

# Representation of the UK Emissions Trading Scheme in Scottish TIMES

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## 1 Executive summary

### 1.1 Aims and findings

Scotland is part of the UK Emissions Trading Scheme (UK ETS), the United Kingdom's carbon emissions trading scheme. The scheme places an overall limit on emissions from large industrial sites and airlines, and facilitates the trading of emissions allowances within this limit.

The Scottish Government would like to understand how emissions from sites subject to the UK ETS are likely to evolve over the transition to net zero greenhouse gas emissions and the implications of steadily reducing the number of permits in the emissions trading scheme.

This study introduced a UK ETS accounting mechanism to the Scottish TIMES model, which is a diagnostic tool to help understand the key inter-relationships across the energy system. This will enable the Scottish Government to investigate these questions.

The Scottish TIMES model is being used by the Government to produce a new net zero pathway for Scotland to support its new Climate Change Plan.

Scottish TIMES does not distinguish between ETS and non-ETS emissions. By adding this capability, ETS emissions can be constrained separately to the overall Scottish emissions target.

The proportion of emissions subject to ETS was estimated for each sub-sector of Scottish TIMES and used to calculate ETS emissions in the model. A flexible mechanism was created to try to enable future changes to the UK ETS to be easily implemented. We created example scenarios with emission constraints and taxes for ETS emissions. A series of tests demonstrated that the model was working correctly.

## 1.2 Recommendations

Based on our research, we recommend that the Scottish Government consider:

- reviewing the ETS sites against the Scottish Greenhouse Gas Statistics to ensure that the data in both are accurate and consistent.
- cross-referencing the ETS site emissions and energy consumption, the Scottish Greenhouse Gas Statistics and the Scottish energy balance, to ensure that all sites in Scotland that are required to participate in the ETS are registered.
- ensuring the representation of gas networks in Scottish TIMES is consistent across the model and that the emission coefficients reflect all gas system losses.
- reviewing modelled emissions against actual emissions for the year 2020 to identify sectors of the economy where unrealistic decarbonisation pathways might have been created, and constrain those pathways appropriately.

# Contents

1	Executive summary .....	1
1.1	Aims and findings .....	1
1.2	Recommendations .....	2
2	Abbreviations .....	4
3	Introduction .....	5
3.1	UK emissions accounting .....	5
3.2	Scottish UK ETS emissions .....	6
3.3	Structure of this report .....	6
4	Method .....	6
5	Analysis of emissions covered by the UK ETS .....	8
5.1	Scottish Emissions Inventory .....	10
5.2	Scottish ETS emissions for stationary sites .....	11
5.3	Scottish ETS aviation emissions .....	16
6	Scottish TIMES UK ETS implementation .....	17
7	Quality assurance .....	18
8	Conclusions and recommendations .....	18
9	References .....	19

## 2 Abbreviations

AR4	Assessment Report 4 from the IPCC
AR5	Assessment Report 5 from the IPCC
CCP	Climate Change Plan
CHP	Combined heat and power
EU ETS	European Union Emissions Trading Scheme
GHG	Greenhouse gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
MW	Megawatts
OPRED	Offshore Petroleum Regulator for Environment and Decommissioning
PFC	Perfluorocarbons
SEPA	Scottish Environment Protection Agency
TIMES	An energy system model generator developed by the Energy Technology Systems Analysis Program (ETSAP), which is an International Energy Agency technology collaboration programme.
UK ETS	United Kingdom Emissions Trading Scheme
UNFCCC	United Nations Framework Convention on Climate Change

## 3 Introduction

Scotland is part of the UK Emissions Trading Scheme (UK ETS). The Scottish Government wishes to: (i) understand how emissions from sites subject to ETS are likely to evolve over the transition to net zero; and, (ii) understand the implications of steadily reducing the number of permits in the emissions trading scheme on the transition.

The Scottish TIMES model is being used as part of a suite of analyses to inform a new net zero pathway for Scotland to support a new Climate Change Plan. The Scottish TIMES energy system model is built using the TIMES platform, which is developed by an International Energy Agency (IEA) technology collaboration programme and used in 63 countries. It contains a detailed and up-to-date depiction of all Scottish energy flows and greenhouse gas (GHG) emissions. It explores the potential future benefits of a wide range of low-carbon fuels and technologies.

Scottish TIMES currently does not distinguish between ETS and non-ETS emissions. Adding this capability to Scottish TIMES would enable ETS emissions to be constrained separately to the overall Scottish emissions target, or for different targets to be used for ETS and non-ETS emissions.

### 3.1 UK emissions accounting

The United Kingdom (UK) uses a range of approaches to emissions accounting for different applications:

- The United Nations Framework Convention on Climate Change (UNFCCC) accounting follows UNFCCC guidelines (e.g. moving from Assessment Report 4 (AR4) to Assessment Report 5 (AR5) global warming potentials by the end of 2024; counting F-gases separately).
- UK Climate Change Act 2008: restricts emissions of 6 GHGs/groups of GHGs.<sup>1</sup> The Scottish emissions budget includes all international aviation and shipping, and the UK Government has agreed to include international aviation and shipping from Carbon Budget 6 (2033–2037).
- The UK ETS applies to regulated activities that result in greenhouse gas emissions, including combustion of fuels on a site where combustion units with a total rated thermal input exceeding 20 megawatts (MW) are operated (except in installations where the primary purpose is the incineration of hazardous or municipal waste) (UK Government, 2023). Sites in Northern Ireland are excluded as these are part of the EU ETS instead. The UK ETS also includes domestic aviation and flights to Gibraltar and the European Economic Area. Other international aviation and all shipping are not included but could be in the future. Scottish participants can trade with the rest of the UK and might be able to trade with other non-UK ETSs in future.
- Some other schemes include non-UK emissions, for example for biomass sustainability.

We aimed to develop an emissions aggregation structure in Scottish TIMES in which all of these applications could be accounted for easily and transparently. We designed the approach to be relatively flexible to changes in these schemes (e.g. for shipping to be added to the ETS in the future).

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<sup>1</sup> The Climate Change Act 2008 covers CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub> and NF<sub>3</sub>. NF<sub>3</sub> was added in 2023. The base year for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O is 1990, and for the other gases it is 1995.

## 3.2 Scottish UK ETS emissions

The UK ETS replaced the UK's participation in the European Union Emissions Trading Scheme (EU ETS) on 1 January 2021. It covers emissions from two broad parts of the economy (UK Government, 2023a):

1. Large industrial sites and power stations.
2. Domestic aviation and flights to Gibraltar and the European Economic Area.

Each static site in the UK is treated individually. Regulation is devolved, with the Scottish Environment Protection Agency (SEPA) regulating Scottish sites. There are 72 sites in total in Scotland. *Table 1* shows that most emissions are from a small number of power stations and large industrial plants.

All UK offshore oil and gas sites are regulated by the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) rather than SEPA. Many of these sites will be in Scottish waters. As Scottish TIMES does not cover offshore emissions, these were not included in this study. Offshore emissions are not part of Scottish territorial emissions and therefore are not included in Scotland's Climate Change Plan either.

Aviation emissions are regulated in the country in which the operator is registered. Only one airline (Loganair) is registered in Scotland but many more aviation emissions involve Scotland.

## 3.3 Structure of this report

The methodology we used is discussed in Section 4. Section 5 analyses Scottish emissions covered by the ETS and derives ETS fractions for each Scottish TIMES sub-sector. Section 6 describes how we implemented ETS emissions accounting in Scottish TIMES. Section 6 discusses our quality assurance approach.

# 4 Method

The analytical approach we used is summarised in *Figure 1*.

The key challenges were estimating the fraction of emissions from each Scottish TIMES sub-sector that are covered by the UK ETS, or might be covered in future, and then to implement an accounting system for these emissions in Scottish TIMES.

The fraction of emissions covered by the UK ETS was estimated using two approaches. First, all ETS emission stationary sites and each overall emission category was assigned to a Scottish TIMES sub-sector (Sections 5.1 and 5.2). The total emissions in each sub-sector were then compared to estimate the fraction of emissions in the sub-sector covered by the UK ETS. A separate analysis was carried out for international aviation emissions, as only international flights to the EU are included in the UK ETS and only UK-wide statistics on flights were available from ETS statistics. Instead, an analysis of flights from Scottish airports was used to estimate the fraction of fuel use for EU destinations (Section 5.3).

A detailed accounting system for ETS and non-ETS emissions was implemented in the "ets\_ucl" branch of Scottish TIMES by sub-sector (Section **Error! Reference source not found.**). A number of wider model changes were required to implement this accounting system. New example scenarios were created to separately limit ETS emissions from total emissions (Section **Error! Reference source not found.**) and to apply a carbon tax on ETS emissions (Section **Error! Reference source not found.**). The revised

model was checked carefully to ensure that all emissions were covered (Section **Error! Reference source not found.**).

Table 1: Summary of Scottish sites subject to the UK ETS and their associated GHG emissions

Description	Number of sites	GHG emissions (ktCO <sub>2</sub> e)	
		2021	2022
Production of electricity	16	1973	2181
Manufacture of other organic basic chemicals	2	1289	1304
Manufacture of refined petroleum products	2	910	1149
Extraction of natural gas	5	552	574
Steam and air conditioning supply	1	564	530
Manufacture of cement	1	459	444
Extraction of crude petroleum	2	350	322
Distilling, rectifying and blending of spirits	10	246	267
Distribution of gaseous fuels through mains	6	203	215
Manufacture of hollow glass	2	189	199
Manufacture of basic pharmaceutical products	2	136	130
Manufacture of veneer sheets and wood-based panels	3	96	77
Aluminium production	1	61	51
Manufacture of other rubber products	1	57	45
Manufacture of paper and paperboard	2	57	39
Tertiary education	2	33	32
Manufacture of other food products	1	30	27
Treatment and disposal of non-hazardous waste	1	20	22
Defence activities	2	24	21
Manufacture of plastics in primary forms	1	18	16
Operation of dairies and cheese making	1	11	10
Manufacture of other non-metallic mineral products	2	8	8
Manufacture of basic iron and steel and of ferro-alloys	2	10	7
Manufacture of bricks, tiles and construction products, in baked clay	1	6	6
Quarrying of ornamental and building stone, limestone, gypsum, chalk and slate	1	7	6
Forging, pressing, stamping and roll-forming of metal; powder metallurgy	1	9	4
Engineering activities and related technical consultancy	1	2	1

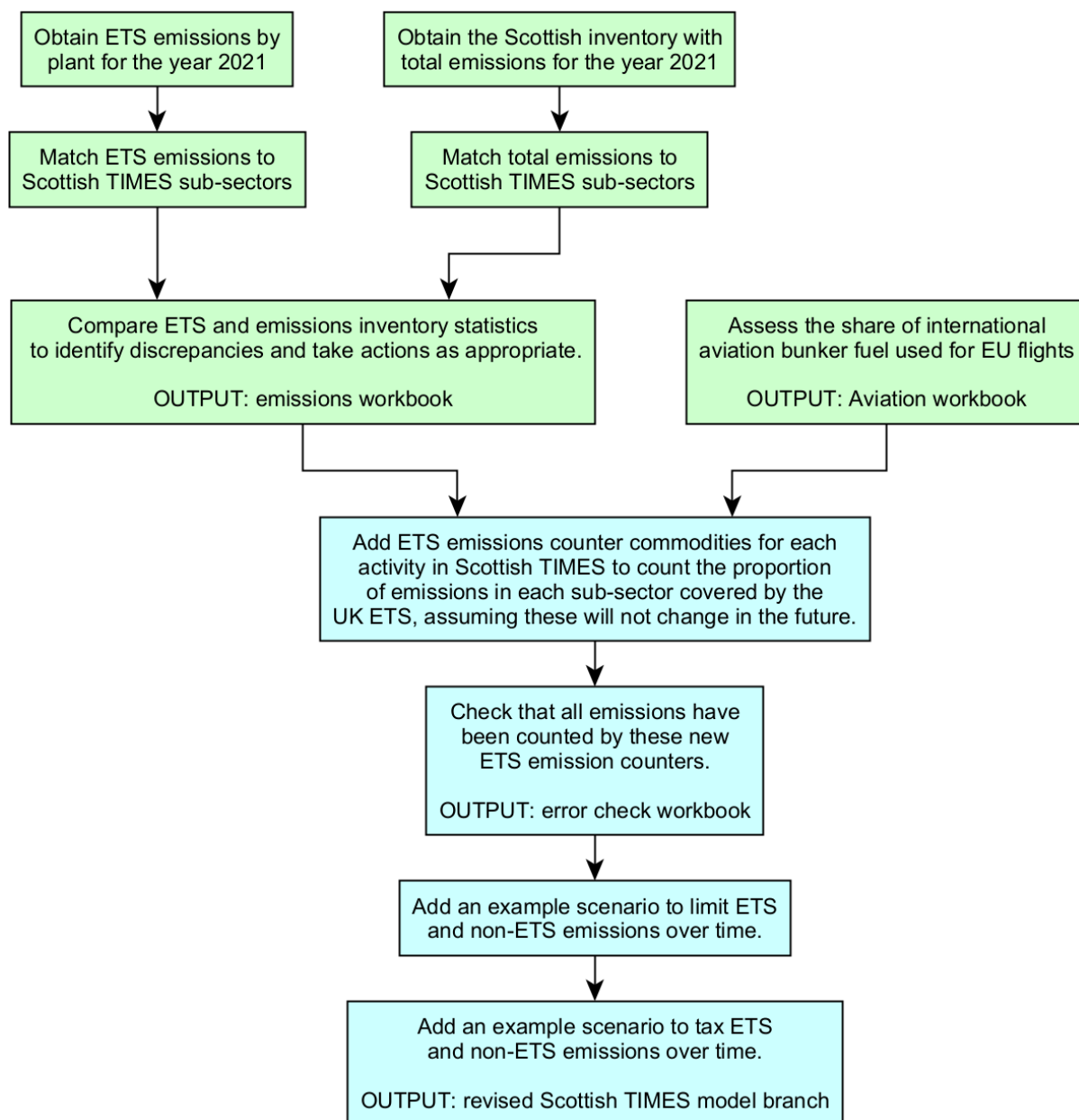


Figure 1. Analytical approach taken by this project

## 5 Analysis of emissions covered by the UK ETS

In Scottish TIMES, emissions accounting could be implemented at the level of sectors (e.g. industry; transport), sub-sectors or individual technologies. Sectors can be quite broad in nature so applying the scheme across a whole sector would be inappropriate as emissions could be cut in areas not subject to the ETS. As individual technologies require a level of detail for the real-world economy that is not available in the model (e.g. categorising all food and drink industries in what is a very diverse sector), this was not a practical option. We therefore estimated fractions by sub-sector and where possible chose our sub-sectors to reflect sites that were likely or not to be part of the ETS.

Table 2 shows the Scottish TIMES sub-sectors that were used to categorise ETS activities and Scottish Greenhouse Gas Statistics data. Sites with larger emissions such as refineries, upstream oil and gas and chemical plants are in sub-sectors where most emissions are subject to the ETS.



Table 2: Scottish TIMES sectors, sub-sectors, and descriptions

Sector	Description	Sub-sector	Description
<b>AGR</b>	Agriculture	Crops & livestock	Crops & livestock
		Energy	Energy
		Land use	Land use and forestry
<b>All</b>		Gas distribution	Gas distribution networks
<b>ELC</b>	Electricity generation and power grids	EfW	Energy from waste plants
		Other	All other generation
<b>IND</b>	Industry	ICH	Chemicals
		ICM	Cement
		IFD	Food, drink, and tobacco
		IIS	Iron & steel
		INF	Non-ferrous metals
		INM	Non-metallic minerals
		IPP	Paper
		IOFFD	Off-road mobile machinery
		IOI	Other industry
<b>PRC</b>	Processing and infrastructure	Bioenergy	All bioenergy processes
		Uranium	Nuclear fuel production
		Refineries	Oil refinery
		Waste	Waste processes
		Other fossil	e.g. coke manufacturing
<b>RES</b>	Residential	RH	All heating
		Other	Other
<b>RSR</b>	Resources and trade	Mining	UK resource extraction
		Upstream oil and gas	Upstream processing
<b>SER</b>	Services	SH	High-consumption heating
		Other	Other
<b>TRA</b>	Transport	TAD	Domestic aviation
		TAI	International aviation
		TB	Buses
		TC	Cars
		TH	Heavy goods vehicles
		TL	Light goods vehicles
		TR, TF	Rail passengers and freight
		TSD	Domestic shipping
		TSI	International shipping
		TW	Two-wheel vehicles
		Other	Other

## 5.1 Scottish Emissions Inventory

Scotland publishes Scottish Greenhouse Gas Statistics annually (hereafter “Emissions Inventory”). For each entry in the Emissions Inventory (Scottish Government, 2023), we added two fields representing the most appropriate Scottish TIMES sector and sub-sector from *Table 2*. Sectors and sub-sectors were allocated according to the following fields in the Emissions Inventory: Climate Change Plan (CCP) category, Intergovernmental Panel on Climate Change (IPCC) codes and source name.

Some emissions are not explicitly represented in Scottish TIMES and were categorised as “None”. The sources of these emissions are listed in *Table 4* summarises the allocation of Scottish GHG emissions in 2021 to each of the Scottish TIMES sub-sectors. One of the challenges is that the IPCC codes used in the inventory do not map easily onto technologies in the energy system. In some cases, a technology produces emissions that map onto more than one IPCC code. For example, industrial plants with process emissions map to both combustion and process emissions codes. Another challenge is that some IPCC codes aggregate emissions from a diverse set of plants, particularly “Other industrial combustion” (IPCC code 1A2gviii) and “Miscellaneous industrial/commercial combustion” (1A4ai), which together accounted for almost 7% of Scottish emissions in 2021. These codes were both allocated to the “industrial other (IOI)” sub-sector.

It is likely that emissions from some of the other industrial sectors, and possibly also the service sector, are included in these two codes and hence allocated to the IOI sub-sector.

## 5.2 Scottish ETS emissions for stationary sites

The UK ETS publishes a compliance report containing emissions for each site and each airline. We used the 2023 publication (UK Government, 2023b).

We assigned each of the 72 sites in Scotland subject to the ETS individually to a Scottish TIMES sub-sector. One challenge was that the NACE description did not always accurately describe the plant operation. For example, the Sullom Voe Terminal description is extraction of natural gas, but it is primarily an oil terminal. The Shell UK Limited Fife NGL Plant description is manufacture of refined petroleum products, but plant best fits into the chemical industry rather than the oil refining sector.

### 5.2.1 Matching Scottish ETS emissions to Inventory emissions

We checked this designation and also assigned IPCC codes that were consistent with the Emissions Inventory where possible. This is challenging for oil and gas upstream and downstream sectors in particular as these are broad and complex in Scotland, so a good understanding of the sector is required to properly assign the plants to the Inventory. For example, Grangemouth combined heat and power (CHP) plant is counted under chemicals in the Inventory, while Grangemouth Infrastructure is counted under refineries, despite both being CHP plants at the same site.

One approach we used was to compare site emissions against the NAEI “Large Point Sources” emissions dataset for the year 2021 (UK Government, 2023c). However, there were notable errors and omissions in the version of the data source we consulted, with several sites having CO<sub>2</sub> emissions missing and many sites having incorrect location data (e.g. Scottish sites categorised in other UK countries, and vice versa), so not all sites could be identified in the Inventory.

Table 3. In total, they comprised only 0.5% of Scottish emissions in 2021.

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Table 3: Emission sources in the Scottish Inventory not represented in Scottish TIMES

Source	Source (continued)
Abandoned oil wells (offshore)	Oil Terminal: Venting
Abandoned oil wells (onshore)	Oil transport fugitives: pipelines (onshore)
Accidental fires – dwellings	Oil transport fugitives: pipelines (to shore)

<sup>2</sup> NACE is “Nomenclature of Economic Activities”, the European statistical classification of economic activities.

Accidental fires – other buildings	Oil transport fugitives: road tankers
Accidental fires – vehicles	Onshore natural gas gathering
Agricultural engines	Onshore natural gas production (conventional)
Anaerobic Digestion (other)	Onshore oil production (conventional)
Closed Coal Mines	Onshore oil production: gas flaring
Coal storage and transport	Onshore oil well exploration (conventional)
Composting (at household)	Open-cast coal
Deep-mined coal	Petroleum processes
Domestic Closed Stove – Basic	Recreational use of N2O
Domestic Closed Stove – EcoDesign	Road vehicle engines
Domestic Closed Stove – Upgraded	Sewage sludge decomposition
Domestic Fireplace – Standard	Sewage sludge decomposition in private systems
Domestic Outdoor	Small-scale waste burning
Gas Terminal: Gas Flaring	Total composting (non-household)
Gas Terminal: Other Fugitives	Upstream Gas Production – flaring
Gas Terminal: Venting	Upstream Gas Production – fugitive emissions
Incineration	Upstream Gas Production – Offshore Well Testing
Incineration – chemical waste	Upstream Gas Production – venting
Incineration – clinical waste	Upstream Gas Production: direct process emissions
Incineration – sewage sludge	Upstream Oil Production – flaring
Industrial engines	Upstream Oil Production – fugitive emissions
Industrial Waste Water Treatment	Upstream Oil Production – Offshore Oil Loading
Marine engines	Upstream Oil Production – Offshore Well Testing
Mechanical Biological Treatment – Anaerobic Digestion	Upstream Oil Production – Onshore Oil Loading
Mechanical Biological Treatment – Composting	Upstream Oil Production – venting
N2O use as an anaesthetic	Upstream Oil Production: direct process emissions
Oil Terminal: Gas Flaring	Well exploration (unconventional gas): all sources
Oil Terminal: Other Fugitives	

Table 4. Allocated Scottish GHG emissions in each Scottish TIMES sub-sector in the year 2021. Units: MtCO<sub>2e</sub>

Sector	Sub-sector	GHG	Sector	Sub-sector	GHG
AGR	Crops & livestock	6.9	RES	Other	0.2
AGR	Energy	0.9	RES	RH	5.8
AGR	Land use	0.4	RSR	Mining	0.0

All	Gas distribution	0.2		RSR	Upstream oil and gas	1.6
ELC	EfW	0.3		SER	Other	0.4
ELC	Other	1.3		SER	SH	1.1
IND	ICH	2.3		TRA	Other	0.2
IND	ICM	0.5		TRA	TAD	0.2
IND	IFD	0.6		TRA	TAI	0.4
IND	IIS	0.0		TRA	TB	0.3
IND	INF	0.1		TRA	TC	4.7
IND	INM	0.1		TRA	TH	1.9
IND	IOFFD	0.5		TRA	TL	1.8
IND	IOI	3.5		TRA	TR, TF	0.1
IND	IPP	0.1		TRA	TSD	1.7
PRC	Bioenergy	0.0		TRA	TSI	0.3
PRC	Other fossil	0.1		TRA	TW	0.0
PRC	Uranium	0.0		None		0.2
PRC	Refineries	1.3		Total		41.6
PRC	Waste	1.5				

We encountered similar challenges as those for the Emissions Inventory described in Section 5.1. For example, glass manufacturers have process emissions (2A3: “glass production”) but most of their emissions are from combustion and are aggregated with many other industries in “Other industrial combustion” (1A2gviii). Some of these sites did not have CO<sub>2</sub> emissions recorded in the NAEI “Large Point Sources” emissions dataset (UK Government, 2023c), perhaps because they are split across IPCC codes. We could not find some other Scottish industrial plants included in the ETS in the NAEI “Large Point Sources” emissions dataset at all.

**Recommendation:** review the ETS site emissions against the NAEI “Large Point Sources” emissions dataset to ensure that the data in both are accurate and consistent, and investigate causes of any discrepancies.

Only three of eighteen plants<sup>3</sup> generating electricity using waste as a feedstock in Scotland are included in the ETS. Installations where the primary purpose is the incineration of hazardous or municipal waste are currently excluded from the ETS.

### 5.3.2 ETS fractions by sub-sector for Scottish TIMES

We added GHG emissions by sub-sector and calculated the fraction of ETS emissions over the total emissions reported in the inventory. For this, we only considered the GHG emissions that are reported in the current ETS – CO<sub>2</sub> and F-gases for aluminium production.<sup>4</sup>

Table 5 shows the fractions for each of the Scottish TIMES sectors/subsectors. In two sub-sectors, ETS emissions exceeded total emissions. For INM (non-metallic minerals), this resulted from combustion emissions from glass production being recorded in “Other

<sup>3</sup> List of Scottish Energy from Waste plants from SEPA:

<https://www.sepa.org.uk/regulations/waste/energy-from-waste/energy-from-waste-sites/>

<sup>4</sup> <https://www.legislation.gov.uk/eudr/2003/87/annex/I>

industrial combustion”, as discussed above. The discrepancy for waste was for a single plant with negligible emissions.

The ETS fractions used in Scottish TIMES were mostly the same or similar to the fractions calculated from emissions statistics. No fractions exceeded 1 (i.e. total emissions). We reallocated IOI (industrial other) total emissions to other industrial sectors where the emission statistics fraction exceeded 1 as we assumed that the discrepancy was caused by emissions being erroneously recorded in IOI. The lower total emissions caused the IOI fraction to increase slightly. We assumed that all fossil fuel resource extraction is subject to the ETS. Offshore extraction is counted in a special category outside of Scotland in the ETS and is not included in Scottish TIMES.

It was necessary to choose ETS fractions for low-carbon technologies that have not been constructed in Scotland but might be in the future. We assumed:

- All plants with carbon capture and storage (CCS) will be subject to the ETS as we expect them to be large to benefit from economies of scale to capture and sequester CO<sub>2</sub>.
- All large hydrogen production plants will be subject to the ETS. Small electrolysers at refuelling stations were excluded.
- All negative emission technologies, including biomass with CCS and direct air capture, are counted using a separate negative emissions category. These could be included in the ETS in future.

Table 5: Fraction of Scottish ETS sites over total reported emissions by Scottish TIMES sector/sub-sector. All emission data have units MtCO<sub>2</sub>e. \* See Section 5.4 for the calculation of the international aviation fraction

Scottish TIMES code		ETS sites		Included in UK ETS?		Total Scottish emissions 2021		ETS/Total Emissions	
Sector	Sub-sector	Number	Emissions	CO <sub>2</sub>	PFC	CO <sub>2</sub>	PFC	Stats	Model
AGR	Crops & livestock	0		Yes		0.3		0	0.00
AGR	Energy	0		Yes		0.9		0	0.00
AGR	Land use	0		Yes		-4.0		0	0.00
All	Gas distribution	0		Yes		0.0		0	0.00
ELC	EfW	3	0.0	Yes		0.3		0.06	0.06
ELC	Other	11	1.3	Yes		1.3		0.99	1.00
IND	ICH	6	2.1	Yes		2.3		0.90	0.90
IND	ICM	1	0.5	Yes		0.5		1.00	1.00
IND	IFD	12	0.3	Yes		0.5		0.52	0.52
IND	IIS	3	0.0	Yes		0.0		0.85	0.85
IND	INF	1	0.1	Yes	Yes	0.1	0.004	0.83	0.83
IND	INM	6	0.2	Yes		0.1		4.07	1.00
IND	IPP	2	0.1	Yes		0.1		0.74	0.74
IND	IOFFD	0		Yes		0.5		0	0.00
IND	IOI	6	0.2	Yes		3.2		0.05	0.06
PRC	Refineries	2	1.3	Yes		1.3		1.00	1.00
PRC	Waste	1	0.0	Yes		0.0		3.51	0.00
PRC	Other	0		Yes		0.0			1.00
PRC	DAC	0		Yes		0.0			1.00
RES	Other	0		Yes		0.2		0	0.00
RES	RH	0		Yes		5.8		0	0.00
RSR	Fossil supply	0		Yes		0.0		0	1.00
RSR	Upstream oil and gas	14	1.3	Yes		1.5		0.84	0.84
SER	Other	0		Yes		0.0		0	0.00
SER	SH	4	0.1	Yes		0.9		0.06	0.06
TRA	TAD	0		Yes		0.2		0	1.00
TRA	TAI	0		Yes		0.4		0	0.68*
TRA	TB	0		Yes		0.3		0	0.00
TRA	TC	0		Yes		4.7		0	0.00
TRA	Other	0		Yes		0.2		0	0.00
TRA	TH	0		Yes		1.8		0	0.00
TRA	TL	0		Yes		1.8		0	0.00
TRA	TR, TF	0		Yes		0.1		0	0.00
TRA	TSD	0		Yes		1.7		0	0.00
TRA	TSI	0		Yes		0.3		0	0.00
TRA	TW	0		Yes		0.0		0	0.00
<b>Total</b>		<b>72</b>	<b>7.3</b>			<b>41.3</b>	<b>0.004</b>	<b>0.18</b>	<b>0.18</b>

## 5.4 Scottish ETS aviation emissions

Aviation ETS emissions are regulated in the UK country in which the operator is registered. Only one operator is registered in Scotland – Loganair – but many operators registered elsewhere operate in Scotland.

All domestic flights are included in the ETS. International flights to EU destinations are also included but flights to other destinations are currently excluded. It was therefore necessary to estimate the proportion of international flight emissions to EU destinations.

Bunker fuel consumption is an appropriate proxy for emissions, but no data are available on fuel use to EU and non-EU destinations. Instead, we used airport passenger statistics from the Civil Aviation Authority (CAA), Table 12.1, which contains the number of passengers flying from each UK airport to each overseas airport (CAA, 2023). One flight from a Scottish airport had destination "Unknown". It was removed from the statistics as the small number of passengers would have negligible impact on the analysis.

Since non-EU destinations are generally more distant than EU destinations, we used the number of passengers multiplied by the distance to each overseas airport as a proxy for fuel use. This approach implicitly assumed that aeroplanes to EU and non-EU destinations have similar fuel use efficiencies. We calculated each flight distance from the coordinates of the Scottish and overseas airports using the Haversine formula (assuming the Earth is a perfect sphere) with airport location data from openflights.<sup>5</sup>

We carried out the analysis for the years 2015–2022. *Figure 2* shows the fraction of passengers and the fraction of passengers multiplied by distance (proxy fuel use) travelling from Scotland to EU destinations. Prior to the COVID-19 pandemic, around 68% of proxy fuel use was for EU destinations, with a small upward trend over time. In 2021, when there were many international travel restrictions, EU fuel use increased to more than 80% of the total, but this reduced towards the long-term average in 2022. We therefore assumed a fraction of 68% in Scottish TIMES in line with the average excluding the year 2022.

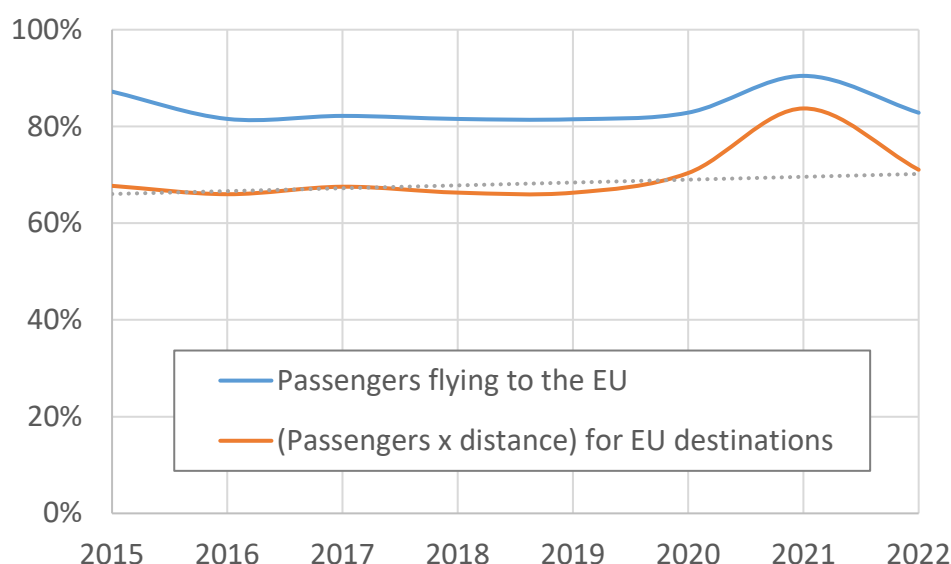


Figure 2. Fraction of international passengers and fraction of (international passengers x distance) to EU destinations from Scotland. Only EU flights are included in the UK ETS. The graph shows the proportion of passengers flying to the EU each year from 2015–2022, and also the distance-weighted proportion as this is likely a better proxy for fuel consumption and hence emissions.

<sup>5</sup> <https://openflights.org/data.html>



## 6 Scottish TIMES UK ETS implementation

We implemented a new ETS emission accounting scheme in Scottish TIMES. This was designed to count all emissions, including those subject and not subject to the ETS, as a quality assurance step to ensure that all emissions were counted appropriately.

We added nine new emission counters categories to Scottish TIMES to account for the ETS and non-ETS emissions. These are described in Table 6. Five categories cover aviation and shipping, with domestic and international travel counted separately and EU and non-EU aviation counted separately. Emissions from stationary sites covered by the ETS or likely to be covered in the future are in SITE-ETS, while those not covered by the ETS are in NON-ETS. SITE-NEG-EMIS is used for future technology-based negative emissions (i.e. excluding nature-based solutions). Finally, LULUCF counts land-use and forestry emissions, including nature-based negative emissions.

For each of these categories, we defined separate emissions counters for CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. For example, for AIR-UK, we defined AIR-UK-CO<sub>2</sub>, AIR-UK-CH<sub>4</sub> and AIR-UK-N<sub>2</sub>O. For SITE-ETS and NON-ETS, we additionally defined counters for HFCs. Defining separate counters enables future changes to the UK ETS in which GHGs other than CO<sub>2</sub> are added to the scheme to be easily represented in Scottish TIMES.

We created two new model scenarios:

- “GHG\_Targets\_ETS\_non-ETS” demonstrates how emissions subject to the ETS could be limited separately from other emissions. The inclusion and role of negative emissions should be considered carefully when setting fixed or upper limits on ETS emissions and choosing the level of those emissions each year.
- “GHG\_ETS\_tax” demonstrates how a tax could be applied to emissions subject to the ETS. This would be the equivalent of a minimum traded carbon price for the market.

The revised model produces no errors. Our testing concluded that all ETS and non-ETS emissions are accounted for correctly.

Table 6. ETS emission counters added to Scottish TIMES

Name	Description
SHIP-UK	Domestic shipping (always outside the UK ETS)
SHIP-INT	International shipping (always outside the UK ETS)
AIR-INT-NON-EU	International aviation outside the UK and EU
AIR-INT-EU	International aviation in the EU that is currently included in the ETS
AIR-UK	Domestic aviation
SITE-ETS	Emissions from a site subject to the ETS
NON-ETS	Emissions not subject to the ETS
SITE-NEG-EMIS	A plant producing negative emissions (BECCS or DACCS); excludes plants in industry using biomass and any plants co-firing or using waste as a feedstock
LULUCF	Land use, land use change and forestry emissions

## 7 Quality assurance

Emissions attribution to Scottish TIMES sub-sectors for the ETS and the Scottish Inventory was carried out by Francisca Jalil-Vega and reviewed by Paul Dodds. Issues were discussed with experts from the Scottish Government.

Our testing of the revised Scottish TIMES model identified no implementation issues.

The international aviation analysis and all model analysis spreadsheets were created by Paul Dodds and checked by Francisca Jalil-Vega.

## 8 Conclusions and recommendations

The Scottish Government wants to understand how emissions from sites subject to the UK ETS are likely to evolve over the transition to net zero. We added ETS accounting to the Scottish TIMES model and created example scenarios with emission constraints and taxes for ETS emissions. Scottish TIMES is being used to produce a new net zero pathway for Scotland to support its new Climate Change Plan, but did not previously distinguish between ETS and non-ETS emissions.

ETS emissions accounting required an estimate of the proportion of emissions subject to ETS for each sector and sub-sector of the model. We analysed ETS and overall emission data for the year 2021 to assess these proportions. We also estimated the proportion of international aviation fuel used for flights to EU destinations as these are included in the UK ETS while destinations outside the EU are not.

We noted some unusual trends in the statistics and so we recommend that the Scottish Government:

- reviews ETS sites against the Emissions Inventory to ensure that the data in both are accurate and consistent
- cross-references the ETS site emissions and energy consumption, the Scottish emissions inventory and the Scottish energy balance to ensure that all sites in Scotland that are required to participate in the ETS are registered.

We implemented a branched version of the Scottish TIMES model at a sub-sector resolution using a flexible mechanism to try to enable future changes to the UK ETS to be easily implemented. A number of model changes were required to enable ETS accounting to function correctly, particularly to the representation of gas networks, which would benefit from a review to ensure they are modelled consistently across Scottish TIMES and that the assumptions used are reflected in the gas emission intensities.

Our comparison of the outputs identified some unexpected discrepancies between modelled emissions in 2020 and actual emissions in 2021, so we recommend that these are compared to identify sectors of the economy where unrealistic decarbonisation pathways might have been projected, and to constrain those pathways appropriately.

## 9 References

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