59 2005 C Voss

we define intensive agriculture as being knowledge-, technology-, natural capital- and land-intensive. The intensity of use of non-renewable inputs must in the long term decrease. This is particularly true for nitrogenous fertilisers that will in future need to be manufactured using renewable sources of energy and hydrogen. Finding ways of reducing the processes of denitrification will also impact positively on GHG emissions and the sustainability of agricultural systems (regardless of the source of nitrogen inputs). However, the task of increasing food availability through production on a constant area of land with reduced inputs is such an enormous challenge that no useful approach or technology can be ignored". The key question is whether Wales can go along one route or, from a risk management viewpoint, should use several approaches.

The major pillars of the scenario would be delivered by the following initiatives (estimated emission reductions from the interventions are summarised in Table 10.1):

Intensive dairy / beef

- the rapid introduction of AD to reduce CH_4 emissions from manure and food waste. Renewable energy from this source would then be used as Biogas and/or electricity to power machinery and vehicles (some electricity for net export and Biogas for local use).
- development of zero grazed, housed dairy systems with gas exchange to scrub CH_4 and eliminate enteric CH_4 from the Welsh milk herd and about 50% of beef production. Excess energy and heat either exported, or the latter (especially) used in associated horticulture enterprises with residual fertiliser re-used for grass or vegetable growing.
- use of local fodder with little or no recourse to imported concentrates. Climate change scenarios for Wales would favour more maize growing on the better land.

Secondary benefits include:

- reduced risk of watercourse contamination from slurry and manures.
- creates the potential for associated horticultural enterprises using the residual heat which, in turn, should decrease the "carbon footprint" in the Welsh diet.
- reduced reliance on artificial fertiliser through better utilisation of farm manures.
- some evidence that digestate/sludge releases lower levels of N_2O when applied to cropland as fertiliser.
- may reduce possible TB transfer from badgers to the herd.

The issues involved are:

Significant development of housing systems will be required to provide controlled atmospheres and effective CH_4 capture technology. Although common in some European countries, zero-grazed, housed systems are very unusual in Wales. Such a system will raise animal health and welfare issues and stringent criteria will be required to overcome such concerns.

Policy instruments that can be used to deliver this part of the Scenario include:

- Glastir.
- EU CAP reform post 2013.
- FITs for renewables.
- loans on reasonable terms.
- co-ordinated push by Welsh Assembly Government and the farmers' organisations working in collaboration.
- joint AD initiative with the food sector.

Major afforestation

A mixed programme of planting and natural regeneration with mainly adapted native deciduous species but with some conifers, based on a soil type and topography to maximise hydrological benefits and improve biodiversity connectivity, whilst minimising agricultural impacts and effects on landscape/tourist values – see Chapter 7. Such woodland would offer a number of additional eco-system services (e.g. bio-fuel, timber for building and manufacture). The species and areas planted must be selected taking into account the future median climate scenario for Wales from 2050-2100.

- afforestation on the poorer grades (3, 4, 5) of land on organo-mineral and mineral soils but not organic peat soils.
- expand area of sustainable forestry from 286,000 ha to about 380,000 ha by about 5,000 ha/year for 20 years to achieve a GHG sink of 1,500-2,000 kt CO_2e/year after 30 years.
- farmers would be encouraged to make plantings on their own land (e.g. given some 20,000 active holdings, 100,000 ha equate to 5 ha per holding in the next 20 years).
- the area of unimproved acid grassland and rough pasture in Wales exceeds 1 million ha of which some 100,000 ha - i.e. a little less than 10% - could be afforested over 20years.

Associated with this policy would be greatly improved management of current forest holdings to maximise their GHG sink capacity. Currently FC Wales has a holding of some 218,000 ha with a further 68,000 ha of farm woodlands. Of the FC holding some 111,000 ha were planted pre-1920 and are assumed to be GHG neutral in the current Inventory. Some will be protected ancient woodlands - often Sites of Special Scientific Interest - but other holdings may well benefit from improved management to convert them into sinks recognised within the Inventory as well as to provide timber for building material or fuel.

As carbon sequestration by tree growth and in soils is initially slow and planting can release some soil carbon, it will take time - perhaps 15 years - for the off-set value to develop. Consequently it is vital that the additional planting should commence as soon as possible.

On-farm biomass crops should be based on farm woodlands and if appropriate some biomass crops - short-term willow coppice in LFA and miscanthus on lower land. Willow coppice in LFA would appear the better option and 50,000 ha would make a major contribution to emission savings.

The issues involved are:

- identification of land.
- owners costs for planting and maintenance
- labour - should Welsh Assembly Government involve youth movements (e.g. Urdd, Youth Clubs, Groundwork, Young Farmers Clubs) in a "national planting campaign"?

<u>On-farm productivity improvements</u>

This pillar of the scenario envisages the retention of an extensive sheep and beef sector on the "middle land" - mainly grades 3 and 4 - whose emissions would be reduced by major efforts to improve productivity (see chapter 6). The remaining emission would be off-set by the increased carbon sink created by the expanded forest sector. In relation to the sheep flock, major improvements (recorded in the Inventory) could be achieved by increasing lambing percentage but maintaining a constant productivity. Further increases in efficiency would arise from increasing average ewe life from about 4 to 5 years, so reducing replacement rates.

On this basis a national ewe flock of 3.43 million could achieve the current production of ~82,000 t of lamb meat and achieve a decrease in GHG emissions of 235 kt CO_2e. Clearly such a scenario would have major marketing and branding possibilities as once the forest off-set is established, Welsh products could be promoted as zero- or low-carbon meat from a clearly GHG neutral system, certified by the IPPC Inventory.

Within the Inventory for cattle a series of potential efficiency gains are possible and are listed in chapter 6. As previously noted these can be applied in all five scenarios.

The issues involved are:

- increased arable production to provide a greater proportion of cattle/sheep feedstuffs from home-grown crops – may increase Wales emissions in the short term, but may still reduce overall livestock system emissions when emissions associated with imported feeds are considered.
- it is recognised that some additional concentrate may be required to complement a higher lambing percentage - this should not come with high embedded carbon from imports.
- with this scenario an organic sector can readily co-exist and flourish although the LUCCG has not received compelling evidence that organic meat production, not withstanding its other potential advantages, has a lower GHG footprint.
- the LUCCG is aware of claims that grassland soil organic matter can be built up in certain grazed system. It should be a priority to undertake definitive research to assess the total net GHG balance in such systems to assess the potential utility. If it is possible to substantiate such claims it would clearly increase the strategic choices available to farmers and to the Welsh Assembly Government.

Exploitation of micro-generation potential of rural Wales

This pillar is relevant to all scenarios and is based on the range of resources available. These are location specific. Community and/or individual farm schemes could exploit wind, PV, solar heat, micro-hydro, bio-gas, fuel wood, and possibly some dedicated biomass.

The main impact would be as an "off-set" for farming and land use emissions. The extent of the offset will depend on the scale of generation, the emission factor used for current UK electricity generation and the LCA for each technology. UKCCC sees the emission factor diminishing over the next 20-30 years as low carbon generation is introduced. Secondary benefits include:

- increased supply of renewable, low carbon, energy which will help with reducing the food preparation carbon footprint (e.g. see potato data – chapter 8).
- potential to reduce carbon footprint of transport. EVs and Plug-in-hybrid EV are anticipated to become common in 5 years. The ability to, at least partly, power such vehicles from a home generated supply is economically attractive as well being a means of off-setting fossil fuels.
- costs of technology for electricity generation and storage systems/devices.
- costs of achieving connectivity to grid, particularly in rural areas with weak grid networks.
- security of global supplies of metals for batteries.

Research and development requirements include:

- research on low cost PV installation including photo-reactive steel cladding.
- infrastructure networks to enable uptake of EV vehicles.

Issues / policy instruments:

- Wales' DNOs to ensure grid accessibility.
- access to UK feed- in-tariffs.
- availability of qualified installers.
- removal of planning constraints except in very special circumstances.
- efficient regulation system (e.g. water abstraction for hydro-power, waste regulation for AD).

The fifth pillar is considered separately in Chapter 11.

10.4 Economic evaluation

The financial implications of these scenarios, especially Scenario 5, require detailed analysis as do the potential support systems (e.g. Glastir). In this context the 2013 EU CAP reform package is obviously highly significant. The LUCCG strongly recommend that either the Group, supplemented by agricultural and resource economists, address these issues urgently or that another working group is established. The new DECC micro-generation feed-in-tariffs will be critical factors in achieving success.

10.5 Overall scenario deliverables

Progress to long-term GHG neutrality should become possible through a mixed land management system combined with intensive, zero-grazed, housed, animal production (possibly mixed milk/beef breeds to maximise useful product per animal - although it is difficult to get evidence for this) for milk, cheese, yoghurt, butter and some meat. This would also involve increased arable/horticultural production on the best land (Grades1, 2 and possibly some 3a) - perhaps up to a total 200,000 ha - and an extensive but efficient mixed sheep and beef animal regime on less fertile land - *c*800,000-900,000 ha - to provide a number of ecosystem services (e.g. habitat management for biodiversity, food, landscape, tourism) supported if possible by animals bred and fed to minimise CH_4 emissions. The upland blanket peats and organic soils would be managed to maximise carbon retention (e.g. through low intensity summer grazing). The very small area of lowland peat would be conserved with no crop production to minimise peat oxidation. Importantly efficient N management would need to be achieved to significantly decrease N_2O emissions, which remain a significant research problem. Conversion of agricultural land to urban development would be minimal. Rural renewable energy generation would be maximised and used both internally and exported into the national grid.

Fig 5 shows the existing and projected future land use in Wales by 2030 on the basis of Scenario 5.

Fig 4 - Existing and projected future land use in Wales by 2030 on the basis of Scenario 5 ('000 ha)

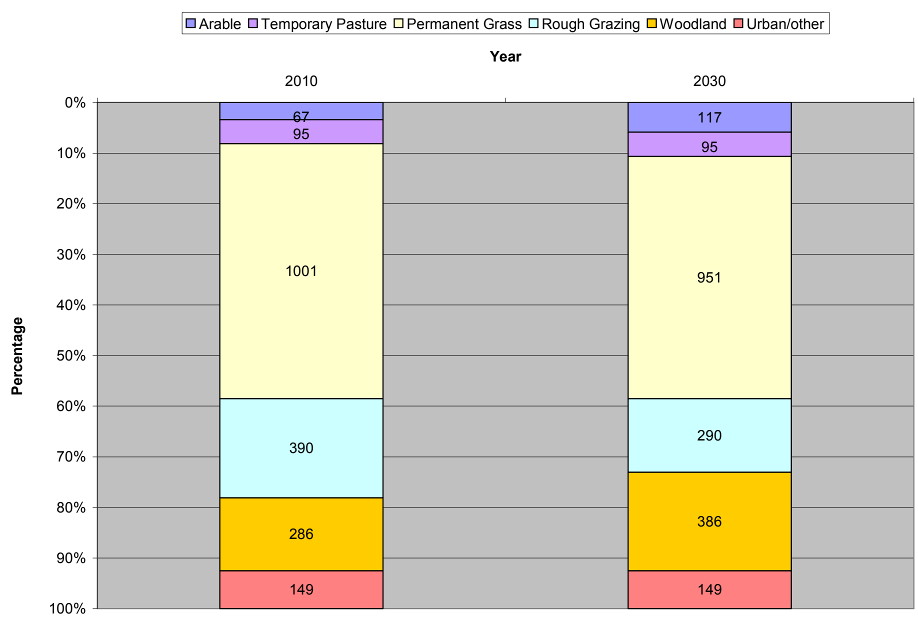


Table 10.1 - Summary of estimated maximum technical potential of interventions in Scenario 5 (kt CO_2e)

i) Agricultural GHGI

GHG Source		**Output in 2007 GHGI**	**Intervention**	**Reduction in 2020**	**Output in 2020-30**
Agricultural engines *etc*			Biogas from dairy (AD)	59	
			Biogas from 50% beef (AD)	38	
			Biogas 90% enteric capture – dairy	28	
			Biogas 90% enteric capture – beef	20	
		554	**Sub-total**	**145**	409
Enteric	Dairy	516	90% enteric capture – dairy	465	51
	Other cattle		90% enteric capture on 50% beef	373	
			15% reduction – additives, genetics for 50% extensive beef	62	
		828	**Sub-total**	**435**	393
	Sheep	922	Increased productivity of breeding flock	230	692
	Horses	17	NIL	0	17
	Others	2	NIL	0	2
Manures	Dairy cattle	127	90% reduction using AD	115	12
	Other cattle	79	90% reduction using AD on 50% beef	36	43
	Sheep/ goats/ deer	22	Increased productivity of breeding flock	5	17
	Horses	1	NIL	0	1
	Poultry	12	NIL	0	12
	Pigs	4	NIL	0	4
Manure systems	Liquid	5	NIL	0	5
	Solid	112	50% reduction by AD for 50% beef	56	56
	Other	35	NIL	0	35
Agricultural soils		2,187	10% reduction by N management	219	1,968
	Total	**5,423**		**1,706**	**3,717***

*** Note:** over 50% of this residual amount comes from N_2O emissions, which is subject to a large degree of uncertainty. If further work shows that the emission factor is different, this would be reflected in the historic and current emissions, and resets the baseline.

ii) LULUCF Inventory

GHG Source	Output in 2007 GHGI	Output in 2020 (BAU)	Output with Interventions		
			2020	2030	2040
Forest – biomass burning	21				
Grass – biomass burning	6				
Settlement – biomass burning	4				
Grass – liming	37				
Cropland – liming	7				
Land to settlement	688	694(i)			
Land to cropland	1,053	1,082	1,334	1,235	1,174(ii)
Harvested wood products	68	-806			
Land to forest	-1,430	449	230	-564	-1,195(iii)
Land to grass	-643	-701			
Cropland remaining cropland	-11				
Total emissions	**1,884**	**2,225**			
Total sink	**2,084**	**1,507**			
Net total	**-200**	**718**			

Notes: (i) This is based on a theoretical conversion of farmland to urban or commercial use

(ii) This is based on conversion of converting 50,000ha grassland to arable on mineral soils converted at 5000ha/year, based on soil carbon densities (0-30cm depth) in Wales and total emissions of 6,420 kt CO_2e over 100 years

(iii) Based on expanding forestry by 5,000 ha/year for 20 years, and expanding cropland by 50,000 ha by conversion from grassland.

2020 Business as usual estimates from 'Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry (LULUCF). Annual Report, CEH July 2009. For 2030 and 2040, the business as usual figures were assumed to be unchanged from 2020.

Forestry expansion estimates from FC projections table.

10.6 Outstanding concerns

- difficulties in the practical achievement of the required rate of change to meet the annual 3% and 10-year emission reduction target. An even greater challenge would be faced if the rate of reduction has to be even more substantial.
- Scenario 5 is likely to lead to increased combined arable and temporary grass. Although there will be a CO_2 emission peak in the first decade of conversion, the longer-term problem will be to minimise N_2O emissions. Table 10.1(ii) above shows that a 10-year increase of 5,000 ha/year in the arable area would increase Inventory CO_2 emissions by 252 kt CO_2e in 2020, but declining to an extra *c*160 kt by 2040. The Group notes that importing additional food (e.g. vegetables, if grown on peaty soils), while showing a benefit to the Welsh Inventory and not currently recorded by the UK Inventory, is in reality a displacement of production to other countries and an abrogation of our responsibility.

- overall funding requirements for AD, afforestation, renewables, and research.
- cultural, structural and organisational barriers to delivery and achieving the required rate of uptake.
- Government at the Welsh Assembly Government, UK and EU levels have a critical role in facilitating this scenario. For example, this includes:
  - support for afforestation at the required scale and rate.
  - underpinning the roll-out of AD technology.
  - removing regulatory and cultural barriers on waste reduction and the installation of renewables and incentivising by supporting improved micro-generation feed-in-tariffs and facilitating connectivity to the Grid.
  - critically, supporting the research and development required in the next 10 years to allow the new systems being advocated to be tested and demonstrated.
  - developing the international Inventory system to track the emissions reductions in a responsive way. There are significant deficiencies both in the methods used to derive the Inventory and in the quality of data Wales is able to feed into the current UK GHGI. This is important for informing the Welsh Assembly Government on Wales' overall performance in meeting domestic and international targets.

Footnote

The current Inventory framework is summarised in Box 3. Most of the initiatives and interventions proposed in Scenario 5 are captured in the current Inventory. This will become increasingly important as international targets are clarified and probably tightened. Also countries and businesses are seeking to use “carbon or GHG foot-printing” as marketing tools, and there are already examples of countries, such as New Zealand, doing this.

11. Waste, efficiency and lifestyle

11.1 Introduction

In all possible scenarios there exists a large number of efficiency and waste minimisation potentials, which although individually quite minor, could, if widely embraced, have collectively a significant impact on demand and emissions. Perhaps even more important they would inform and influence our lifestyles. In this they pave the way to public acceptance of the initiatives discussed and to secure a more sustainable and low-GHG future. It is significant to note the recent WWF report[71] which concludes that consumption-based measures in combination with decarbonisation of the general economy, production efficiencies, reductions in waste and abatement of N_2O and CH_4 emissions will be required to meet a 70% reduction target for the UK food system by 2050.

11.2 Possible initiatives

The list below outlines some possibilities:

- in terms of agricultural production *per se*, individual inefficiencies and waste (e.g. excessive and wasteful application of N fertiliser), have been noted under the various sectoral headings. Reviews of organic compared with conventional livestock systems show a range of conflicting results with no clear advantages. In the context of making substantial cuts in emissions, the differences appear not to be significant, particularly taking account of the differences between individual farm management practices. Extensification of production can reduce emissions on an area basis but for a given production level, it could lead to greater pressure on habitats that need protection for biodiversity.
- the waste within the food chain of around 25-30% has been commented on in this report as in many others. The Waste Resource Action Programme Report 2009 suggests food waste causes emissions of around 2 t CO_2e/person i.e. 12% of the total emissions of about 15.6t CO_2e/head in Wales. The report also suggests that in the UK some £10 billion (out of a total outlay of £66 billion on food) is wasted on discarded edible food. Obviously cutting such waste would have beneficial effects on CH_4 emissions from landfill, on total food miles and unnecessary transport, on international food availability and on household budgets. While individuals, families and caterers can themselves address this issue, it also requires the co-operation of the retailers so as to provide packs/helpings of the appropriate size to an ageing fragmented society. See also recommendations on packaging in chapter 8.
- cultural issues exist insofar that animal consumption is restricted in the UK to the main meat fraction, and blood, offal etc are used only to a limited

[71] E Audsley, M Brander, J Chatterton, D Murphey-Bokern, C Webster, A Williams. How low can we go? An assessment of greenhous gas emissions from the UK food system and the scope to reduce them by 2050. WWF-UK

extent – possibly some going to pet food. The BSE crisis in cattle has limited the use of these materials for feedstuffs, and also limited the use of food waste for animals. Regulatory and cultural barriers need to be removed or framed in a better-targeted way and a comparative study with New Zealand would be instructive.

- the current UK and Welsh diet is too high in meat, dairy and sugary foods and too low in fruit and vegetables. WRAP reports that UK males consume some 3,424 calories per day - at least 1/3 too much as the UK recommendations are respectively 2,550 and 1940 calories for men and women.
- for example, referring back to Table 8.1 a 10% decrease in local consumption of lamb would bring about an emission decline of 27 kt CO_2e per year.

Therefore, GHG footprints should be cut by:

- lower individual food calorie consumption (>1/3).
- less meat and dairy in individual diets.
- less waste of food at all points in the food chain. The demand side interventions would complement the supply side analysis in the preceding chapters.

The Group recommends that the Assembly Government harnesses the resources of the Food and Drink Advisory Partnership and the LUCCG to identify and implement resource efficiency improvements between farmer and consumer through reduction of waste and energy use in the processing and distribution chain and via better consumer education. This will require detailed data collection and modelling of the demand and supply side to assess the overall potential for GHG reduction.

Of course there is a major issue of balancing supply and demand. In normal seasonal conditions, supply will exceed demand, otherwise we are in a vulnerable position in times of disease and poor harvests.

The LUCCG does not consider this advice as incompatible with maintaining Wales' current production (e.g. Scenario 5 - if achieved with a low/zero GHG footprint). Much of the output would need to be exported. The food trade is essential for the resilient supply of food, given the variability of supply because of weather and diseases. It is not possible to run the food supply and demand balance too closely, lest local shortages or even famines result. A trading system also helps to ensure that food is grown in the most favourable places for efficient production including in GHG terms. Food miles are not universally the key driver in determining GHG emissions of a food commodity. Welsh (largely meat) exports, either to those countries / communities whose production potential is impaired by climate change or whose development trajectory favours a modest increase in the consumption of these items would improve their diets and be entirely legitimate.

It is not axiomatic that local food has a lower carbon footprint than imports. However there is clear evidence that a combination of seasonal food and enhanced local supply could have significant GHG mitigation effects. Over 40 farmers markets operate in Wales and small retailer outlets supported by local distributors. The Group welcomes these initiatives and recommend they are promoted and extended, acknowledging that they are highly unlikely to replace the bulk food purchases from the major supermarkets chains. Similarly there is scope for many more local products on supermarket shelves. In Scenario 4 and 5 especially, additional local vegetable and horticultural production is envisaged. Some increase in local seasonal supply within a balance of trade making use of Wales' comparative advantages and climate change scenarios - always governed by the need for a low GHG Welsh countryside – seems a reasonable policy objective.

In relation to the sustainability agenda and to the engagement of the public in both the quality of their own food, in decreasing food miles and the wider global issues, there is merit in encouraging all towns, villages and communities in Wales to set aside land for allotments and for householders to grow vegetables in their own gardens. This could complement farmers markets. The Group is not aware of any specific studies on the GHG effects of such initiatives but they may be positive.

The rate of change in food purchasing and supply may be driven more by transport cost and international water resources than by a direct concern for global climate change. Chapters 6 and 9 consider the possibility of local renewable energy generation of electricity and CBG contributing to fuelling local transport and the food production chain as EV and plug-in EV, and CBG, vehicles become available more widely.

Decreasing and localising food-miles entail, not only local production but local distribution networks, slaughter houses and meat processors. Urgent attention must be given to retaining and increasing the local small slaughterhouses and we recommend a specific study of how this problem can be met.

Trading recognises comparative advantage. Wales' comparative advantage, which could increase in the next century due to climate change, lies in a long growing season for grass and fodder and a relatively consistent water supply, suggesting that the historic base of meat/dairy production will continue with a high level of embedded water in the products. Even with increased arable production, grain and fruit and vegetable imports from England and mainland Europe are certain to continue.

Export and import of foods introduces a range of conflicting issues. Export of prepared carcasses leads to higher value added product within Wales, but requires transport and refrigeration which add to GHG emissions. Imported foods provide some local employment at source, but may cause diversion of scarce local resources e.g. water to grow food for export at cost to local supplies in addition to GHG emissions from air transport of the product.

Local siting of retail outlets and transport provision is important for reducing GHG emissions. Apart from the obvious impact on transport emissions, from a land use emission perspective, a decrease or cessation of green field development in Wales would decrease emissions by 688 kt CO_2e – about 1½ % of Wales total emissions - noting that this figure has a contribution from historic land use change.

While we see trade between Wales, other parts of UK and other countries as essential for Wales to play its part in supplying food and maximising emissions reduction, on a purely food sufficiency basis, it is unlikely that Wales could be realistically self-sufficient. However on a UK basis, with a change of diet, the population could feed itself.

Box 7 shows the impacts on food security and GHG emissions of an extreme situation which could be faced at some point in the future.

Box 7 - *In extremis*

This report is predicated on the continued functioning of a coherent world order with the concomitant advantages of trade *etc.* Some (e.g. James Lovelock[72]) foresee much greater disruption, even more extreme than John Beddington's perfect storm. Under such circumstances there might be much greater emphasis on self-sufficiency despite its inherent risks, as noted previously.

FAO suggest a basic requirement of 50 to 100 kg of grain per person per year depending on the other calorific inputs in the diet. Hypothetically 1 ha of good land (with a very high levels of applied N) may yield annually 10 t of grain sufficient for 100 to 200 individuals.

Mellanby[73] suggests that in the UK 1 ha of arable plus 1 ha of grazing land can feed 10 people.

On the basis of the historic record (see Box 2), Wales has about 250,000-300,000 ha of potentially arable land and a population approaching 3 million, but yields on these soils are unlikely to reach those currently being achieved in East Anglia. On the other hand there is ample grazing land.

In GHG terms such an "island Wales" scenario has serious implications. Ploughing up about an extra 250,000 ha of land would produce a major CO_2 emission spike of perhaps 1,500 kt initially and declining to about 1,000 CO_2e/year after the first decade. Given the linear relationship of crop yield and available N, there is also a real danger of addition emissions of N_2O - as noted previously there is little evidence that organic or legume-fixed N produces less N_2O emission per unit product than conventional imported inorganic fertiliser N. It should also be noted that in a localised (e.g. 30-40 miles) production/consumption scenario, Wales is not a natural unit. In such an extreme scenario it is more probable that the various historic regions (e.g. Gwynedd or Dyfed or Glamorgan/Gwent) would seek greater self sufficiency, but nevertheless that trade within Britain would remain essential.

It appears clear from this cursory analysis that an "island Wales" strategy will be pressed to feed the current population and than the N requirements of crops and the implications for land use changes from grassland to arable will need careful consideration in GHG emission terms. It is not clear that this offers a straightforward answer to problems even *in extremis.*

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72 James Lovelock 2009: The Vanishing Face of Gaia, A Final Warning
73 Mellanby, K: Can Britain Feed Itself (The Land, 4, 2007-08)

Appendix 1

Evidence-base reports commissioned within the Group:

1. **Actions within livestock systems -** Prof. Nigel Scollan, Aberystwyth University *.

2. **Improving the Welsh uplands for biodiversity: implications for carbon management -** Dr John Taylor, Countryside Council for Wales.

3. **Potential of soils and land use change to reduce GHG emissions from agriculture in Wales -** Prof. D L Jones, Bangor University and Prof. B A Emmett, NERC's Centre for Ecology and Hydrology, Bangor.

4. **The mitigation and adaptation potential of woodland creation in Wales -** Clive Thomas, Forestry Commission Wales.

5. **Identifying GHG efficiencies in the Welsh food supply chain –** Gareth Edwards-Jones, Bangor University.

*** Note:** includes extracts from Dr John Taylor's paper.

The Group also received valuable contributions from Prof Peter Midmore, Aberystwyth University, Michael Pitcher, FC Wales and Grenville Ham, BBNP.

Appendix 2

Terms of Reference – Remit and Objectives

Remit

The immediate aim of the Land Use and Climate Change Group is to produce a discussion report by Autumn 2009, advising on new actions that will help to deliver the 3% target to cut greenhouse gas emissions and help Welsh agriculture become carbon neutral by 2020

The Group's objectives are to:

- Advise Welsh Ministers and the Climate Change Commission on the most effective way to deliver relevant commitments of the Climate Change Strategy, and contribute to related policy review, development and implementation;
- Raise awareness among stakeholders at all levels about the impacts of climate change in rural areas through existing and/or new knowledge networks; help develop and promote appropriate responses to climate change and contribute to the implementation of a climate change communications strategy for land managers;
- Identify, propose and promote practical actions and policy options, including the uptake of research findings:
    - to reduce and offset greenhouse gas emissions from rural land uses
    - on adaptation measures for rural land uses (including for conservation purposes and new agricultural uses)
    - on the potential for managing the impacts of climate change (e.g. flooding) through changed land management practices.
- Identify data needs taking account of variability of data quality, and research needs and priorities.

The Group will use an integrated approach based on assessing the trade-offs between benefits and disbenefits in delivering ecosystem services:

- provision of food, fibre, water and fuel,
- delivery of fundamental support services – primary production, nutrient cycling, soil formation,
- delivery of regulating services – flood control, climate control, disease control, air quality control, and
- delivery of cultural services – landscape, biodiversity and recreation.

The scope of the Group's work will be on:

1. how to reduce emissions from agriculture and land use, taking account of:
    - the lifecycle of the food production chain from field to fork,
    - the inputs to the sector from other sectors (e.g. fertilisers, transport, chemicals)
    - the overall rural economy in terms of resource needs (e.g. energy)
2. how agriculture and woodland can adapt to climate change – taking account of opportunities and threats of climate change, and
3. how to manage our land to improve the capacity of other sectors of society to adapt to climate change.