CLIMATE CHANGE PLAN
The Third Report on Proposals and Policies 2018-2032
Technical Annex

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Introduction

This report provides background information on the Scottish TIMES (The Integrated MARKAL EFOM System) model. This is a high-level strategic model, covering the Scottish energy system, as well as non-energy sectors, including Agriculture, Land Use, Land Use Change and Forestry, and Waste. It was commissioned by the Scottish Government to enhance its analysis of the impact of emission reduction legislation on the energy system. Although this is the first time that a model like this has been available for Scotland, there are more than seventy country versions of TIMES, and TIMES modelling has underpinned a large number of studies in both environmental and energy economics produced by governments, NGOs and in academia.

Scottish TIMES belongs to a group of models that were developed by the IEA-ETSAP (the International Energy Agency's Energy Technology Systems Analysis Program) in order to examine long term energy dynamics over a time horizon.

Figure 1: Contracting Parties (Members of the IEA ETSAP Program) and MARKAL/TIMES Users; ETSAP

The Scottish TIMES model was built by an international consortium of experts from E4Tech, E4SMA, KANORS, SYSTRA and University College London (UCL), building upon work done by the Department for Business, Energy and Industrial Strategy (BEIS) on the UK TIMES model. TIMES models allow us to explore long-term energy scenarios and are ideally suited for the preparation of emissions reduction strategies, such as the Climate Change Plan. The application of the whole-system model has been a significant step forward in ensuring that our climate change planning captures the complex interactions within and between sectors, and ensures a greater consistency of approach than would be possible if we were to rely solely on sector models.

TIMES is a whole system energy model that captures the key characteristics of the Scottish energy system today, and considers the impacts on the future energy and emissions flows that result from the deployment of a range of processes and technologies. TIMES accounts for all the steps as energy flows through the system, from primary resources, through their transformation and distribution, to the ultimate objective of meeting demands from energy consumers. The chart below shows a simplification of how energy is currently supplied and consumed within the Scottish energy system.

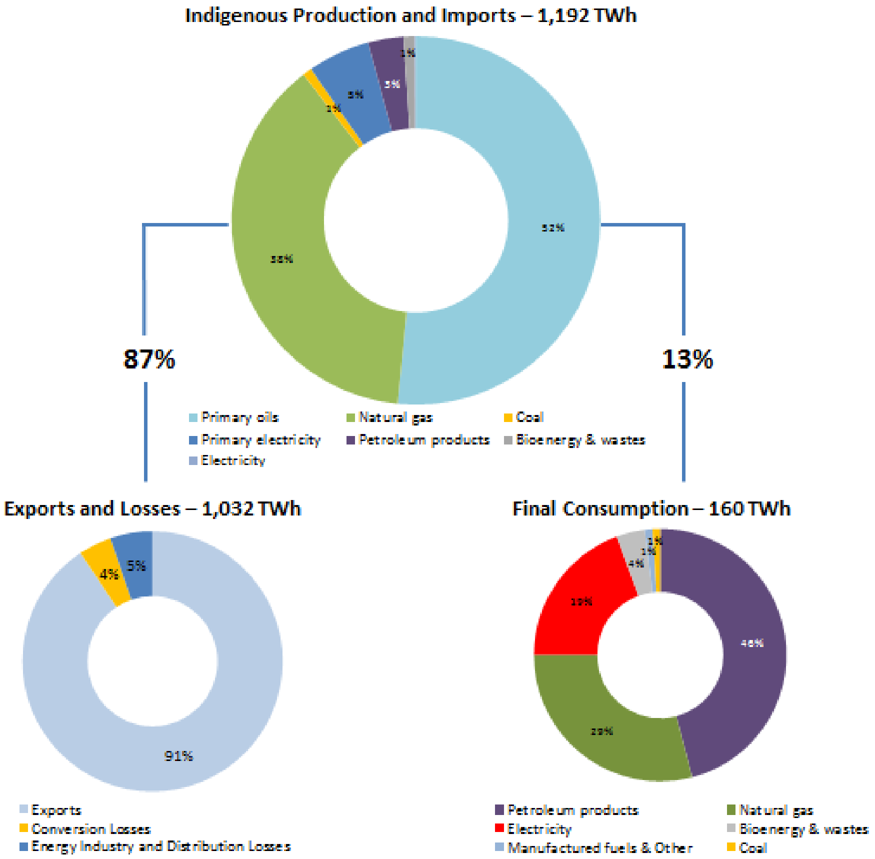

Figure 2: Scottish Energy balance, Source: Energy in Scotland 2018

Given the central role of energy in delivering a low-carbon Scotland and the extent of the challenges faced in delivering secure, affordable and low-carbon energy, a separate Energy Strategy[1] also informed by the TIMES model was published in December 2017. This explores the options for delivering increasingly decarbonised electricity and heat, and the potential technological options for doing so.

This technical annex sets out:

- The Scottish TIMES model overview
- Model development from draft Climate Change Plan to final Climate Change Plan
- Sector Analysis – data inputs, constraints and results

[1] http://www.gov.scot/Publications/2017/12/5661

Scottish TIMES Model

The Scottish TIMES model, at its simplest, is a diagnostic tool to help understand the key inter-relationships across the energy system. The approach relies on a specified set of data inputs being collected which capture the characteristics of the system being studied, a series of constraints being applied to reflect practical or policy constraints and a set of results being generated that are informed by those inputs and constraints.

Energy Flows

The figure below sets out a simplified overview of the TIMES model. TIMES contains a series of domestic and imported resources that the model can draw from, shown in the blue section of the figure below. The minimum or maximum amount of each resource that can be extracted or imported is set by the modeller, as well as resource prices. The modeller also inputs policy targets (such as the Scottish climate change targets), baseline energy demand for relevant sectors and drivers that influence how baseline demand will change over time. There are a range of drivers that influence demand, including number of households and service sector floor space projections, amongst others. The model is constrained to meet the defined climate change targets and energy demands over a specified time horizon.

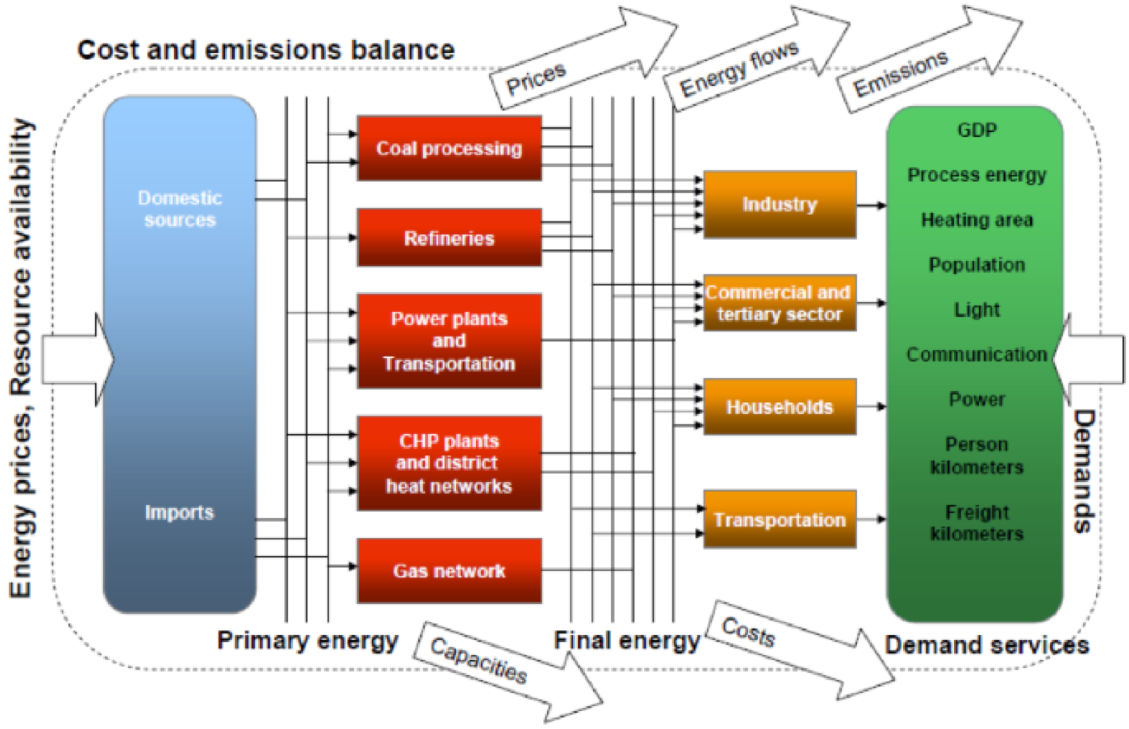

Figure 3: TIMES Inputs and Outputs; source (Remme et al., 2001)

Primary resources can be transformed into fuels (such as hydrogen or electricity) using a range of existing and future technologies and processes (red) that are then redirected into the different sectors (orange), where they feed into a range of technologies, such as gas boilers, heat pumps, etc. that ultimately meet energy demand.

The figure below highlights a simplified version of specific supply chains within TIMES. Space and water heating in the Residential sector can be generated from gas, electricity or other sources. Electricity, in turn, can be generated using a variety of inputs, including gas.

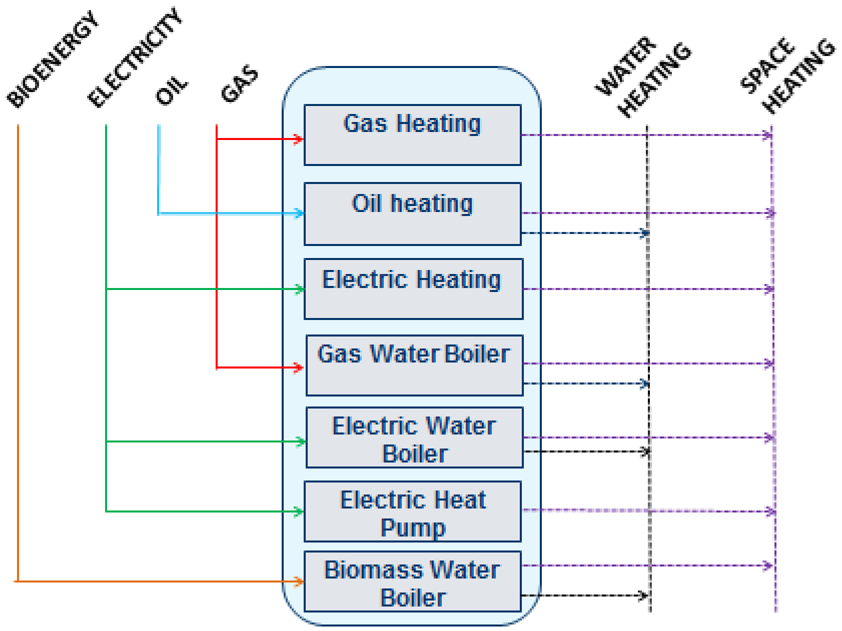

Figure 4: Based on "Using the TIMES model in developing energy policy, 2017"[2]

However, this example highlights only one form of energy demand being considered by the TIMES approach. In addition to considering the most appropriate method of delivering heat demand, TIMES is also simultaneously considering that approach in the context of delivering all other energy demands (hot water, transport, appliances) and the impacts those demands have on competing and complimentary parts of the supply chain.

There are, in fact, over two thousand technologies and other carbon abatement measures in the Scottish TIMES model, both existing and future. There are a series of variables associated with each, such as fixed and variable operating costs, investment costs and technical potential, amongst others.

TIMES models use linear programming (LP) to identify the least-cost pathway for meeting our climate change targets and energy demands over a specified time horizon. LP is a mathematical technique by which we obtain an optimal result by minimising or maximising a function (finding its maximum or lowest point), given a set of constraints. In the context of TIMES, we minimise the total cost of meeting a series of final demands, given a set of constraints.

The resulting pathway will include a specific mix of primary energy supply that can optimally meet Scottish energy demands. The least-cost pathway also contains a suggested mix of technologies, fuels and other carbon abatement measures for achieving our targets, as well as a set of carbon envelopes that indicate the potential future pathway for emissions within sectors.

In addition to the whole system TIMES model, we utilise a number of more detailed sector models. These have been used to compliment the TIMES whole system approach. Sector models can provide more detail on the individual sectors than is possible within the TIMES

[2] http://www.climatexchange.org.uk/reducing-emissions/using-times-model-developing-energy-policy/ by Christian Calvillo, Karen Turner, Keith Bell, Peter McGregor, Graeme Hawker

framework. We have made adjustments to the TIMES model to take into account these sector-specific analyses.

The pace at which the energy system changes (and has changed over the past decade and a half) as a result of changing market, policy, technological and regulatory drivers means forecasting the precise breakdown of the 2032 energy system is not feasible and the actual distribution of technologies and processes within and between sectors could be different over the period. For example, bioenergy is identified as being a potential input to the industrial sector, but the form this could take may differ depending on how different technologies and processes develop.

The current work underway to upgrade the mains gas system could facilitate a greater share of biogases in the gas network, which could provide a low-disruption means by which to decarbonise the non-domestic sector. This issue of how to model uncertainty was a consistent theme in our discussions with the academic modelling community, and an area that we will look to develop further as we continue to develop our modelling expertise.

Model Development from Draft to Final Climate Change Plan

Overview

There have been three milestone TIMES runs that have informed the development of the final Climate change Plan. This section discusses the main components of each. Further detail is provided in the sector-specific discussion in the following section.

A number of technical changes were made to parameters, as well as changes in the categorisation of variables. As a result, it is not possible to make comparisons across these runs nor isolate the individual impact of each change.

Draft Climate Change Plan

The figure below presents the emissions envelopes from the draft Climate Change Plan.

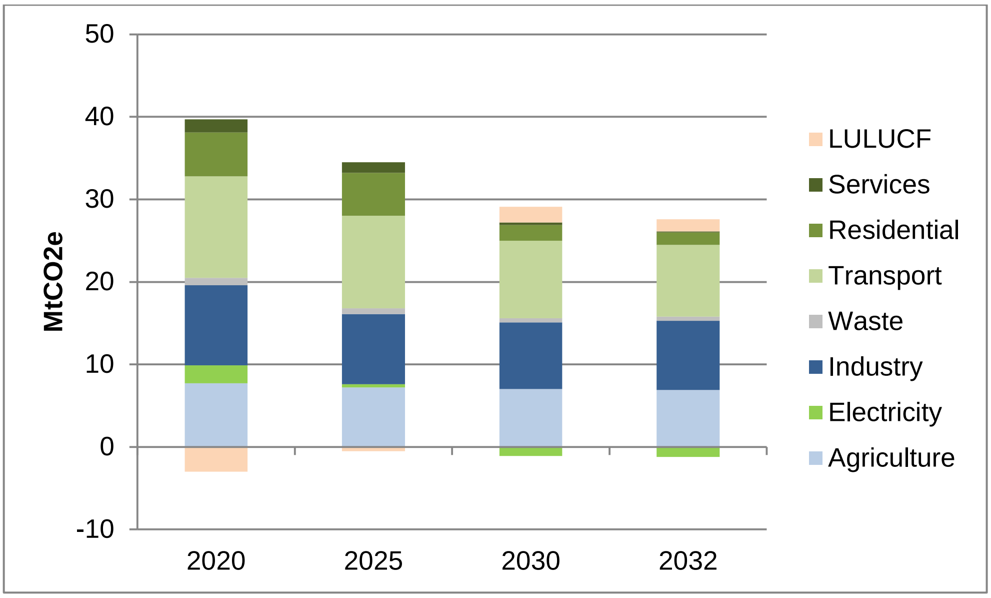

Figure 5: Sector Envelopes from Draft Climate Change Plan, TIMES model results

September 2017

A number of updates were made to the model between the draft Plan model run and the end of September 2017. Of these, one of the largest changes in terms of impact on results was the update to the Land Use, Land-Use Change and Forestry (LULUCF) projections. Updated projections were provided by the Department for Business, Energy and Industrial Strategy (BEIS), which are consistent with those used for their January update to the Updated Energy and Emissions Projections[3]. These were produced by the Centre for Ecology and Hydrology (CEH), and reviewed by BEIS. Net removals from the LULUCF sector are now approximately 6 $MtCO_2e$ higher per annum, on average, than in the data used for the draft Plan, and the sector now remains a net sink over the timeframe of the Plan.

Alongside this change, Transport emissions were revised exogenously and coded into the model, to take account of the Programme for Government announcement on phasing out the need to buy petrol and diesel engine cars and vans by 2032. The emissions released from

[3] https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2017

the changes to the LULUCF and Transport sectors have resulted in changes to the Residential, Service and Industrial sectors. Electricity emissions in this run are lower in early years, with the envelope increasing in later years, relative to the draft Plan. The Waste envelope and the non-energy component of the Agricultural envelope have both been revised using sector specific analysis, with the new emissions profiles coded into TIMES.

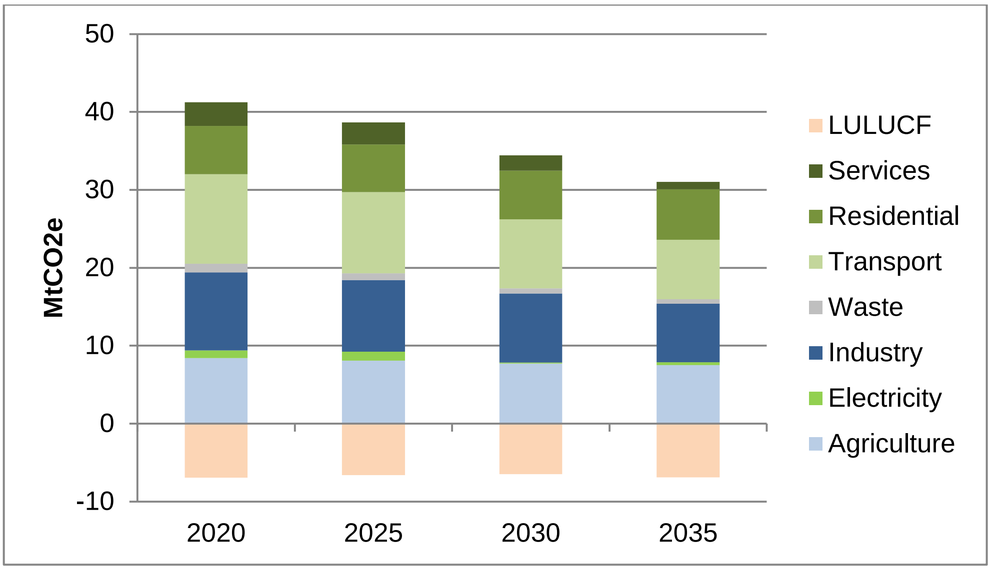

Figure 6: Sector Envelopes from September 2017, TIMES model results

Updates made to the model between the draft Plan and end-September 2017 are summarised as follows:

- In response to the feedback on the draft Climate Change Plan and Energy Strategy, we have revised our assumptions about the application of carbon capture and storage (CCS). The feedback we received highlighted the challenge of deploying CCS at scale in the period set out in the draft Plan. We have therefore constrained the use of biomethane and other biomass in electricity generation and industrial processes that produce captured emissions over the modelling timeframe, eliminating the model's ability to produce negative emissions. The final Plan, therefore, does not depend on negative emissions

- We added a new minimum constraint for offshore wind electricity generation capacity between 2020 and 2025, reflecting installed and planned capacity. We also added a new floating wind technology that is made available for the model to use, drawing from Scottish-specific project data

- The share of Scottish non-domestic building energy demand as a share of the UK demand was updated to the most recent data available on non-domestic energy consumption share

- We incorporated smart meters into the Residential and Service sectors, with updated energy savings potential drawing on the UK Government cost-benefit analysis of the smart meter roll-out. Smart meters are expected to allow consumers to develop more energy efficient behaviours, leading to reduced energy consumption

- The aviation and shipping emissions cap was modified within the TIMES model, so that it includes all domestic technologies, as some were previously missing from the cap definition (but still being captured elsewhere in the modelling)
- The Transport emissions profile was updated to reflect the impact of the Programme for Government announcement, on phasing out the need to buy petrol and diesel engine cars and vans by 2032
- We incorporated a new emissions profile for Agriculture, derived from the latest Greenhouse Gas Inventory figures. The agricultural transport demand driver was revised, reflecting the downward trend in baseline non-energy emissions
- Tonnages of organic and inorganic municipal solid waste, wet biomass waste, landfill gas, sewage sludge and animal slurry available as resource inputs to the model, have been updated
- We incorporated a new set of baseline LULUCF projections provided and reviewed by BEIS, and produced by the Centre for Ecology and Hydrology (CEH)
- CO_2 removals from woodland planting which would have occurred without policy intervention were not included in the new planting figures
- We updated the assumptions regarding the potential availability of future biomass
- We constrained the application of hydrogen with natural gas in the existing gas network over the period of the Climate Change Plan

October 2017

Further updates were applied during October 2017. These are detailed as follows and had the combined impact of adjusting the sector envelopes to those shown in the figure below. The largest impact was on the Electricity sector, where emissions increased in all years and in the Residential and Service sectors, where the envelopes became relatively tighter.

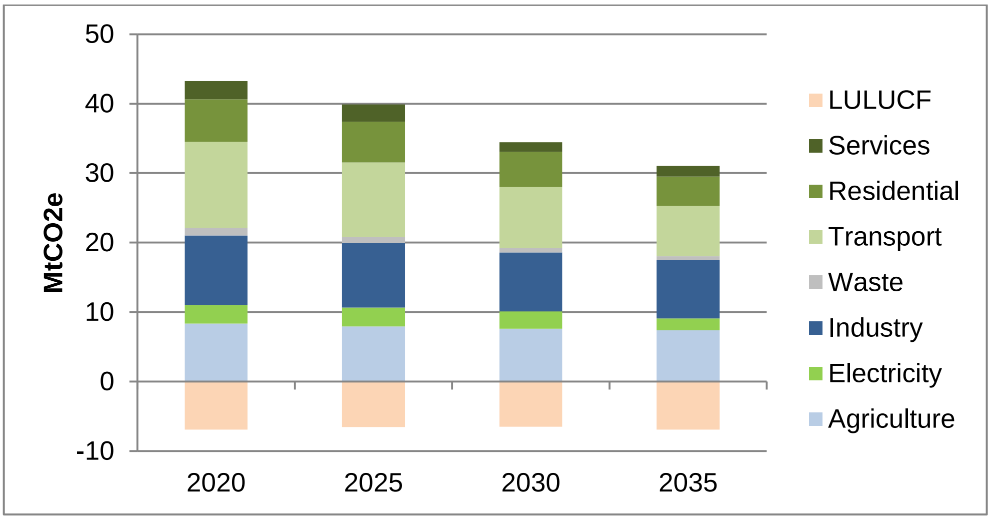

Figure 7: Sector Envelopes from October 2017, TIMES model results

Further constraints added between September and October 2017 were as follows:

- The model was updated to reflect the 2015 Greenhouse Gas Inventory (published in 2017)

- In response to the feedback on the draft Climate Change Plan and Energy Strategy, we have delayed the use of CCS in electricity until after 2030

- We have updated the constraint on exports/imports of electricity to ensure the system maintains sufficient capacity to continue exporting to the rest of the UK, and that Scottish climate targets are not met by exporting emissions to other parts of the GB system

- We have conducted an update of the historical generation, capacity and load factor data inputs in the electricity sector in Scottish TIMES, drawing from BEIS Energy Trends December 2016, DUKES 2016, BEIS Renewable electricity capacity and generation (2017), BEIS Regional Statistics – 2003 – 2015: Standard Load Factors, the Renewable Energy Planning Database (2017), and from an updated version of UK TIMES

- We updated the energy saving potential and cost of phased conservation measures in the Residential sector, which included expanding the set of conservation measures modelled, drawing on data from the National Household Model. We also updated the energy saving potential of phased conservation measures in the Service sector

- We have constrained the potential deployment of district heating to align with figures in the UK's National Comprehensive Assessment of District Heating and Cooling (2015)

- Base year average space heat and hot water demand in the Residential sector was calibrated to account for differences between modelled and actual data, based on data from the UK TIMES model. New build average space heat and hot water demand is based on the (now calibrated) base year demand

- We have now defined an increasing share of heat and hot water demand in the Residential sector that must be met by low-carbon technologies and fuels (including electricity) over time. The share of heat and hot water demand that must be met by low-carbon technologies and fuels in the final Plan is limited to broadly align with the proportion of properties that are not on the gas grid and advice from the Committee on Climate Change (CCC)

- The Transport emissions profile was rebased to reflect the impact of the 2015 Greenhouse Gas Inventory

Final Climate Change Plan

Updates

There were a number of small changes introduced to the model between the October 2017 run and the final run to take into account some technical adjustments:

- The cumulative emissions shortfall on targets in previous years that has been accounted for in the current Plan has been updated to reflect the latest Greenhouse Gas Inventory

- We resolved a technical issue where commodities continued to be imported and not used by the Electricity sector. This has no impact on emissions, as the commodities are not transformed

Overall, these have led to a minor reduction to the Electricity and Industrial emissions envelopes in later years.

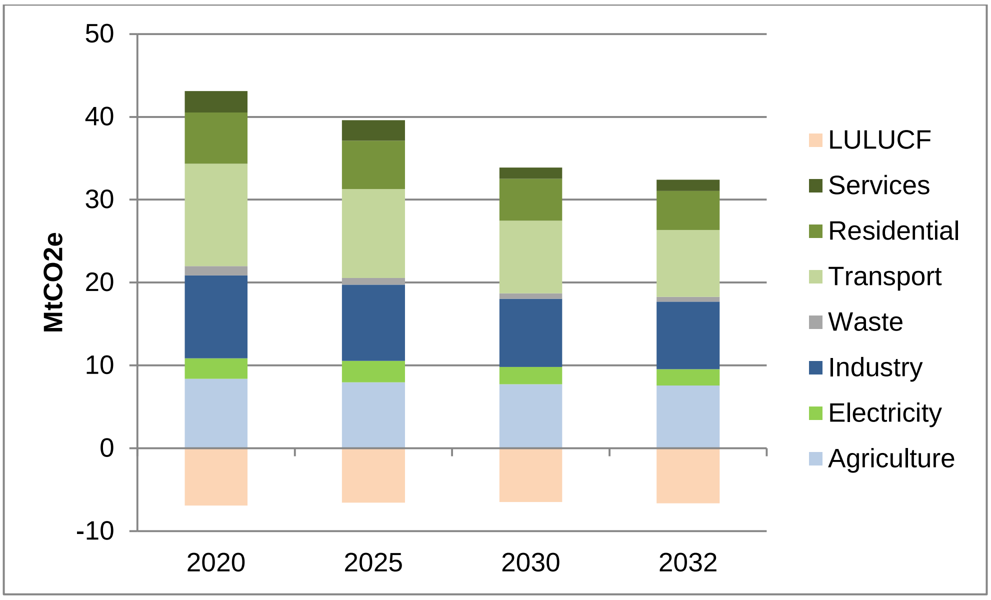

Figure 8: Sector Envelopes in final Climate Change Plan

The table below sets out the final Climate Change Plan sector envelopes.

Climate Change Plan - Sector Annual Envelopes (MtCO2e)															
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Agriculture	8.4	8.4	8.4	8.3	8.2	8.1	8.0	8.0	7.8	7.6	7.7	7.7	7.7	7.6	7.6
Electricity	2.7	2.6	2.5	2.5	2.5	2.5	2.6	2.6	2.5	2.3	2.2	2.2	2.1	2.0	2.0
Waste	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6
Industry	10.3	10.2	10.0	9.8	9.7	9.5	9.4	9.2	8.9	8.6	8.4	8.3	8.2	8.2	8.1
Residential	6.1	6.1	6.1	6.1	6.0	6.0	5.9	5.8	5.6	5.4	5.3	5.2	5.1	4.9	4.7
Services	2.9	2.8	2.6	2.6	2.5	2.5	2.5	2.5	2.2	2.0	1.8	1.6	1.4	1.4	1.4
Transport	12.8	12.6	12.4	12.1	11.8	11.5	11.1	10.7	10.4	10.0	9.6	9.2	8.8	8.4	8.1
LULUCF	-5.3	-6.1	-6.9	-6.9	-6.8	-6.7	-6.6	-6.6	-6.6	-6.5	-6.5	-6.5	-6.5	-6.6	-6.7

Table 1: Sector Envelopes in final Climate Change Plan

Sector Analysis

Overview

Outputs are grouped into seven final sectors in Scottish TIMES – Residential and Services (these are grouped in the Climate Change Plan in the Buildings chapter. Note that Services comprises commercial and public sector buildings), Industry, Transport, Agriculture, Waste, and Land Use, Land Use Change and Forestry (LULUCF).

In terms of emissions, electricity is considered a final sector, while it is also an intermediate sector in its role transforming energy. Upstream processing is an intermediate sector and emissions are incorporated in the industrial envelope. Primary resources are also discussed below and are a model input.

These sectors correspond to the Greenhouse Gas Inventory sectors as follows:

Climate Change Plan:	Greenhouse Gas Inventory:
Electricity	Power Stations
Residential	Residential
Services	Public Sector Buildings and Services from Business and Industrial Processes
Industry	Industry Emissions and Refineries Industry from Energy Supply
Transport	Transport, including all domestic and international Aviation and Shipping
Agriculture	Agriculture and Liming
Waste	Waste Management
LULUCF	Land Use and Forestry and Development

Table 2: Climate Change Plan and Greenhouse Gas Inventory Sector Comparison

For the demand driven sectors (Residential, Services, Industry, Transport, and heat and transport within the Agriculture sector), the model must meet the defined final energy demands. In the Electricity sector, demand is determined endogenously by the model and is driven by demand for electricity as a fuel in the other sectors (for example, through the electrification of Transport or heating demand).

Scottish TIMES also incorporates non-energy sectors (most of Agriculture, Waste and LULUCF). Although these non-energy sectors, for the most part, do not have final energy demands nor long potential supply chains, the model does incorporate future emissions projections for each, informed by sector analysis and models. This is a standard approach used to address non-energy components of whole system models and ensures that once the climate change targets are taken into account, emissions from energy sectors are not able to increase beyond a level consistent with the overall targets.

The Transport sector is incorporated into TIMES via fuel shares and emissions projections. While both are determined exogenously, changes to Transport fuel shares will ripple through the rest of the system, as Transport supply chains are fully incorporated into the model.

Transport emissions projections are taken into account in deriving sector envelopes in the same way as for the non-energy sectors; their inclusion ensures total emissions from all sectors do not exceed the overall targets. The emission projections and fuel shares for Transport in the draft CCP were based on data provided by Transport Scotland and sourced from research by Element Energy, providing a detailed representation of the transport sector in Scotland. The original projections have now been updated by Transport colleagues following the Programme for Government announcement.

By ensuring that emissions trajectories for all sectors are informed by sector-specific models and analysis, we can be confident of the robustness of sector emissions envelopes.

Incorporating the Scottish climate change targets and other policy and technical constraints allows the model to be used to highlight how best to deliver on our climate change ambitions, taking into account Scottish-specific data.

Cross-Sector Assumptions

There are a series of principles and assumptions that underpin the TIMES model. First, as discussed above, the model is internally consistent. Should the modeller change any assumptions, the effects will ripple throughout the model, for example, increasing one sector's use of biomass will reduce the amount available for use by other sectors.

Scottish TIMES minimises the discounted cost of meeting a series of fixed final energy demands by deploying specific technologies and other carbon abatement measures, and using a specific mix of feedstock and fuels. The costs in TIMES include capital costs, fixed and variable costs, import cost, revenues for exporting, delivery costs of inputs and any capital costs incurred just past 2050 for investments occurring right at the end of the time horizon covered by the model. The unit costs associated with each parameter are inputs to the model. It should be noted that the cost inputs to the model and the cost output (the discounted cost of the least-cost pathway or system cost) are resource costs; they represent the cost of purchasing the equipment and fuels to deliver the pathway. It should also be noted that the model does not make any assumption about who incurs these costs.

Although final demands are fixed, intermediate demands are endogenous to the model. For example, demand for electricity is derived in each TIMES run, as a decreasing/increasing function of quantity demanded by other sectors, depending on the decision within the model regarding which final demand can be met through electrification.

TIMES assumes linearity in the input to output relationship for each of the technologies, and uses linear programming to arrive at the least-cost pathway. The (shadow) price of carbon in the model therefore represents the marginal change in the discounted system cost (typically a reduction) associated with a unit increase in carbon emissions beyond the production of carbon constrained by the climate change targets. All fuels in the model also have a shadow price, which, as for the shadow carbon price, is the marginal change in the discounted system cost of requiring one more unit of the fuel or reducing demand of the fuel by one unit (perhaps by using more efficient technologies). It should be noted that the shadow fuel prices derived by TIMES do not represent the market price of fuels, which also include network charges, energy supplier operating costs and margins, and energy and climate change policy costs.

Finally, TIMES also assumes perfect foresight over the entire planning horizon, from 2012 (the base year) to 2050, so that decisions made in early years are all consistent with this overarching goal of minimising cost throughout the 38 year period, as agents know all past, present and future variables. By ensuring the model is run beyond 2032, we can be more certain that technologies and fuels deployed by the end of the Plan remain consistent with future decarbonisation efforts.

The TIMES model is run to produce data in 5 year blocks, rather than annually, in order to reduce processing time while retaining sufficient detail. We have interpolated linearly to derive values for 2018 and 2032.

It should be noted that actual emissions in the TIMES model have been updated to reflect the most recent Greenhouse Gas Inventory[4] for all sectors.

The TIMES results set out in the next section provide information on the potential future fuel share and technology mix, and as such, provide an indication of how Scotland may choose to approach the decarbonisation challenge, but should not be viewed as a prescription for the future technology mix. As set out in the Scottish Energy Strategy, the precise make-up of the future energy system is uncertain. Changing market, policy, technological and regulatory drivers means forecasting the precise breakdown of the 2032 energy system is not feasible and the actual distribution of technologies and processes within and between sectors could be different over the period. Our ability to store and control energy is changing dramatically, driven by growing demand for storage, technological innovation, smarter networks and the growth of the digital economy. Scotland's energy future will be, and needs to be, much more flexible than in the past, with far more choice for domestic and business users.

[4] http://www.gov.scot/Publications/2017/06/9986

Electricity sector

Sector Overview

The base year capacity of the generation technologies, broadly categorised as fossil fuel, nuclear and renewable, are calibrated to the actual installed capacity in Scotland in 2016. The future installed capacity of these technologies is estimated according to the current planned or under construction generation projects, and constraints on deployment potential.

In order to check that the generation mix proposed by the selected TIMES scenario is feasible, it was stress tested using the Scottish Electricity Dispatch Model (SEDM). This confirmed that the proposed capacities were technically feasible, alongside use of interconnection with the integrated GB electricity network, relying on existing and proposed network projects.

Data inputs:

Since publication of the draft Plan, we have updated historic generation, capacity and load factors, based on BEIS' Energy Trends December 2016, DUKES 2016, BEIS Renewable electricity capacity and generation (2017), BEIS Regional Statistics – 2003 – 2015: Standard Load Factors, the Renewable Energy Planning Database (2017), and from an updated version of UK TIMES.

Other sources used in the sector include the Scottish Government's Energy in Scotland publication and the SEDM, as well as data inherited from UK TIMES.

Floating wind generation is also now available to the model, based on Scottish-specific project data.

Additional constraints since the Draft Plan:

A series of further modelling constraints have also been applied to the Electricity sector in response to feedback on the draft Climate Change Plan and Energy Strategy, as follows:

- We have constrained offshore wind electricity generation capacity between 2020 and 2025, reflecting installed and planned capacity

- We have updated the constraint on exports/imports of electricity to ensure the system maintains sufficient capacity to continue exporting to the rest of the UK, and that Scottish climate targets are not met by exporting emissions to other parts of the GB system

- The introduction of Carbon Capture and Storage (CCS) for electricity generation has been delayed to after 2030, and the use of biomethane and other biomass in electricity generation processes fitted with CCS has been constrained to zero, eliminating the model's ability to generate negative emissions in the electricity sector

- We have also maintained capacity for a natural gas electricity generation plant at a minimum of around 1 GW for the duration of the Plan

Results:

The figure below presents projected electricity generation and consumption in 2020 in the Climate Change Plan. Renewables are the largest source of electricity, amounting to around 33 TWh, followed by nuclear and fossil fuel generation. After accounting for a small efficiency loss and net exports, electricity consumption is nearly 33 TWh. This represents an increase over actual electricity consumed in 2015 (30.9 TWh[5]),

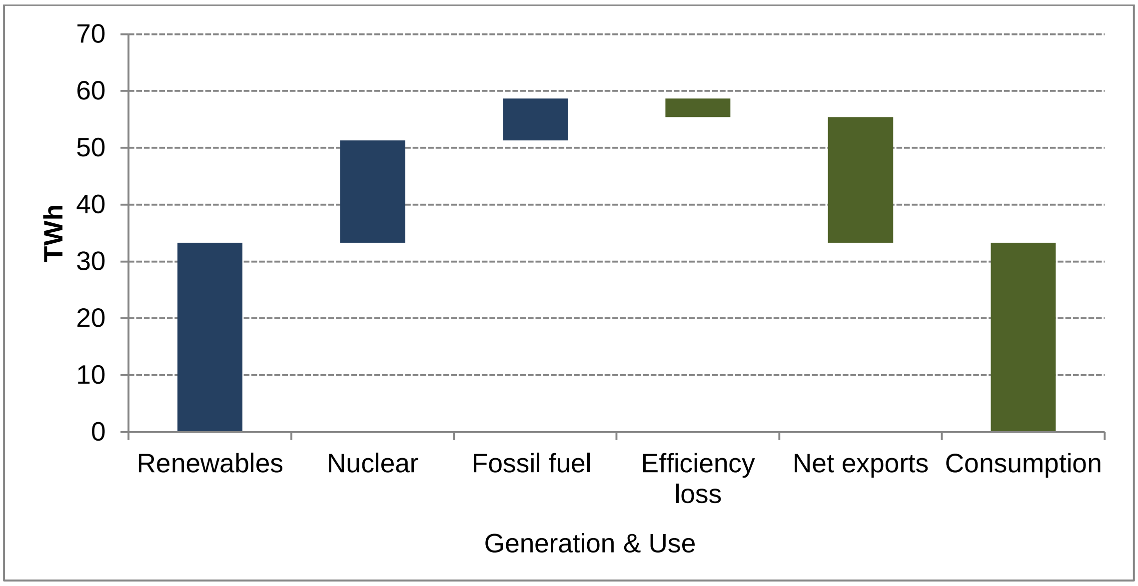

Figure 9: Electricity Generation and Use in 2020 (TIMES model results), (Electricity storage technologies are not in the above as they are deployed further down the supply chain)

The results are similar in 2032. Overall electricity generated is lower than 2020, with around 39 TWh of renewable electricity generated, followed by nearly 7 TWh of fossil fuels. The system remains a net exporter in that year with net exports around 12 TWh. In 2032, consumption of electricity is expected to be higher than what it was in 2015, at around 32 TWh.

5 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/669750/Energy_Trends_December_2017.pdf

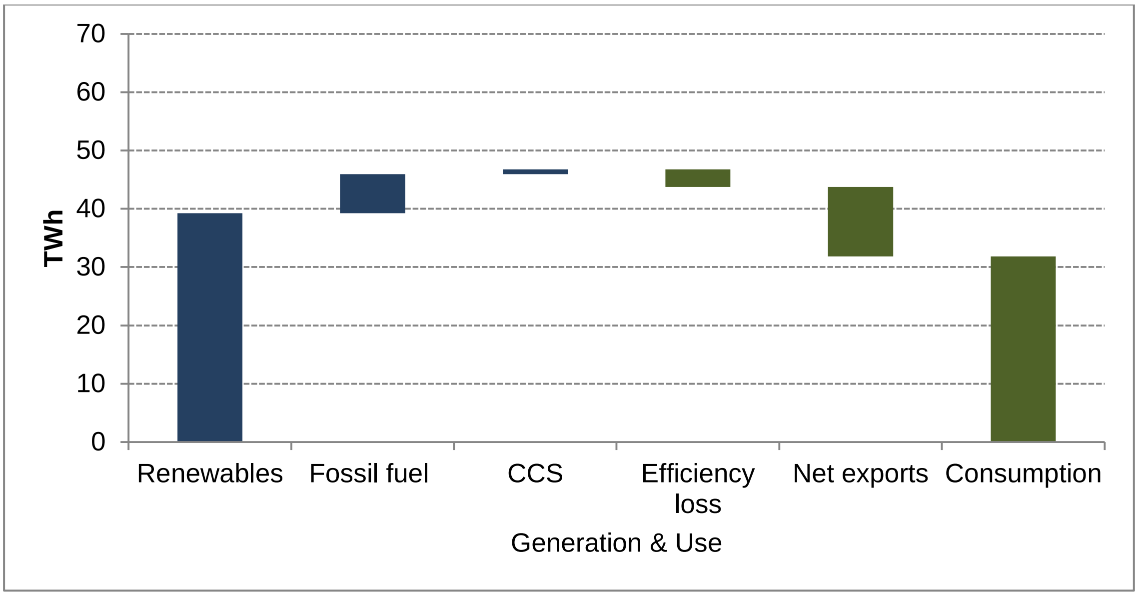

Figure 10: Electricity Generation and Use in 2032 (TIMES model results) (Electricity storage technologies are not in the above as they are deployed further down the supply chain)

Emissions in the electricity sector are projected to fall by 28% over the lifetime of the plan. This is driven by the switch away from natural gas and coal towards onshore wind (which becomes the main source of electricity generation in Scotland), and offshore wind (which sees the largest increase in electricity generated between the two periods).

However, it should be noted that Scottish TIMES does not model electricity generation within the rest of GB system, which presents a challenge when dealing with markets with the degree of integration inherent in this system.

The National Grid is responsible for balancing the GB network. It balances supply and demand by using the full range of generating assets across the system. It is therefore important to consider how Scottish generation assets can contribute towards achieving wider GB emissions and renewable energy ambitions.

Recognising the potential limitation of TIMES in this area, we used the SEDM, a more detailed model of the GB and Scottish electricity system to look into Scottish renewable generation and capacity in terms of wider GB decarbonisation goals.

The results from TIMES indicate that the total deployment of renewables in Scotland is around 12 GW by 2030. However, modelling from the SEDM, which highlights potential impacts across the integrated GB electricity system, shows that the total renewable deployment in Scotland could be as high as 17 GW in 2030, reflecting the strength of the resource available in Scotland and the potential for Scottish renewable technologies to help meet wider UK decarbonisation efforts. This is similar in magnitude to potential renewable deployment in Scotland set out by the Committee on Climate Change advice on Scottish emissions targets from 2016[6]. As a result, renewable electricity generation has the potential to produce the equivalent of around 140% of Scottish gross consumption by 2030.

[6] https://www.theccc.org.uk/publication/scottish-emissions-targets-2028-2032-the-high-ambition-pathway-towards-a-low-carbon-economy/

The introduction of CCS in electricity has been delayed until after 2030 and is applied to natural gas generation only. Given the small amounts of CCS that are deployed post 2030, the electricity envelope does not depend on the deployment of CCS to be delivered.

Buildings:

Residential Sector:

Sector Overview:

The Residential sector includes all energy service demands and emissions from the Scottish housing stock. Scottish TIMES splits the sector into three broad demand sub-sectors:

- Heating (space and hot water heating), using a range of fuels
- Cooking, using a range of fuels
- Appliances (lighting, refrigerators/freezers, wet appliances, consumer electronics, computers and other appliances), which consume electricity

The National Household Model (NHM) is designed for detailed modelling of the residential sector, and it can therefore be run using all dwellings sampled by the Scottish House Condition Survey (SHCS). Following a statistical review, the various dwellings sampled by the SHCS were aggregated into six different archetypes in TIMES, to strike a balance between computational simplicity and capturing the variability of the housing stock. These were:

- Existing urban houses
- Existing rural houses
- Existing flats
- New urban houses
- New rural houses
- New flats

Assumptions are made for each of the energy service demands in the base year for urban houses, rural houses and flats. The only demands for which a distinction is made between existing and new dwellings are the space and hot water heating demands. For all other energy service demands, dwellings of all ages are combined but the distinction between urban house/rural house/flat is maintained.

Data Inputs:

Final demands for space heat, hot water and appliances are exogenous to the model. These are determined based on average space heat and hot water demand for existing and new dwellings from the Scottish House Condition Survey; existing and projected future number of dwellings from the Transport Model for Scotland (used to derive existing and future demand for space heat, hot water and all appliances, except computers and consumer electronics); as well as number of lighting units per dwelling and growth in demand for computers and consumer electronics consistent with the UK TIMES model.

Base year average space heat and hot water demand has been calibrated to account for differences between modelled and actual data, based on data from the UK TIMES model.

New build average demand is lower than for existing homes to account for tightening building standards over time, with the reduction based on data from the Scottish House Condition survey.

Technical potential and cost data for the Residential sector were originally based on UK TIMES, but subsequently the range of conservation measures, as well as their potential future energy savings and costs, were updated to be consistent with NHM outputs based on data from the Scottish House Condition Survey. Potential energy savings from smart meters were taken from the UK Government's Smart Meter Roll-Out (GB): Cost-Benefit Analysis[7]. Smart meters are expected to allow consumers to develop more energy efficient behaviours, leading to reduced energy consumption.

Additional constraints since the Draft Plan:

In addition to updating existing model assumptions, several new constraints have been added to the model since the version underpinning the draft Climate Change Plan. These include, in addition to the Greenhouse Gas Inventory:

- Ensuring a minimum share of future non-electrical heat is supplied by biomass boilers, reflecting current activity levels
- Incorporating smart meters, as detailed above
- Ensuring the phased implementation of conservation measures is in line with expected delivery under Scotland's Energy Efficiency Programme (SEEP), as well as updating the range of measures, their savings and costs to be in line with the NHM for Scotland, as discussed above
- Constraining the potential deployment of district heating to align with figures in the UK's National Comprehensive Assessment of District Heating and Cooling (2015)[8]
- Defining an increasing share of heat and hot water demand in the Residential sector that must be met by low-carbon technologies and fuels (including electricity) over time. The share of heat and hot water demand that must be met by low-carbon technologies and fuels in the final Plan is limited to align with the proportion of properties that are not on the gas grid and advice from the Committee on Climate Change (CCC)

Results:
Energy efficiency saves the equivalent of around 2% of demand for space heat and hot water in 2020, rising to around 15% in 2032.

The breakdown of total space heat and hot water saved by conservation measure is given in the figure below. The figure only shows those conservation measures that have been selected by TIMES and that save at least 0.1 TWh of energy in the TIMES run underpinning the Plan. Energy savings from smart meters are additional to these savings, and are assumed to be around 2% of final space and hot water demand. Cavity wall, floor and solid

[7] https://www.gov.uk/government/publications/smart-meter-roll-out-gb-cost-benefit-analysis
[8] https://www.gov.uk/government/publications/the-national-comprehensive-assessment-of-the-potential-for-combined-heat-and-power-and-district-heating-and-cooling-in-the-uk

wall insulation deliver similar savings, with the proportion of total energy saving delivered by each remaining fairly consistent over the lifetime of the Plan.

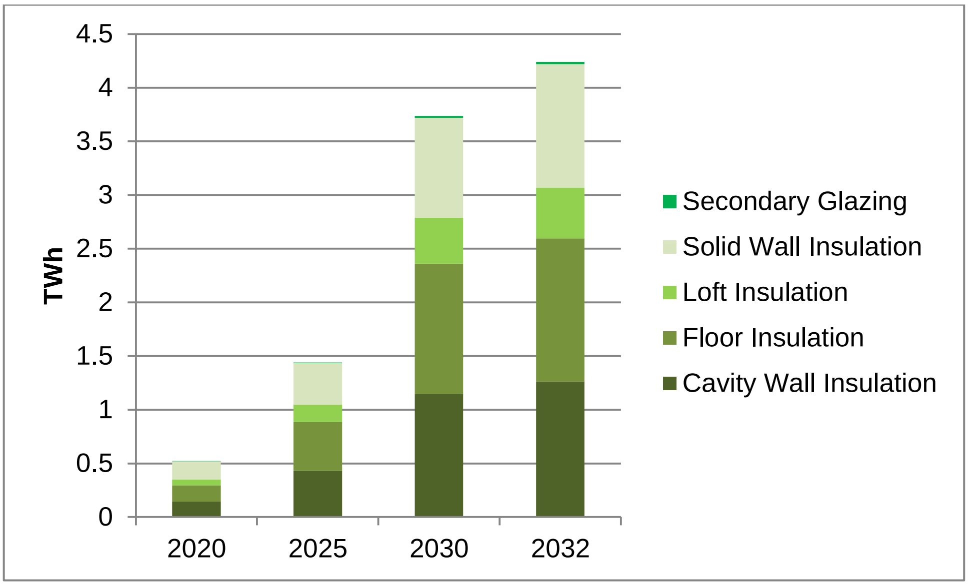

Figure 11: Total Saving (TWh) by Conservation Measure in Residential Sector, TIMES model results

Total fuel use by the Residential sector falls from approximately 47 TWh in 2020 to 38 TWh in 2032. Gas continues to be the main fuel source for households over the lifetime of the Plan but declines in prevalence. The use of electricity falls from 15 TWh in 2020 to 13 TWh in 2032, as a result of energy conservation and efficiency and the use of efficient heat pumps.

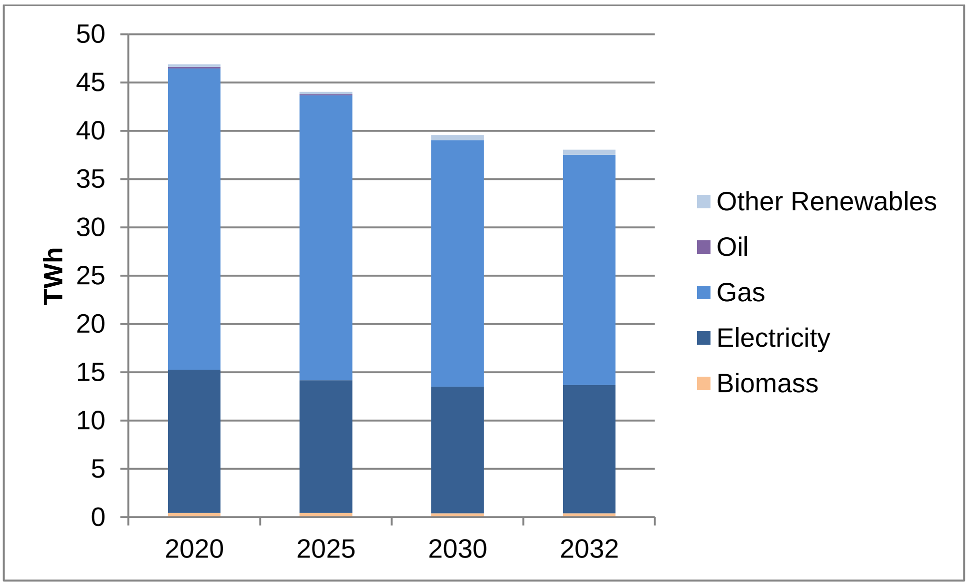

Figure 12: Fuel Use Breakdown (TWh), TIMES model results

Service Sector:

Sector Overview:

The Service sector is broadly defined in the same way as the Residential sector. The primary energy service demands are space heating/cooling, water heating, lighting, computers, cooking, refrigeration and other electricity. The sector is divided into public and private buildings and, within each of those sectors, the building stock is divided into high- and low-energy consumption buildings. The technology options available to the model are very similar to those available in UK TIMES, with the base year stock adapted to reflect the current capacity in Scotland. Data is currently not available on the split of public to private buildings or the current total energy demand in the Scottish Service sector, though there is data development work underway in this area. The public/private buildings split is estimated based on the public/private sector building greenhouse gas emissions in Scotland from the Greenhouse Gas Inventory. Total energy demands are estimated as set out below.

Data Inputs:

Demand for space heat/cooling, hot water and lighting are driven by floorspace projections, based on the UK TIMES model. For computing, cooking, refrigeration and other appliances, demand is based on Scottish Government Gross Domestic Product (GDP) forecasts and the elasticity of energy to GDP from the UK TIMES model.

Technical potential and costs of all technologies for the Services sector are based on UK TIMES. Potential savings from smart meters were taken from the UK Government's Smart Meter Roll-Out (GB): Cost-Benefit Analysis[9].

Additional constraints since the Draft Plan:

New constraints added to the Services sector since publication of the draft Climate Change Plan include the following:

- The share of Scottish non-domestic building energy demand as a share of UK demand has been updated to the most recent data available on the Scottish share of UK non-domestic energy consumption, using data from BEIS

- A minimum share (2%) of future non-electrical heat is now supplied by biomass boilers, reflecting current activity

- Potential energy savings from smart meters are now incorporated in the model, as detailed above

- The phased potential introduction of conservation measures is now in line with expected potential energy savings under the SEEP programme

[9] https://www.gov.uk/government/publications/smart-meter-roll-out-gb-cost-benefit-analysis

Results:

Energy efficiency saves the equivalent of around 2% of demand for space heating and cooling, and hot water in 2020, rising to around 20% in 2032. Savings from smart meters are additional to this and are assumed to be around 4% of total demand for space heating/cooling and hot water.

The breakdown of total space heating and cooling, and hot water saved by conservation measure is given in the chart below.

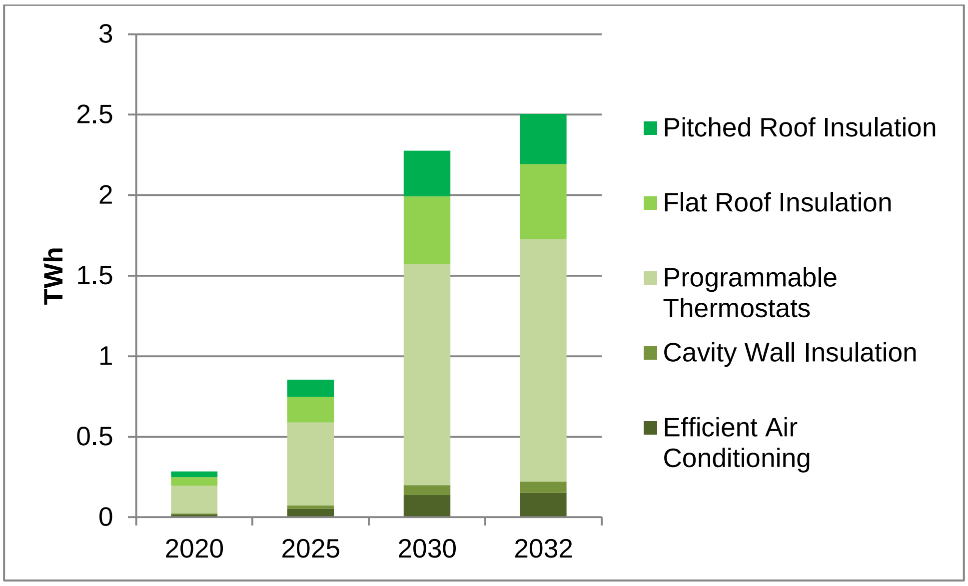

Figure 13: Total Energy Saving by Conservation Measure (TWh), TIMES model results

Total fuel use by the Service sector falls from approximately 20 TWh in 2020 to 14 TWh in 2032. Almost equal shares of gas and electricity are used over the lifetime of the Plan. Gas usage is estimated to reduce from approximately 9 TWh to around 7 TWh in 2032. Electricity use falls from about 9 TWh in 2020 to about 6 TWh in 2032.

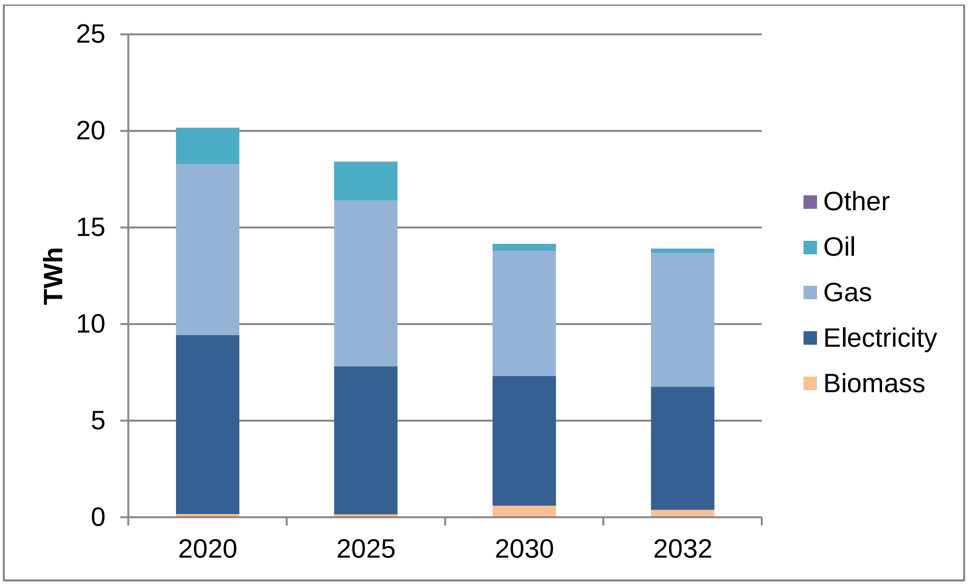

Figure 14: Fuel Use Breakdown (TWh), TIMES model results

Industry

Sector Overview:

Industrial emissions are comprised of three components within Scottish TIMES: A refinery subsector, a hydrogen–manufacturing sector, and a further industrial module composed of six subsectors, which can consume oil products and hydrogen, as well as a range of other primary feedstock and fuels to produce products and meet their final energy demands.

The refining and hydrogen manufacture components are the upstream processing industries that convert primary fuels into secondary products. The industrial component comprises: Chemicals, Cement, Iron & Steel, Food & Drink, Paper & Pulp and other smaller industries.

Data Inputs:

Current final energy demands, estimated future growth rates and costs for each sector were inherited from UK TIMES and scaled down for Scotland, using Scottish data where possible. Figures for industrial base year production were derived from a variety of sources, such as publicly available company data, and analysis published by the UK Government (2015)[10]. All demands were then calibrated to the emissions for each specific industrial sector in the inventory.

Additional constraints since the Draft Plan:

We have constrained the use of biomethane and other biomass in industrial processes fitted with CCS, thereby eliminating the model's ability to produce negative emissions in the industrial sector. We have also delayed the adoption of CCS in all industrial processes until after 2030.

We have ensured that a minimum share of non-electric heat is supplied by biomass boilers, reflecting current activity.

Results:

The figure below presents the breakdown of fuel consumption for energy use by type. There is a shift away from fossil fuels such as natural gas and oil products and towards bioenergy, including waste.

This coincides with a fall in fuel consumption for energy use of over 5% over the period, which reflects the move towards more efficient technologies and processes, in the context of increasing overall demand growth.

[10] https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050

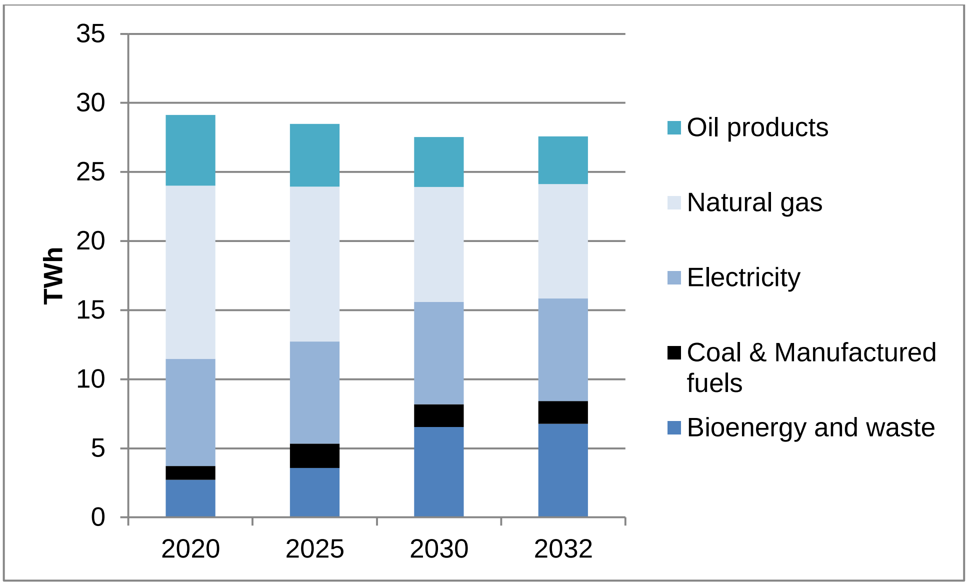

Figure 15: Breakdown of Fuel Consumption for Energy Use by Type (TWh), TIMES model results

The volumes of hydrogen produced throughout the Plan remain low, with negligible production in 2020, increasing to around 0.4 TWh in 2032. Until 2030, all hydrogen is made from Steam Methane Reforming. After 2030, there is a shift towards the manufacturing of hydrogen from Steam Methane Reforming with CCS. CCS has been constrained until after 2030 and, as a result, there are negligible levels of captured emissions by 2032.

***Transport*:**

Sector Overview:

The Transport sector is incorporated into TIMES in the same way as other energy sectors, with a set of final energy demands that must be met using a range of technologies (diesel, electric and hybrid vehicles amongst others) with varying efficiencies, costs and lifetimes. These technologies each consume one or more inputs, such as electricity or petrol, which are manufactured within the rest of the system or can be imported. As a result, demands in the transport sector compete for resources with other sectors.

The emission projections and fuel shares for Transport in the draft CCP were based on data provided by Transport Scotland and sourced from research by Element Energy, providing a detailed representation of the transport sector in Scotland. These were incorporated into TIMES by aligning the emissions and fuel shares in TIMES to those in Element Energy. The original projections and fuel shares have now been updated following the Programme for Government announcement on phasing out the need to buy petrol and diesel engine cars and vans by 2032, and have been coded into TIMES. Changes in the transport fuel shares incorporated in TIMES will ripple through the rest of the system, as Transport supply chains are fully incorporated into the model.

In future, we will aim to increasingly align underlying parameters for the sectors, such as efficiencies and costs by mode, with those supporting Element Energy, which will allow us to produce greater granularity of results in TIMES.

Data Inputs:

During the course of developing the Plan, it became clear that Transport Scotland's commissioned research, undertaken by Element Energy, offered additional detail over the core TIMES Transport module and, as such, it was used to develop the Transport fuel shares by subsector and emissions envelopes. Element Energy's work included the construction of a detailed Scottish vehicle database, including number, age and turnover of the Scottish vehicle parc, a peer review of their database of technology costs across transport modes (used to refine their cost models for alternative fuels and technologies) and finally, used their consumer demand model to develop realistic scenarios for the take up of alternatively fuelled vehicles, particularly cars. Finally, demands for air travel and shipping, including both domestic and international, are incorporated into the overall transport demand and energy requirements.

Data for the Transport sector has been sourced from UK TIMES, the Transport Model for Scotland, Scottish Transport Statistics, the Scottish Government's Energy in Scotland publication, as well as publications from BEIS and Ricardo-AEA.

Additional constraints since the Draft Plan:

Fuel shares and emissions envelopes resulting from the Element Energy work have now been adjusted for the Programme for Government announcement and coded into TIMES so that their wider impact on the energy system can be considered.

Results:

The figure below shows the TWh breakdown of fuel consumption in the Transport sector. By 2032, the share of petrol and diesel falls by around 17 percentage points over 2020 levels. At the same time, there is a general increase in all other fuels, in particular electricity, which increases by nearly 9 percentage points over the period, reaching around 10% in 2032.

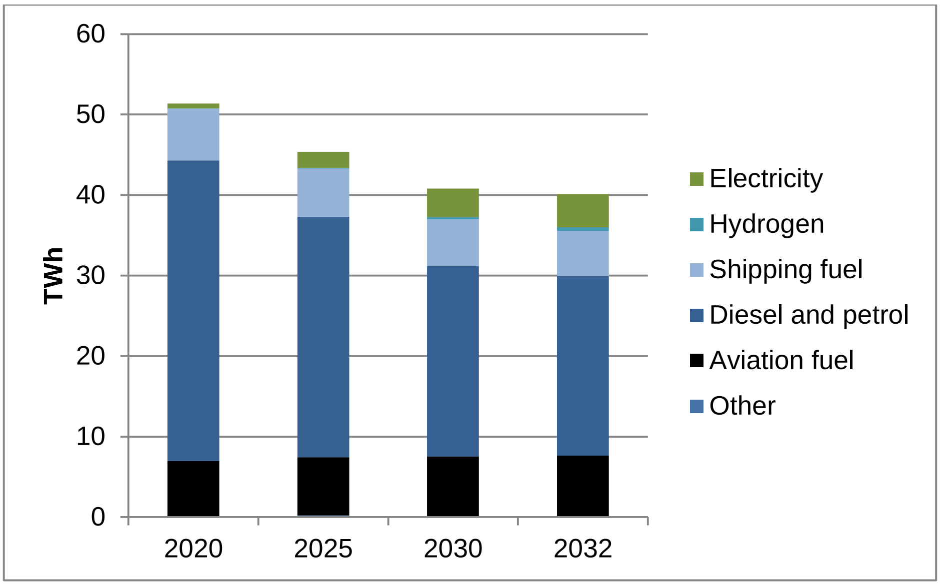

Figure 16: Fuel Mix for Transport (TWh), TIMES results based on Element Energy fuel shares, adjusted where appropriate to take into account the Programme for Government announcement

Overall, energy used to power transport falls by over a fifth between 2020 and 2032, as a result of an increase in the efficiency of future transport and the move towards electric cars and vans, which are significantly more energy efficient than existing engines.

Agriculture:

Sector overview:

The Agriculture sector includes all energy consuming processes related to Agriculture, as well as land use and non-energy processes. Relative to the UK, Agriculture is a more important sector in Scotland. Scottish TIMES considers the energy demands for heat and transport related to agricultural activities. It also includes baseline land use emissions, as well as emissions from agricultural practices. Non-energy emissions were calculated exogenously following discussion with sector teams and mapped into Scottish TIMES.

Data inputs and additional constraints since the Draft Plan:

We have incorporated the latest 2015 Greenhouse Gas Inventory data, which has resulted in a revised emissions profile for non-energy agricultural emissions.

Agricultural transport and heat data has been inherited from UK TIMES, while fuel efficiency data has been adapted from figures sourced from Scotland's Rural College. Since the Draft Plan, the rate of change in agricultural transport demand has been revised to reflect the downward trend in baseline non-energy emissions.

Results:

The below chart breaks down emissions within the Agricultural sector by source. While energy emissions (from agricultural transport, given that agricultural heat is decarbonised by 2020) remain relatively constant throughout the period and amount to around 0.6 MtCO2e, non-energy emissions fall by over 9% between 2020 and 2032.

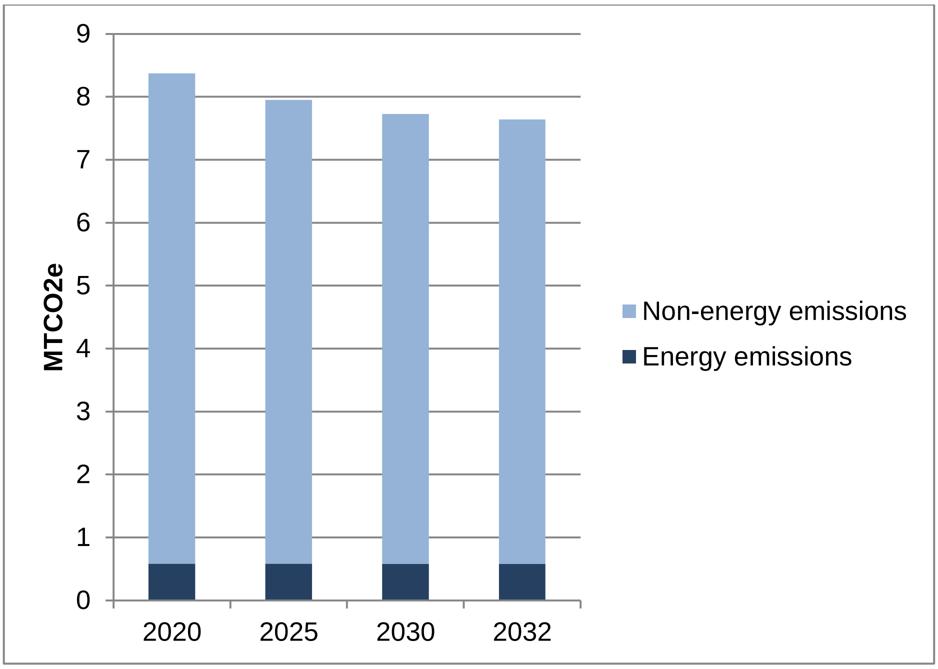

Figure 17: Agricultural emissions by component (MtCO2e), TIMES model results

Waste:

Sector Overview:

The Waste sector is incorporated as a potential source of energy input to other sectors. Scottish Government policies around reducing waste are also captured in the declining waste emissions envelope. The envelope was generated using the Scottish waste emissions model, and was coded into TIMES.

Data inputs and additional constraints since the Draft Plan:

The waste emissions model has been updated for the latest Greenhouse Gas Inventory, with the emissions profile in future years adjusted to reflect this update.

Since the draft Climate Change Plan, tonnages of organic and inorganic municipal solid waste, wet biomass waste and landfill gas, available as resource inputs to the model, have been updated to be in line with data from Zero Waste Scotland, thereby ensuring that the volume of waste that can be drawn on to satisfy energy demand is consistent with Scottish Government waste targets. Availability estimates for sewage sludge and animal slurry have been updated to reflect the latest data from a study commissioned by BEIS from Ricardo, scaled to Scotland using total waste availability in Scotland, relative to the UK from the Scottish Environment Protection Agency (SEPA) and the UK Department for Environment, Food and Rural Affairs (DEFRA), and cattle numbers from the Scottish Agricultural Census.

Results:

The figure below shows how waste in used throughout the period of the Plan. Some waste goes directly to the sectors, where it feeds directly into energy generation technologies; some is used upstream of the sectors in anaerobic digestion (AD) plants, the output of which is upgraded to biomethane and injected into the gas grid. The quantity of waste used increases to 2025, falling back to around 2.8 TWh per annum from 2030, with industry consuming the largest proportion. The higher volume used in 2025 is down to use of municipal solid waste in Industry, as fuel in combined heat and power (CHP) steam turbines, which, in later years, shifts to using non-waste biomass feedstock.

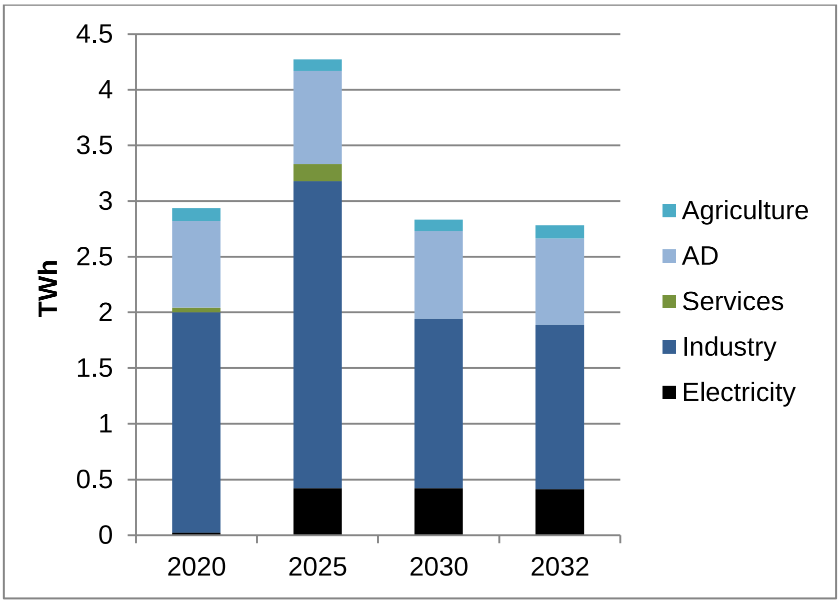

Figure 18: Waste Use by Sector (TWh), TIMES model run

In the industrial sector, waste is primarily used as a heat source and in Combined Heat & Power. Waste is also used as fuel in waste combustion plants to generate electricity. Over the period waste accounts for around 2% increasing to just under 3% of all primary energy supplied to the system.

Land Use, Land-Use Change and Forestry (LULUCF) Sector:

Sector Overview:

The LULUCF sector is a carbon sink throughout the period of the Plan. The sector includes:

- Baseline woodland creation

- Baseline carbon capture in harvested wood products

- Baseline other land use and land-use change, comprising:
  - Settlements
  - Indirect nitrous oxide emissions from managed soils
  - Cropland
  - Grassland
  - Wetlands

- Afforestation

- Peatland restoration

Data Inputs:

Projected future baseline land use areas and emissions were provided by BEIS, consistent with their Updated Emissions Projections[11], and are taken from analysis from the Centre for Ecology and Hydrology (CEH).

Afforestation rates are as advised by the Forestry Commission and future peatland restoration rates are as advised by the Rural Environmental Science and Analytical Services team in Scottish Government.

Additional constraints since the Draft Plan:

Since the draft Climate Change Plan, we have made a number of updates to the TIMES model, in addition to incorporating the latest historic GHG Inventory data.

The draft Plan was based on baseline emissions and land use projections produced by CEH in 2013, which, at the time of publication of the draft Plan, were the most up-to-date projections available.

We have now updated the baseline emissions and land-use projections used in TIMES to reflect a number of recent data developments.

The 2015 Greenhouse Gas Inventory, published in June 2017, included a number of changes to the treatment of historic LULUCF emissions. These included:

- Using the National Forest Inventory dataset (2011-2015), rather than the less timely National Inventory of Woodland and Trees (1995-99)

- Including woodland between 0.1 and 0.5 hectares in area

[11] https://www.gov.uk/government/collections/energy-and-emissions-projections

- Including carbon stock changes in biomass from cropland management and grassland management

- Incorporating revisions around planting on organic soils

The new emissions and land-use projections, which were provided by BEIS and produced by CEH, and used in the final Plan, incorporate the above changes, as well as further changes, including:

- Previously, CEH assumptions did not consider that trees are planted on soil that is covered with plants and litter from ground vegetation, which sequester carbon. They have now included these assumptions in the model, recognising that while planting trees will lead to emissions from the soil, this will be balanced by the carbon sequestration by these plants and litter on the soil

- The CEH has also made changes to the assumptions used in incorporating small woodland (0.1-0.5 hectares) in their modelling

The above changes will be reflected in the 1990 - 2016 GHG Inventory, alongside other updates, which will be published in June 2018.

The new projections, together with a slight amendment to peatland restoration rates, increase the scale of the carbon sink across the LULUCF sector by approximately 6 MtCO2e on average, relative to the sector data used in the draft Plan.

CO_2 removals from woodland planting which would have occurred without policy intervention were removed from the new planting figures to avoid double-counting baseline afforestation.

Results:

Total net removals for the sector reach 6.9 $MtCO_2e$ in 2020, which is largely due to baseline forestry removals of 10.7 $MtCO_2e$ in 2020. Total net removals fall slightly to 6.5 MtCO2e by 2030, due to a fall in baseline forestry removals and a slight increase in emissions from other land. Total net removals increase to 6.7 $MtCO_2e$ by 2032, due to an increase in removals from afforestation and peatland restoration.

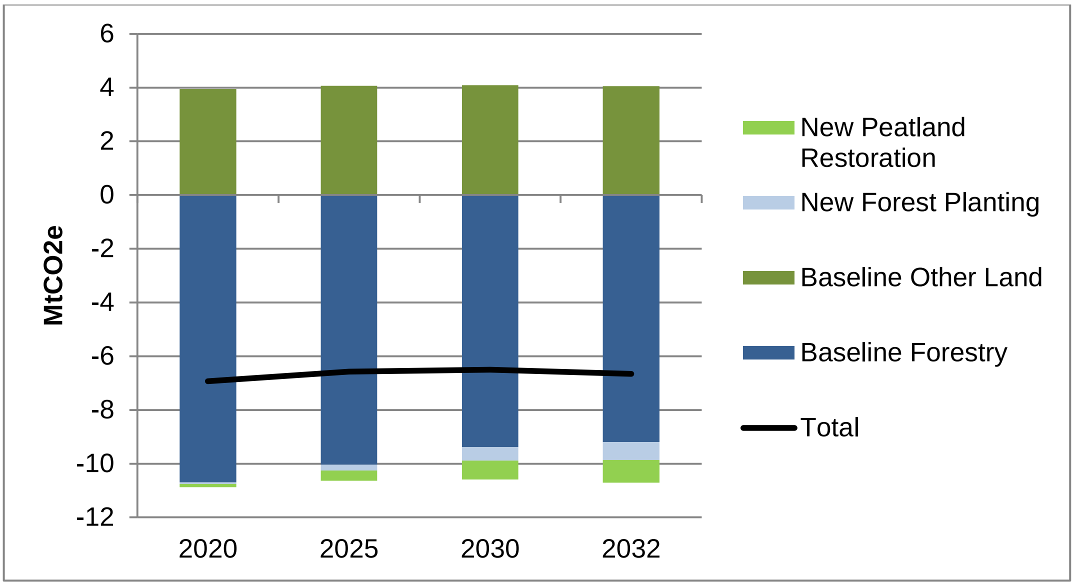

Figure 19: Breakdown of Emissions/Removals for LULUCF Sector (MtCO2e), TIMES model results

Resources

Overview

This encompasses all domestically produced and imported/exported primary resources.

The energy resources are available to the model directly, through processing technologies, or through infrastructure networks. The model aims to find the cost optimal mix of import, export and domestic creation of primary and secondary energy forms to meet the energy service demands.

Primary resources are broadly broken down into:

- Fossil fuels
- Biomass and Waste
- Nuclear
- Renewables

Data Inputs and additional constraints since the Draft Plan:

Primary energy supply data from the Scottish Government's Energy Balance provides the resource base year availability data for fossil fuels, nuclear and renewables that feed into TIMES. Biomass potential availability assumptions have been updated since the draft Plan. They were sourced from a study commissioned by BEIS from Ricardo, the latest emissions and land-use projections from the Centre for Ecology and Hydrology (CEH), the Forestry Commission (FC) and DEFRA. They represent a reduction in the amount of biomass available across the system relative to availability in the draft plan. Waste availability assumptions have also been updated as outlined in the Waste section above.

Results:

The figure below shows the proportion of each fuel consumed by the system between 2020 and 2032. These represent final energy consumption, and as a result do not include energy fuels used to manufacture intermediate fuels such hydrogen, and electricity. The share of low-carbon fuel inputs (including electricity) increases by around 10 percentage points, reaching approximately 35% in 2032[12]. This is driven by increases in the share of both bioenergy (including waste) and renewable electricity, while the share of oil products and natural gas falls by 8 and 1.5 percentage point respectively, over the period.

This switch in fuels takes place in the context of falling energy used, as a result of improved system efficiency and conservation measures, which see overall energy used fall by around 17% between 2020 and 2032.

[12] The share of low carbon fuel meeting final demand is higher, as these figures do not include the impact of ambient heat output from heat pumps.

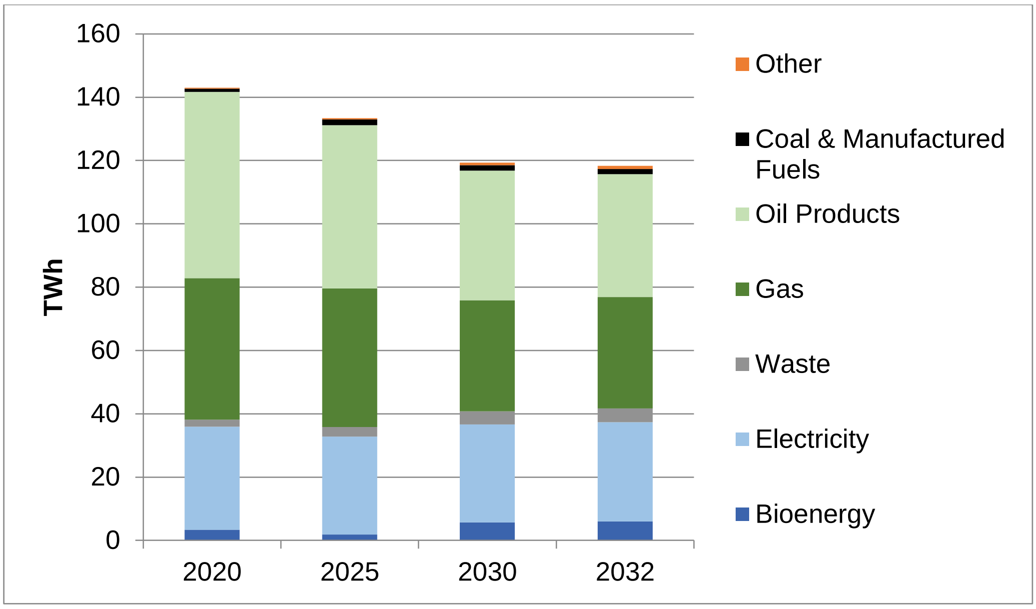

Figure 20: Fuel Use in the Scottish system (TWh), TIMES model results

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