



Future flying: Up in the air?

Better Connections for Growing Edinburgh



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Preface

Scope and Purpose

All the participants in this research project, funders, researchers, and interviewees, shared two concerns. The first was that the city of Edinburgh, the emerging metropolitan area around it, and Scotland as a whole to progress on a fair path to prosperity, whether defined in terms of real incomes or other agreed wellbeing measures. That interest included establishing what growth now means, and how it can be measured, as individuals and governments embrace wider notion of progress, and to understand how best to pursue growth in the new times ahead.

The second, ubiquitous concern was to hasten the reduction of greenhouse gas (GHG) emissions to attain net zero carbon goals, and thereby abate, then end, the climate emergency for Scotland and the wider world. There is wide awareness that just over 2 percent of global greenhouse production (GGP) arises directly from aviation and more, almost 5 percent, from flight plus related activities. There is an arithmetic certainty that this share will rise over the next two decades, both because aviation, now recovering from the Covid-19 disruption, has recommenced its century long growth trajectory, and other economic and transport sectors will reduce their dependence on fossil fuels. Unless, of course, there are either, or both, reductions in kilometres flown globally or in the suite of GHG emissions per mile flown associated with the movement of goods and people by aviation.

Limiting the effective demand for flying will have major economic consequences as aviation and prosperity, as presently defined and delivered, are strongly causally connected. Physical connections between places create social, cultural, and economic gains for households, firms, and governments. Mobility both shapes and is shaped by the growth and wellbeing of nations, cities, and neighbourhoods. Constraining mobilities reduces, unequally, significant gains for households, businesses, and places. Increasing emissions in movement processes similarly damage, again unequally, the wellbeing of households, firms, and places.

For policymakers, and households and firms too, this implies a trade-off between growing prosperity and increasing GHG emissions in mobility processes.

Unless either everything that gives households a sense of wellbeing or mobility processes can be decarbonised, that trade-off will inevitably exist. However, the steepness of the trade-off is not fixed and there is the possibility of rising prosperity and zero carbon in a range of key activities. Just transition with no jobs, is neither desirable nor, if understood and delivered effectively, essential. Most obviously, the potential for alternative energy supplies that are 'greener', cheaper and with more locally secure supply are the 'low hanging' fruit in the decarbonisation of energy and transport systems: but policy also has to grasp and deliver purposive change for economically and socially beneficial systems and activities that are more difficult to decarbonise.

Policy, Progress, Paths

Aviation is typically regarded as a particularly difficult economic activity to decarbonise. There is much debate about probable and possible outcomes of decarbonisation strategies, explored further below. Different strategies imply markedly different prosperity and distributional outcomes. In consequence choosing the ways in which to progress towards net zero is not only an imperative for cities but it involves complex, uncertain, long-term policy choices where economy-emission relationships are not well understood nor are the specific sector, timing and place effects arising from climate change. Choosing the 'carbon descent paths' for aviation requires real clarity regarding the evidence, analytical and strategic decision capabilities of a polity and its bureaucracy and it assesses their capabilities to connect present actions to better future outcomes for the 'wicked systems' that they have the responsibility to manage.

This report explores the strategic challenges that have arisen for Edinburgh, the UK's second fastest growing city, as new climate concerns have to be reconciled with maintaining the momentum of the metropolitan economy as well as fulfilling other key social goals. The policy autonomies that potentially control decarbonisation rest at different orders or levels of government, and this multi-level pattern of autonomies is important in net zero and aviation decarbonisation so that the focus on Edinburgh has to be set in the policy actions of the Scottish and UK governments.

Similar growth-GHG trade-off issues, with multi-order government policy responses, arise in most advanced regional/metropolitan economies. Reductions in aviation emissions to secure zero carbon pose severe short run economic growth-sustainability dilemmas in most cities. New policy imperatives have led to rethinking, by governments, citizens, and firms, about growth in key sectors of economic activity, for instance tourism, changing infrastructure provision, and promoting different modes of travel.

Contrasting the transition strategies of Edinburgh, and Scotland, with other growing cities and regions, in different contexts, does not challenge the aim of net zero carbon by 2045 or 2050. It does, however, raise questions about whether the governments of the UK, Scotland and Edinburgh have had an effective, transparent process for choosing the best path not only to a just transition but to a future with the best possible prosperity and wellbeing.

All cities across the OECD aim to be green and reach net zero GHG but they choose different time paths for carbon descent, different sectoral and spatial routes, have different goal trade-offs, and have different approaches to understanding and deciding for the future. Governments appear to have different competences of how to achieve change. Can Scotland and Edinburgh learn from how other jurisdictions understand and frame problems, design and deliver strategies for change and undertake collaborative governance with the citizens and businesses involved in net zero transitions? And as part of that, the key purpose of this report is to assess whether strategy for aviation decarbonisation for Edinburgh and Scotland is both clear and designed to achieve the best possible future outcomes for prosperity and inclusion as well as net zero?

Participants

The project was financially supported by Global Infrastructure Partners, who are the owners of Edinburgh Airport and part-owners of Kingsford-Smith Airport in Sydney. The Toronto and Sydney metropolitan areas, though significantly larger than the Edinburgh City-Region, with a spatial scale similar to Central Scotland, were selected as comparative case studies as they are both competitive, growing city-regions with commitments to environmental improvement and achieving net zero. Edinburgh Airport has, in terms of its own business operations, become a net zero airport

(Edinburgh Airport Report 2022), it aims to be a good neighbour for adjacent communities and seeks ways to contribute to their shift to net zero. It is also committed to strengthening prosperity and wellbeing in Scotland and to promote, wherever possible, a fast decarbonisation of aviation consistent with these other goals (Edinburgh Airport Strategy, 2023). The research was also supported with generous contributions of time and insight from more than forty business leaders, airport/airline executives, community commentators, government officials (from city, Scottish and UK levels) in Edinburgh, from a similar mix of twenty change leaders in Sydney (New South Wales) and fifteen in Toronto (Ontario). Professor Julie Miao (University of Melbourne) led the Sydney case study.

Processes

The project involved three stages of work. The first reviewed the existing literature on how governments are (or are not) framing the metropolitan/regional challenges of reaching zero carbon, the decarbonisation of aviation and how the roles of major infrastructure in metropolitan development and of aviation in metropolitan change may alter in the decades ahead. The second stage involved interviews (of approximately an hour in duration) with key business leaders, officials, consultants, and academic experts, in Edinburgh and Scotland, involved in shaping and delivering current build-forward better and net zero strategies. Similar topic interviews were conducted in Sydney and Toronto as a third stage.

Sir John Elvidge, Gordon Dewar and Gordon Robertson from Edinburgh Airport constituted an informed and patient informal 'steering group' for the project. I am most grateful to them and to the seventy-five interviewees on three continents who contributed so much time and input to this study.

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CHAPTER 1

Climate Change, Aviation, and the Economy: Policy Trilemmas?

1. Global Warming and the Net Zero Goal, Aviation and Airports.

Climate change, consequent to global warming, arising from greenhouse gas emissions, and attributable to human behaviour is now well established by both the evidence of climate science and the experience by the public of the growing frequency of adverse weather events with 'record' temperatures, high and lows, and unprecedented storm and precipitation intensities. The threats to the ways and wellbeing of how we live now in Scotland and the UK, let alone of the vast poor populations of sub-Saharan Africa, are also being imagined and experienced.

There is, in most rational thinking societies and governments, acceptance of the unambiguous evidence that as the result of human behaviours, primarily the use of fossil fuels as the major energy source boosting carbon dioxide emissions into the atmosphere, that the world is 1.1 C warmer than 150 years ago. The International Panel on Climate Change (IPCC) is the globally recognised locus of scientific advice on climate change and its consequences. They report (IPCC, March 2023) that global warming is accelerating, not slowing, and, that based on their modelling and scenarios, there is a more than 50% chance that global temperature rise will reach or surpass 1.5 degrees C (2.7 degrees F) between 2021 and 2040. Higher-emissions pathway will accelerate reaching this increase that is widely believed to be a key tipping-point towards irreversible, damaging climate change. This is only two decades away.

The COP21 agreement, reached in 2016, concluded that GHG should be reduced by 45% by 2030 and reach net zero by 2050. Yet by the end of 2022 it was clear that commitments by the 196 signatory governments had put in place policies that would not abate GHG emissions but see them rise by 11pc to 2030 (COP 28 concluded in late 2023 that this estimate had fallen to 9pc). The Policy Pact following COP 26 in Glasgow in 2021 called on all countries to revise, by the end of 2022, their plans and strategies to achieve their Nationally Determined Contributions to GHG reductions.

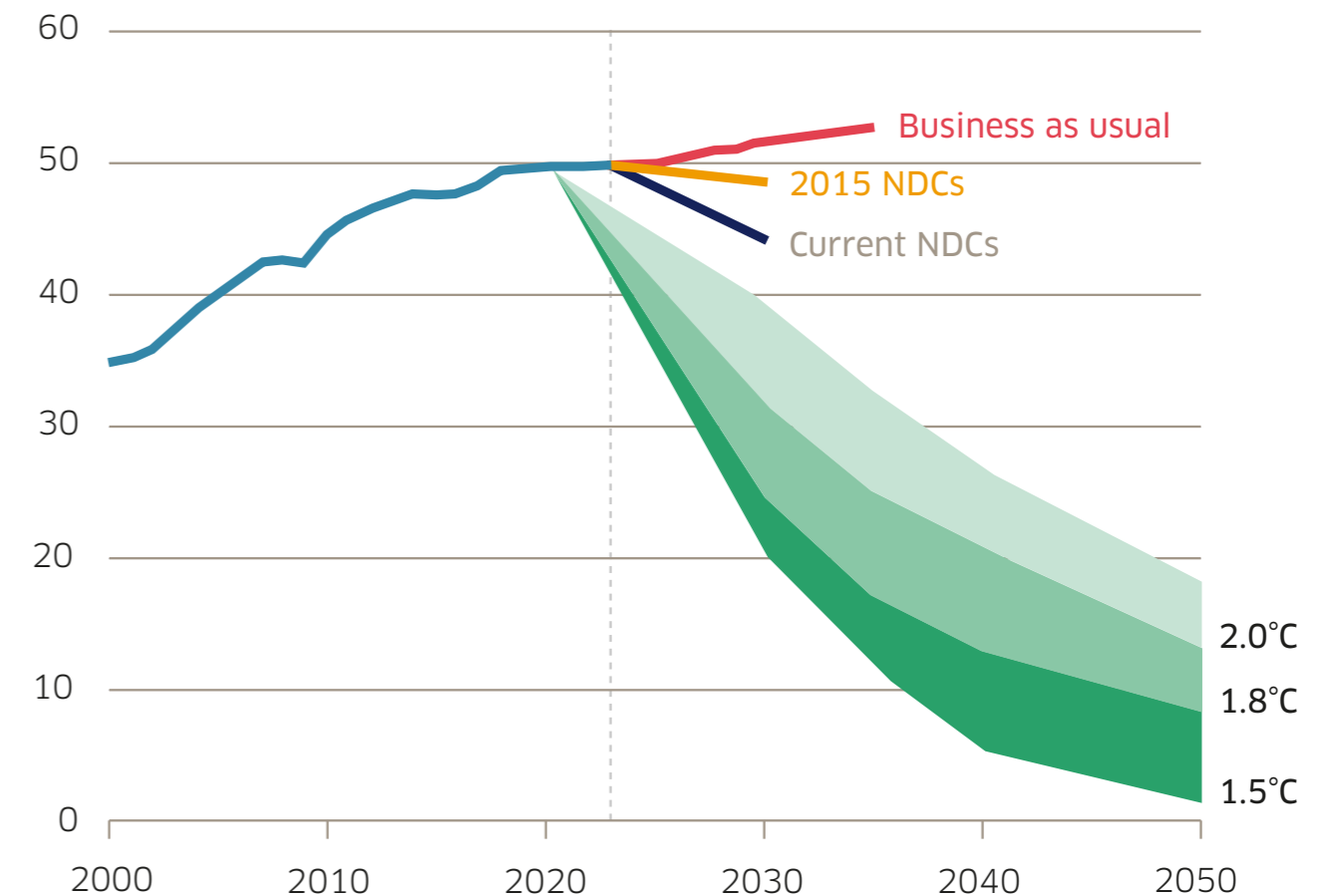
Policy action to deliver COP targets has fallen well below COP 2016 targets. By the 2022 deadline, fewer than one in ten countries had undertaken the strategic revisions agreed at COP 26 a year earlier. Most are committed to achieving net zero by 2050 at the latest. The UK climate Change Committee (2023) has highlighted that the UK and Scottish governments have failed to achieve their emissions targets every year since 2016. In consequence, as COP 28 (end 2023) commenced global GHG emissions will now need to fall by 45pc in 6 years rate to meet the IPCC 2030 reduction target that is required to maintain a habitable planet for most people. The IMF (2023) assessment of required and actual projected emissions descent is depicted in Figure 1.

Figure 1

Falling short

Current climate commitments will still only reduce global greenhouse gas emissions by 11% by 2030.

(global GHG emissions, GtCO₂e per year)



Sources: Intergovernmental Panel on Climate Change 2022; and IMF staff using CPAT.

Note: Excludes land use and land use change emissions.

NDCs = Nationally determined contributions; GHG = Greenhouse gas; GtCO₂e = Gigatons of carbon dioxide equivalent.

2. Aviation, Airports, and Decarbonisation

Audits of the local and global sources of GHG emissions highlight their diverse sources, from cows to cars. Mobility, involving the consumption of fossil fuels, comprises a major share of emissions produced by businesses and households. Policy discussions then consider how best to reduce such emissions (decarbonise activities) either by reducing carbon based mobility (such as commuting to workplaces less often or facilitating active travel or shifting from petrol driven to 'clean' electric cars or, better, public transport) or reducing carbon emissions per kilometre moved (by developing new carbon free fuels and improving fuel system and vehicle designs). Shaping these shifts to decarbonised travel often requires strategic policy decisions in which governments, with decarbonising missions in mind, use spending, taxes, and regulatory powers to shape new markets, behaviours, and choices, and this is particularly important where new infrastructures are required.

The decarbonisation of aviation, despite the currently small share of aviation emissions in overall GHG, is a particularly challenging process, in comparison with, for instance, residential energy use and metropolitan car commuting. This arises, in part, because of the expensive nature of the infrastructures involved, not only of on-ground structures of buildings and runways but because of the cost, uncertainties, technological challenges and protracted time periods for designing and testing efficient and safe aircraft. New energy sources for aviation also involve discovery processes and new or additional infrastructures and grids of connection between energy sources and airports. In this regard, technologically and economically, aviation infrastructure is relatively fixed in the short term (at least a decade long) but the innovation processes are long and complex. The nature of the industry is that some core aviation activities, by their nature, have to hasten slowly to effect change that may indeed involve 'rocket science', as aerospace technology is now being used to develop zero carbon aircraft and fuels. Patient investment may be essential despite the impatient aims of policy.

A Chain of Fuels.

Moving people and goods by plane involves much more than the in-flight phase. Reducing the direct and indirect GHG emissions arising from air travel requires addressing a connected suite of activities involving energy-use and the production of GHG. Journeys comprise multiple distinct phases some of which are on the ground and not all of which are in the control of airports or airlines. A 'travel' or 'journey' chain perspective is helpful.

Individuals and freight move from their origins to an airport by a more or less intensive GHG travel mode. On arrival at the airport, travellers enter structures with embedded carbon that use energy for lighting, heating, and cooling and then undertake essential processes of checking in, progressing through security, and boarding aircraft. All use energy, though innovative airports are now installing walkways to absorb the potential energy used by ambulatory passengers. Travellers also have options to make use of commercial choices located within the airport (in addition to those in the wider airport precinct). The aircraft they board will have been re-fuelled, cleaned, and maintained at the airport site.

Once loaded, aircraft, appropriately heated or cooled for passenger comfort, then use energy to taxi to take-off points. In flight emissions arise from ascent, flight and descent with on-ground and gate to destination processes creating further GHG as journeys are completed. Arriving passengers then, in completing their post flight journey, essentially replicate these processes.

The materials and labour used to produce all these in airport and in-flight services for passengers have to move to the airport on a regular, often daily, basis and this process has a considerable carbon footprint. Workers return home and the removal of the waste produced in the departure and arrival processes has to be removed too.

The multiple processes within the curtilage of an airport that use energy are now, typically, audited annually in airport sustainability strategies. All the airports in our case study, in relation to their in-airport activities, are now at or close to net zero in their operations. Toronto Pearson has been at the forefront of such developments in North America.

Edinburgh Airport (2022), which has an annual, independent audit of its 'own activities, is progressing rapidly towards not just net zero but carbon zero functioning. The airport uses its own solar energy sources to produce 8 megawatts of green electricity per day and requires only 40pc of that total to power the airport. The rest, as an example of how fragmented energy policy systems are, is unused and earthed into the ground as there is insufficient capacity to upload this clean power into the Edinburgh energy system!

In this report airport operations as GHG producers receive little attention. All of the airport owners involved in the case studies had clear corporate strategies and commitments, reflecting investor interests, both to decarbonise their own activities and seek to contribute to wider community goals for net zero. Airports, as such, are not the problem now, and will be net zero by 2030. Three main areas of concern that remain, and that are touched upon throughout the report, are GHG emissions in the gate-to-gate on ground and in flight phases (95 pc) of the total, and the emissions arising in on ground movement of materials, fuels, staff and passengers to and from the airport, and finally (and often neglected in policy discussion) the extent to which the vicinity and overall accessibility of the airport, as a major strategic location, can be used to shape reduced GHG emission by firms and businesses in the metropolitan area. Gate to gate emissions are explored in Chapter 4 and accessibility and strategic land use and location questions in Chapter 5.

3. Aviation: Significant Economic Consequences and Complex Economic Geographies

In the absence of technological change and decarbonisation, GHG goals will have to be primarily achieved by reducing flight numbers and passenger and freight movements. An airport, like any other major transport terminal infrastructure, impacts GHG emissions in the different ways outlined above. There are gate to gate (or quay to quay, or platform to platform) emissions, energy use within the facility (the airport, the ocean terminal, or the train stations) and there are the emissions involved in moving from the terminal to journey origins and destinations and in moving materials and labour and labour to provide airport activities and flight services.

These sets of activities have different geographies that extend forward from the airport, into the skies and destination locations. They also reach backwards into the attached airport precinct; the attached property around (and often owned by) the airport; the adjacent neighbourhoods, and suburbs; around the routes to the airport; and

the dispersed geographies of passenger and freight destinations. Airports have not just an environmental and carbon 'footprint' they also have major economic 'handprints' that touch and shape economic wellbeing across extensive and complex geographies.

There is a further important, strategic spatial consideration. Airports are not simply a crucial but passive infrastructure node through which goods and human capital flow, and which add to aggregate demand and employment in the local economy, both directly through airport activities and through multiplier effects from subsequent expenditures locally. These direct effects, discussed below in Chapter 3, are significant in scale but they are far from the most important growth effects of metropolitan aviation connections. Rather, airports are also a significant strategic accessibility point within a city or nation. Their nature and location create or contribute to potential geographies of agglomeration, linkage, and synergies in innovation,

production, and living, that may raise productivity and create new economic opportunities. Airports have to be seen, in economic terms, not just as a least cost transport sites but as potentially key economic infrastructures that should be at the centre of metropolitan and wider regional economic development strategy as well as spatial planning and transport development. Many airports have grown in locations, chosen from the 1910's onwards, originally distanced from the core of the cities they serve, for security, land cost and environmental (primarily the minimisation of noise pollution) reasons¹. Subsequent city growth has seen first suburbanisation and then significant polycentric metropolitan developments sweep past the originally detached airport location. These spatial growth patterns differ from city to city and have become apparent more recently in Edinburgh than for Toronto and Sydney. These new urban geographies require that planners and development strategists need to drop a tendency to define airports in relation to their CBD proximity, that remains important, but to see them as a potential hub (indeed a 'central place') within parts of a polycentric urban system.

When airports are seen in these terms, any metropolitan economic strategy that will require external connections beyond a three hour (say) for ground based transport isochrone has to make an explicit consideration of whether clustering emerging enterprises close to the airport (in essence rethinking the relevance of the aerotropolis concept) might raise productivity, potentially reduce metropolitan commuting and, in consequence, the aggregate GHG footprint of a set of economic activities otherwise dispersed across the metropolitan region. Or indeed, whether potentially pervasive negative economic effects from reducing metropolitan flight connectivity and disconnecting the economic base from significant volumes of suppliers and customers will substantially reduce local employment and wellbeing.

Equally, with new geographies of production of renewable energy sources airports, as large-scale energy consumers, may now be efficient locations for upscaling local renewable energy production, such as green hydrogen, and using their land and structures to generate, for example, solar power. Identifying the actions needed to stimulate flight infrastructure (planes), fuels and access on-ground infrastructures that will reduce the GHG intensity of metropolitan based aviation should now be central concerns for regional and urban development and competitiveness policies. The extent to which 'just transition' strategies have embraced the complex economic consequences of curtailing aviation, or indeed framed they key economic questions, is explored for Edinburgh and Scotland in chapters 3 to 5. Have they, and associated planning and infrastructure strategies had an adequate conception of the airport's role in the development of the metropolitan area?

Policymakers cannot think of airports simply as conduits for the consumption of fossil fuels and narrowly defined economic impacts. Equally, taking that broader spatial perspective of the economic handprints and environmental footprints of airports also leads directly to the recognition that multiple levels of government, and their economic and environmental strategies will shape airport outcomes.

4. Net Zero Pathway Governance for Thriving Places

Policymakers have an imperative to make an informed choice from the options of how aviation and airports can be shifted towards net zero. As for any other travel mode, there must be coherence regarding how consumer behaviours can be changed and nudged. There also must be a major investment of policy time and effort in considering the likely shifts in aircraft energy technologies and alternative fuel sources over prolonged energy descent paths.

These GHG reduction choices must be made subject to the constraint of achieving multiple policy goals as well as the public and private financing of change (with the net fiscal cost of achieving net zero goals often missing or opaque in transition strategies, especially at sub-national scales). The policy debate is no longer about whether to reach net zero, but when and by what decarbonisation paths and whether paths taken may slow or eliminate progress on other major policy goals. There may be a widely agreed goal, with some debate about whether net zero, zero or true zero carbon is the best target for mid-century, but there are multiple, different pathways to it. In There must be a concerted, informed, transparent effort to explore not just GHG change but the sectoral and spatial consequences and changes required within the metropolitan and regional economy and its major institutions and infrastructures, such as the airport and whether they can maintain employment and incomes as GHG is reduced.

There is much discussion of green jobs and opportunities, and some localities have explored and modelled possible changes in incomes and economic structures, the City of Toronto for example-with comforting results (2021). But some jurisdictions have been vague and more speculative on economic base changes. At the same time there is a growing recognition that transition to net zero and the cessation of the use of fossil fuels will require a new, third, 'industrial' revolution with pervasive technological, social, economic, and behavioural change has to be fashioned over the next few decades, and the sooner the better, if human wellbeing is to be maintained or, preferably, enhanced as GHG falls. There is much emphasis that this 'transition' will also have to be 'fair' or

'just' to ensure that the major costs of GHG do not impact the poorest people, locally, nationally, and globally and that they share the benefits from the new 'green economy.' A just transition strategy that sets change in play without coherent, resourced, and simultaneous missions for economic and social change will indeed be just (in the sense of only, rather than fair) transition, but fewer jobs and reduced wellbeing.

This task is as formidable as it is urgent. Missed policy targets locally (Edinburgh will not meet its always aim of major GHG reductions by 2030; the Scottish and UK Parliaments have both been recently castigated for missing targets by the Climate Change Committee) hint at limitations in Governance competence. Unclear strategies and missing delivery plans, apparent in many jurisdictions, national and local, there is a growing concern that policy actions to timeously reach net zero without damaging wellbeing and prosperity are not being effectively progressed and the economic consequences of GHG reductions are neither well estimated nor transparently presented.

Many see this as politics de-emphasising net zero aims in a potentially difficult trilemma of reducing GHG, maintaining prosperity and their electability. But other possible explanations may arise from the broader context for policy decision taking, the efficacy of policy governance structures, and the competence of bureaucracies to deliver the goals espoused (Gonzalez and Gale, 2023). There are key questions for future methods and styles of public policy making at city and Scottish levels. It may be that dealing with the multiple 'wicked systems' that both drive and result from climate change may already have left redundant the silos and spatial level separations that governments typically now use in shaping policies and strategies. Confronting the new system challenges requires integrative, collaborative actions across multiple sectors and layers of government, and between government, private and community sector actions. Is such an approach apparent in devising policy and action for the scale and nature of future aviation at Edinburgh Airport?

5. The Governance of Aviation and Airport Roles in GHG-Economy Pathway Choices

This report, addressing the issues and questions outlined above, brings together the dilemmas and trade-offs in shaping and delivering trajectories for both net zero GHG emissions and economic prosperity arising from aviation and airport activity for Edinburgh and whether, and how, they might be more effectively governed. The outcomes of the policy approaches implemented will have major implications for the prosperity of people and places in the City of Edinburgh, the surrounding, emerging, successful metropolitan area and for Scotland that is most connected to the wider world through Edinburgh Airport. The substantive arguments presented below, given the significance of the city-region economy in the social and economic functioning of Scotland, touch on the future prosperity and wellbeing of all Scots. More widely, the questions about synergies and trade-offs between aviation, airports and metropolitan economic development are pertinent to framing strategies for net zero in all major metropolitan areas.

The paper, in exploring these issues adopts an applied economic policy perspective on the challenge of decarbonising the economies of Edinburgh and Scotland whilst attaining the multiple other goals embraced by governments. This requires considering how governments understand the relationships between actions to achieve net zero and other policy aims and the missions to achieve them. How do these relationships between net zero actions impact economic outcomes for households, businesses, cities, and the nation. How were policy trade-offs and choices modelled and made? How were the best first moves on missions towards energy descent and the descent paths chosen? In short, has Scotland set out towards the zero carbon economy on the right path or are changes in speed and direction of travel required as understanding of problems and possibilities changes. In recent months there has been a significant revisiting of sectoral deadlines for ending carbon fuelled

caruse in the UK and replacing residential energy systems reliant on fossil fuels (in Scotland and the rest of the UK). These sectoral fossil energy descent paths have been reconfigured because they were deemed by government to be too ambitious, given resource and labour shortages. What about aviation decarbonisation strategies for Scotland? What shape is the descent path implied in policy and does it too need to change, not least as new technologies for aviation emerge?

Asking these questions does not challenge the urgent imperative of reaching net zero. However, the 'net' in net zero and a range of different potential carbon descent paths does allow for different economic policy choices. This report seeks to explore how, to date, the economic dimensions of the transition to net zero and their relevance to future roles for aviation and Edinburgh airports appear to have been considered in Scottish policy approaches. To date the Scottish Just Transition Team have not shown in public 'their working' for their implied aviation descent path in nor were they able to meet with the research team. It also draws comparisons with approaches in other growing metropolitan contexts.

This introductory chapter has set out the major challenges in reducing GHG and decarbonising aviation whilst achieving other policy goals. It has posed questions about policy problem framing, action, and progress. briefly outlines, in section 2, the essential trade-off between GHG outcomes and aviation and airport activities. The multiple government structures, present difficulties and near future context for making pertinent policy changes are discussed in section 3. The ways in which evolving styles of policy making (by no means restricted to Scotland) may be inhibiting clarity in policy formulation by setting major policy targets without framing supporting missions, strategies, and delivery strategies (part 4). Nobody is saying transition governance is easy: the question is whether it is done well! And that applies to airports and airlines as well as governments.

Posing Questions, Providing Answers?

The next chapter, 2, discusses the difficult policy governance context of the 2020's, the multiple orders of government involved, the broad fashion in which the Scottish Government and Edinburgh City frame policy aims for economic policy issues and their implications of GHG reduction (and vice versa), how choices are addressed in policy debate and strategy formation and delivery, and how aviation and the airport are considered in such approaches.

To better inform how aviation emissions versus prosperity outcomes can be framed and balanced with national and local policymaking, Chapter 3 sets out evidence on the impacts of airports on metropolitan economic growth. That review suggests that there is, at least, a prima facie case that the airport is Scotland's critical regional and international transition/connection point, a marketplace, an economic neighbourhood/vicinity, and a major metropolitan node of accessibility. The airport is vital to the connectivity, wellbeing and competitiveness of the places and people which it serves as a focus of accessibility and locus of employment but appears to gain scant recognition of that role in policy actions.

Chapter 4, accepting the imperative of net zero aviation emissions, reviews literature on the possibilities for GHG reductions in aviation and airport operations and their likely broad effects on economic outcomes. Complex economy and energy systems are involved and that requires careful analysis both by governments, at national and local scales, and aviation providers and aviation users. Complexity also offers significant prospects for re-engineering the energy, operational and engineering systems involved and many of the major policy autonomies lie at UK, and less often, at Scottish levels.

The findings in Chapters 2, 3 and 4, are used in the concluding Chapter, 5, to explore policy choices for net zero aviation pathways and economic, planning and infrastructure decisions for the city-region that, at worst, maintain and, preferably, grow prosperity and wellbeing and are consistent with net zero ambitions. It concludes with an agenda for action to rethink how aviation and airport strategies and regional planning, infrastructure and economic policy and its governance can energise and make more transparent a more informed discussion of how the Edinburgh city region and Scotland can choose the best aviation paths to net zero.

The complexity of the issues involved is evident. The difficulty of the times, in public finances, trade and geopolitics is also critical and there is a sense of what Peter Handy (1994) called a 'Change of Age' rather than just an age of change. The question arises of how governments in Scotland address these changes, and their economic implications, in the major statements of aims and policies for the 'green, wellbeing, fair, inclusive, and productive economy? Ministers cannot simply say they do not like air travel, imply that autarky is good, and that air travellers are, or soon will become, a disliked elite. Good democracy would at least explore the options. What might they be?

6. Findings: Carbon, Connections, Challenges and Changes.

This, introductory, chapter set out the complexity of the ways in which airports and aviation contribute to GHG emissions, the imperatives of reducing them and the multiple paths to doing so.

1. There is widespread recognition by the public, policymakers, and the providers of aviation services in Scotland that increasing greenhouse gas (GHG) emissions from human activities are exacerbating the processes and problems of global warming and that significant, extensive action is required to constrain temperature increases below critical levels by the middle of the century.
2. Aviation, and related activities, in using fossil fuels create under 4pc of GHG emissions and that share is set to rise as aviation is an inherently difficult sector to decarbonise quickly.
3. Flight journeys, for passengers and freight, involve a number of stages and activities, such as getting to and from the airport, using services near or in the terminal, checking-in and boarding, as well as taxiing prior to take-off, cruising and landing. All these journey stages, as well as the assembly and dispersal of staff and materials to service them, create GHG emissions.
4. Airports are major nodes of international (Spain), intranational (Southampton) and intra-regional (Shetland) connection that make them infrastructures and points of connection of national importance.
5. By their, usually suburban, existence airports also create points of accessibility and potential economic activity both in the immediate vicinity of the airport and for the multiple metropolitan locations that have grown around them and they have become sites of production as well as passage.
6. Airports have an environmental 'footprint', that reaches from local noise pollution to global warming, but they may also have a major economic 'handprint' of flows of people and goods that not only moulds much of the metropolitan economy but reaches out across central Scotland, to Fife and the North-East as well as south to the North of England.
7. Reducing aviation emissions can be achieved by restricting flight or by decarbonising airport and (predominantly) aviation fuels involving new fuels and aircraft designs. Restricting flight will have significant, negative economic and social consequences, but new technologies may take time to design and implement.
8. Policymakers have to choose not just a carbon reduction target, such as the Scottish Government's net zero carbon GHG by 2045, but they have to choose a 'descent path' that recognises the need to meet other goals of fairness, wellbeing and prosperity as well estimating the sequencing and feasibility of new technologies.
9. In making these 'transitions' much attention has to be paid to the new opportunities emerging and how they can replace the declining 'old carbon' jobs in the economic and social structures of Scotland.
10. Successful decarbonisation of aviation is likely to require new collaborative partnerships for, and governance of, change involving multiple sectors, multiple levels, and Departments of government.

¹ Edinburgh Airport emerged from Turnhouse Airport that was opened in 1915 as a base for the Royal Flying Corps that was located close to the East Coast main rail line and nine miles from the city centre.



CHAPTER 2

Difficult Times, Mounting Problems, and Hard Decisions

1. Challenges: Recognising, Embracing, Understanding and Resolving Problems.

The Importance of Policy Clarity.

The introductory chapter outlined how most governments, at all scales, had by the COP 24 meeting in Paris in 2015, recognised the reality of climate change and the social, economic and governance challenges it posed. By 2021, at COP26 in Glasgow, there was a wide recognition that the efforts set out in the Paris Agreement to reduce GHG by 2030 needed to be accelerated. The core problem had been widely recognised and the need for action embraced.

COP28, in 2023, at Dubai heard even more urgent concerns about the likelihood of failing to abate global temperature increases by 2030 and 2050, and also created some new worries that not all major fossil fuel producing nations are definitively aligned with reduced production goals. Some countries expressed a concern that early-mover policies and strategies to decarbonise may not always have been effectively designed. Emission targets set after the Paris agreement are not being met by national governments, including highly committed Scotland (Climate Change Committee, 2023).

These uncertainties, not about 'whether' but 'how' to deliver GHG transitions, face all governments. They are compounded by a growing urgency to meet an emerging ecology of 'wicked' problems (Sarkar, 2023) and a new diversity of narratives about what constitutes economic progress, and how to manage it (Raworth, 2017). Major policy uncertainty is apparent too in sub-national/city level governments, who have often led the calls for tackling net zero within their nations, which are now being asked to address a widening set of urgent goals, such as the too prevalent housing

crises, with relatively inelastic fiscal resources. The metropolitan case study areas in this study all have carbon reduction targets more ambitious than their national governments and less elastic tax bases.

There is now a variety, at best, and confusion, at worst, in the ways in which governments understand, define, and pursue growth and prosperity. Choosing and, more importantly, delivering the best path to net zero requires governments to have a clear, consistent understanding of economic (and other) policy aims, levers, and means that minimise any reductions in, and maximise opportunities for enhancing, wellbeing. Metropolitan and national policy choices critically shape the economy-environment trade-offs in decarbonisation and the route maps that the private sector can follow. Some governments appear to have more coherent approaches than others, especially at sub-national scales, to the decarbonisation of aviation and its consequences.

Strategic Futures Start Now.

This observation is central to understanding how aviation futures for Edinburgh, and indeed Scotland are designed and delivered. To date there has, in Scottish policy literature, been reference (Scottish Government, 2023) to the long term necessity of reducing Scope 3 GHG aviation emissions, a responsibility of the UK government for all UK airports, including Edinburgh but no outline reduction strategy exists. However, there is an inevitability that aviation emission reductions will be required in the next decade and the update of the Scottish GHG reduction strategy in 2023 notes that they will begin to be considered (implying there is no clear action plan at present) by 2030

Airports and airlines are already building into their forward strategies their expectations of what such actions might look like. They are businesses with long term assets and anticipated future costs and returns that already have to play into their decisions and that are made in a globally competitive set of industries. Neither airlines nor airport investment capital will inevitably come to Edinburgh, nor indeed remain here, if transition plans are opaque, raising risks, or failing to support the public actions that might decarbonise aviation that still allow opportunities to make competitive returns.

Scottish policymakers, as well as airport and airline boards, have to have some outline, evolving aviation strategy, which looks at post 2030 possibilities, in place now. Policy decisions, in relation to supporting future ground infrastructure, innovation and production pertaining to new fuels and aircraft, are essential now because they will shape the possibilities and probabilities for action by 2030. Policy neglect today will seriously curtail policy options in the future. Moreover, policy decisions have to pay significant attention to how competing cities and regions are already changing and investing.

Scottish industry complacency hastened the death of the economic base of the west of Scotland, half a century ago, ignoring too long new competition in the construction of railway engines and shipbuilding. (Checkland, 1976). Complacency about future connections required for multiple sectors of the economy to remain competitive would, as outlined in Chapter 3 below, be equally problematic for the East of Scotland now.

There are already some decision takers in the public and private sectors of Edinburgh who, in the absence of any coherent outline economic/aviation transition plan are acting on their own assumptions about uncertain policy change for aviation and the economy. For instance, there is a common assumption in the bureaucracy of the City of Edinburgh, that chimes with local political messages, that domestic flights within the UK will end (in the 2030's) as passengers switch to faster trains (discussed further below). City business sectors are aware of that sentiment and that one of the political parties in the Scottish coalition government explicitly wants to see the end of Edinburgh based aviation. That, reported in

Chapter 3, shaped interviewees potential Edinburgh business plans for the future.

In the absence of some coherent, well evidenced carbon emission reduction path for aviation change, these negative expectations for the sector may become self-fulfilling. What if Scotland and the city of Edinburgh are perceived to have a particularly difficult economic-transition context, or lack of a conceptual framework for economic and related policies, or few capabilities to make coherent choices, or fail to collaborate across levels of government and with other economic sectors? Then the 'green' capital to fund just transitions, and take the real economic opportunities arising from it, may be flowing away from the city and region rather than towards it.

To frame the subsequent discussion of the aviation sector and the Edinburgh economy, this chapter explores these issues of context, concepts, competence. and collaboration that shape public policy support for future aviation. The MacPherson report (2023) explores how perceptions of the Scottish context on the part of international investors and financial institutions will be essential to whether or not Scotland can attract the private 'green capital' that is widely available to support GHG transitions. It notes important respects in which Scottish attractiveness to change capital is currently impaired. In many respects this review of policy approaches to Scottish aviation and Edinburgh Airport provides an illuminating example of the problems of investing in Scotland highlighted by the MacPherson Review. What are the barriers in the policy process?

The next section of this chapter highlights the difficult context policymakers face, section 3 reviews the diverse economic concepts and policy rhetoric that appear to frame policy actions, system competences are considered in part 4 and propensities for collaboration in part, 5, of the Chapter. Summary Findings are located in Section 6.

2. A Calamitous Context!

Adverse Shocks and Wicked Systems.

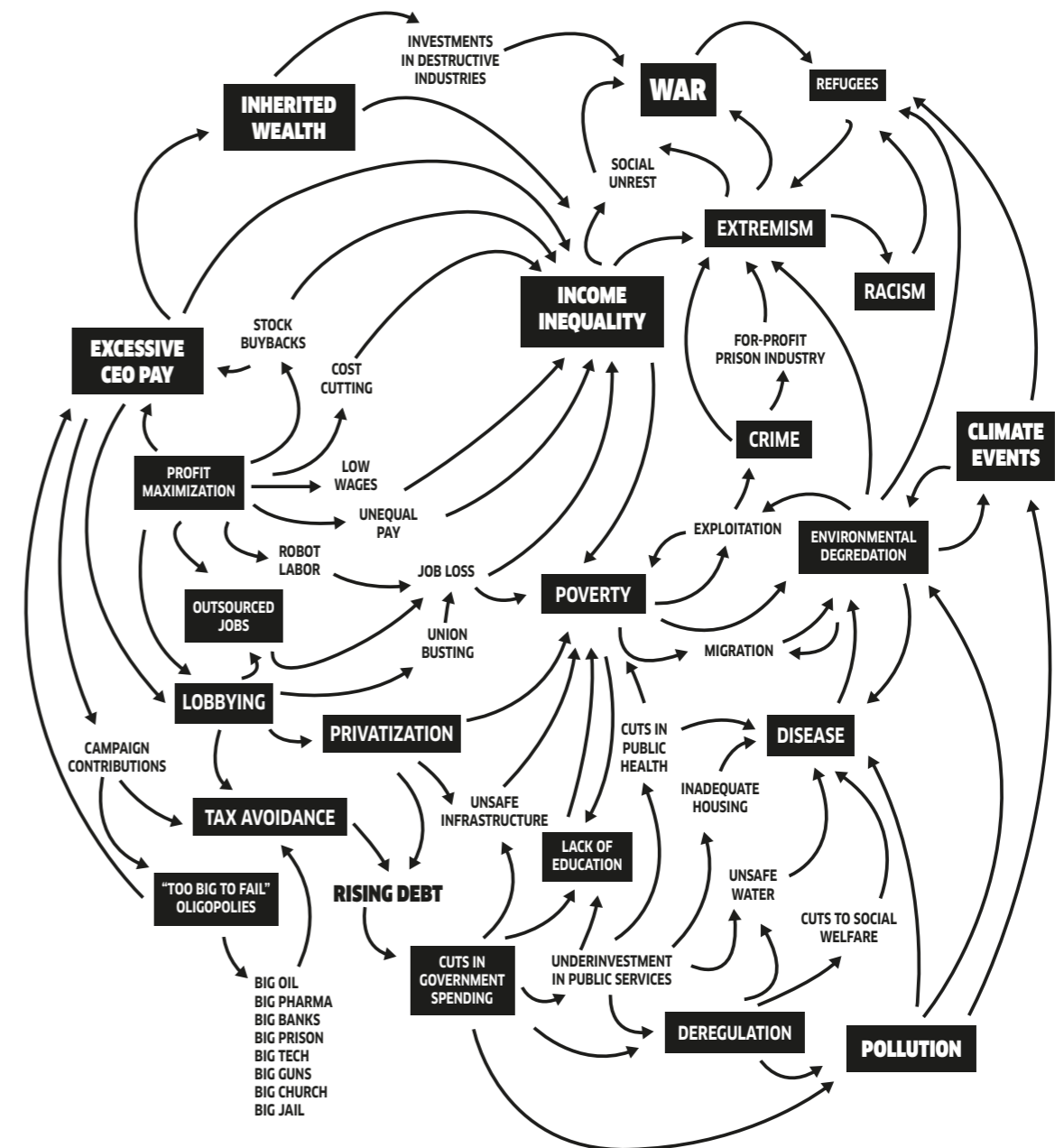
Since the Global Financial Crisis, and the ending of the long '1990's' boom, a new age of multiple different, uncertainties has unfolded at global, national, regional, and metropolitan scales. The times challenge households and firms in new and different ways and question the roles, beliefs, understandings, and resources of governments at all scales. The difficult times in which we live, firms invest, and governments act, may arise from short-term shocks with long-term consequences (and origins), such as Russia's attack on Ukraine and the Israel-Gaza tragedy. Or they may be political-economic in origin, such as the Truss-Kwarteng macro-policy anomaly that, destructively tested in the context of harshly practical capital markets, significantly damaged the UK economy.

They may also be medium term concerns about how to recover economic momentum in the wake of the Covid-19 pandemic, and finance the government debts stockpiled in abating it, or how to deal with the trade barriers and labour market disruptions consequent to Brexit. The disturbed post-Cold War balance of power has seen the emergence of new tensions betwixt, China, America and the Anglosphere, and Europe and Russia, for example, which are disrupting flows of trade and factors of production.

In an unfortunate coincidence of timing, governments are also now having to deal with difficulties that, as a result of their own short-term focus on retail politics, have 'kicked down the road' over the last three decades. Strategic infrastructure shortages, housing system problems, income and wealth inequalities, child poverty, population ageing, and its health and social funding challenges are now demanding urgent policy action.

It has become imperative for governments to recognise, embrace and act upon the system wide challenges of global warming and reducing biodiversity. However, even with an urgent, absolute, numerically expressed policy target to achieve, net zero by 2050, it cannot be exclusively prioritised to the detriment of progress on these other key aspects of wellbeing. Poor health, poverty and poor housing may not be existential threats for all, but they are for some, and arguably too many, and sooner rather than 2050. Moreover, the outcomes of these processes create and reinforce recursive effects, of left behind places and wealth and income inequalities, and rising intergenerational inequalities, which begin to redesign political landscapes and choices. These emergent, wicked systems, see Figure 2 below, may not yet be a dystopian future but they are an extraordinarily difficult set of policy imperatives that challenge not just the siloed structures and separated levels of governments but make growing demands on the resources for resolution.

THE ECOSYSTEM of WICKED PROBLEMS



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Governments have to act on these challenges. Action requires public resources. And more government resources, as always, have to come from redistribution or from a growing economy. Key decisions then involve understanding how major redistribution strategies may impact economic growth of a particular nation or region. These difficult choices are not just about what

the nature of the economy and the environment are to be but what sort of polity and society we are to become. Households and firms need some sense of, and choices about, what 'big' aims they are to live with. Undoubtedly the recent unsettled constitutional arrangements of the UK are a potentially further difficulty in making policy. New South Wales and Ontario have their differences and

resource debates with their Federal governments but protecting rather than radically changing their constitutional arrangements takes less focus and time in strategic government thinking than in Scotland. There has, however, never been, in peacetime, a more difficult context in which to make policy decisions in and for all three of the case study cities. Are there resources and route-maps for problem resolution?

Resources: From Faltering Growth to Fiscal Difficulty.

The long-boom of the late 20th century has long-ended. The GFC, consequent austerity actions, and the Covid-19 pandemic have all beset governments with problems in economic management. More widely, a decade of non-traditional monetary policies involving extensive quantitative easing have, post pandemic, left economies (including the UK) with a difficult mix of high national debt to GDP ratios, record elevated levels of household debt and significant inflationary pressures that are being addressed by sustained high interest strategies. In the UK, Brexit has demonstrably damaged trade and factor mobility so that productivity and growth remain low by OECD standards, and in Scotland, the long, inconclusive wrangle over independence has not facilitated progress either².

In the second half of 2023, for the UK and Scotland, energy and food price increases have abated and, with them inflation pressures have eased faster than expected. However, the world economic outlook still appears difficult for the immediate years ahead. The IMF, at time of writing, expect growth in the advanced economies to fall from 2.7pc for 2022 to 1.5pc this year and remain low at 1.4pc until 2025. The euro area, still reeling from 2022's sharp spike in gas prices caused by the war, is set to decelerate sharply and the evidence suggests that the UK will perform below the EU average and a probable recession is predicted for 2024. Scotland, according to the Scottish Fiscal Commission, is likely to grow at a rate less than the rest of the UK.

Edinburgh led Scotland's growth in productivity and prosperity through the long boom until the GFC, subsequently and through the post-Covid recovery, and this is discussed in more detail in Chapter 3. It is important to note that over that

period increasing globalisation of trade, finance and skilled labour flows, the growing mobility of resources, goods, people, and ideas was the handmaiden of growth, not just in Edinburgh and the other case study cities, but in the OECD, the BRICS and elsewhere. Should the shift to net zero have to rely on reduced mobilities, what will replace trade as Scotland's future economic base (that provides the private incomes and public resources for wellbeing)? Revaluing natural capital and promoting community wealth (both laudable goals, see below) are unlikely future bases. Half a century ago Hoover (1972) noted 'cities and regions do not thrive by taking in their own washing'. That remains as relevant now as then. What happens if the Scottish economy becomes disconnected from trade and innovation possibilities? How much poorer will we become if we give up the gains from trade? (see Chapter 3).

The weak fiscal position of the UK government is even more apparent at the Scotland level where the Fiscal Commission predict below UK growth rates in incomes and population (and faster population ageing) that will see, in the absence of significant increases in Scottish tax rates, acute spending pressures for the Scottish Government. The most recent estimates suggest that the already high Scottish public debt to GDP ratio will increase at an average of 1.7pc per annum over the next decade.

At the same time, 'kicked down the road' difficulties are all now placing 'crises' demands for the constrained fiscal resources available for Scotland. Municipalities, initially told in spring 2022 that they would have to significantly raise municipal taxes have, in an already centralised local government finance system, were then told in the autumn that they would not be allowed to do so. This is a strong signal of both short-termism in Scottish government fiscal thinking and in an evolving budget crisis. These difficulties remain after the spring budgets of 2024.

Estimates of the costs of policies to achieve net zero transition goals for Scotland 2030 have not been adequately developed and publicised. UK level government estimates of the additional costs of net zero policies have been made, revised, critiqued and are generally regarded as unreliable (Ward, 2023), but suggest a cost of between 1 to 2pc of GDP per annum (and that is much lower than estimates of the costs of not implementing policies).

Yet finding that additional amount for public spending each year will be a challenge for the UK government, more so for the Scottish government.

Even if clearly defined missions and delivery plans for GHG reductions-fairness-wellbeing-inclusion-productivity can be constructed, there is little real prospect that public resources to drive net zero programmes will be in sufficient supply to meet 2030 interim targets for the Scottish government and that the 2030 net zero aims of the City of Edinburgh have essentially been infeasible since they were announced. They will need rising levels of green finance and that, in MacPherson's terms will require Scotland to be seen as a worthwhile destination for mobile, global green capital. There needs, without relaxing net zero goals, to be a new era of policy realism regarding what just transition paths Scotland can actually afford, and policy thinking has to go beyond the standard Scottish response of estimating green skill requirements to consider capital requirements and the policy settings to meet them. This requires much more than virtue signalling policy intentions.

There is an important insight for future Scottish policy choices, not least for aviation, to be drawn from the current poor growth performance of the economy (effectively zero growth from autumn 2022 to 2023) and constrained fiscal resources. Slow or no-growth over the next decade will mean that inclusion goals, and the crises in health and housing will not be resolved without significant redistribution of income and wealth. Fiscally induced mobility may often be overstated but there should be a recognition that the scale of redistribution required to accelerate net zero investment could trigger fiscal mobility of firms and households, especially with low or zero growth, if it is unmatched elsewhere, or if there is a sharp increase in regulation controlling the energy use and mobility behaviours of households.

With reaching net zero a global challenge, it has to be recognised that Scotland, even the UK, will have overall climate outcomes set by other countries (we are, in conventional economic terms, not climate 'makers' but climate 'takers' (unless we are spectacularly, and improbably, successful as 'moral leaders'). Some nations will choose longer shallower paths to net zero, with (as discussed in Chapter 3) probable innovations in energy sources and efficiencies in aviation emerging a

decade and more from now that will ease growth-net zero trade-offs. If major metropolitan areas with which Edinburgh competes choose different slower descent paths, then strong regulatory and redistributive choices for the next decade could diminish city competitiveness and reduce Scottish growth rates even further.

Alternatively, well thought through energy descent-green economy growth strategies could offer Edinburgh and Scotland real gains in disposable incomes (see discussion for Toronto below).

In short, in choosing the absolutely essential energy descent path for Scotland and its places, there has to be an explicit and coherent approach to identifying the green growth path that will allow the economy to produce the resources that households require as well as the net zero environment in which we will live. In development economics there has been long debates about low and high income and employment outcomes and a similar issue arises in the growth-net zero transition. Are we seeking a relatively fast and, with the concerns and technologies that exist now, certain net zero (the precautionary approach) that will actually reduce real wellbeing on 'non-green' objectives? Or can more dynamic and evolving missions for change need to be set in place that emphasise net zero with higher outcomes for 'non-green' dimensions of wellbeing? Like the route to Loch Lomond, are we taking the high road or low road to future wellbeing as we attain net zero? There is little evidence, in undertaking the work for this paper, that suggests that these issues have been adequately addressed to date in Scotland and in relation to aviation policy, and they will be discussed further below.

A Change of Age: After Globalisation and Beyond Human Intelligence?

The gloomy economic and fiscal forecasts for the near future (2025) convey little about other emerging challenges for Scotland's economy. For instance, the growth of Artificial Intelligence applications will have some positive effects for research and 'data intensive' economies, such as Edinburgh, but they may have a drastic impact on employment in relatively unskilled activities that do not require 'human' contact, with call centres an obvious example. It is clear, and discussed further in chapter 3, that both Edinburgh and Glasgow (the

latter after a half century of economic struggles) have relatively modern economic bases (reflecting long boom processes with Scotland remaining a major destination of FDI inflows into Europe) with sectors such as innovation, bio-medical research, advanced manufacturing as well as well as leisure and tourism driving jobs and incomes. The critical questions are not just will they remain innovative but whether global trade will continue to grow and how rapid movement of people and goods are more less essential to the capability of these modern economic sectors to thrive.

One of the major concerns for the future is that as well as slower growth, that the world economy is 'de-globalising'. That is international mobility and trade demands will fall with economic 'localisation'. Goldberg and Reed (2023) in a recent review of trends and prospects in globalisation suggest that prior to the pandemic there was no substantive evidence of the end of economic 'globalisation'. However, adding to the anti-trade consequences of the pandemic and the Russian war, some major governments (including China, India, and the USA) have implemented policies to limit international economic trade and to adopt protectionist economic policies.

Yet, they note *'there is still no conclusive evidence that international trade is deglobalizing. When measured in US dollars, global trade growth slowed after the global financial crisis in 2008-09 and declined sharply at the onset of the pandemic in 2020. But since then, trade has rebounded to the highest value ever. As a share of GDP, global trade has fallen modestly, driven mostly by China and India'*.

Fast globalisation, through the 1990's, had significant benefits for households and firms in the case study cities. More widely, Goldberg and Reed comment that *'Consumers in economies open to trade gained access to an extraordinary variety of goods sourced from all over the planet at affordable prices. Smartphones, computers, and other electronics allowed people to be more productive and to enjoy more varied entertainment than previous generations had ever dreamed. Declining prices of air travel allowed people to visit other countries, exposing them to new cultures and ideas—an experience once reserved for the ultrawealthy.'* They attribute these increases in wellbeing for many households to the growth in

relatively free trade and world peace and, in effect rising connectivity. These effects are recognised in Toronto and Sydney policy debates but are not given the prominence they deserve in Edinburgh where immigration from overseas has driven population growth since 2011.

Critics can quickly highlight the adverse effects for particular regions or socio-economic groups from the globalisation process. The 'revenge of the left behind places' (Rodrigues-Pose, 2019) has had significant economic and political effects that rightly caution governments against working with 'only market' aims and means. And cities have also reacted to the sometimes excessive growth of tourism and other consequences of growth (localised hyper-globalisation), including, recently, Edinburgh. There must be real concerns about whether Scotland, and Edinburgh, have managed these growth, and subsequent regulation, processes effectively. But this is a different policy perspective from essentially ignoring growth benefits or making simplistic decisions to stop growth processes.

The evolution of anti-globalisation arguments in trade policy has evolved through different stages. From the reaction of the left behind places, through concern about China's subsidised global expansion to, now, rising international tensions. Yet Goldberg and Reed (2023) suggest that trade (like travel and tourism) has remained robust and by 2021 had recovered to pre-pandemic levels. The future, with the USA banning high technology exports to China, is now uncertain but with an increased prospect of a world divided into major pro-US or pro-China camps and locked in a new trade 'cold war'.

Future Connections.

In this future of technological change and potential geo-political fragmentation, Scotland has to be sure where its prospects, loyalties and connections lie. This cuts to the heart of the argument about how economic progress is considered in relation to net zero. In articulating its multiple goals, and considering its fiscal resource potential, what do governments for and in Scotland assume about and try to shape where they will be trading a decade from now? And what mobilities of people and resources will be involved? In particular, how critical is non-local mobility to maintaining economic performance. For instance, what are

the costs of reducing aviation that currently serves a metropolitan area, and what is the nature of the mobility-prosperity-sustainability trade-offs involved? Are such trade-offs part of net zero thinking? Are they apparent in the policy documents of the Scottish Government and Edinburgh city actions? Has government in

Scotland adopted a more autarkic view of how to run the economy? What will more local lives and trading patterns mean for the wellbeing of Scots? Will shifting to net zero deglobalize the Scottish economy, and what will the impacts be. Does zero wellbeing growth have to come with net zero carbon? These issues are explored below.

3. Changing Concepts for Economic Policy.

Changing Understandings.

How do governments understand problems and design policy solutions for the difficult new times? Is the only growing clarity that these times are more difficult and policy problems more complex than previous decades? Are governments finding new ways to cope?

In the economic dimensions of Scottish policy there are new policy narratives and decision rules emerging. Government Ministers in Scotland in recent years have, often in the same sentence, talked about the importance of having a green, and blue, inclusive, and fair, wellbeing economy that creates community wealth and is productive and innovative. This might be a reasonable, if somewhat long, statement of the overall aims of the government but, at the same time, an unhelpful and confusing 'guide to policies for the economy'. It is an opaque statement of economic intent because the grand aims, which are difficult to disagree with, are seldom translated into observable action measures and uncertainty of meaning is exacerbated by an underlying implication that some new, but unspecified, 'model economy' is being delivered. This may be both confusing and misleading rather than signalling, at home and abroad, clarity of intention and action.

In Toronto and Sydney, where governments do have environmental and redistribution goals, economic policy narratives are much more clearly focussed on conventional measures of growth and productivity. Economic statements in Edinburgh more typically emphasise that distributional outcomes are always important, green-sustainable processes and outcomes matter, there more to

life and wellbeing than conventional measures of economic outcomes, and that building the wealth of communities can be important. These matters are not regarded as unimportant in the other case studies, but they have not displaced or diminished GDP, growth and productivity in economic policy thinking and the formation of government strategies. Green, inclusion, and wellbeing narratives have been largely absorbed within, augmenting, existing economic and related narratives. Policy debate in Scotland over the last decade appears to have edged from, correctly, suggesting GDP per capita is an incomplete measure of wellbeing towards, mistakenly, ignoring its crucial role in reflecting and underpinning national and individual prosperity.

In Scotland, much of the critique of measures of economic progress by advocates of green, wellbeing, and inclusion priorities (ideas that all contain important insights for policy action) has been developed by attacking 'conventional' or 'mainstream' economics. These critiques typically, and mistakenly, equate 'economic thinking' with the strong 'neoliberal' consensus that prevailed in from the early 1980's through the long boom period. Influential advocates of wellbeing, green, community wealth perspectives often treat the economics discipline, not to be confused with neoliberal/neoconservative economics, and its insights as a 'straw man'. And as the aims of these ideas, inclusion-wellbeing-net zero, are successively embraced by policymaking for the economy, they have diffused the focus of economic policies and displaced concern about growth and productivity, and that is a major difficulty.

This 're-positioning' of economics in economic policy making in Scotland appears to involve a number of elements, all of which are misplaced. The first argument is, typically, that GDP per capita does not measure wellbeing, which should be the central aim of policy. I was taught, as an undergraduate student in Political Economy student at the University of Glasgow in 1968, that GDP omitted not just the labour of women in the home and multiple aspects of natural capital, but also the importance of, kindness, closeness, love, hate, fear, and esteem in our lives (Hook, 1968). That said, we also learned that it was a particularly important measure of resources available to households, and potentially governments. Wider measures of wellbeing are essential to good policymaking and the development and systematic use of an agreed set of indicators would much aid Scottish policymaking (see further below). That might not be sufficient for many 'wellbeing' advocates.

Recently McCartney et al. (2023) commented that 'A *'wellbeing economy'* has been proposed as an alternative approach to designing dominant economic systems to address global challenges, including achieving social equity and improving population and planetary health'.

Aside from an agreed wider set of measures of wellbeing, happiness, utility (whatever terminology is preferred) does this alternative approach involve changes in 'dominant system' government regulation, tax, and spending priorities? What is the proposed extent and means of the intended alternative distribution of social equity? How will the priorities for health and environmental spending be set and what share of national budgets are they likely to absorb? What is the balance of consumer, citizen, communities, corporate, municipality and the state power in shaping decisions and delivering the outcomes? Is this really technically a different economic system in terms of its discovery and allocation mechanisms or just a different set of value judgments about more redistributive policies and priorities? Such a world might be attractive, even to economists, but voters and investors need to know the offer, how the system will work, and who will pay for it. It hardly constitutes a different economic system, nor does it displace growth and productivity as potential routes to growing and redistributing wellbeing.

Mainstream economics is also much concerned with issues of inclusion and consequences of inequality, for instance the work of Stiglitz, Fitoussi and Blanchard in the wake of the Sarkozy commission or the sustained stream of work from Amartya Sen, Thomas Piketty, Angus Deaton and, in the UK, the late John Hills. Equally the pioneering work of Ed Mishan and David Pearce from half a century ago to Partha DasGupta and Nicholas Stern in the last decade has shifted understanding of environment-economy interactions globally.

Deidre McCulloch (1989), writing in the USA at the Chicago School zenith, made the important observation that the daily practice of economists as applied economists often differs from the mathematical models and reductionist simplifications that they use in teaching, research, and academic publications.

Raworth's (2017) 'doughnut' approach is a reasonable proxy for what many applied economists actually economists do when working in government or on applied policy studies. Economics practice within governments, say within a public spending round, often pays much attention to what are now discussed as 'wellbeing' effects. Of course, different governments, and different bureaucracies, as well as external critics may differ on what they consider to be a good thing (wellbeing inducing) and how to deliver it. However, economic policymaking is rarely the mindless mathematically driven calculus of maximizing GDP². Whatever the word used, welfare or utility or satisfaction or real incomes or, for the historically inclined, 'ophelimity', economic policy thinking was always concerned with making complicated decisions not calculations about major aspects of what is now called 'wellbeing' (Nath, 1971). Indeed, with almost half of Scottish GDP spent by the public sector expenditures on redistributive 'wellbeing' policies are already a major component of Scottish economic policy.

Economic policy making and debate have not, since its inception in 1999, been a strength of the Parliament, few Members have backgrounds in economics and finance and only one First Minister in a quarter century has spoken about economic issues with any real confidence. The Parliament has found it difficult to set economic and spatial priorities and has been more comfortable discussing universal social justice and wellbeing measures. In consequence, the presentation of

Scottish economic policy has become a multi-faceted, interesting, but confusing discussion. Paul Johnson, on standing down from the UK Climate Change Committee in 2023, noted the absence of explored economy-environment trade-offs and well defined routes and delivery plans for decarbonising the economy and said 'Tackling climate change will require careful long-term, honest planning, decision making and delivery that has not exactly been the hallmark of British governments in recent years' (Guardian, 25/9/23). Similarly, in the Scottish context the multiple, sometimes contradictory, economic policy narratives leave much ambiguity about what matters in the Scottish Government's 'economy-environment' trade-off, or whether there is a trade-off at all. That lack of clarity matters in shaping the future of aviation, and other, policies!

Speaking to a delegation of business leaders at a side-meeting at COP28, the First Minister correctly emphasised the green growth skills of the Scottish labour force and the appetite of Scottish business for technology and innovation that were available and 'can be applied in the race to net zero' (Scotsman, 4th December 2023). Potential investors drawn in by that accurate statement will then confront the barriers highlighted in the MacPherson (2023) report and one of these will be how Scotland will connect globally in the future.

To make Scottish economic policy discussion more coherent and restore some notion of growth and productivity to the forefront of policy, and investor confidence, the Scottish Government need to make it clear that they have no intention of pursuing the 'post-growth, no-growth' perspectives of some green economists (Cosime, 2017; Mastini et al, 2021) but that 'green growth' is the core economic policy goal. They should also embrace broader definitions and measures of productivity and growth that reflect the new green and inclusion concerns and set explicit goals in a revised National Performance Framework.

The time for virtue signalling is past and real delivery of GHG reduction, productivity growth, and wider inclusion, is here. To move forward, Ministers need to emphasise the benefits of growth and productivity, and stress that the resource discovery and allocation processes in the economy are primarily driven by the choices and efforts of households, communities, firms, and governments.

They must also use the National Performance Framework to make coherent sense and shape a unitary economic policy narrative. Each new emphasis in economic policy over the last decade has added a new adjective but also often undeclared beliefs in how economic mechanisms operate, and value judgements about the distribution of income and the power to change it. It is a credit to the Scottish Government to have green objectives with timeous net zero goals; to be concerned about boosting inclusion and improving distributions of income and wealth; and raising productivity and embracing wellbeing progress. These goals should be at the core of the national performance framework, and it should be used to design, deliver, track, and talk about policy progress. But the ends and means have to be clear and coherent.

When government divides all the key goals into different policy spheres (GIWP), with their different implicit resource allocation and distributional mechanisms then what we get is not an achievable grand vision but a 'babble' of different resource claims and disparate policy approaches. Little wonder the coherent framing of the National Performance Framework is seldom used, for in the broadest possible sense these components of policy, as economic policy, just do not add up. Perhaps they never will. This raises the question of competences and capabilities to deliver this approach.

4. System Competences for Change.

Changing Times

The Scottish Government, and the City of Edinburgh, should be praised and not criticised for their enthusiasm to embrace the goals of net zero GHG, greater inclusion and wellbeing and to declare an obligation to undertake 'moral leadership' towards a better world. And they are unfortunate in that, as outlined above, they have faced a difficult global, UK and local context in which economic growth and fiscal capacity have faltered and costs risen. However, lack of progress, notably the persistent failure to meet emission targets, reflects more than fiscal resource constraints in the Scottish policy process. Lack of clarity in the articulation and understanding of economic policy was discussed above as was the unwillingness, or inability, of government to connect major strategies and other policy actions to its own National Performance Framework. More specifically in relation to decarbonisation, the continuing absence of the 'just transition' plan for major sectors of the economy and the absence of a purposive discussion regarding future aviation are legitimate causes for criticism of the Scottish Government.

There is also a worrying tendency in Scottish public policy making. Others, such as the Fraser of Allander Institute, have remarked on the multiplicity of short-lived economic, and related, strategy documents. There is also a pattern in the content of key Scottish Government strategy documents. Typically, an introductory chapter sets out a grand vision of what needs to be achieved and changed and is often an inspiring statement. A second part will briefly outline conceptual ideas and evidence and apart, from health documents, they are usually weak. The third part then becomes really problematic as longer term missions for change are rarely defined and plans, resources, and mechanisms for programme delivery are rarely articulated.

In effect, these are policy 'sketch plans' rather than strategy statements and they are not adequate for the tasks of change now faced. Without careful consideration of delivery processes strategies will often fail to recognise the constraints that will slow and diminish progress.

In recent decades Scottish and municipal levels of government have reduced their thinking research and planning capacities. This may explain the sketchiness of strategies. Or it may be that unwillingness to make specific priorities, and this is apparent in infrastructure and national spatial plans, reflects an inability of the Parliament to think about space and time. That is, where 'Scotland' will be decade or two ahead and what needs to be done to deliver that change. If these capabilities really are missing, then it is hardly surprising that a definitive action plan for 'just transition' has not yet appeared.

Marriana Mazzucatto, one of the Economic Advisers to the First Minister, has set out in her academic writing a convincing system of actions for envisioning and for delivering change in grand goals shaped by, often, imperfectly understood, wicked systems. The Government should adopt her published advice (Mazzucatto, 2016) in framing economic and net zero strategies. They have to move from vision to an articulation of desired long-term outcomes; frame missions for change; then implement the best possible delivery actions to move towards these outcomes in the medium term; monitor progress intensively; and amend actions (or aims) when progress is inadequate. This seldom happens in Scottish policy making. In recently reviewing the National Economic Strategy, the Auditor General noted that it 'lacked political leadership and clear targets for delivery and progress' (the Times, 8/2/24). That comment echoes Johnson's earlier observation on UK, and Scottish, zero carbon aims as an 'easy consensus and lacking any serious policy scrutiny' (Johnson, op. cit.).

In the strategy for aviation change to support net zero GHG for Scotland, the best first move is not yet articulated, let alone a coherent statement of mission, and means, made. Some UK Cities are embracing this approach for aspects of policy change and Waite et. al (2022), outline the pros and cons of the approach in the specific context of an aspect of transport policy for Glasgow. The Scottish Government need to develop real competence in this strategy-delivery approach if they are going to deliver net zero. It does not yet appear to have done so.

Scotland, as noted above, already has developed a framework for tracking change, the National Performance Framework. It is impressive, and capable of improvement, but seems little used. In the way that some municipalities now score their projects against the UN's 17 goals for Sustainable Development, one would expect the anticipated impacts of sectoral strategies, policies, and investments of the Scottish Government to be scored against the National Performance Framework. This does not happen in any systematic way, and this is unfortunate. The weight that government gives to sectoral objectives can only be revealed ex post by exploring the resource allocations actually made. It is decisions, not ex ante rhetoric, which reveal the trade-offs that are made, and priorities chosen. There may be merit in having more local regional or metropolitan measuring frameworks nested within and cascaded down from the national approach.

As part of this study, the outcomes of Edinburgh Airport activities were matched into the National Performance Framework with significant effects on more than ten 'indicators. No such cross-reference for Edinburgh and other Scottish airports appears to have been undertaken for the government's aviation strategy review. Has the Scottish Government ever assessed how Scottish international and interregional mobility, and more specifically the aviation sector (and Edinburgh Airport), contributes to progress, and problems, in the National Performance Framework? Why not?

Changing Places

The translation of economic and other goals into coherent spatial and infrastructure plans is a further vexed question that is discussed in the concluding chapter with only preliminary remarks here.

The National Planning Framework for Scotland outlines the principles and potential patterns for place change in Scotland. There is much constructive debate, and action, about shaping neighbourhoods and Scottish city structures to reduce domestic, daily, mobility related GHG emissions. Scotland has, in recent years, tended to think effectively about the small and local in spatial economic development policy (MacLennan, 2021). There is, however, a somewhat neglected consideration of the implications of major place structure changes within Scotland and how the Scottish economy fits into changes in the regional structure of the UK. These observations, are particularly true in relation to the emerging spatial structure of the Scottish economy and, given these likely new geographies, the trading and mobility patterns required to achieve whatever economic policy objectives are embraced to sustain the net zero economy.

The National Planning Framework has to be, and is, more than a restatement of (long-recognised) principles of good place making. It also has to serve as the indicative which that shows where public and private actions (including major infrastructure investments) should be taken, and connected to each other, to best achieve, over the long term, progress towards the multiple goals of governments expressed in the national performance framework.

It does not. The current, Fourth, Framework, is dominated by net zero concerns, and is weak in its conceptualisation and regionalisation of Scotland's spatial economies and its required internal and external connectivity. connectivity. It is almost devoid of any evidence-based understanding of the nation's economic geography. For instance, whilst building houses in north-east Edinburgh appears as a 'national priority', Scotland's strategic external connections and the Edinburgh Airport do not feature at all. Scotland needs to get a grip on clarifying these economic and economic geography policy issues, and quickly.

There are, in contrast to the case study contexts, relative weaknesses in Scotland's strategic city-region planning and subsequent delivery for ambitious change, especially in economic policy articulation, and national spatial and infrastructure planning and this will impair the achievement of net zero with the highest possible achievement of wellbeing.

5. Collaboration and Change.

Taming Wicked Problems.

Governments are organised in layers (levels, orders) with different autonomies (powers) to tax, regulate and spend for each level, although overlapping powers and responsibilities often occur. Within each order of government major functional responsibilities are segmented into different departments with 'central agencies' tasked with securing aspects of cross-departmental coordination. Horizontal silos and vertical separations characterise the framework for government actions.

Real functioning systems respect neither the boundaries of silos nor territories of governments. This is especially true where multiple causes have multiple outcomes with recursive effects. Achieving net zero carbon is a classic, complex wicked system management and change problem. Governing for achieving net zero is unlikely to be effectively achieved by conventional silo-level government approaches.

Governments know this multi-level, multi-sector complexity is the nature of the problem. Achieving global net zero, or net-zero of any one country is dependent on all or most countries. For any country to be free of the effects of global warming the sum of the emissions of all countries has to fall below critical levels. And that connected complexity of emission-warming-climate damage cascades down through levels of government within a nation. Co-ordinated, collaborative action has to be the hallmark of change for net zero.

Equally, within an order of government, there has to be aligned actions across departmental silos to best achieve energy descent and net zero carbon outcomes. It is not enough for governments to collect Ministers and departmental heads around Cabinet tables and agree that all have to act. They all have to act together and a continuing collaboration.

Both the collaboration successes and failures at international scales are evident at COP 28 but are not explored here, though cross-national coordination aspects of future fuels and aircraft will become more essential as decarbonisation of aviation intensifies. Here the focus is intra-national.

In all three case studies there were obvious non-alignments between metropolitan and federal/national scales of action. This reflected, in Canada and more particularly Australia, a desire of metropolitan scale politicians to embrace change to net zero GHG faster than Federal governments. Aspects of this 'vertical' difference of appetites for change are evident in Scotland too, but less obviously so. For instance, the City of Edinburgh has stated aims to achieve net zero by 2030, Scotland by 2045 (these two goals are obviously inconsistent) and the UK by 2050 (potentially consistent with Scottish aims).

Within the UK, with these different target dates, there are also gaps in the design and coordination of actions to reach net zero and overlapping autonomies that are not yet effectively aligned. Most worryingly, for the aviation sector in Scotland and Edinburgh airport is that presently, there is no coordinated strategy for decarbonising aviation and airports across the UK. Within Scotland there is no policy discussion forum that places a premium of working towards effective low carbon mobility within and beyond the UK. In the statements and evidence available from all three orders of government there is considerable, justifiable, emphasis on decarbonising energy and mobility systems and that discussion for change should start now.

As discussed in subsequent chapters delivering net zero aviation from any airport will require action on locally and sub-nationally controlled programmes for planning, infrastructure, and local-regional economic development, for example. National programmes may overlap into similar areas of policy, for instance the Levelling-up, Green Freeport and City Deal projects within the Edinburgh metropolitan area. But they may also have heft in areas of science, innovation, energy, and industry policies that may constrain or support local action.

Where sub-national governments think local or regional rather than national and global, they may disconnect their policy thinking from wider systems and, for example, ambitious but infeasible targets for reaching as quickly as possible a hard net zero outcome. The project interviews revealed a view from business leaders and sector experts that this 'national disconnect' may be an issue for Edinburgh. The outcome risk of locally conceived 'isolated' policy change includes both potentially lost metropolitan economic prospects and continuing adverse climate change driven by other jurisdictions. There has to be a local awareness of how behavioural and technological change in other localities facilitates new possibilities to reach net zero and shifts the trade-offs between environmental and economic outcomes to one of positive synergies.

Governments, at all levels, have to be constantly reviewing how, and with whom, they govern for the attainment of net zero. Open, collaborative government and governance for achieving net-zero is required. It is not clear that this has evolved widely across all places and key sectors in the Scottish economy. There was in the case studies a much more open discursive approach between levels of government and airport operators regarding future aviation and net zero/economy consequences in both Toronto and Sydney than in Edinburgh with a much stronger sense of collaborative discussion about how to meet targets and maintain the growth of prosperity. They are having a different conversation about aviation in the future economy.

Aviation and the Edinburgh Economy.

Subsequent chapters will explore the measures needed to acquire or create the technologies, skills and infrastructures that could ensure that attaining net zero by 2045 does not drive net lost jobs, lower incomes and wellbeing and leave stranded capital assets and discouraged potential investors. This chapter has questioned whether overall emissions reductions and green growth for the city and Scotland is facilitated or impaired by the diverse, unclear narratives for creating the 'green, inclusive, fair, wellbeing, productive' economy that Scottish policy now talks about. Can this demanding set of goals be demystified and, despite the difficult times, a more coherent, delivery-oriented approach for government decision taking adopted.

There needs to be a more coherent, transparent approach to how Scotland moves forward to net zero whilst maintaining progress in wider wellbeing. In relation to the specific aviation sector interests of this report, which will not happen without a much more coherent understanding of how government can fashion geographies and mobilities that serve economic and social as well as net zero goals.

With these broader contexts, concerns and questions established, the next chapter starts a narrower focus on Edinburgh, the economy and aviation. It reviews key connections between Edinburgh airport and economic change in the city-region and the nation. Chapter 4 explores technological and procedural changes that may ease emission-economic activity trade-offs. Chapter 5 looks at a range of policy actions that governments might take to explore and the ease trade-offs by supportive, long-term investments in infrastructure related to aviation.

6. Findings: Difficult Context, Diffuse Thinking and Strategy Disarray.

GHG emission reduction targets are falling behind aims set after 2016, globally as well as in Scotland. The global context for policy making is particularly difficult and this is an age of 'wicked problems' amidst global uncertainties. The Scottish fiscal position is difficult, partly because growth has been de-emphasised as a Scottish policy objective for almost a decade, and embracing widely supported goals has led to a confused narrative and conceptual basis for government policy thinking. The absence of any coherent aviation strategy for Scotland and the failure to recognise airports as key infrastructures in both major infrastructure and national planning strategies has orphaned airports, and not just Edinburgh, in national economic and environmental policy debates. Confused economic and connectivity strategies damage investor interest in Scotland.

1. There is a growing realisation that the rapid embrace of net zero by 2050 goals by national governments, and by metropolitan areas for at least a decade earlier, are not being matched with actual goal fulfilments and required policy/strategy adjustments. This has been globally evident at COP28, the UK Climate Change Committee has criticised the UK and Scottish governments for not only failing to meet their emissions but not yet publishing a strategy for reaching net zero. Worryingly, the Just Transition Commission for Scotland in its Annual Report for 2023 express concern that there has been an absence of transformative leadership to reshape the Scottish economic base to prevent lost jobs and incomes.
2. Net zero strategies may be missing targets for a variety of reasons. Adverse global shocks to trade and growth (pandemic and war) and a range of policy issues requiring long-term strategic action but 'kicked-down the road' (infrastructure, housing, old age care, pensions) have created an 'age of wicked problems' for governments to address in a context of high public and personal debt, high interest rates and low productivity growth.

3. Some governments have exacerbated these global difficulties through their own policy choices and econometric research suggests that both Brexit and the Truss-Kwarteng effect of late 2022 are both stunting UK incomes and productivity. In the Scottish context the Fiscal Commission point to the budgetary constraints of the Scottish Government are likely to be heightened to 2030 by Scottish productivity and growth lagging the UK average.
4. The Scottish 'growth' problem arises in part from a lack of conceptual and strategic clarity in high-level policymaking but also a neglect of the benefits of growth in policy conversations. The Scottish government have embraced a range of laudable goals on zero-carbon, fairness, inclusion and with them adopted a range of diverse policy rhetoric that fails to provide a coherent basis of thinking to shape the economy. The absence of a clear economic narrative in Scottish public policy is problematic in designing coherent strategy and is potentially confusing for investors and voters.
5. The style of major Scottish strategies that impact decarbonisation and aviation is to have a grand vision of virtuous change, which is almost unexceptionable, a very partially evidenced and conceptually weak middle section, followed by no clear indications of intended delivery arrangements but often an articulation of principles of how others can 'deliver' better. This constitutes and abandonment of the 'indicative' and 'prioritisation' roles that governments can fulfil in transformative periods of new times.
6. There is a strong case for the Scottish Government to articulate clear missions for change and set their progress review within the context of the National Performance Framework

7. A coherent strategy for decarbonising aviation has been deferred as the Scottish government focusses on other elements of change to net zero. This seems a mistaken approach, that may lead to a push for damaging demand reductions. Aviation decarbonisation requires industry/economic strategy clarity (taking the new opportunities), science, technology and research strategy, skills strategy and critically clear infrastructure and national planning strategy inputs. Orphaning aviation policy, and airports, is an odd feature of Scottish policy making and there needs to be an immediate shift in emphasis now.
8. The Aviation sector is widely affected by the consequences of policy uncertainty for investment that the MacPherson Review recently articulated.
9. Edinburgh Airport, as a major Scottish connectivity node, requires more coherent consideration in Infrastructure policy making at Scottish and regional levels.
10. The 4th National Planning Framework, recently adopted by Parliament, needs to be reconsidered to pay urgent attention both to the economic geographies of how Scotland lives and works and to what key patterns will link Scotland to the rest of the UK as well as the wider world. It presently does neither and has to give some sense of the what the best geography of the new green economy will be.

²This is not a comment on the 'right' outcome of the independence debate but on the effects on a long period of potentially uncertain referendums and their outcomes.

³Nor was it when I was Special Adviser to the first the First Ministers in the Parliament, nor Chief Economist for the Department of Sustainability and Environment in Victoria, Australia, nor Chief Economist for the Federal Department of Infrastructure in Canada. From a decade spent in these posts I do not recognise the ways in which 'wellbeing' academics often describe how economics influences policy decisions.

AIRPORTS AND METROPOLITAN ECONOMIC GROWTH: EDINBURGH

1. Complex Connections: Airports, Mobilities, Net Zero and City Economies.

The previous chapters drew attention to the chain of economic activities, on the ground as well as in the air, which are associated with aviation and airports as strategic, accessible locations and the complex economic geographies (handprints) they create. They also highlighted the complexity of the policy environments that all governments, local, devolved, and national, now face and the challenge of choosing decarbonisation paths, which are likely to alter these chains of activities, to achieve a net zero GHG that will also be 'just' and increase wellbeing. Chapters 4 and 5 return to the questions of policy choices for achieving that trilemma. This chapter explores the chains and geographies of economic activities arising from aviation and airports.

Most of these activities, unlike the discussion of fuels and aircraft in Chapter 4, relate to 'on-ground' activities. The importance of knowing who gains, and to what extent, from these activities, is to assess the need for aviation and justification of the costs of decarbonising the process (especially Category 3 emissions). The on-ground activities also, however, impact GHG production and should consider (green growth) opportunities for contributing to wider net zero strategies.

This chapter addresses key questions that Edinburgh city, other local authority, and Scottish policymakers, aiming for a just, and prosperous, transition to net zero should be currently asking in making planning and policy decisions that impact the airport. The two critical questions are: how does the existence of passenger and freight flight, and other airport based activities, impact the economy: and how are current policy directions and future limits on GHG emissions, the decarbonisation path

for aviation, likely to impact the economic base and wellbeing of the city and the wider Scotland that it serves. It will be difficult to be precise regarding the latter as there is not yet any published aviation/economy transition strategy for Edinburgh and Scotland but there are some implicit directions in other policy actions. Possibilities for different paths are highlighted. The decarbonisation path chosen will not just sequence the economic effects, positive and negative, of transition but also create different 'green economy' opportunities associated with technological change in aeroplanes and aviation fuels. They also shape a new significance for the airport as a green energy producer and accessible location for ex-centric, polycentric, zero-carbon development of the metropolitan area. These are by no means certainties, but their probable benefits cannot be ignored (as they currently are in policy and planning discussions in Edinburgh).

Technological change in aviation, as noted in Chapter 1, is typically a decade (at least) long process. 'Carbon' risk averse policy action to reduce aviation as fast as possible may not be the strategy that results in maximum wellbeing or fairness accompanying net zero. If early, low technology/ low investment decarbonisation descent measures are deployed, in the absence of a green jobs strategy (and that absence is real) then significant 'shocks' could stimulate decline in metropolitan economies and compromise their fiscal capacity to deal with other problems. These 'shocks' are likely to trigger, wider, longer-term economic difficulties that will be difficult to model and predict. Edinburgh, unlike Toronto, has not modelled the income and economic effects of decarbonising the

the city and there is simply not the coherent understanding, and significant investments, that link infrastructure, connectivity and the economy that characterises public policy in Sydney.

Changing flight numbers, and freight and passenger volumes will, for instance, directly impact airport activity, the accessibility values and uses of immediate vicinities, and the metropolitan housing, and labour markets of airport employees. Such changes will alter the region-wide set of places involved in freight journey origins and destinations as well as the spatial handprint on economic activities of those passengers who land at and leave from the airport. For individuals, they may be holiday or family related consumption activities, or they may be regular or infrequent trips to work or learn. They may be business related trips forming networks, building trust, securing contracts, and seeking, or selling innovative products and processes. These activities may all have different geographies and impacts and short term sectoral effects in metropolitan economic development.

Short term mobility reductions could quickly evolve into wider, systemic challenges for the metropolitan economy as a whole when poverty concentrations grow and the new left behind places appear. Avoiding short-term shocks and the long term erosions of social and human capital that they may evolve into should be in policy thinking now for the selection of the just transition. This is not an argument against achieving net zero in Scotland, but it is a plea to get serious, and explicit, about the economic consequences of different transition path for key economic sectors such as aviation.

This chapter presents evidence from different kinds of sources and localities that substantial airports, such as Edinburgh, can have growth as well as income and employment effects on the spatial economies they serve. Part 2 briefly reviews the extensive academic economics evidence on aviation/economic growth interactions at metropolitan scale, and little of that evidence arises from UK research, and none from Scotland. Section 3, reports on industry consultancy studies that usually take a shorter term perspective and assess the employment and income effects in the short term. Part 4, building on the wider insights of the two prior sections, then reports evidence of airport-economy effects for Edinburgh that includes industry impact studies and the findings of qualitative interviews with forty business and policy leaders for Edinburgh and Scotland. Part 5 draws attention to airport vicinity economic developments that seem to have received little attention in planning and local economic development policies for Edinburgh. The concluding section, Part 6, then briefly draws conclusions and questions for economic policymakers in Scotland that need to be addressed now to shape policy change for a 'high road' to net zero by 2045/50.

2. What is the Evidence from Academic Research?

Relevant academic research studies, published in economic geography, regional and transport economics journals, are concerned with how geographies of population and economic activity are connected by flows that favour some locations, and not others. And with centrality and accessibility that influence connections, costs, and revenues in economic activity. Remoteness and detachment for a place may reduce or preclude economic activities.

There have, over the last three decades, been rather sharp swings in consideration of just how important accessibility is in constraining economic activity.

After the 1990's scholars, (O'Brien, 1992; Cairncross, 2001) argued about the 'death of distance' as new communication technologies and reduced transport costs, excluding carbon externality costs, prevailed. Lennaerts et. al (2020), in reviewing the emergence of that view, highlighted the role of aviation, noting that (again carbon costs excluded), 'the real price of air freight declined by 0.5 per cent per year between 1973 and 1993 (Hummels, 2007)'. They also stress that with globalisation of economic activity air travel became a particularly important travel mode in shrinking the world and raising growth and productivity.

Beneath these grand claims of improved accessibility for all, the importance of distance and connection never went away in shaping the 'marginal' advantage of different places. Geography always mattered. Lennaerts et. al. (2020) highlight this by reporting that in remoter countries, such as New Zealand and Australia, OECD's 2008 'Going for Growth' report concluded that their remoteness lowers average GDP per capita by 10 per cent. By contrast, the report associates the centrality of Belgium and the Netherlands with an increase in GDP per capita of more than 5 per cent (OECD, 2008). It is at least arguable that Scotland has never taken its remoteness from key European and even UK markets sufficiently seriously (as reflected in, for example, in the incomplete motorway links from north of Newcastle, via Edinburgh and the still unclear commitments to extending any benefits of the now shrinking HS2 high speed project for travel from London to Scotland, and the disregard of external connections in Scotland's NPF4).

Once the GHG, and other, externalities of transport and aviation became considered important, the counter swing in debate and policy has been to highlight the high costs of aviation and the importance of minimising emissions, and with given technologies and fuels, aviation mileages. It is argued further below, and especially in Chapter 5, that the 'localisation' of life and 'end of globalisation' may be as inaccurately exaggerated as the 'death of distance'. Hard statistical scrutiny and coherent economic, infrastructure and spatial strategies are required to shape policies to meet net zero and maintain other aspects of wellbeing.

In the three decades since 1990, aviation continued, and accelerated, its century old growth path (Profillidis and Botzoris, 2015) and arguments for its beneficial effects and 'productivity/growth inducing' properties have been widely propounded. Carbo and Graham (2020), as a preface to their own impressive research on airport effects for Chinese cities, have provided an extensive and insightful review of the literature on airport/economy effects. They note the extensive empirical literature on the effects of transport on economic development, with key reviews Redding and Turner, 2015; Venables et al., 2014; Melo et al., 2013). They stress that the weight of research is on road and rail modes with effects arising via influences on 'the location of economic activity (Redding and Turner, 2015), the demand for skills (Michaels, 2008), trade patterns (Donaldson 2018; Duranton et al., 2014), urban growth and market access (Duranton and Turner 2012; Banerjee et al., 2012), and via positive benefits from agglomeration economies (Venables, 2007; Graham, 2007)'.

Carbo and Graham conclude that the effects of aviation on economic performance remain understudied because modelling the causal relationships between aviation and the economy is complicated by the highly endogenous (chicken and egg) relationships of air transport and economic activity. They affirm that 'Consequently, there is a lack of consensus in the existing literature on the magnitude of economic impacts from air transportation'. They then tabulate, annotate, and summarise key results found in the literature (and Table 1 below simply replicates their work).

Table 1. Literature Review Of the Effect of Aviation on Economic Activity.

Source: Carbo and Graham, (2020).

Article	Air transport measure	Economic measure	Pooled sectors	Goods related	Pooled sectors	Country & period
Irwin and Kasarda (1991)	Air network centrality	Employment	0.429	0.513 (manufacturing)	0.505 (producer service)	US 1950-1980
Button et al. (1999)	Passenger	High technology employment	-	12000 more high technology jobs in hub cities	-	US 1979-1997
Button and Taylor (2000)	Passenger	Employment	-	1.5 jobs created per 1000 air passengers	-	US 1996
Brueckner (2003)	Passenger	Employment	0.08	0 (goods-related)	0.1 (service related)	US 1996
Green (2007)	Passenger Cargo	Employment	0.028	-	-	US 1990
Percoco (2010)	Passenger	Employment	0.045	-	-	Italy 2002
Sheard (2014)	Airport size	Employment	0	0 (manufacturing)	0.22 (tradable service)	US 2007
					0 (non-tradable service)	
Sheard (2019)	Airport size	Employment	0.03	-	-	US 1991-2013
		Output (GDP)	0.03			
McGraw (2014)	Airport presence	Population	0.14 to 0.29	Tradeable industry 0.26 to 0.42	-	US 1900-2010
		Employment	0.17 to 0.26			
Bloningen and Cristea (2015)	Passenger	Population	0.031	-	-	US 1978-1998
		Output (GDP)	0.14			
Gibbons and Wu (2017)	Airport access	Output (GDP)	0.2591	0.4164 (manufacturing)	0	China 2001-2010

Greater insights about the research problems involved in establishing the causal mechanisms for airport influences on city/region growth can be gleaned by considering in more detail some of the key studies cited in Table 1, as well some more recent studies and in the USA, Europe, and China. There are no Scottish studies to review.

USA

Blonigen and Cristea (2012) reported that remarkably little evidence on the contribution of air services toward regional economic development existed (as still holds in Scotland). The US 1978 Airline Deregulation Act induced significant changes in patterns of aviation. They used these market changes to assess the link between airline traffic, and local population, income, and employment growth for almost three hundred Metropolitan Statistical Areas (MSAs) over the period 1968-1988. They found that growth in air services has a significant positive effect on regional growth, with the magnitude of the effects differing by MSA size and industrial specialisation.

Blonigen and Cristea note the longstanding propensity of airports and regional development advocates to argue for government policies in the belief that air transport is crucial for regional/metropolitan economic growth. They note that there is a variety of evidence, including many anecdotes, that air transport facilitates growth. They usefully review a number of studies (still regarded as significant) that suggest air travel:

1. facilitates face-to-face communication that is essential for innovation, technology diffusion, and for coordination and efficient allocation of resources (Gaspar and Glaeser, 1998; Autretsch and Feldman, 1996; Hovhannisyan and Keller, 2011).
2. reduces transaction costs, increasing the openness of a region to trade (Poole, 2010; Cristea, 2011) and this fosters labour and industrial specialisation at micro level, as well as product diversification at regional level, leading to increased aggregate productivity (Glaeser, Kallal, Scheinkman and Schleifer, 1992; Feenstra and Kee, 2006)
3. raises regional productivity via agglomeration effects and the associated positive externalities (see, among others, Rosenthal and Strange, 2004)

4. influences the location decision of exporters and multinational firm headquarters (Lovely, Rosenthal, and Sharma, 2005; Bel and Fageda, 2008) that exert positive spillovers raising local businesses productivity (Blomstrom and Kokko, 1998; Arnold, Javorcik and Mattoo, 2011).

They stress how difficult it is to disentangle causality in assessing infrastructure investments (airport growth) and economic change. However, their 'natural experiment' approach strengthens their findings that airport growth did drive metropolitan economic growth for the cities and time periods they studied. They also, in a very balanced contribution, highlight that it is unclear (even in growth contexts) how much economic activity relies on air service, *'nor the extent to which other modes of transportation and communication can easily substitute for air services.'*

This last observation, returning to a focus on Edinburgh, is critically important in assessing the potential economic effects of net zero. This will depend not only on substitute transport modes for passengers and freight but also the extent to which cities are spatially distanced from their markets and suppliers.

Liao (2021), exploring patterns of aviation growth between China's cities notes that the widespread availability of high speed rail in China reduces aviation growth rates. In the middle of the European Union with short distances between major cities and already developed fast rail connections then air services may be non-essential. For instance, the Government of France decided in 2022 that flights from Paris could no longer serve cities accessible by a train journey of 2.5 hours or less (approximately three hundred miles or 500km). Paris to Lyon is just less than two hours by TGV. The fastest train trip from Edinburgh to Cambridge, approximately the same distance as Paris to Lyon, takes 5 hours minimum to connect these significant parts of the UK technological and life-sciences research communities, for example, roughly double the air-based travel time and double the Paris-Lyon travel time.

In the Sydney and Toronto case studies senior executives, both in nations with slow or limited inter-urban rail infrastructure between significantly separated major cities, simply did not see fast

rail as an alternative to air travel, nor do their governments. And, interestingly, in both Sydney and Toronto senior airline and airport officials were surprised that Scottish governments thought that an adequately expanded fast rail alternative to Scotland to London flights existed now. There may be a Scottish (and UK) government failure to recognise the geographic remoteness of Scotland, especially north of Edinburgh, (the Inverness to central London journey by rail typically takes 8-10 hours and, including travel to airports, half of that time by air travel) within Britain and its peripherality within Europe.

The City of Edinburgh holds a belief that it will be possible to near eliminate within intra-Britain flights from Edinburgh Airport, at least for southwards travel, by diverting passengers to mainline rail travel. The likelihood risk evaluations, rail network feasibility and time and cost implications of such a diversion are not in the public domain. There has never been a clear commitment to extend HS2 to Scotland and the likelihood of it reaching beyond Birmingham by 2040 appears to be rapidly receding. The importance of air connections from Scotland to the rest of the UK, Europe and the wider world for the city and Scottish economies may now be growing rather than receding and, see below, all of the business and finance interviewees stressed the urgent need, especially in the wake of the Brexit disruptions to trade and business relationships, for clarity on external connections. In the next Chapter the ways in which the relatively certain development of low, or zero, carbon flight with thirty-five seater aircraft with 300-400 mile range by the early 2030's may create quite different travel possibilities around the network of Britain's cities and regions. Air Canada are already ordering a considerable fleet of such planes for strategic regional connections around their major metropolitan areas. Could Edinburgh be the 'regional hub' for northern Britain?

Returning to US evidence, subsequent studies, with improved econometric estimation techniques, tend to confirm a causal effect of airport growth on incomes and employment. The findings vary in the nature of the effects involved. McGraw (2017), using advanced statistical research techniques, explored an extensive, data set for US cities and analysed the impact of airports on city economic

growth for smaller and medium sized cities (Edinburgh would be described as the latter). She found that, on average, airport activities raised population and employment growth by 0.2 - 0.6% per year over the period 1950-2010. The analysis also demonstrated that city specific factors influence airport success (defined in passenger and freight growth terms), including close proximity to a major research university, a capital city location, and climate factors, particularly higher January mean temperatures and/or hours of sunshine. It was also found that city size was also an influence as cities in larger metropolitan areas, with larger shares of employment in the population, also captured the economic effects of airports more effectively.

A further paper by McGraw (2015) explored the effects of an airport as being designated as a 'hub' by one or more airlines by contrasting the growth experiences of cities with hub and non-hub airports. She found 'while hub airports do not significantly affect city employment levels overall, hubs do contribute an effect of 1-2 percent on personal income to their respective cities, as well as establishment growth of 1-2 percent.' The strongest effects were on the hospitality and airlines industries and were greatest closest to airports. The major effects of hub airports were likely to operate through facilitating business travel.

Sheard (2017) also estimated the effects of airports on economic growth in US metropolitan areas, identifying the effects of changes in local airport sizes from overall changes in the air travel network. He found that airport size has a positive effect on local employment and that for every job created at an airport by an exogenous increase in traffic, around four and a half jobs are created outside of the airport. This is largely an effect on services employment. He also noted that 'airport size is also found to have positive effects on local GDP, the number of firms, population size, and the rate of employment. The magnitudes of the effects on population and the employment rate suggest that the jobs created by airport expansion are spread between existing residents and workers who migrate to the area. In addition, the effect on local employment is concentrated in parts of the metropolitan area that are nearer the airport.

More recently Sheard (2018), also looking at the USA over a long period (from 1944 onwards), and controlling for simultaneity effects, found that airport size had a positive effect on the size of the tradeable services sector within cities (but not manufacturing) but that the airport effect tended to shift the structure of employment, or patterns of specialisation, rather than total employment.

These American studies confirm the strong nexus of increasing aviation and growing prosperity. However, that nexus involves significant variety and scales of local political/policy intervention to secure strategic routes, attract new airlines and developing or retaining network status (or indeed the major infrastructure and other investments made locally to facilitate airport development. It is worth noting the extent to which airports in the Sydney and Toronto case studies were, unlike Edinburgh, at the centre of economic and strategic spatial thinking for their metropolitan economies. But what does the patchwork of evidence suggest about European experiences?

Europe

Pot and Koster (2022) explored the growth of airport hubs (and subsidies involved in the process) and expressed similar misgivings about firmly identifying causality in airport-economic growth relationships. Regarding economic benefits, most evidence is derived either from larger hub airports within metropolitan areas or from aggregate analyses that ignores the variety of airport sizes and types involved (e.g., Bel and Fageda, 2008; Florida et al., 2015; Hakfoort et al., 2001; Hakim and Merkert, 2016; Hu et al., 2015). Many studies suggest economic benefits but evidence from regional airports is ambiguous with some case studies suggesting much lower benefits than might be anticipated (e.g., Baker et al., 2015; Breidenbach, 2020; ECA, 2014). They assessed how airport size and context impacted the association of airport growth and economic expansion. Their focus on regional airports (mostly smaller than Edinburgh) established a positive association between the scale of airport traffic and regional growth and this effect was much stronger for larger than smaller regional airports. Econometric tests suggest a causal relationship: above a certain size, airport growth drives regional growth.

Their conclusions from assessing accessibility to air services and regional airport scale were that 'long-run relationships between air accessibility and GDP are strongest for large airports and much weaker for regional airports, while correcting for scale furthermore causality mainly runs from GDP to air accessibility, especially considering regional airports.' They note, with some significance for the overall Scottish context, that this may reflect 'that regional airports are, for historical and commercial reasons, located in more peripheral locations and exposed to an extremely competitive environment with footloose airlines and consumers. Consequently, regional airports may not provide stable and consistent networks and, accordingly, little reliable basis for economic growth.' The scale effects and evidence from the interviews noted below suggest that Edinburgh has passed, as noted in the next section, the minimal scale and connectivity that leads to growth effects. The Scottish government have to reflect on whether it is in fact the only Scottish airport that has the scale and connectivity to have reinforcing growth effects.

Subsequent to the Carbo and Graham (2020) review paper, Hui Zhang and Tingting Xie (2022) explored the growth airports in small and medium sized Chinese cities. Their major conclusion was that airports have a positive effect on local economic development where cities had an economic base associated with strong industrial and tourism sectors. They have little effect in remote or poor areas with little potential. Airports raised wider market accessibility for enterprises in small and medium-sized cities and reducing the time distances between cities 'significantly increases the productivity, sales, output, exports, and investment scale of industrial firms' and particularly enhanced the economic vitality of small firms.

Carbo and Graham's own empirical work, with strong research methods and appropriate caveats, also highlighted the positive effects of airport growth on economic development of the cities they studied.

Activity complexity, multiple time periods, and different spatial reaches of impact pose a challenge in identifying the metropolitan and regional impacts of an airport. A further, major difficulty arises, above, in statistically identifying the ways and extents to which airports cause metropolitan economic growth. There is a 'simultaneity or endogeneity' (the chicken and egg) problem, in that airport growth may drive the metropolitan economy but equally other sources of expanding metropolitan jobs and incomes may raise aviation demands.

There is not, in the public domain, a rigorously researched statistical/econometric understanding of airport-metropolitan economy growth interactions for any of the Scottish cities. There are no papers that reveal any modelling of the relationships or how reducing aviation might impact the metropolitan economy. That really needs to be done, and well-crafted energy descent paths designed, if net zero is to be achieved without significant losses to the regional and national economy. In many respects this chapter is making a case for the Scottish Government and Edinburgh City to regard the airport as a major strategic infrastructure by piecing together fragments of plausible evidence, much of it generated in different operational contexts and times and undertake serious modelling and scenario assessments revealing the likely effects of intended GHG reductions.

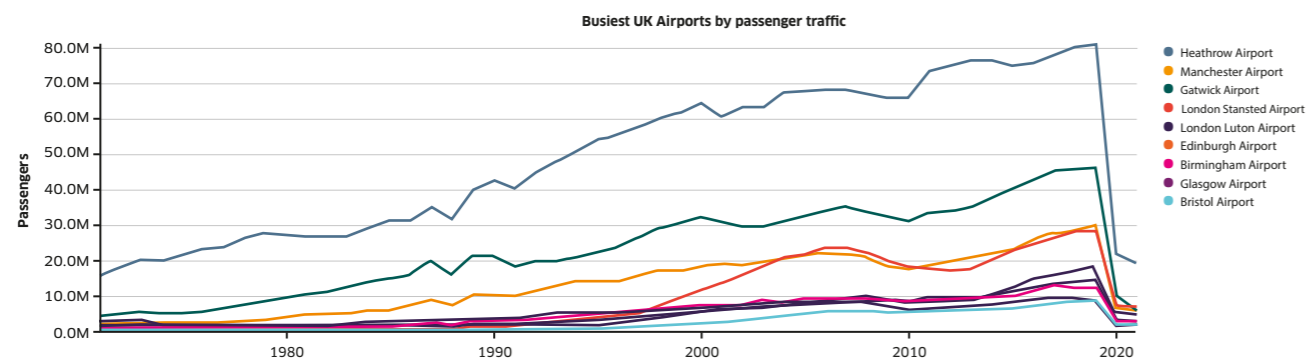
The question of whether airport growth, for any specific city (or defined set of cities) has long term growth and productivity effects, as opposed to short term income, employment, and multiplier impacts, cannot be assumed a priori. It is not proven, until it is proven.

3. Industry and Sector Studies of Economic Impacts.

There are industry/consulting studies that focus on short-term income and employment effects of airport activity. In relation to the reach of airport effects, evidence available from Edinburgh reveals that the handprint of arrivals through the airport is firmest in the Edinburgh City Region and Central Scotland but reaches more widely across all of Scotland and into the North of England. This handprint, recognising that its GHG emission impact has to be reduced, is a major, strategic concern for the Edinburgh City Region but also for much of Scotland. The peak hour journey to airport isochrones for Glasgow and Edinburgh Airports suggest that car and bus travel time is now shorter to Edinburgh from the north-eastern suburbs of Glasgow (heading eastwards). Any aviation reductions from Edinburgh will have significant effects across most of the Central Scotland.

Often, governments, airports and industry bodies cannot wait for the kinds of precise, qualified, findings available from econometric research. When they are used out of context and without caveats, they make constitute 'fake findings.' For example, there are some UK local airport studies that apply positive economic growth impacts identified at national or larger scale airports, or aggregate figures for the UK, to any airport that is the focus of attention. When suitably framed industry research may indicate some important information with the better examples providing useful insights, especially of short term income and employment effects.

Figure 1. Passenger Growth through UK Airports until the onset of Covid-19. (source, Capital Economics).



The patterns in Figure 1, above, show the sustained growth of air travel at the largest UK airports until the start of the Covid-pandemic in the first quarter of 2020. Heathrow, Gatwick, London Stansted, and London Luton serve global and domestic air travel demands for London and the South-east and, in the case of the first two, significant UK wide demands for global connections. After strongly growing Manchester, Edinburgh is the second largest regional airport in the UK, and for the last two decades it has exceeded in scale and grown substantially faster than Glasgow airport, the only other possible 'regional, as opposed to 'local' airport in Scotland. The growth and recovery of aviation post Covid, with passenger flows by end 2023 through Edinburgh close to pre-Covid levels has re-stimulated industry comment on

the aviation-economy nexus in the context of net zero GHG debates but some older studies still highlight relevant questions.

Oxford Economics and IATA.

Oxford Economics prepared an influential paper, commissioned by IATA, for the World Economic Forum in 2012 on 'The Economic Benefits of Aviation and Performance in the Travel & Tourism Competitiveness Index'. It is repeated biennially but with a less full discussion of economic effects. Its specific empirical findings are a decade old. The approach, however, poses the questions that cities and regional governments should be asking and answering in framing airport and aviation strategies to reach net zero.

Their starting point is that by providing services that move goods and passengers between places, the aviation industry enables economic growth that generates economic and social benefits. They assessed, for more than eighty countries over the previous three years, the conventional economic handprints of aviation including contributions to gross domestic product (GDP), jobs, and the tax revenues generated by the sector and its supply chain (with, in effect no estimates of negative carbon effects included in measures and that would require corrected in future studies). They argued, correctly, that the economic effects of aviation go beyond these conventional measures and need to incorporate the effects of the connectivity provided by air transport services. Some of these consequences were explored in the previous section and focus on how connectivity impacts productivity by enabling foreign direct investment (FDI), business cluster development, specialisation, and other spillover effects (that is many of the growth mechanisms that are difficult to identify without detailed econometric and airport specific research).

The aviation's direct impact on jobs and GDP is reflected by the domestic resources used to deliver services and are (and again this excludes use of natural capital) are measured by their gross value added (GVA). Using this approach Oxford Economics estimated aviation's direct contribution to the world economy, for 2010, as 8.4 million jobs and US\$539 billion to global GDP. They then estimated the sector's economic 'multiplier' effects by adding to this direct contribution the output and number of jobs from industries indirectly connected to aviation, as well as the output and jobs supported by the spending of those employed in aviation's direct and indirect workforce. They also added, and this would be important in any more local estimate for Scotland and Edinburgh, jobs induced by the aviation sector through tourism (arguably a more complete estimate would also include other sectors for which connectivity induced major effects, see next section on the claims of such effects in many of Edinburgh's major sectors of employment and incomes). Indirect industries are, in effect, the aviation supply chain, including fuel suppliers, construction companies, and professional service providers for the aviation sector. The aviation industry supply chain supported 9.3 million jobs worldwide in 2010 and contributed US\$618 billion

to global GDP. Direct and supply-chain effects then have multiplier impacts on consumption and jobs that added, globally, a further 4.4 million jobs, with a GDP impact of US\$288 billion globally in 2010.

Taken together, direct, supply-chain and multiplier effects channels shaped a total aviation sector impact of over 22 million jobs and US\$1.4 trillion in GDP. The Oxford Economics study also reported that geographically isolated and island states, such as Iceland and New Zealand, showed a greater economic dependence on their aviation sectors with the sector generating more than 5 percent of their total GDP in 2010. They recognise, but do not estimate, the weight of endogenous interactions between airport developments and economic growth.

The numbers may have changed, and significantly increased, but the major findings remain. Aviation, and related supply and demand activities, comprise a substantial share of current metropolitan jobs and incomes and may also shape growth prospects. Any just transition strategy should have the potential economic consequences of anticipated and actual aviation strategies to support net zero as a major concern in both transition and spatial planning strategies. The careful and caveated approach undertaken by Oxford Economics should really be the minimum standard of evidence research for informed government actions on airport and aviation. Unfortunately, often, it is not.

The Airport Operators Association, and Capital Economics.

The Airport Operators Association (AOA) in the UK is, in effect, 'The Voice of UK Airport Authorities' and it lobbies for supportive policy frameworks by making generalised cases that aviation growth drives rather than reflects economic growth. For the years just prior to Covid (2017), AOA, based on a report by Capital Economics, argued that 'Aviation is crucial to the UK: the sector creates £52 billion for the economy and supports around one million jobs and that future growth in flying would drive rising incomes'.

They extend this national argument to more local scales and claim that 'the UK requires excellent aviation connectivity right across the country, both vibrant point-to-point airports and worldclass hub capacity. In order to ensure the UK is connected to

international economies and all the opportunities they have to offer; airports need to have the ability to grow.' Given the academic observations about the need for careful analysis of local and different airport size effects on economies relationships, the AOA could be regarded as making a claim that is not firmly based in statistical evidence. They certainly need stronger evidence (of some kind) for the claim that 'facilitating increased passenger numbers and improved connectivity.... provides greater inward growth and investment. It creates economic benefits for the local, regional, and national economy.' For the national UK economy that assertion is undoubtedly valid, but for every local and regional economy would it attract, without more local causality evidence, a 'not proven' verdict.

That said, the statistical evidence of the growth in scale and network of the Airport over the last decade, albeit interrupted by Covid-19, allied to the interview evidence presented below, would suggest the AOA arguments are likely to apply to Edinburgh. Some of their policy proposals may be worth exploring for Edinburgh. The AOA argue for better (lower carbon) surface access to airports for workers, freight, and travellers and for a much better integrated transport strategy linking less carbon intensive aviation with zero carbon on-ground systems and structures. This raises the question as to whether if Scottish and Edinburgh City governments accept that Edinburgh airport, as all the major sectors in the city believe,

facilitates economic growth, do they feel that enough has been done to integrate the airport into the transport, major projects, economic and spatial strategies for the city, the city-region and Scotland? Indeed, given the results reported above for other countries, is there any sense that Edinburgh may well be the only Scottish airport that has the scale and network to ensure a viable, sustainable future air connectivity for Scotland. We return to these issues in the concluding chapters.

The AOA study reinforces the Oxford Economics conclusions that airports have major direct and multiplier effects on local incomes and employment. They also conclude 'airports are big employers in their regions, providing direct benefit to the economy through those employed by the airports and airlines operating there. Airports also support a whole series of economic activity further down the supply chain, from the food manufacturers producing airline food to the oil refining activities for jet fuel. The employment these activities generates creates further economic activity as those wages are spent in the wider economy.' They then assert the not proven, at the individual airport scale, claim that 'the greatest impact on the economy, however, comes from catalytic effects caused by airport activity. These effects generate economic activity that would otherwise not occur - through tourism, international trade, productivity improvements and attracting foreign investment.'

Edinburgh's relative economic success is even more important in the Scottish context. The Resolution Foundation have recently reiterated the dire tale of UK productivity growth lagging behind EU rates, but the evidence also shows that since 2010 productivity growth in Scotland has been half the low UK rate. Edinburgh's experience has been different and a more positive tale. Why is that performance, and its contrast with other Scottish localities, not at the forefront of Scottish economic policy and research?

Emphasising the Negative?

Governments for Scotland devolved or not, of all political shades, and all levels, have spent almost half a century focussing, often with some success, on abating the consequences of the sustained, long decline in the old industry based, and empire oriented, Scottish economy. Glasgow and the West of Scotland were the particular focus of that long, damaging process but Fife, the Lothians already had problematic places by the 1970's. Scotland had 'left behind places' before Mrs Thatcher became Prime Minister. A lasting lesson from the 'deindustrialisation' transition is that a coherent, informed, and relentless strategy that deals in notions of markets, innovation, competition, and productivity as well as community and redistribution is required for coping with declining job sectors. The imminent 'decarbonisation' process will be tested in similar ways and there is a worrying lack of concern for key, feasible ideas of economic transition and productivity growth. The drivers of relative economic success within Scotland, and the areas of policy weakness, need to be urgently reviewed and rectified.

And there are positive messages to take from this millennium. There are more, stronger signs of a new economic base, and a new economic geography for Scotland emerging. Although the focus of this report is on Edinburgh, it is worth noting that Glasgow had made major progress in shifting its employment base and, relatively, improving its housing outcomes although the costs and challenges of coping with places of multiple deprivation echoing past decline remain. The city, and increasingly the Glasgow City region, now talk with some basis in reality of a more positive economic future.

The economic growth process, and the shaping of a modern, productive, and competitive economic base, has been easier and more apparent in the emerging metropolitan region focussed on Edinburgh. That growth story, and the policy measures that might be required to sustain it and deal with the downsides of growth processes, have not arguably had sufficient attention in Scottish economic, infrastructure and planning strategies. Inclusion and net zero are essential policy goals but, as noted in Chapter 2, they dominate planning and infrastructure debates that are damagingly silent on economic productivity and growth. The Parliament has not had strength in discussing the emerging and, potentially best, economic geography for the nation and has been relentlessly more comfortable considering the difficulties of communities and remote places rather than how regional geographies may promote and sustain economic growth. Edinburgh's success story too often disappears in policy debate.

Lang May Your Lum Reek (Carbon Free)!

Edinburgh's growth performance, as could be expected from the discussion of international evidence above, has been central to the expansion of the scale, range, and scope of Edinburgh Airport. And, as is recounted below, major employment sectors in the economy now see a thriving airport as central to the sustained competitiveness of the metropolitan economy. That understanding of city, regional and Scottish business does not seem to be substantially reflected in the economic narratives and associated policy and planning actions of Scottish and local governments. In this section, as a precursor to assessing current policy positions in later chapters, the emphasis is on characterising the Edinburgh city-region as a critically important locus of economic growth, for its residents and for all of Scotland.

The growth success story, as well as the problems that growth invariably generates, is obvious in the City of Edinburgh's own 'Edinburgh by Numbers' (City of Edinburgh Council, 2022) as well as multiple government and industry reports. Over the decade 2011-2021, Scotland's population grew (modestly by international standards) by 3.4pc, the Edinburgh City-Region grew at double that rate and the core Edinburgh City authority at triple the Scottish rate. Core-focussed metropolitan growth was the story of the last decade. OECD

4. Edinburgh, Economic Success, and the Roles of the Airport.

Amidst the difficult decades of this millennium, with consumer, voter, and investor confidence levels relatively low for Scotland and the UK, there has been a tendency for the public and policymakers to lose sight of the growing size, prosperity and productivity of the economic region centred on Edinburgh. There has been much focus on 'growth' in tourism, jobs and demands to live in the metropolitan area as constituting 'problems.' Difficulties of 'tourist' congestion, affordable housing, and high levels of greenhouse gas emissions per capita are real and need to adequately managed and abated

but this involves reshaping rather than failing to recognise growth processes and their wider benefits. Outside of London and the South-East, the Edinburgh region has had the fastest growth of productivity and incomes of any UK city since 2000. Interestingly, the Royal Society of Arts in a recent major statement (RSA, 2023) about Britain's cities, included Glasgow as a major city, but not Edinburgh, despite including some smaller English metropolitan cases⁴. That seemed an odd omission given the growing global interest in Edinburgh not just as a world leading city to visit but as a location for investment and innovation.

predict that metropolitan growth, with higher density developments in a polycentric network of connected suburbs, will be the key settlement evolution until 2050 and beyond. OECD have green and wellbeing aims but they see them unfolding in growing, better connected and more compact, but dispersed, metropolitan settlement structures. Old administrative boundaries and structures will come to mean less and less. No insights about whether such growth patterns are assumed to apply in future metro-Edinburgh, on indeed the GCR, can be deduced from NPF4 or metropolitan structure and infrastructure plans, for they do not substantively exist. The contrasts with Sydney are stark and revealing.

The Edinburgh City Region (ECR) has been 'opening' as well as growing. There was a net loss by migration of population to other regions of the UK between 2011-21 (that should concern policymakers) that offset net natural population increases in ECR (that was, in contrast to Scotland as a whole, positive over the decade). In consequence, population growth in the region was largely driven by net immigration from overseas (five times faster than net natural increases). In effect, Edinburgh has been substantially growing and connecting, through flows of, often skilled, human capital to the wider world (and these figures exclude equally large growing inflows of overseas students and visitors, short and long-term).

The growth story for the regional economy goes well beyond the limited, but important, summary measures of productivity and GDP per capita (with Edinburgh outperforming most UK cities on these measures). Outside of London, Edinburgh has the highest economic activity rate, lowest unemployment rate, highest share of graduates in the labour force and highest median pay level of all UK cities. And, recognising how prosperity is reflected in wellbeing, it has the highest performance on health, happiness, and wellbeing scores on cross-city studies in the UK. These outcomes have major positive consequences for residents of the city region and for Scotland more widely.

Growth processes in economies are invariably unbalanced in their sectoral, and spatial, effects and in patterns of returns from growth and pressures of scarcities. Failure to manage growth processes shapes rising wealth and income inequalities,

exacerbates shortages of essentials for living, notably affordable housing, public services, and green space, and has significant environmental consequences. Signs of these growth problematics have also become more apparent in the ECR over the last three decades. Housing shortages and excessive housing costs are acute by Scottish and UK standards, wealth inequalities are stark and growing, and the level of per capita carbon emissions is high by UK city standards (though reduced by 47pc between 2011 and 2021). This is not a case to abandon growth and productivity drivers but to manage them better.

These two sides of growth, the significant increases in wellbeing, and the unequal incidence of gains and shortage effects, make a case for putting the growth process and its consequences at the core of policy thinking. Aiming for no growth (somehow defined) is not a credible public policy option for Edinburgh and Scotland, nor is unfettered, narrowly defined GDP per capita growth, and a confusing, unlinked discussion of the different, unmeasured outcomes of growth processes is equally unhelpful for future Edinburgh. Scotland could follow the example of New South Wales and establish a Productivity Commission that would review poor productivity in the emerging 'green economy.'

Now, post-Covid, and in the difficult global political economy of the 2020's, Edinburgh has a strong, flexible, and highly skilled economic base; business administration, education, finance, accommodation and food provision, information and communication, and the arts and culture, form almost half the of the economy, in contrast to less than a third for the rest of Scotland. Edinburgh, and Glasgow, have both become powerhouses in new tech investment and innovation, and ways strongly related to international higher education.

Within the ECR, there are close to 30,000 college students and 70,000 University students. A third of the latter group are from overseas (now mostly from outside the EU), and this is the highest rate of overseas students in any UK city except London. Managed badly (and it has been) this remarkable recruiting and reputational success, and export for Scottish skills and credibility, becomes a housing problem; managed well it strengthens city-region incomes and employment for today and creates skills and innovation and trade-links for the future. Either way, along with the other changes in the ECR

economic base, it emphasises the growing connection of the city to the wider world. That connection is not primarily made by foot, or car, or train but by air.

Flexible, affordable housing and feasible fast connection to the wider world are both requirements for maintaining the competitiveness of the innovative, changing Edinburgh economy. Industry studies predict a bright future for Edinburgh. For instance, in a recent review of property sector prospects across UK cities, CBRE (2022) predicted that Edinburgh would be likely to enjoy the third highest rate of increase of per capita GDP growth and be in the top half of expected investment rates in a wide range of property sectors, with strong performances in life sciences, hotels, higher education, and corporate offices. With the major emerging opportunity/threat of AI related developments the City Deal emphasis on making Edinburgh a major European data centre appears to have been a strategically adroit choice. The economic prospects for Edinburgh seem well placed to thrive assuming no wider global deterioration in trade and investment flows (and the Glasgow City region is also displaying significant signs of potential economic success).

At the same time, and despite inward investors generally doubting the economic efficacy of Brexit, Scotland remains the most effective regional competitor for inward foreign direct investment to the UK, with Ireland it's major European competitor (with particularly advantageous corporate tax arrangements, EU single market presence and 64 direct flight connections from Dublin to North America) for non-European origin projects (Ernst and Young, 2023). Over the decade to 2022, Edinburgh, had been the top UK city for inward investment, Glasgow the 4th and three more Scottish cities were in the UK top twenty. International business often accesses these cities through Edinburgh Airport.

Ernst and Young (2022) report that firms locating to Scotland, in choosing where to put their money, typically stress the importance of workforce skills (with an English speaking population), good quality and affordable property, the availability of high quality of life for staff and, importantly, effective connections within the UK, forward to EU markets and backwards to, usually, North America. It is not difficult to conclude that should Edinburgh

offer a reducing, slower, network of external air connections relative to static or improving offers from cities such as Manchester or Dublin inward investment, and prosperity in the ECR and Scotland would wilt. Edinburgh Airports links to Amsterdam, Paris, Frankfurt, Copenhagen, New York and (most recently) Toronto were regarded by this studies interviewees, as critically important links for Scottish trade and innovation activities that still need face to face interactions. Indeed, the Scottish Government's Aviation Review Consultation (2022), whilst asking important questions about connectivity within and to remoter rural and island Scotland pays relatively scant attention to how Scotland will connect to the still growing and emerging markets of India and the East.

There is a serious evidence gap regarding current 'trade/innovation/business' connectivity out of Scotland and how demands, and (more importantly) hidden or latent demands, might be served should, as the Just Transition Energy Strategy suggests, aviation from Scotland is reduced from 2030 onwards. Is this is the right, or necessary, approach for achieving net zero GHG in an intendedly thriving or prospering economy should ask is discussed at length in Chapters 4 and 5. There was a unanimous response from the leaders of the major economy sectors interviewed for this study that have driven Edinburgh's sustained growth and prosperity leaders that if the economies of Edinburgh and Scotland are to remain competitive and wellbeing grow then Edinburgh Airport has to not only maintain but grow its networks of international connections. Indeed, with few exceptions business leaders, emphasised that regional flight connections within the UK (especially to localities well-off the main east and west coast rail lines) also need to be radically strengthened. What does the Edinburgh specific evidence suggest.

Research Evidence of the Edinburgh Airport Economic 'Handprint.'

Edinburgh Airport (Edinburgh Airport, 2022) make a claim of significant short-term impact. In the last full pre-Covid year the 'Airport generated £1.4 billion GVA to the Scottish economy in 2019, supporting 24,000 jobs across the country. Over half of that economic benefit and job creation is realised in Edinburgh and its surrounding areas'.

Biggar Economics- Findings (2020). Edinburgh Airport: Estimated Economic Impacts

Annual Economic Impact (2019)

Edinburgh Airport generated **£1.4 billion Gross Value Added (GVA)**¹ and **28,000 jobs** in Scotland. This includes:

- **direct Edinburgh Airport employment** of **750 jobs** and **£172 million of GVA**.
- **direct impact** associated with **on-site operators** (including airlines, retail, and food services), of **£356 million GVA** and **5,100 jobs**
- **direct impact** associated with **off-site operators** in the vicinity of the airport (such as nearby hotels, trams, and car parking) of **£27 million GVA** and **650 jobs**.

This is a **total direct impact around the Airport of £556 million GVA and 6,500 jobs**.

Further **Wider economic multiplier effects** include:

- spending on **supplies of goods and services**, creating **£121 million GVA** and **3,100 jobs**
- impacts from **staff spending** in Scotland, generating **£144 million GVA** and **1,750 jobs**.

The passengers using Edinburgh Airport generate major impacts for the **tourism sector**, estimated at **£576 million GVA** and **16,700 jobs** in Scotland.

The Airport's estimates of impact are based on a report commissioned from by Biggar Economics (Biggar Economics, 2021) that essentially follows the broad Oxford Economics approach are noted in the box above. The key findings are noted in the box opposite.

These figures make clear the large the economic impact the airport makes on West Edinburgh-Livingston, the wider economies of Edinburgh, the Lothians and Fife as well as immediate, significant income and employment effect for Scotland. Even without including the unmeasured wider growth

and wellbeing effects or curtailing aviation from the Airport would have major negative impacts on jobs and incomes not just in West Edinburgh but the wider city region. The scale of the shock would almost certainly trigger other negative, longer term economic consequences. If low or zero carbon aviation is possible, see Chapter 4, then diminishing the airport without a really focussed exploration of the options for reaching next zero might needlessly throw away a significant source of employment, productivity and growth and future wellbeing for Scotland. We explore the options in the next Chapter.

Biggar Economics- Findings (2020). Edinburgh Airport: Un-estimated, Wellbeing Arguments

Edinburgh Airport also impacts the well-being of its staff, the businesses that supply the airport, those that depend on tourism and trade, its domestic passengers, and millions of visitors to Scotland. Those arise from:

- *allowing freedom of movement.*
- *bringing opportunities for people to live more meaningfully and experience other cultures.*
- *promoting Scotland's culture and heritage.*
- *enabling people to remain in contact with friends and family; and*
- *enhancing Scotland's accessibility for visitors.*

Edinburgh Airport boosts well-being measured in the National Performance Framework:

- *the national economy: by supporting economic growth and the functioning of businesses, government, and tourism, which are all vitally important to Scotland.*
- *the international community: it provides an essential link with the wider world: as the first and last physical contact with Scotland it adds to the country's international.*
- *the cultural economy: by enabling people to come to Scotland from all over the world it helps to increase international footfall at cultural and sporting events and conferences, broadening and enhancing Scotland's reputation in these areas.*
- *the local community: as well as engaging with the local community regularly on operational matters, and the Edinburgh Airport Community Fund supports local initiatives for health, well-being, the environment, and education.*
- *education and skills: the Airport requires people with a broad range of skills and brings an opportunity to work in a dynamic environment.*
- *staff: as an employer, the Airport offers its employees a range of support services and benefits for staff to enhance the quality of their working lives*

Impacts, Dissenting Views.

Before doing so it is important to note that not all commentators accept the notion that airport activity in the UK now drives growth and productivity. Chapman (2023), for the New Economics Foundation, argues that current UK policy assumptions about supporting airport expansion are based on government review work that is a decade old, that passenger growth over the last decade has replaced business related travel with tourist traffic, largely comprising UK residents

flying abroad, and that government ignores the risks of potential failures to develop carbon free flying and methods of carbon capture and storage (see Chapter 4).

Chapman takes a narrow focus of jobs in the aviation service provision sector rather than the economy as a whole, and that is a very partial perspective significantly underestimating the job and income effects of aviation. He stresses that

flying has created, increasingly, low paid jobs and is associated with low productivity growth. He also argues that the gains from aviation expansion are 'typically captured by a small and wealthy subset of the British population while, each year, around half of British residents do not fly at all' and that with explicit consideration of GHG emissions and their impacts 'Growth in air traffic implies a significant transfer of welfare from the majority, who suffer the ill effects of greenhouse gas emissions, noise, and reduced air quality, to a wealthy minority of frequent flyers'.

Macfarlane and Brett (2022) make similar arguments. In an otherwise excellent review of community wealth, wellbeing, and the just transition in Scotland, they note that the share of GHG produced by the richest 5pc of Scots is ten times that of the poorest 5pc. Livingston, for Oxfam Scotland, (Livingston, 2022) reinforces the point by highlighting that the factor of 10 increases to 11 for aviation emissions and concludes that *'in Scotland, the climate crisis is being driven disproportionately by the excessive lifestyle of the richest people'*.

Whilst there is merit in the 'polluter pays' approach suggested, the wider argument regarding 'flying elites' need scrutiny. Although a minority of fliers undertake a large share of overall trips, half the population of Scotland fly. For Scotland, the 90th/10th percentile of the relevant overall inequality ratios are 224, for wealth, and 10 for incomes. These inequalities may be unreasonable and unsustainable, and they undoubtedly underpin unequal GHG emission distributions. However, aviation would not seem to be a markedly high transformer of inequality into GHG. Reducing aviation by focussing on frequent fliers, who are likely to be making business related flights, will have a disproportionately negative effect on productivity, whilst wider cuts are more likely to impact low-cost vacation trips accessed by below averages income households.

Observations from Edinburgh -Based Business Leaders and Policy Strategists

Businesses, and their sector organisations, must have their bottom line as their main concern but across the 72 interviews conducted with business and sector leaders, in all three case study cities (40 in Edinburgh), there was also a widely espoused

commitment to reduce carbon emissions and a recognition that attaining net zero need not spell loss and closure in their sectors. The interviews were conducted between the autumn of 2022 and mid-2023, in the period when most businesses had begun to recover from the restrictions and other effects of the Covid-pandemic. Edinburgh (including East and Mid-Lothian), for all of this millennium, has experienced faster employment, productivity, and income growth than all other areas of Scotland, but experienced a sharper Covid contraction before being forecast to resume its leading Scottish economic performance (as conventionally defined) (SDS, 2023).

The discussion above highlighted Edinburgh's strong, flexible economic base and above average skills and capacity for both invention and innovation. Financial services, fintech, research, higher education, tourism, culture, and leisure activities are major sectors of the economic base along with government administration (one of several advantages of being a 'capital' city) as well as health services and related administration). The interviews were spread across these sectors and were aimed to draw out the ways in which business regarded the airport as facilitating or constraining current successes, innovation and productivity and the likely implications of aviation and airport changes as the shift towards net zero gains momentum.

Business Views of Net Zero goals and Economic Policy

All of the interviewees were in organisations that had developed their own net zero plans, either as a result of their own corporate ESG governance preferences or requirements placed upon them by lenders and equity partners. All agreed with the goal of attaining it by 2045/50. None thought that 2030 was a credible attainment date for Edinburgh City. They were also broadly supportive of most of the aims of the Regional Prosperity Strategy, in particular they welcomed the data driven approach, the emphasis on more sustainable transport systems (with the delivery caveats noted below), regenerating the Forth and maximising the role of existing institutions. The City Deal was regarded as generally well-conceived and effectively delivered.

They also commented on how much more difficult business and investment planning had become for them in embracing zero carbon goals and empathised with governments in that regard. In some areas of government activity, they welcomed and supported actions by the Scottish Government, local governments, and the UK government too. That said, all those interviewed were currently more preoccupied by how Brexit had increased their costs, shrunk their labour pool, and diminished important revenue sources and also felt the Truss-Kwarteng anomaly had significantly damaged business. The UK government, through the interview period, could take no comfort from the views of Edinburgh business.

At the same time there was a clear sense across a majority of the interviewees that, generally in relation to the 'just transition' strategy, and more specifically in relation to decarbonising air transport and sustaining, or strengthening the airport, that Scottish and local governments were failing in a number of important ways. There was a view that influential government ministers were openly hostile to future aviation and business travel and constantly pressed to downgrade the significance of business connection travel limitations and the airport in national strategies. Transport decarbonisation plans, in general, were regarded as somewhat vague, and there were too many, multiple, disconnected strategies that did not 'link-up' policy for planning, infrastructure and the economy. It was also widely, and strongly, felt that business had largely been excluded by the Scottish government from debate and policy formulation of economic and infrastructure policies that would support net zero without diminishing the wider wellbeing of Scots. Their views were close to the observations subsequently made by the MacPherson report (2023)

The multiple rhetoric of Ministers about the significance, or otherwise, of economic activity in relation to other (laudable) objectives was confusing for business and raised uncertainties about future investments in the city and Scotland. In relation to government modelling of the path to net zero and economy strategy impacts, there was a sense that the models were too abstract to capture real economic development processes, for instance the importance of agglomeration economies and external connections. Few regarded

the National Planning Framework as a useful basis for thinking through their own sectoral or corporate locational strategies and it did not reduce their 'locational uncertainties' in any substantial way.

At a general level, all sectors stressed the importance of the airport and aviation in relation to: intra-Scottish access to remote locations, especially islands; fast access to southern England and especially to sub-centres not on the East Coast mainline (such as Cambridge, noted earlier, Southampton and Bristol) and were concerned that governments would not deliver a suite of connectivity improvements for the future including; expanded net zero capacity on high-speed rail by 2045; improved access to mainland Europe in the wake of Brexit as firms work harder to maintain and secure European business; strengthened wider global routes, especially to India and North America.

Business wants thriving net zero aviation and its assumptions about that possibility and what government actions might support are quite different from and more optimistic than those prevailing within government and the bureaucracy. The Scottish civil service is regarded, by most business leaders as risk averse and unwilling to challenge Ministers on the lack of strategy coherence and has allowed the development of a culture of unclear delivery plans and absence of spatial prioritisation in investment and infrastructure strategies. One said, 'The first rule in Scottish government strategising is to make clear that everybody is a winner.'

There was a general sense that a wider 'team Edinburgh/team Scotland' had permeated City Deal discussions but that there are few signs of the same approach to transport decarbonisation consistent with economic success, and associated aviation. An intensive, major rethink involving business is required. Most organisations made these responses not just because it maintains what they have (the city drives the airport) but because they believe the airport will be a major source of future growth. This involves not just maintaining Scotland's leading position as an attractor of FDI, that business sees as being driven by a strong quality of life on offer (that business believes will be enhanced by many zero carbon measures) and a substantial flow of skilled labour. In the future, with endogenous population ageing and

potential decline, labour supply will come to rely on increased inward flows of immigration and retention of overseas students after graduation. That talent attraction is likely, to be effective, if immigrants can stay in touch with their homes as the Scottish diaspora does with Scotland. That, usually, involves air travel. A quarter of the leaders interviewed in Edinburgh had commenced their education or careers outside of the UK.

Business organisations highlighted the Economic Strategy aim of 'expanding the share of exports in GDP.' With an estimated 40pc of Edinburgh exports going outside the UK, and the remainder mainly to England, there was a feeling that this goals was inconsistent with early discussion of the 'just

transition' strategy and not adequately reflected in national planning, infrastructure, and aviation policies. The city and regional transport strategy was over-focussed on future walking and cycling and neighbourhood infrastructures and not export related transport decarbonisation and strategic infrastructure investment to underpin it.

Specific Sector Concerns.

Most of the major city economy 'export' sectors stressed the importance of aviation for continuing and growing their business and the boxes below are illustrative vignettes of the more detailed discussions that underpinned the summary above.

FINANCIAL SERVICES

Edinburgh's financial sector has long deep local roots and sustained global connections global connections that have given it remarkable resilience and diversity. The Global Financial Services Index ranks Edinburgh as the 21st largest centre in the world, and the 7th in Europe and, after London, with which has strong synergies, it is the 2nd in the UK.

It is diverse, with varied non-electronic connectivity requirements. There are UK headquarters with strong links to London markets, large overseas organisations, from North America and east of Dubai using Scotland as a major base (Blackrock, JP Morgan, large locally originated but internationally focussed institutions, with only 2pc of financial assets managed in the city Scottish owned, and finally and smaller Scottish institutions.

The sector believes that their presence 'touches', in different ways, some 40pc of the Edinburgh economy. They also believe that in an era of major uncertainty and technological change that face-to-face, in person communication and fast business travel will be critical to their continuing strategic business activities. They are strongly in favour of maintaining UK air connections and strengthening links overseas.

HIGHER AND FURTHER EDUCATION

Scottish Universities are still well regarded 'seats of learning'. They also need to be seen, not least for their own survival, as highly competitive businesses and selling education services to students from the 'rest of the UK' and, increasingly overseas students is a key activity.

The Scotsman of 20/11/23, reported that at a conference held in Edinburgh, the previous day, and attended by 400 international delegates discussing the internationalisation of Higher Education, the Director of the British Council, Peter Brown remarked on the standing, quality, and vitality of the Scottish HE sectors. He noted the 'the global demand for higher education is growing exponentially' and whilst facing up to 'issues of sustainability and equality' that 'we are building connections from Scotland to the rest of the world through, English, education, arts and culture'.

The development of AI may lead universities to demand more and not less time on campus for students to attend classes and exams in person. Edinburgh exports higher education by bringing the clients to the city. Edinburgh University, after London, now has the highest share of students from overseas. There are now close to 70,000 full-time students in the city-region (and a similar number in Universities, such as St Andrews and Stirling, often accessed from Edinburgh airport by overseas students). A third of Edinburgh University students, approximately, are from overseas, and the European share of that total has reduced significantly since Brexit. There is a concern that deteriorating relations with China may reduce student inflows to the UK but student numbers from India are now set to rise significantly. Overseas students don't, usually, take boat and train to Scotland! They, and their families, mostly fly and may use the airport multiple times in a year (going home for holidays, exploring Europe).

The fees they pay are critical to the financial viability of most Scottish universities, and especially Edinburgh and Glasgow, and obvious surpluses have made significant additions to University infrastructures and capacities to drive knowledge mobilisation and innovation. Estimates suggests that these fees are in the range of £2bn for Scotland by 2023 with almost a third of this accruing to Edinburgh University alone. Losing this source of income would be a major negative shock to Scottish Higher Education and maintaining the Scottish university sector would either require significant expansions of Scottish government payments for student courses and research capacity. Overseas student spending on food, accommodation and other activities in Scotland is reported to be in the range of £15,000 per annum, adding, roughly, a further £0.75bn to aggregate demand.

TOURISM, CULTURE AND FILM

Of the 900,000 Google searches per month for 'Scotland' 40 pc are from the UK, a similar share from Canada, Australia, New Zealand, and the USA. Interest in 'Edinburgh' falls from UK sources, long-distance interest is maintained, and EU countries comprise the remainder. These interests are reflected in growing tourism that, in the year prior to Covid, saw tourism become 5pc of Scottish GDP and with 15 million visitors arriving in Edinburgh the city became, again, after London, the second most visited tourist destination in the UK. Visitors from overseas to Scotland spent £2.5 billion, and UK visitors spent double that amount. A fifth of visitors to Edinburgh arrived via the airport.

The tourism sector trade bodies do not have estimates of the effects of the existence of the airport on tourism to and through the city, but they are clear that the presence of the airport has been critical to the growth and diversification of the sector, its post-Covid recovery and the strengthening of the flourishing international 'image' of the city. Whilst embracing the idea of more sustainable tourism with a zero carbon 'footprint' they are concerned that reduced aviation access will seriously damage the industry and Scotland's fiscal. Tourism sector leaders stressed the synergies between tourism, creativity, and festival sectors and now, links to a growing film sector in the city.

More specifically, the sector leaders interviewed had welcomed the new City-led ETAG strategy of 2020, but they are critical of Scottish Government and ECC action subsequently and feel that both policy levels are complacent about the sectors, on launching ETAG the Edinburgh Evening News (22/1/20) quoted the CEO of the City, as saying 'it is likely we are going to have growth on growth for the next 10 years. There is no need to go out and seek more growth of any visitors'. The onset of the pandemic, a month later, changed that dynamic. In-mid 2023, the Scottish Tourist Association reported a sharp drop in UK originated Scottish 'staycation' bookings and Chief Executive Marc Crothall believes 'we can no longer rely on the domestic UK market, the source of two-thirds of our revenue, as the key driver of Scottish tourism'. He and other sector leaders interviewed, in the accommodation and the festival sector also, reported that difficulties in finding short-term accommodation and reliable internal travel within Scotland are putting the reputation of the sector at stake.

Within the tourist sectors there was a strong sense of a need to; improve the growing 'heritage' tourism offer; make significant strategic investments, like other leading 'competitor' European festival cities; develop much stronger short flight connections to access growing demands from affluent Scandinavian markets for walking/golfing/sailing short breaks with short flights needed much more development.

These linked sectors are concerned that tourists have wide destination choices and that Edinburgh's strong image, hard won over decades, could be quickly lost, and future growth lost through badly designed and coordinated policies. Footloose industries quickly lost in a competitive world. The sector reported that they were immediately concerned with the likely effects of intended changes in policy, for instance the cost and availability of accommodation for visitors and performers and were unimpressed by the ways policies had been constructed and delivered. The sectors welcome the aim of carbon free tourism by 2045 but are concerned by the absence of any emerging discussion of a 'route-map' to zero-carbon and thriving aviation at the airport. Retaining, indeed growing, the airport they regard as essential and flight reductions an existential threat to the high-quality and international tourism industry.

INNOVATION AND TECHNOLOGY

The innovation and new technology sectors are increasingly concentrated in larger global centres, such as Toronto and Sydney, and their locational economic requirements require the agglomeration economies of skilled labour and the fast connection for in-person dialogue. They are inherently outward looking, seeking ideas, skills, investors, and markets.

There are tangible signs that Scotland is on the cusp of the innovative/entrepreneurial shift that it has been seeking since the 1970's. Policy decisions at Scottish, Edinburgh and UK government levels are now regarded, in the sector and in economic strategy thinking groups, as significantly supportive and forward looking in nature. Interviews with leaders in this sector were significantly different from the tourism/creativity/festivals sectors.

With the advent of AI technologies both widely welcomed and feared, Edinburgh is set to lead, again after London, UK city change in this field of activity. In 2023 it was identified in the SHSAI Cities Index (based on AI job adverts and education opportunities) as the UK's most AI and technological change 'ready city'. Sector leaders interviewed felt that standing was clearly helped by the University of Edinburgh's long term global reputation in the field, wise decision taking in the City Deal, and helped by the clarity of the Scottish Government's AI strategy of 2021.

In the new technology sector, more widely, the British Business Bank reported in November 2023 that, over the period 2011 to 2023, 475 equity deals for 'tech and IP', worth £710m for Edinburgh/Fife/Mid and West Lothians. This was second only to the London/Oxford/Cambridge Arc. Glasgow was the 4th best performer, with 257 deals worth £427. Taken together Central Scotland exceeded the volume and value of any English region (London excepted), including Greater Manch. UK wide deal making fell in the last year of the period, reflecting macroeconomic conditions.

Put bluntly, Edinburgh, and Central Scotland, and indeed the smaller, specialised successful developments in Dundee and Aberdeen need, an effective, fast connection system to the growing 'world cities' that compete and collaborate in these sectors. Those interviewed felt that for major global success in developing the new technologies not just of AI but the 'green economy' and 'healthier wellbeing' there needs to be urgent action towards zero carbon aviation for Scotland.

5. Proximity and Productivity.

In Toronto, Richard Florida (2022) has outlined the ways in which growth in the downtown airport ('The Island'), located in the core of the CBD, has major roles in shaping the competitive, productive dynamic that facilitates Toronto's economic success in North-East America. At Toronto's major international Pearson airport there is an explicit recognition that past metropolitan planning has underestimated the economic potential of the near vicinity of the airport. There is now active consideration to the strategic retrofitting of an 'aerotropolis' around Pearson that will provide employment in the complex set of polycentric suburbs that metropolitan expansion of Toronto has

created around the Airport. There are substantial traffic flows, with major carbon, congestion and costs now arising as residents in these localities travel to workplaces into and around the congested metropolitan infrastructure.

Metropolitan planning for Sydney, in recent decades, has been more strategic than in the Golden Horseshoe around Toronto. The Greater Sydney Commission³ addressed the westwards spreading of residential suburbs, unintegrated with employment locations, by proposing the development of a '3rd' Sydney. That 'city,' supported by Australia's largest City Deal, was

to be focussed on the development of a new international airport at Badgery Creek. These developments are discussed in detail in the Sydney case study, but in essence the new airport was to be the anchor infrastructure to promote suburban employment growth not just at the adjacent municipality but at a range of proximate local authorities. The case study highlights that by 2022 the project was progressing, broadly, as intended.

These Toronto and Sydney developments involve assumptions of future aviation decarbonisation, discussed in the next Chapter, but they also align strategic spatial planning, infrastructure provision and economic development policies in ways that no longer seem to exist in Scotland. For instance, might the metropolitan area around Edinburgh, spreading out into West Lothian, North Lanarkshire, and Fife, have lower future GHG emissions if connected by public transport to a strengthened employment core around the airport? How many more jobs, with high airport accessibility, and lower GHG emissions would this entail than other possible spatial patterns of employment growth in the city-region or the new Freeport zone? What if the Airport were to support the development of a non-profit, mixed tenure, housing provider (sharing airport generated green energy) close to the airport that would reduce housing and transport costs for many of the moderate income workers employed at or close to the airport? There are even wider strategic questions, beyond the scope of this report, as to just what airport infrastructure will be required for a thriving Scotland in a world of decarbonised on ground travel. Indeed, the just transition strategy will have to grasp this question by 2030.

The spatial-economic question for strategic planning for Edinburgh, and Glasgow (no other Scottish cities have the scale and suburban complexity to require such an approach) is whether there may be sufficient demands for new locations for production, innovation, distribution, and accommodation within metropolitan rings around city cores that do not require moving into or through city centres. That is, airports at the metropolitan edge need to be seen as an effective growth pole reducing suburban commuting and pressures on space in city cores.

In the Glasgow context there is a substantial stock of undeveloped land in the city core but struggling economies in the west of the GCR. The Edinburgh

context is different. Property and housing shortages (across all tenures and price ranges as) in the city core have, with the rise of other metropolitan sub-centres (Livingston, Dunfermline, for instance), spread across the metropolitan area. There is a strong prima facie case for considering an 'aerotropolis' for Western Edinburgh. Neither Edinburgh nor Glasgow city regions now have strategic spatial structure plans (it is no longer a statutory obligation) nor do they have integrated strategic infrastructure plans in any sense comparable to Sydney or Toronto. Put bluntly, every 'public' body has place principles and no 'public' body has coherent infrastructure strategies, linked to key economic and GHG initiatives, to build them (MacLennan, McGregor and Waite, 2020).

The near absence of this kind of strategic spatial economic, transport infrastructure discussion in Scotland, especially in relation to its best connected location at Edinburgh Airport, suggests a potentially serious disconnect in thinking about policies for wellbeing, prosperity, transport, and net zero. How might a 'green' aerotropolis be beneficial?

Airports, Accessibility, and Aerotropolis: Ideas and Evidence

There is incontrovertible evidence that access, and particularly rail access, to metropolitan airports significantly raises productivity in connected localities. For instance, Murakami et.al. (2016), analyse the relationships between airport rail links and productivity for the world's busiest one hundred airports (in eighty-two major cities). They found *'that cities with airport rail links or shorter access time enhanced by rail have higher productivity than those without airport rail links or with longer access time by other modes.'* They drew the reasonable conclusion that *'This macro-geographic snapshot could justify greater investment in airport rail link infrastructure and dedicated express services for the wider economic benefits derived from airport-connected accessibility premiums and agglomeration economies in central business districts.'*

The Sydney case study revealed how a metropolitan economy with a supportive State, and national, government can make plans and investments to effectively connect major transport infrastructures. As this study was ending (late 2023) the government of NSW was actively seeking

to complete major rail links to the new Badgery Creek Airport (Western Sydney). That was one component of announcing plans for rail and tunnel infrastructure to connect all the major airport and port structures in the metropolitan region in ways that will increase freight movement integration with, in the longer term, zero carbon transport modes. And, as noted, they were also fashioning an aerotropolis around Badgery Creek. The Edinburgh focussed City Deal improved road access around the airport. The main rail lines connecting west and north-south from Edinburgh speed, unhalting, past the western and eastern ends of the Airport runway.

Where airports are located amidst growing suburbs with poor public transport links to metropolitan cores, fashioning an economic activity cluster in the vicinity of an airport seems a plausible economic development strategy. The essential idea, that economic development strategy should consider raising investment and productivity from just beyond airport limits and along high access corridors (the aerotropolis), was first elaborated by Kasarda (Kasarda,2006; Kasarda and Appold, 2014). The initial focus was on how airports, and especially hubs, could give competitive advantage, through fast access to 'multinational corporate headquarters as well as 'outward' facing business sectors such as international finance and management, advanced producer service, high-tech manufacturing, trade, logistics, hotel, leisure and tourism, and medical services. These are all growing sectors in the Edinburgh economy. A near airport location would allow them to avoid costs of travel (including time and congestion) to metropolitan business cores that they might not need to use and also reach wider regional suburban markets without negotiating the core. With the complex geographies of polycentric suburban metropolitan development, for jobs as well as homes, this was a recognition that airports, often with outer suburban locations could provide an efficient pole for growth with lower cost and lower carbon footprint.

OECD, and others, predict that growing economies, and populations, will be increasingly metropolitan (and at higher densities than in the past). If globalisation, or mega-regionalisation, continues as a basis for flows of capital and labour then there is an expectation that competitive firms, and workers will be increasingly attracted to cities

with thriving airports. Sydney and Toronto are expecting, to paraphrase Murakami's argument, that a wide array of airport-linked business clusters will emerge to shape new metropolitan forms, generally stretching up to 30 km outward from the airports. These places, to quote Murakami will have 'greater economies of scale and scope in the long run.' The degree of such aviation-oriented agglomeration economies (or productivity gains), hence, depends not merely on the regional connectivity enabled by the development of multiple hub-airport systems but also on local accessibility enhanced by the integration of ground transportation infrastructure and services with appropriate land use controls (Kasarda and Appold, 2014)'.

There is now an extensive literature on the advantages, and limits, of the 'aerotropolis' approach and the origins, development and implementation and impacts of the idea are succinctly summarised in Chohan (2019). He suggests that the aerotropolis framework relates to key ideas in metropolitan economic development outlined in Table 2 below. Most of the developments he suggests are consistent with promoting an Edinburgh aerotropolis at the heart of the New Green Freeport declared for the broader region.

The Scottish Government, Edinburgh, and surrounding municipalities, need to refocus, urgently, on how new geographies of mobility, infrastructure and economic activity could flatten the trade-offs in simultaneously achieving net zero, economic and wellbeing objectives. This would involve considering how the airport could be better connected to the metropolitan suburbs and regional rail network (it is well connected to the 'old' geography of the CBD) through decarbonised mobility systems. In some scenarios for technological change in aviation, expanding the airport may be the solution and not the problem. The Scottish Government should be exploring the options for maintaining the connections of Scotland's thriving, new patterns of spatial development, to the wider world.

Table 2. Key factors conducive to the development of a well-functioning aerotropolis.

Source: Chohan, 2019.

Attribute	Explanation
Connectivity	An aerotropolis is effective when it has maximal connections to other cities, airports, and network nodes. This has a multiplicative aspect: the number of connections between airports multiplied by the density of those connections will make the aerotropolis most effective.
Smart Infrastructure	Well-designed and technologically efficient (smart) infrastructure will advance the function of the aerotropolis, in terms of the ability to manage its complexity as well as reduce its long-term costs. For the manufacturing component of the aerotropolis, particularly for Logistics and just-in-time (JIT) manufacturing, smart infrastructure will help keep a high rate of production and transportation efficiency.
Special Economic Zones	Tax Exemption Zones are encouraged in the practitioner literature, because these create incentives such as minimal tax impositions which enables goods to be landed, stored, handled, and re-exported under customs regulation (and generally not subject to customs duty) for boosting exports.
E-Commerce and Distribution	Given the rise of commerce facilitated by internet communication, E-Commerce and Distribution should be prioritized, such that a rapid response to customer orders is made possible.
Flex Tech	Flex Tech (from flexible technologies) involves the processes for fast and reliable information technology consulting, which is a basic source for economic activities involving assembling, repairing and shipping of industrial output.
Intermodal Freight Hub	An Intermodal Freight Hub is a system aimed to comprehensively bring airways, railways, roadways and waterways (if any), together. An intermodal freight hub reduces cargo handling, improves security, reduces damage and loss, and allows freight to be transported more quickly, and so would be a valuable element in the Aerotropolis.
Office parks and office corridors	Office parks and office corridors situated on common grounds which are air travel-intensive add an important commercial element to the aerotropolis, as they connect executives and

6. Findings: Economic Importance for Edinburgh and Scotland, Missing in Policy Thinking.

This chapter has brought together a range of different kinds of evidence to explore the ways in which accessibility to aviation impacts current prosperity and likely future prosperity for Scotland and why the widely agreed need to transition to net zero GHG, for both the economy as a whole and the aviation sector, is designed and implemented to maximise the contribution of future flying to Edinburgh's green economic growth. Ten concluding observations are made.

1. Edinburgh has become a steadily successful city over the last three decades, and although acute issues of poverty and growth pressures remain as pressing policy problems, the successes and spread of the Edinburgh region economy need to be both better recognised and understood and that involves fostering green growth capabilities that both reduce carbon emissions and raise wellbeing for the decades ahead.
2. Passenger and freight traffic through Edinburgh Airport have grown with the rising prosperity, diversity, international repute, and emerging metropolitan nature of the economic region surrounding the capital City. There is clear evidence of the scale and immediate positive impact on income and employment of the Airport on not just the City and metropolitan region but Scotland as a whole. Any reduction in that scale will require significant 'economic' transition if prosperity is not to fall. There has, surprisingly, been no serious econometric attempt to estimate the impact of airports on Scottish economic growth, let alone Edinburgh specific definitive research, but wider international research suggests that city growth, otherwise induced boosts airport scale, but also the scale and structure of aviation options from a city boost growth and productivity for the long term. The qualitative evidence is that the business and strategy sectors of the Edinburgh economy have a strong view that future city prosperity needs a growing Edinburgh Airport but with reducing associated on-ground and in-air emissions.
3. The business leaders and senior officials interviewed for this study have a strongly expressed commitment to net zero for 2045 and they do not fear the transition to net zero and many regard the shift to alternative, non-fossil fuel energy and a prospect of cheaper, more secure energy sources. There is, however, across major sectors of the region's modern economic that local and Scottish governments have lost sight of the aims and processes of prosperity and have failed to, yet, articulate the economic base that will underpin the laudable 'just transition' promised for 2045.
4. Business, and policy commentators across the metropolitan region see the Airport as the major Scottish gateway to a wider world of markets, skills and ideas, and some, including tourism, festivals, creativity, new-tech and higher education are particularly concerned that the now resurgent international image of Edinburgh (at least outside of Edinburgh!) can be as quickly frayed as it was long made in opinion pieces in key global and trade press highlighting issues of accessibility, accommodation and attitude. Finance, higher education, and tourism 'leaders' all embrace the 'net zero' aims of government but are acutely concerned that reduction in airport links and flying volumes to achieve net zero will significantly damage how they business and attract new opportunities.
5. There was in the interviews undertaken a widely stated unease with policy statements and attitudes for future national and global connectivity for the city. There was a concern that the City and the Scottish Government might be 'hostile' to aviation, that they placed an unrealistic faith in future rail accessibility to the rest of the UK and had failed to link a very general aviation strategy statement to strategic discussions for 'just transition' and the 'economic strategy'. Government aims and processes were widely viewed as being 'opaque.'

6. Cities (and their enterprises and institutions) both collaborate and compete and major multi-locational business sectors with an Edinburgh presence felt that more attention should be paid to green economy strategies in relevant metropolitan areas. All the business sectors had been impressed by the Regional Prosperity strategy but felt it should be urgently refreshed with a 'green twist' informed by relevant, comparative experience.
7. The wide sense of a lack of any coherent policy clarity regarding connectivity for business in the green transition, and what roles decarbonised aviation might play by 2045, was frequently highlighted with reference to the gaps between vague policy references to connectivity and any detailed policy strategy thinking in the major GHG and economic documents and debates of government in Scotland and, some believed that reflected a failure to recognise the relatively remote position of Scotland within the UK and the EU. The Scottish Government needed to address these issues urgently and with a metaphorical 'route-map' for a real future route map.
8. Business leaders interviewed had, mostly, been impressed by metropolitan and Scottish Government work on green skills strategies. There was, in relevant sectors, an impression that little work had been undertaken to think about the skills and industrial strategy measures that could support decarbonised aviation in Scotland, and that, as the government recognises, there had been little serious work on future aviation-economy strategy. That needs to change, urgently.

9. There was, in a strong majority of the interviews, little regard for the economic content of the National Planning Framework and an equally widespread view that the absence of a coherent, major 'external connection' infrastructure strategy was becoming a major barrier to doing future business in and for Scotland. Interviewees were generally supportive on measures to support active travel, more integrated neighbourhoods and switches to low carbon and public transport modes but critical of major infrastructure disconnections.
10. There was an interesting strand in the responses of interviewees that policymaking too often thinks of Edinburgh as how it was rather than what and where it now is. This highlights the importance of understanding how connectivity has grown prosperity and diversity as well the spatial dynamics of the metropolis. 'Edinburgh' is now a spreading functional economic area with polycentric suburbs and linked towns, but too often policy focus falls on the pressurised, iconic core. John Kasarda's aphorism of twenty years ago that 'in the future airports will create cities' may be highly relevant to how and where 'Edinburgh' grows. New patterns of suburbanisation, potentially changing metropolitan transport structures, and new energy resources prompt the question that the local, as well as global, accessibility features of suburban airport infrastructures could favour their development as a locus for green metropolitan growth with higher productivity and lower overall 'on the ground' GHG emissions than core city development. The Edinburgh Airport futures debate has to get serious for national city policymakers as well as local investors.

⁴This omission is not without irony. The RSA has been located in John Adam St, London since 1774, in a building designed by the Adam brothers. They were both born in sight of Edinburgh, near Kirkcaldy, and both educated in Edinburgh.

⁵The GSC became the Greater Cities Commission in 2021 and has now been ended as the Government of New South Wales have reintegrated strategic planning, infrastructure, and economic development within the State government structure.



FLIGHTS OF THE IMAGINATION: FUTURE GHG DESCENT PATHS.

11. Bright or Dull Green? Why Technology Matters so Much.

Climate science has produced successively clearer, and now more urgent targets for reaching net zero CO₂, by 2050 (at the latest) and other greenhouse gas emissions, by 2100, to contain global temperature increases to a critical maximum 1.5 C. Scientists also recognise that 'Among the most difficult emissions to avoid will be those from aviation given the industry's need for energy-dense liquid fuels that lack commercially competitive substitutes and the difficult-to-abate non-CO₂ radiative forcing' (Bergero et.al, 2023).

All the documents of national and sub-national governments reviewed and responses of business and policy thinking leaders interviewed for this study have recognised both the imperative and difficulty of reducing carbon emissions in aviation. The previous chapters emphasised the difficult context for driving towards the net zero imperative in agreed timespans, the complexity of the environment-economy-technology system changes involved, and the economic significance of non-local mobilities for nations, cities, and neighbourhoods.

It is clear that there are multiple paths to aviation decarbonisation paths to net zero. Each path involves different costs, benefits and risks and different distributional, social, and economic outcomes. There is no universal right path, no obvious single path in any setting and no well charted route for change. It is a macro-scale disruption of how we live, travel, and do business. On any frontier the pioneers find and create routes, the possible routes for net zero change by 2050 are not all known now. However, reflection on what is possible and what is probable, constantly reviewed as the journey unfolds should mean that the trek to net zero is a purposive rather than a random walk.

Managing complex 'wicked' multi-system evolution is not always the strong suit of governments. How do they balance responsible attention to the probable with the lure of the best possible outcomes of uncertain changes? They have to start with transparent, long-sighted aims and shorter well informed and monitored steps. There are multiple descent paths for politics to choose to deliver aviation decarbonisation. At one end of the possible spectrum there is a rapid carbon descent involving sharp reductions in aviation and mobility that will localise economic activity with, in all likelihood, falling trade and reduced individual and state resources to pursue wellbeing aims. At the other, a longer descent path to net zero could be associated with a technology led evolution of airports, aircrafts and fuels and shifts in skills that would not only facilitate decarbonised aviation but could potentially lower energy costs and increase the real incomes of households and the potential for fairer redistributions. By 2045 the surviving, thriving economies will be those who work to make the best possible more probable.

The Scottish and Edinburgh intended transition paths are, as argued above, are unclear and current early paths are considered further below. The previous chapter noted, for Scotland, the incomplete integration of economic, infrastructure and planning strategies with just transition aims, the absence of a wider carbon reduction plan and a misstep in not thinking through aviation sector 'delivery' measures until emission reduction targets become more urgent.

It is important to be clear on what shapes the time paths of decarbonisation. For instance, new evidence on the future timing of global temperature triggers must always be central to revising current actions. The Brundtland sustainability mantra '*that we should not act to foreclose on environmental options for the future*' highlights forward thinking. In other areas of social and economic policy that impact wellbeing, it is also important to use foresight and recognise that the fastest strategy to reach target goals for net zero may not always be the best. It is equally important not to foreclose on important behavioural and technological changes that may require time to develop but that will allow a descent to net zero by 2050 without collateral damage to achieving other aims of governments.

Even if the net zero target is set for 2045 or 2040, there may be benefits to hastening slowly towards the target selected. This observation should not be misinterpreted as deferring target achievement dates but as selecting the best time path towards that date. This is not the same, as is now becoming apparent in many advanced economies, including the UK and the EU, of deferring policy actions because targets have been unrealistically set (for example, many major economies will not achieve their domestic energy reduction targets for 2030 because there is a global shortage of skilled residential construction labour). Such deferrals require remedial policy actions to get change back on the chosen track. Even more emphatically, it is quite different from slowing agreed transition paths to satisfy the aims of retail politics.

These alternative paths to net zero imply that quite different behaviours and policies are required. Scotland, and Edinburgh, need to be as clear as they can be on what path is being chosen for aviation, the wider consequences and the policy actions required. It is difficult to draw a clear conclusion on what the economy-mobility-aviation-net zero strategy actually is from the major policy and strategy documents of governments in Scotland. Is our mobility future being well founded or does the economic policy babble conceal a strategy and delivery muddle? That critical question is addressed in the concluding chapter. In this chapter the key aim is to outline the options for reducing GHG emissions from airports and aviation.

Fast and Slow Thinking for Net Zero.

The quite different approaches to net zero implied by these bright green (slower, optimistic) and dull green (faster, pessimistic) paths to aviation carbon descent revolve around whether there is clarity in the economic arguments involved and, more importantly, how the prospects for technological change are viewed. Previous chapters argued for a more coherent discussion of the economic consequences of chosen energy/aviation descent paths. In this chapter there is a review of the major possibilities for technological change in aviation and energy systems that might lower the GHG effects of flight. The solutions will indeed have to be technologically innovative, but they will also need to be considered, reviewed, accepted and or rejected by well-advised and imaginative political decision takers. How they are assessed and developed will have a critical effect on how the city and Scotland will benefit not just from continuing connectivity but from the new production and financing opportunities of the green economy

Decision takers will have to be imaginative and look beyond more than the local, and beyond the electoral politics of the short term. The goal of net zero, is about long term wellbeing but also technological change is not a process with immediate outcomes, whether in aviation or agriculture. In aviation it is widely recognised that the development and extensive safety testing of new fuels and aircraft is commonly a 10-15 year process. Existing aviation assets, which may not be compatible with the new solutions, often have life cycles of at least a quarter of a century. If politics chooses a virtue signalling short time path to net zero, then it forecloses on significant options for technological change that will offer progress to net zero without the economic and social costs of shorter term reduction by regulation strategies. Additionally, a sudden descent strategy may fail to see the policy, and market, actions required to make the significant shifts in skills and investments that will underpin a different era for aviation and potential prosperity.

With a speedy embrace of fast net zero targets the options for a bright green outcome are narrowed and will be delivered by regulating and reducing aviation in ways that will sharply increase structural unemployment in the regional economy. Without new technologies in fuel and energy there will be no significant rise in green jobs. It is important not to neglect the IPCC warnings of the need for faster change than envisaged at COP 26, but they should not diminish the importance of new technology paths to change.

Clearly it is absurd to assert with certainty that by 2050 technology will have resolved the carbon footprint of aviation. And it is equally absurd, not least give their limited policy levers in relation to aviation (for instance the City of Edinburgh has no powers to require the reduction of Scope 3 aviation emissions), for metropolitan governments to embrace with equal certainty net zero by 2030 goals without accepting massively negative shocks for their regional economies. Imperfect knowledge of the future is inevitable. Inadequate knowledge about the present is not.

2. Decarbonising the Journey, and the Airport.

Stop making journeys, i.e. demand, or divert or decarbonise? The GHG effects of aviation and airports arise, as discussed in Chapter 1, from complex chains of activities. The production of GHG emissions is involved at every stage in an aviation journey from origin to destination. GHG emissions arise in transit to and from airports, are embedded in airport structures, and produced in the essential processes of moving through from airport entrance to departure (and from arrival) gates. As travellers progress through an airport, they may also use the services of the additional commercial activities they have attracted to the airport by their presence as consumers. Similarly, attached to and in the immediate vicinity of an airport, more activities may be attracted to an airport because of its accessibility to a flow of customers as well as flight accessibility.

Decarbonising transport to and from an airport is as technically and economically feasible as for the metropolitan area as a whole. It is usually the responsibility of strategic planners, infrastructure,

imaginative but realistic options for individuals, cities, policymakers, airlines, and airports are urgently required. In this chapter aviation emission reductions, including demand reductions and major technological options are outlined and their implications for aviation/energy/economy scenarios that are likely to preserve the economic resources for private and public spending on wellbeing. The next section of the paper briefly discusses the different ways in which GHGs are produced through the different stages of 'the aviation journey' and the operation of airports and focusses on the challenge of reducing 'gate to gate' emissions. The third section of the chapter focusses on potential technological changes and major modelling of their effects on aviation GHG emissions costs and (limited) economic outcomes. The final part, 4, summarises major features of decarbonisation strategies and indications of the early Scottish/Edinburgh path for change.

and transport policymakers for the rest of the metropolitan area.

Removing GHG from essential 'journey processes' within the airport is the responsibility of airport owners. Edinburgh Airport, and the other case study airports, have demonstrated that airports can, and do, reach net zero through process redesign and, primarily, the use and generation of clean electricity for running, heating, and cooling buildings and fuelling on-ground vehicles. Edinburgh Airport's sustainability goals, improvements, and performance are documented in EA (2022), and the performance of Toronto Pearson, which was rated the outstanding net zero performing airport in North America is documented in Toronto Airport (2022).

Airports have also significantly decarbonised the commercial activities located within airports and on airport land (food outlets, retail activities, car parking etc).

The ability of some airports, including Edinburgh (but not Billy Bishop in central Toronto) to use the extensive unbuilt spaces within the boundaries of, or adjacent to, the airport to produce clean (predominantly solar) energy are currently being developed. Edinburgh Airport already produces solar energy significantly in excess of its current (non-aviation) energy use that is wasted because of poor infrastructure provision in the regional energy system.

It was also noted above that airports provide accessibility peaks that might reduce regional transport demands in the future economy, but these depend on strategic regional economic policy and infrastructure decisions that lie with local and Scottish governments.

In short, with airport owner commitment, it is already clear that airports can become net zero.

Further, and less well recognised, in constructive collaborations with local and national governments airports can potentially become net zero contributors on wider a sectoral and spatial spread of land uses and activities around the airport. That range of discussion was most obvious in the Sydney case study, and with the development of the new Western Sydney Airport. It is also active in Ontario in relation to Pearson Airport and future regional economic planning for the Toronto metropolitan area. However, such discussion appears to be missing in planning statements for the City of Edinburgh, since the early 1990's, and in the transport, infrastructure, and economic strategy for Scotland. The implications of these perspectives are discussed further in the concluding chapter.

What airports cannot do is decarbonise the aviation journey from gate to gate, other than improving taxiing and other on-ground aircraft movements. Better planning of flight paths for take-off and landing, the responsibility of air traffic control authorities, can also reduce carbon emissions and progress has been made in both these regards. Much as these airport located operations are decarbonising significantly, they comprise, typically 5 percent of the

GHG emissions associated with air travel that occur between take-off and landing. The decarbonisation problem predominantly arises in the air (the Category III emissions) and the

crucial choices will have to be made by airlines, about the range of innovative fuel and aircraft infrastructure providers.

In highlighting the urgent need for the UK government to address aviation emissions Lord Debben (2019) noted that they had doubled since 1990, while emissions for the economy as a whole have fallen by around 40%. The dilemma is clear. Either stop flying if Category III emissions are to be met or continue flying and near completely remove carbon emissions in flight. The particular solutions are, however, not clear and they require careful strategic, long-term thinking and decision taking. Fuel and aircraft choices place key decisions in the hands of airlines and aircraft constructors rather than airports and, in the policy domain, usually in the upper layers and offices of government that are responsible for promoting research and development, airline regulation and regional policies. This constrains the policy choices of governments with more local autonomies and highlights the importance of strategy discussions and alignments across government levels.

Fantussi (2022) re-emphasises that, aviation is a particularly difficult sector to decarbonise because 'alternative fuels are relatively expensive, produce highly distributed greenhouse gas emissions in their production and combustion, and should preferably be compatible with existing aviation infrastructure'. That said there is already extensive research in science and engineering to develop alternative fuel sources that reduce GHG emissions from existing planes, which amend existing aircraft to reduce emissions, for the next decade, or perhaps two. Within these two decades, by 2045, new technologies will develop carbon free fuels and, of course, the aircraft designs that will allow such fuel to be economically carried and safely used in the air.

What are the options?

Lord Debben (2019) assumed some aviation demand reduction would be required in the UK. Now most global studies consider that demand for aviation will likely to double or treble by 2045 (Dory, 2023; Jet Zero, 2023) and that by 2050 aviation will contribute (in a business as usual scenario) 40pc of transportation related GHG emissions (Simulations for the UK by Jet Zero, 2023). In either case, demand growth or

demand reduction, there is the stark reality of the immediate necessity of using lower carbon fuels that can be used with existing aircraft and that in the longer term both more energy efficient ways of flying and decarbonised fuel sources are developed.

There is much debate about both how to deliver immediate reductions in aircraft energy use and increases in the utilisation of low carbon fuels. And, by some foreseeable future time, the aim is to deliver decarbonised flight. IATA, in 2021, committed member airlines to achieving net-zero carbon emissions from their operations by 2050. This pledge brings air transport into line with the objectives of the Paris agreement to limit global warming to 1.5°C. The UK government is also committed to net zero by 2050, and arguably, as it is responsible for Category 3 emission reductions, that time horizon is important for

3. Routes to Reducing GHG in Flight.

Reducing Demand

Modelling studies, noted above, now estimate that the demand for aviation will grow. Liao (2021) notes that measures to reduce aviation emissions by modest tax measures, for example, aviation fuel tax (Gonzalez and Hosoda, 2016; ICAO, 2016; Fukui and Miyoshi, 2017) or ticket tax (Faber and Huigen, 2018) have been largely unsuccessful in limiting demand growth. Unless there are significant increases in the taxation of aviation or carbon or direct regulatory restrictions, Dury et.al. (2023) note that with rising incomes for a wider share of the global population that demands for aviation will grow by 2.4-4.1% per year, implying a more than doubling by 2050. They note that omitting demand suppression effects from rising aviation costs that modelling will imply a demand overestimate. Other demand projections (Zero First, 2023) suggest that a business as usual approach by airlines would see the demand for individual air passenger journeys in 2050 potentially exceeding 10 billion with an unsustainable emission 'over the 2021-2050 period of approximately 21.2 gigatons of CO₂. Mitigating that amount of carbon will be an enormous technological challenge'. Demand limitation without, as noted, major tax changes is not a likely route to net zero.

Edinburgh airport but suggests some issues in reconciling the shorter net zero achievement dates of the governments of Scotland (2045) and Edinburgh (2030).

It is important, therefore, to review the different ways in which gate to gate aviation emission effects can be reduced and mitigated. Reducing demand for aviation, offsetting aviation emissions and carbon capture and storage will be briefly reviewed, but the main emphasis in the next section is in exploring the ways in which lower carbon fuels and redesigned aircraft capable of using them can offer a realistic prospect of net zero aviation that is also economically feasible for airlines and passengers.

Should the UK government start to enforce Scope 3 emissions reduction targets for individual airports, essentially regulating the supply of flights, there are important Scottish and Edinburgh issues to consider. Is there a case the remoter regions of the UK, including all of Scotland, to receive a lower share of Scope 3 reductions required, given government failure to produce UK wide fast rail connections? Will airlines ration the restricted regulatory demands by simply letting fares rise to clear the market? Will there be a policy interest in maximising Scottish economic and social wellbeing per air mile flown (eliminating a holiday week on the Costa del Sol in favour of an entrepreneurial week spent in Copenhagen)? Will there be a case for keeping an effective Scottish connection of routes by consolidating non-regional flights at one core Scottish hub? Has Scottish aviation strategy thought about how to best meet reduction targets if technologies do not improve?

Offsetting

In many respects the demand figures suggested above also highlight how carbon offsetting will also be a limited, usually local, contribution to net zero from aviation. Instead of directly reducing their

own emissions, airlines can purchase, as noted by IATA, 'certificates for CO₂ emissions reductions in other sectors or carbon sequestration measures.' Dury et. al (2023) note offsetting approaches have the limitations that offset schemes 'may not fully ensure that emissions reductions would not have occurred otherwise, are permanent, are not double-counted and are verified. IATA recognise some of these limitations and aim to reduce reliance on them as sustainable aviation fuel is developed but also highlight they remain useful in the longer term if other measures do not completely reach net zero targets.

Carbon Capture and Storage

IATA describe Carbon Capture Utilization and Storage (CCUS) as 'a technology that can capture up to 90% of the CO₂ emissions produced from the use of fossil fuels in electricity generation and industrial processes' and 'that the use of CCUS with renewable biomass is one of the few carbon abatement technologies that can be used in actually taking carbon dioxide out of the atmosphere.'

'The CCUS chain works by capturing and transporting the carbon dioxide, recycling the CO₂ for other industrial purposes, and securely storing it underground'. There has been limited use of the approach, despite long available technology, to date and some concern that it allows prolonged use of fossil fuels in energy production. The North Sea Transition Authority have estimated that the UK needs 100 CCUS facilities. Given that aspiration the UK has committed to invest £20bn by 2030, creating 50,000 jobs and £5bn of output whilst capturing 20/30m tonnes of CO₂ annually. There has been an active UK government initiative over the last two years to galvanise some major projects and, after initially being omitted from government funding priorities, the St Fergus Carbon Capture and Storage project, has been supported to use underground, residual infrastructure from past North Sea oil development. The Dutch government,

in 2023, made a commitment to \$1.3bn to have a CCUS facility operating by 2026. Oxford Net Zero Project has recently argued the fossil fuel extractors/producers should be required to have a 'take-back obligation' for carbon emissions produced from the fuel they produce that would boost CCUS.

IATA also note that the 'Intergovernmental Panel on Climate Change (IPCC, 2021) states that CCUS will be absolutely critical to limiting global warming to 1.5° C and that without the use of these technologies the target cannot be met'. Further, 'the International Energy Agency has indicated that CCUS could reduce global carbon dioxide emissions by 19%'. Dray et.al. (2023) consider that much work is still required to progress carbon capture from the atmosphere in commercially viable fashion.

Demand limitation, offsetting, and Carbon Capture, Utilisation and Storage will not, according to most expert studies, be major routes to reducing aviation emissions in the long term though they may play significant roles as new technologies are developed and tested (for at least the next two decades) and may regain importance as the major change agents reach their limits. In this regard, in setting their targets for net zero by 2030 and 2045, see section 5, what assumptions did Edinburgh City and the Scottish Government (respectively) make regarding demand changes at Edinburgh Airport (and how were they modelled?), the likely use of and limits to offsetting in a Scottish context, and how the St Fergus, and other future carbon capture schemes (particularly carbon capture from the air) might have a role in moving external connection emissions towards net zero. How do these influences play in the net zero strategies of Scotland?

4. Decarbonisation of air travel: Fast and Slow.

The essence of solving the aviation carbon problem lies not primarily in demand reductions, nor offsetting, nor capture and storage but in decarbonising flight emissions. Net-zero aviation requires eliminating fossil fuel sourced carbon in both direct emissions and the emissions of the supporting energy system. Fantussi (2022) also emphasises that aviation energy change has to have to regard to non-carbon pollutants produced such as (NOx), water vapour, particulates, carbon monoxide, unburned hydrocarbons, and sulphur oxides (SOx). These have a 2-3 times greater climate change impact than CO₂ alone. IATA (2020a), report that whilst aviation accounts for more than 2% of total global carbon emissions that contribution reaches 4.9% when these other GHG emissions are included (Lee et al., 2010; Grewe et al., 2017).

Refashioning Fuels.

There is a major effort in research and development currently underway, to develop fuel sources that will contribute to decarbonising aviation. Dray et. al. (2023) summarises the major alternatives current reliance on fossil hydrocarbon Jet-A 'which partly or entirely mitigate fuel GHG emissions, include 'drop-in' fuels usable in existing aircraft and 'non-drop-in' fuels, for example, cryogenic fuels such as liquid hydrogen (LH2) and electricity, which require novel fuel infrastructure and aircraft designs.

Drop-in fuels are synthetic hydrocarbons produced from sequestered carbon atoms, for example, from biomass (biofuels) or from the atmosphere (power-to-liquid fuels) (P-t-L), so that direct CO₂ emissions are offset over the fuel lifecycle'. All-electric aircraft have a limited range and payload.

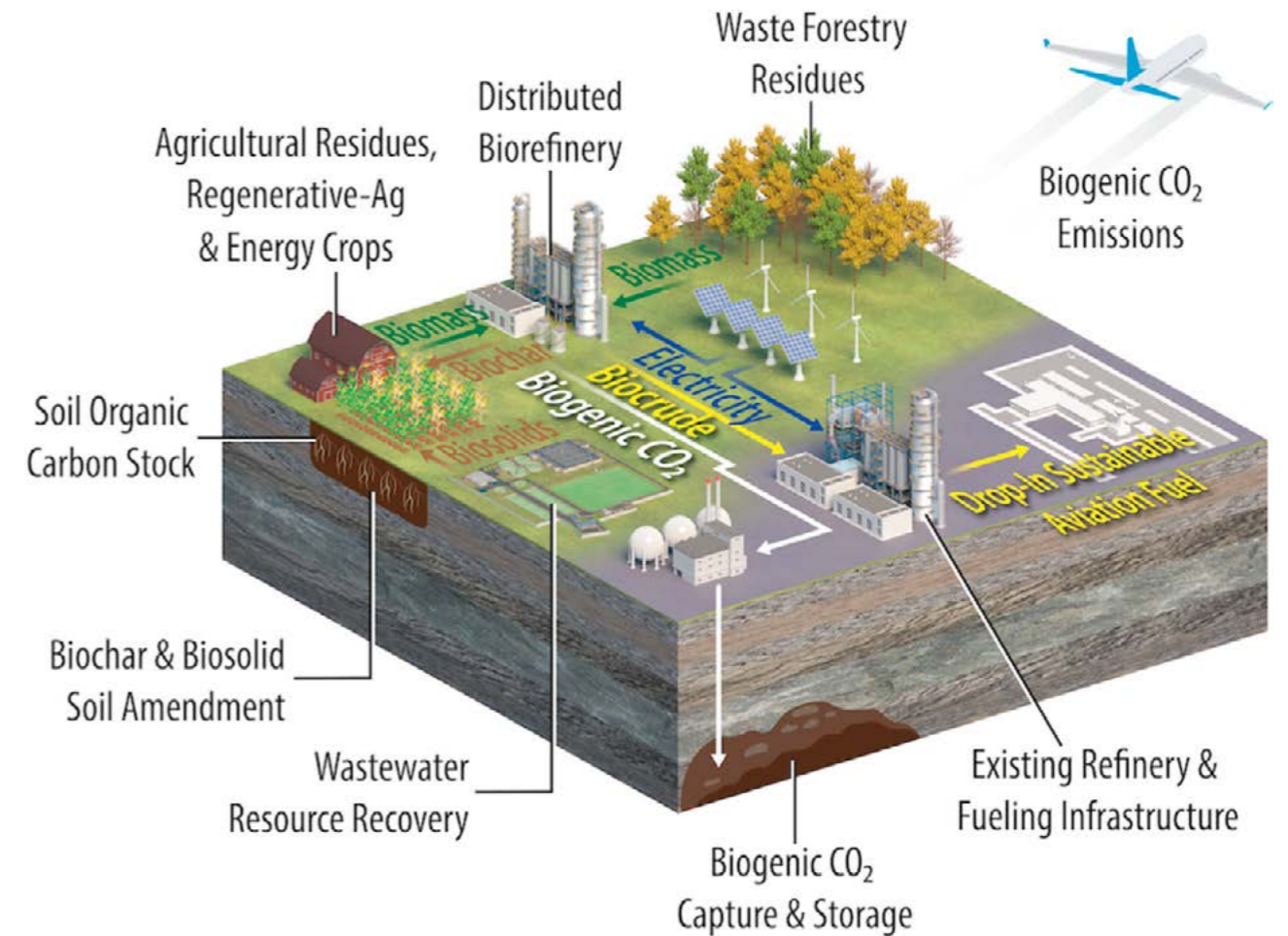
Sustainable Aviation Fuels (SAF).

IATA stress that SAF recycles the CO₂ which has been absorbed by the biomass used in the feedstock during the course of its life.

Biofuels are the most immediately available alternative to kerosene with well-developed technologies, feedstocks, and multiple uses (Vardon et. al., 2022). The variety of ways in which SAF (including P-t-L, see below) might be produced are illustrated in Figure 1. Accounting for carbon flows produced and used in these processes can be problematic.

Once produced SAF is blended (50:50 at most) with kerosene for use with existing aviation infrastructure, and that automatically decreases potential CO₂ emission savings. They can be sourced from a range of feedstocks, including agricultural and forest products, but in the UK, regulations restrict sources to waste materials. With competition from other activities, it means that biofuel will, at most, (Fantussi, 2022) meet a fifth of UK aviation fuel demand and reduce overall emissions by just under 10pc. Differently sourced SAF (P-t-L), may have lower emission reduction rates and it is important to note that diversion of agricultural and forestry waste to bio-jet fuel production deteriorate soil quality.

Figure 1. Strategies for net-zero-carbon SAF
Source: Joule 6, 16-21, January 19, 2022, 19



Power-to-Liquid (PtL) fuels offer better longer term prospects for SAF. They are synthetically produced hydrocarbons, first developed a century ago by the Fischer-Tropsch process. Presently, clean energy (green electricity) is used to power electrolyzers to produce green hydrogen that is then synthesised with carbon feedstock (produced from climate neutral CO₂ gathered by direct air Carbon Capture), to produce liquid hydrocarbons.

PtL has the dual advantages that it can be used and transported via the existing infrastructure of pipelines, filling stations and aircraft and, for now, be blended with kerosene. They reduce emissions by a significantly greater multiple than biofuels. The major difficulty is that technological change is required, and now ongoing, to reduce production costs and increase scale.

Independent, serious, modelling of aviation decarbonisation pay particular attention to the importance of using SAF, both whilst technological change processes play out and thereafter when residual emissions may remain in flight. For instance, Bergero et. al (2023) note that 'Without ambitious reductions in air transport demand and improvements in aircraft energy efficiency, decarbonizing aviation will require important quantities of 'drop-in' sustainable aviation fuels (SAFs), especially given the number and long lifetime of commercial aircraft (~23,000 and >25 years)'. They estimate that the quantity of biofuels produced in 2019 may have to increase five-fold by 2045, with the ethanol and bio-diesel industries increasing at 4 times the annual rate of the early 2000's, and that stock for aviation will have to be secured in competition with other users. They note

that SAF is currently 2-4 times more expensive than kerosene though synthetic production costs are expected to reduce as the cost of producing captured carbon and electrolytic hydrogen costs will fall over time. Bergero and colleagues also note that such improvements in the cost, price, and production of SAF can be induced via specific policy incentives such as cleaner aviation fuel tax credits (as those included in the Inflation Reduction Act in the United States). Carbon pricing could also change the incentive structure and make SAFs more competitive, potentially hastening deployment and further reducing costs via learning and economies of scale. They also point to limitations on the efficiency of SAF biofuels but are optimistic regarding synthetic SAF use, with manufacturers such as Boeing aiming to produce engines using 100pc SAF (rather than kerosene blended mixes) by 2030. Aircraft ranges will be lower than for conventional fuels. Policies, they believe, need to focus on scaling up SAF production and innovation and cost reductions in technological development and process efficiencies. Airbus reported, in 2022, that the slow development of SAF by governments is delaying the rate of innovation in net zero aircraft.

The observations above prompt the question for the Scottish Government of whether, with a potential major user at Edinburgh airport, and port users in the new Forth Freeport, located in close proximity to a major refining facility at nearby Grangemouth, policy should be facilitating the development of a major PtL production site, with scale economies, to provide the regional economy with SAF at scale? It does not appear in the new green industrial/economy strategy for Scotland and that needs to be urgently revisited. This issue is raised more urgently in the concluding chapter.

The major constraint on increased production of PtL to date has been the availability of clean, low-carbon electricity and storage capacity to power production of green hydrogen and the availability of CO₂ from direct air capture. This not a technological constraint but an infrastructure and industry gap, that Scottish government could address. Resolving these issues would not only allow major gains in aviation emissions reductions over the next decade but provide a clean source of fuel to cope with residual emissions not reducible with new hydrogen fuels and planes emerging in

the longer term. A recent report (Way et.al, 2023) makes clear that by 2050 clean energy sources could supply ten times the national UK requirement and at lower costs than at present.

Hydrogen

Hydrogen, that can now be produced as 'green hydrogen', has long been used as a propulsion fuel, for instance in launching rockets. Currently hydrogen is predominantly produced from fossil fuel sources (98pc) and as noted above, the production of green hydrogen requires a step change in low-carbon electricity generation capacity. Once again this is an infrastructure constraint rather than a technological puzzle. Hydrogen, unlike SAF, cannot be used as a drop-in fuel to blend with kerosene to power existing aircraft. It also requires careful (cryogenic) storage and handling, and its use will have to await the development of significantly redesigned aeroplanes. That wait may be worthwhile and allow refinement of production and storage capabilities because carbon free electricity with green hydrogen would allow the potential to end fuel blending and reduce carbon emissions by 95pc, almost completely decarbonising aviation (FlyZero, 2022).

The costs of SAF and Green Hydrogen currently significantly exceed kerosene but there is relatively wide agreement that, as technologically induced production efficiencies and scale economies come into play, their costs will fall substantially as supply increases (as typically happens in major shifts in innovation eras 'industrial' eras). FlyZero (2022) forecasts these future fuels will have market prices below kerosene 'with and without the impact of carbon pricing' and that carbon taxation will favour hydrogen (zero carbon) as the aviation fuel choice. Airbus say commercial hydrogen planes will be flying by 2035.

The clean production of hydrogen needs clean electricity. As noted above the potential production of green electricity in Scotland and the UK could outstrip national demands by 2050 by a significant margin. However actual supply will depend how quickly and extensively UK electricity producers are able to secure the finance, skills, and consents to deliver change. Anticipating some of the broader concerns of the subsequent MacPherson Report, SSE (Scotsman, 19/10/23) warned that there is a

need to speed up planning permission and consent processes for the development of wind farms and the creation of power grids, and to improve pricing in the SS chain if clean energy targets are to be met and renewables increasingly dominate Scottish energy supply.

Changing Aviation Infrastructures

Reducing the carbon intensity of fuels used in aviation is central to decarbonising flying but the efficiency with which fuel is used to transport given volumes of freight and passengers matters too. Ensuring full capacity utilisation on planes that do fly is one, relatively small contribution, but reductions in GHG emissions can be achieved by improving existing aircraft operations and efficiency in the short term.

Improving The Efficiency of Existing Infrastructures

IATA note that 'The aviation industry has a history of continuous improvement in efficiency. Until the pandemic, there was a steady improvement in the passenger load factor to a record average of over 82% in 2019. Operational efficiencies have resulted in a 55% improvement in fuel burn per passenger km since 1990.' It remains the case, however, that some long-sought infrastructure improvements have not progressed as rapidly as originally envisaged in both aircraft operations (including weight reduction, improving aircraft aerodynamics, efficient systems) and infrastructure (such as improving air traffic management, energy saving at airports such as single engine and shorter taxi distances) (ATAG Waypoint-2050, 2021).

Incremental improvements for existing aircraft infrastructures could attain a further 15-25% fuel efficiency improvement over the next two decades. That progress, allied to (say) SAF, would make substantial progress but still leave aviation less than half-way to decarbonisation by 2045. What then becomes critical is the design, prototyping and delivery of new-style aircraft with radically new propulsion technologies to use zero or near zero GHG emitting fuels, and to do so more efficiently. Green Electricity (with SAF hybrids) and Green Hydrogen are the future flight fuels that will be embedded in the design of new aircraft.

Hybrid-electric

Hybrid-electric planes will use both combustion (SAF) and electric engines to provide the required thrust for take-off with the combustion engine (smaller and lighter than at present) throttled back during cruising and landing. Hybrid-electric aircraft could contribute to achieving CO₂ reductions of up to 40%. They are however seen as a medium term solution. Small aircraft (15 - 20 seats) with hybrid-electric propulsion are expected to be available in the late 2020's. Commentators suggest that regional aircraft (20-35 seats) will be available in the 2030s and larger ones from 2040. Net zero aviation by 2045/50 is much less likely to be achieved with existing fleet replacement by larger planes offering only 40pc reductions emissions.

Electric

The case for hybrid power planes is much less clear when pure electric propulsion alternatives are considered. Using energy stored in batteries, or fuel cells, electric motors are used to drive propellers. Battery weights are considerable and limit the size and range of planes. If green electricity is used to charge batteries, then GHG emissions will be close to zero and non-CO₂ effects (such as contrails and NOx emissions) will also be eliminated.

IATA (2022) note that all-electric test aircraft with up to 9 seats are already flying (including in the Orkneys and north of Scotland), that aircraft up to 19 seats are planned to be in flight by the end of the decade, and that regional aircraft will be deployed in the 2030s. They further note that Norway has the goal of operating, and decarbonising, all domestic and short-haul flights electrically by 2040. The Scottish Government has not yet articulated a similar aim for Scotland. Given the physical size of Scotland and the widely dispersed structure of towns across Scotland from Lerwick to Campbeltown and Stornoway to Dundee, it is possible that new, lower cost electric planes could underpin thriving aviation within Scotland and more widely to regional destinations in the rest of the UK. It is assumed in Canada and Australia, by airport operators and policymakers alike, that there will be a substantial expansion in regional flight activity towards 2050 and airlines have already ordered available aircraft.

Grander Designs, Uplifted by Hydrogen.

Amending existing aircraft and introducing new designs make sense if a coherent GHG descent path is in place for aviation, with a potential for two fleet replacement cycles between now and 2050 (so that lowered but not zero emission hybrids are replaced by then). A critical issue, however, is that aircraft that will carry larger loads for longer distances are unlikely to be developed for propulsion by electric means. More radical aircraft and propulsion designs are already being developed.

IATA argue that *'The development of radical new aerodynamic designs for commercial airplanes could create significant efficiency improvements and make it easier for alternative propulsion systems to succeed.'* Canard style wings (already used in military aircraft, potentially available by 2035-40), Blended Wing aircraft that generate lift to save fuel and a range of designs are in development.

These design changes may be important but the key to the potential for decarbonising flight by 2040 is the successful development of a green hydrogen fuelled plane and the phasing out of other alternatives by 2050 (save for the use of SAF to cope with residual issues). Typically, three critical risks are recognised in the creation of hydrogen fuelled planes:

- *Will there be sufficient clean electricity to produce PtL SAF and green hydrogen:* The UK Hydrogen Strategy and Way et.al. (2023) suggest that this is not a technical risk and is readily achievable with appropriate planning and investment.
- *What about the availability of suitable, safe aircraft?* Advocates for hydrogen flight have a positive view that such technological issues will be overcome by the end of the next decade and that with airlines replacing planes in that time horizon they will choose the lower cost, and carbon free, hydrogen alternative.

- *What about a failure to provide hydrogen infrastructure to support route networks and required traffic volumes?*

These questions about the future need to be addressed today. Aerospace, aviation, airport, energy, and policy making arenas need to do their best work, in risk assessment and aligning fuel innovation time scales with the safe development of new planes and the economic obsolescence of older GHG producing planes, to make the best start in providing required supporting infrastructure and skills. This requires a common vision, agreed missions, and coordinated action plans across airlines, airports, and all orders of government.

There was in this study a much clearer statement and sense of collective purpose on working towards that future in Sydney, especially at Badger Creek, and Toronto. Perhaps because they recognise the existential threat from climate change but are also acutely aware that there is a significant threat not only to wellbeing in their metropolitan economies, but also national coherence and international relevance should long-distance aviation wither away (the flight time from Halifax NS to Vancouver is 6hrs and 43 minutes, marginally longer than from Edinburgh to Halifax, and the drive is two days and 7 hours non-stop). That collective sense of urgency and understanding to rethink the aviation-economy nexus and purposively aim and plan for decarbonised aviation is currently missing in Scotland and the UK.

AN INDUSTRY VIEW ON 4 KEY QUESTIONS (Adapted from Waypoint, 2021)

Q1. Can aviation meet net-zero CO2 emissions by 2050?

Yes. But it will take an enormous effort by committed industry experts, governments, the finance sector and the research community to make it a reality. It will mean a rapid and massive transformation of aviation's 'drop-in' liquid energy supply using sustainable aviation fuel – from both traditional sources and new sources such as power-to-liquid – over the course of just 30 years. It will also require an acceleration in aircraft and engine technology development, including faster progress towards new types of propulsion: electric, hybrid and hydrogen powered aircraft. Net-zero will also likely require using carbon removals to deal with residual CO2 emissions. It is possible, but it is going to be a significant challenge. For net-zero is an even greater challenge, but with the right support from governments and particularly the energy sector, it is also achievable.

Q2. Will aviation rely on offsets to meet its goals, or to shift to net-zero emissions?

The expectation is that offsets (or other forms of out-of-sector carbon reductions available in 2050) are not primarily relied on to meet the goal, although there will be some emissions that offsets can help mitigate and these will be needed to meet a net-zero 2050 goal. In the near term, high-quality offsets will be key to aviation meeting its climate obligations. In the long term, the removal of CO2 from the atmosphere will be key, not just compensating for unavoidable emissions. Depending on the progress of technology development (both in carbon capture / direct air capture and for aviation technology and energy deployment), there may be an increased role to play for some form of market mechanism or offsetting as the sector transitions to wider use of new energies.

Q3. Will shifting to sustainable aviation fuels require large amounts of land?

No. Airlines have committed to ensuring a shift to sustainable aviation fuel will be done with fuels "which conserve an ecological balance by avoiding the depletion of natural resources"⁵. Analysis has shown that 100% of aviation fuel by mid-century can come from sustainable sources – including some (non-food or rotational) crops, waste sources and fuels made from low-carbon electricity and CO2 removed from the air. Robust mechanisms need to be put in place to ensure the sustainability of these fuels – a global industry can also lead to pockets of less stringent regulation – but a full shift to sustainable sources is possible.

Q4. When will passengers be able to board electric or hydrogen aircraft?

Already, there are small commercial aircraft being test flown using retrofitted electric engines. The mid-2020s may see up to 19-seat aircraft flying on new forms of energy. Scaling this up to regional and some short-haul aircraft will take the next 15-20 years, but passengers might be able to purchase tickets for electric, hybrid-electric or hydrogen flights around the 2035 timeframe. There is a lot of work still to be done. Battery technology is progressing quickly but needs to be accelerated to provide enough energy for the right size of aircraft over reasonable distances. Hydrogen is an increasingly viable option, but aircraft and engine systems need to be developed and storage must be progressed. And then the manufacturers must complete safety and operational certification in completely new types of technology, as well as sell these novel aircraft types to airlines. Importantly for both options: increased production and new distribution systems of low carbon electricity and green hydrogen are required to make them a reality.

Galvanising an effective net zero transition for aviation and the economy is not just supported by interested 'producer' parties and 'spun' by airlines. The box on the previous page highlights 'informed industry' views on four of the key future fuels/planes issues.

There is enough encouragement from the results of high quality and disinterested party' multi-sector modelling of probable fuel, aircraft innovation, cost, and demand outcomes and their GHG consequences to indicate qualified optimistic outcomes for reducing GHG in aviation and then near decarbonisation of the process by 2050.

Learning from the Models.

What, briefly, do recent integrated modelling exercises tell us?

Many national, and some sub-national, governments use different modelling and forecasting approaches to help explore possible futures for outcomes with multiple interacting and recursive relationships. Bergero et. al (2023), recognising the complexities and uncertainties in the systems involved sets out how modelling results 'may inform investments and priorities for innovation by highlighting plausible pathways to net-zero emissions aviation, including the relative potential and trade-offs of changes in behaviour, technology, energy sources and carbon equivalent removals.' Models are always limited by uncertainty, assumptions and reductionisms made, and data availability but do have the virtue of examining some sub-system interactions in ways that univariate accounts do not. Their results are best viewed as broad likelihoods of change rather than precise calculations.

They conclude 'that ambitious reductions in demand for air transport and improvements in the energy efficiency of aircraft might avoid up to 61% and 27%, respectively, of projected business-as-usual aviation emissions in 2050. However, further reductions will depend on replacing fossil jet fuel with large quantities of net-zero emissions biofuels or synthetic fuels (sustainable aviation fuels)—which may be substantially more expensive. They also note that with moderate growth in demand, continued improvements in aircraft energy efficiency and operational and infrastructure improvements, new propulsion systems for short-

haul trips, greatly accelerated production of SAFs and the possibility of balancing non-CO₂ radiative forcing with equivalent amounts of CDR, the aviation sector could achieve net-zero emissions by 2050.

The work of Dray et. al. (2022) models, with modifications of the AIMS model and clearly stated assumptions; the carbon effects of different single and multiple fuel paths; with and without changes in aircraft types; with and without supply constraints in key clean power and carbon capture activities; with demand expansion with and without price feedback effects; and other key variables that influence emissions reductions.

One of Drays modelling scenarios suggests that new fuel pathways of 'synthetic fuels from biomass and green hydrogen and atmospheric CO₂, and the direct use of green liquid hydrogen—could lead aviation towards net-zero climate impacts. Together with continued efficiency gains and contrail avoidance, but without offsets, such an energy transition could reduce lifecycle aviation CO₂ emissions by 89–94% compared with year-2019 levels, despite a 2–3-fold growth in demand by 2050. The aviation sector could manage the associated cost increases, with ticket prices rising by no more than 15% compared with a no-intervention baseline leading to demand suppression of less than 14%. These pathways will require discounted investments of the order of US\$0.5–2.1 trillion over a 30 year period. However, our pathways reduce aviation CO₂-equivalent emissions by only 46–69%; more action is required to mitigate non-CO₂ impacts' (with a target of zero emissions by 2100).

That optimistic modelling indicates the possibility of net zero aviation carbon emissions, with modest aviation price increases and with system change costs largely absorbed by airline operators, in a context of substantial demand growth. It also highlights the scale of expenditures and coherent policy decisions required by governments to get towards net zero. Dray reports that a market-led solution without government support will make no more than a quarter of the required progress in reducing aviation emissions to net zero by 2050.

The 'modelling', the social-economic-management science, with more nuance and caution broadly supports the informed industry claims about the

prospect of zero carbon aviation. It would seem much too soon to choose the 'low road' for change. But what decarbonisation approaches have been emerging with different levers for change and descent path choices indicated above?

What Strategies?

Roland Berger (2022) reviewed the decarbonisation strategies in the public domain in the autumn of 2022, including Waypoint 2050 (2021), the ICAO (2022), Sustainable Aviation UK (2020), and Destination 2050 (2021). Nikhil Sachdeva (2022) summarised the results. He categorised the more risk averse decarbonisation solutions, with potentially damaging effects on wellbeing, that focussed on mixed offsetting, SAF and shorter flying distance options as 'probable'. The more radical solutions that embraced, SAF and new technologies in fuels and planes were identified as 'possible'. Both 'probable' and 'possible' strategies required a dramatic ramp up of at least one decarbonisation lever (such as SAF or hydrogen fuels) and that both approaches are difficult, largely because of shortages of clean electricity and green hydrogen rather than missing known technology, but that neither are impossible. Sachdeva also emphasised that, looking beyond 2050, more attention should be paid to the warming effects of non-CO₂ GHG and contrails. So, no silver bullet and no universally best path, but potentially significant decarbonisation with well-designed policy frameworks and significant private and public investment.

And Scotland?

The delay in articulating the Scottish aviation decarbonisation strategy means it is difficult to assess any explicit descent path, though there are elements of policy and strategy which reveal possible splinters from the framework. The Aviation strategy in the Scottish Transport statement succinctly states the benefits of aviation, the imperative and complexities of decarbonisation and highlights most of the main GHG reduction levers without indicating which, if any, might be, as suggested above, dramatically ramped up and any possible resource implications.

The Scottish 'Decarbonising Transport Review' (2021), by Element Energy, for the Scottish Government, did not undertake new aviation

oriented modelling work of the type cited above. It took a more pessimistic view of the technological change possibilities, based on 2018 assessments, for reducing aviation emissions than either of the industrial or academic reviews noted above (though in eras of industrial change innovation rate assumptions can become unduly pessimistic in the light of accelerating innovation). They assume, for instance, 'we do not expect to see any electric or electric-hybrid propulsion aircraft enter service until after 2045' and in relation to sustainable aviation fuels it 'is expected that these will initially be based on biofuels' and 'aviation fuels will need to transition to production via Power to Liquid (PtL) with early blending occurring from 2030 and ramping up to reach high blend levels by the 2040s'. The first assertion re electric planes is now redundant and the second seems to disregard the possibility of possible Scottish level policy action and expenditures, assuming that Ministers for Transport and the Economy work with and speak to each other, to synthetically produce SAF as a major economic sector initiative (see above, and below). Again, the review emphasised how difficult it will be for Scotland to increase the SAF blending rate as arriving aircraft may have unblended fuel. One might ask why other European countries, the main locus of flight origins, will not be implementing the use of SAF, with, for instance, Denmark already well ahead of Scotland in this regard. These pessimistic assumptions may now need to be discarded.

The review concluded 'that in order to meet its emission targets domestic and international aviation emissions assigned to Scotland need to fall by 33% between 2019 and 2030, this is against a baseline scenario with expected significant growth in demand'. Why stick with this demanding reduction when they explain that their study 'does not consider aircraft with fewer than 70 seats', that are expected to be flying with much reduced GHG emissions by 2030, on the basis of the very static assumption that such planes 'in Scotland represent a very small proportion of total aviation emissions and demand'. Why would this remain the case, even for shorter European routes?

But the conclusion, the advice given to Government, has major, damaging, traffic implications for all Scottish airports, and particularly Edinburgh. The sectors of the Edinburgh economy that, as noted in the previous chapter, had expressed worries about

future air connections by 2030 appear to have justifiable concerns. It could have been expected that policy predictions of this kind would have been subjected to intensive modelling and annual review and update. But they do not appear to have been. The income and employment effects of such proposed reductions are not apparent in forward economic and financial forecasts for the Scottish economy and budget, for example. Nor are they picked-up in the economy strategy and just transition strategies.

Further, Element Energy (2021) tell us that the 'Demand for domestic and international aviation is not included in the Transport Model for Scotland' and that UK averages are substituted. In terms of modelling, risk assessment, and the GHG-wellbeing trade-off this policy significant review seems to have produced a rather one-sided assessment.

The Scottish Government have modelled some economic aspects of climate change (and there may be modelling work completed that is not in the public domain). However, there is no detailed, published modelling of the aviation sector for the Scottish economy. Some metropolitan areas have economic-environment modelling capacities. For instance, the City of Toronto has modelled different transition paths for the city towards net zero that also predict likely future energy costs and implications for household incomes. Their results suggest a net zero future in which per capita incomes will be higher. Scottish city regions have shown little interest in modelling any aspects of change in their metropolitan economies. This is an important gap in how Scotland understands the possibilities and problems associated with measures to reach net zero.

Scottish aviation sector-economy-net zero modelling currently tells us more or less nothing.

Allied to the weak 'fairness' arguments⁴ presented (that flying out of Edinburgh is predominantly conspicuous consumption for the elite), there is a prima facie case to challenge how effectively the role of aviation has been assessed in shaping the energy, economic and transition policy strategies for Scotland. Some serious, sustained joint economic-technology modelling and innovation reassessment is urgently needed to give some rigour to thinking about the Scottish aviation sector. The Just Transition strategy, without articulating any clear aviation GHG reduction path, states that aviation GHG should decrease towards 2030 more rapidly than increasing fuel decarbonisation rates. That implies shrinking flight mileages, but there was no indication of the economic and budgetary consequences of that aviation reduction. Aside from very general expressions of support in the aviation strategy and minor mentions in the economic strategy a 'due for surgery: do not resuscitate' sign seems to have been hung around the neck of Scottish aviation. Nothing of this sort of approach was observed in the Canadian and Australian case studies.

5. Findings: Net Zero Strategy, Ready for Landing?

The account in this Chapter of potential technological changes and how they are included, or not, in Scottish aviation-net zero strategies can be seen in either a positive or negative light. On the downside, it is critical of the neglect of missing missions in aviation policy thinking and the non-visibility of aviation in the major net zero, economics and national planning strategy statements. On the upside, now is an important juncture to recognise that the potential to have a substantially decarbonised, but not diminished aviation sector by 2045 and to take a major initiative to re-connect aviation to mainstream Scottish and metropolitan level policy thinking and analysis. Ten key conclusions are drawn from this Chapter.

1. Politics, business, and the public are now aware of the imperative of achieving net zero and scientists and policymakers recognise the particular challenges in decarbonising aviation.
2. It is now widely recognised that there is an ongoing 'swarm of innovations' in energy engineering generally and in aviation fuels and infrastructures more specifically, so that the potentials for feasible decarbonisation change not by the decade but by the year; this means that the already complex modelling, and policy design, of the interactions between connectivity and economic change need to be repeatedly updated to include appropriate assumptions about and linkages to technological change. That process is not apparent in publicly visible Scottish policy thinking.

3. Decarbonisation of aviation involves Scope 1, 2 and 3 reductions. Edinburgh Airport, and Glasgow too, have committed to achieving net zero in running the airport and on ground services and have more than achieved that goal, particularly through onsite solar energy production. Reductions in on-ground emissions related to transport to and from the airport are largely attributable to municipal planning and transport infrastructure decisions though further progress can be made (either by improving decarbonised bus and rail links or allowing increased electric vehicle access to the airport).
4. Whilst airports can aircraft reduce carbon emissions on ground movements and air traffic control authorities implement better planning of flight paths, and this has been progressed at Edinburgh, 95 percent of the GHG emissions associated with air travel occur between take-off and landing. Reducing aviation GHG involves either reducing the demand for/supply of flights or decarbonising the in-flight process.

5. Although the delivery plans for aviation carbon reduction in Scotland are as yet unclear, the net zero transition strategy implies a significant reduction in emissions, and flying, by 2030, and the technology change assumptions are unclear. In other jurisdictions studied for the report the assumptions are that aviation will increase and technological shift in fuels and planes deliver significant emissions reductions by 2035. Modelling of global changes usually supports these more optimistic strategies and estimate that demand for and supply of flights will increase whilst emissions fall. Is Scotland more impatient for zero carbon and less concerned about reducing wellbeing by curtailing mobility? In the study neither airports nor airlines saw 'offsetting' as a credible long term measure for maintaining zero carbon aviation. There was a wide view that there had been a relative neglect and slow development of Carbon Capture, Utilisation and Storage options in the UK and that investment in North Sea storage capacity in Scottish waters could be substantially accelerated.
6. The development of new fuel sources for aviation is critical for shorter and longer carbon descent in aviation. SAF is critically important for the short and long-term decarbonisation process and synthetic SAF production needed to be significantly boosted in Scotland as there were potentially relevant skills and infrastructures from the oil and gas sector that could be redeployed to that end. The likely elastic supply of 'green' electricity in Scotland will be important not only in producing synthetic SAF but critical in developing supplies of green hydrogen aviation fuel as well as battery and hybrid fuel arrangements. There is a growing awareness that the barriers to such fuel source use in aviation are not now technological and organisational and that cost barriers are likely to be reduced and removed as occurs in most innovation eras.
7. In relation to aircraft infrastructure many of the technological problems have been resolved or seen as likely to be overcome by a decade ahead. Small electric planes are already flying in the North of Scotland. Zero or low carbon planes capable of carrying 15-35 passengers (estimates vary) 'regional' distances (250km) are now designed and being ordered by airlines in Canada and Australia in substantial numbers. Longer distance decarbonised flight remains challenging, though synthesised SAF fuelled new planes with engines designed for its sole use will be, according to both Airbus and Boeing, available by 2035 and capable of decarbonised Transatlantic flight. Both manufacturers also now assert that hydrogen powered, zero carbon flight will not be constrained by technology but by the availability of green hydrogen.
8. Scotland, and Edinburgh, have to review and model these different possible carbon descent paths for aviation and to do so with the best science, social and management science resources available to the nation.
9. Better understood carbon descent paths, with a clear understanding of their prosperity and wellbeing consequences, need to lead to a coherent mission, and initial delivery plan, for decarbonising aviation that is explicitly linked to, and factored into, all major national and city strategies. Mission formation and management requires a new sense of collaboration between governments, business, communities, and the aviation sector, for Edinburgh and the rest of Scotland too.

⁶Critiqued above in Chapter 3



A NET ZERO LANDING WITHOUT A CRASHED ECONOMY.

1. Reaching Conclusions, Resolving Dilemmas?

The Airport is a major economic infrastructure for Edinburgh, the surrounding, growing metropolitan region, and Scotland as a whole. This report was commissioned to explore the ways in which the expansion of the airport both reflected and drove that extended geography of economic growth and prosperity. The study adopted a broad and long view of economic change. The need to understand these relationships arose both from the process of building back better from the deep negative shock of the Covid-19 pandemic, and from the recognition of the imperative to decarbonise airport operations and, more critically, the aviation process to meet net zero goals. The Airport, in traffic and freight volumes, has built back to pre-Covid levels of business, and is well on the way to achieving net zero GHG emissions in its own operations.

Aviation emissions, however, continue to increase, so that the multiple economic consequences, handprints, as well as environmental, footprints, of flying for Edinburgh, and Scotland, are the core concerns of the report. The review naturally embraces a longer view, as both decarbonising aviation and maintaining regional prosperity are long term, interrelated, processes.

It was unsurprising, in the review process, to uncover multiple perspectives on, and uncertainties about, the technological change possibilities of what has been labelled the 'third industrial revolution.' Joseph Schumpeter observed that major innovation eras are typically characterised by 'swarms' of inventions and innovations, as is happening now, in Scotland, in the formation of the green economy. What was less expected, however, was an emerging profusion, arguably confusion, of government narratives regarding how to frame Scottish economic performance and policy goals without much attention to questions of productivity and growth. A growth conversation appears to have gone missing at the Scottish level since the

publication of the Wilson report five years ago (Scottish Growth Commission, 2018).

The report also took a wider than Edinburgh view, in two senses. On impact, within Scotland, the airport has its strongest 'handprint' not just on the City of Edinburgh and the surrounding growing metropolitan region, but its firm imprint also reaches out strongly across Central Scotland and touches the rest of the nation and northern England. On governance, governments, cities, and airports in other contexts face similar challenges and case studies or Toronto and Sydney, in quite different contexts, were explored to pose questions about the Scottish approaches to problems and solutions.

The report does not offer any quantitative estimations of the future trajectory of the metropolitan or regional economy along the early steps on the path to net zero. That would require detailed investigation of possible descent paths and, as yet none have been defined for Scotland. Nor has an adequate, serious baseline of modelling pathways for carbon descent for the city and the region, let alone for the aviation sector, been developed. Explicit alternative pathways and transparent modelling of their implied net zero, wellbeing and wider missions are urgently needed as a basis for discussing policy trade-offs.

Instead, having established the significant roles of Edinburgh Airport in the metropolitan and Scottish economies, the study addressed what airport and wider policy actions and partnerships might facilitate better outcomes in relation to environmental, economic, and social goals for Edinburgh and Scotland as they moved towards the net zero goal.

2. Conclusions

The Overall Conclusion.

This report concludes that the imperative achievement of net zero GHG by mid-century will not be achieved with enhanced wellbeing unless policy also develops a renewed, coherent understanding of how to sustain green economic growth and productivity gains. Failure to do so will leave Scotland, and Edinburgh, without the fiscal resources, policy skills, business base, and required institutions to manage a transition to net zero that is just and, also, enhances prosperity. There is a danger, that without a rapid development of coherent environment-economy policies, Edinburgh, and the rest of Scotland will take 'the low road' of ever increasing regulation of problems rather than 'the high road,' of new technologies, infrastructures, and skills to embrace the opportunities of net zero. The map to take the 'high road' still needs to be articulated and will need to indicate how Scottish aviation emissions will be achieved by smart decarbonisation rather than diminished demand and falling connectivity to the wider world.

This overall conclusion is supported by more specific conclusions, outlined below in bold, arising from ten areas covered in the report. *Specific recommendations for policy changes are in italics.*

- I. The Dilemmas in Imminent Reconciliation of GHG Emission-Rich Aviation with Net Zero are well understood in the Scottish policy context, both nationally and locally: pathways to long-term solutions that flatten trade-offs between expanding aviation and reducing carbon, and that may find positive synergies between flying and transition to the green economy, are either opaque or still unexplored.**

There is now a wide consensus, not just in the policymaking process but in airports, airlines, and business sectors, that global warming poses existential threats to the future of humanity, and much pain and damage along the way, and that it is driven by anthropogenically induced greenhouse gas emissions (GHG). There is also, as confirmed, at COP28, wide agreement that net zero GHG emissions should be curtailed faster than current progress rates, with prominence to phasing out

fossil fuel use, to net zero by 2050, to limit further increases to less than a critical limit of 1.5C. The immediate dilemma arises because aviation is currently fossil-fuelled and comprises 3 percent of current emissions. As aviation decarbonisation is a longer innovation-investment process than for other sectors, that share will increase in the decades ahead unless GHG emissions from the sector are reduced.

- ii. Cutting Aviation GHG Emissions can be achieved quickly by limiting the supply of, or demand for, flights. This may also involve demand diversion to lower carbon transport modes (usually longer distance high-speed rail) and behaviour change, and by reducing GHG emissions per kilometre flown, and by blending SAF with fossil fuels for existing aircraft: a decade ahead decarbonisation of flying is probable by changing the fuels and flight performance through technological change radical aircraft redesign. The shape of the chosen decarbonisation path that meets net zero and other goals is critical.**

The key policy decision facing governments now is not choosing a net zero target by 2045 (Scotland) or 2050 (the UK), for that policy commitment is made. The major issue for governments is to choose their transition path recognising that new challenges, technological change and new positive opportunities for growth and wellbeing will arise over the next quarter century. Government cannot ignore the risks that desired, dilemma-destroying technical change may fail to become real, but they must also be careful not to foreclose on these possible options, especially if other short-term actions impose significant costs to income and wellbeing.

- iii. Scottish policymakers, at Edinburgh City as well as the Scottish Government had a greater explicit or implicit commitment to aviation demand reduction by 2030 than in the other case studies. They also believed that internal UK aviation would be substantially reduced by growing fast-rail capacity south to London. Interviews with the business sector in Edinburgh confirmed that they were aware that**

was the implicit assumption by government for the future internal mobility of staff and customers and they were concerned by it.

Enhanced high speed rail capacity is now unlikely to be supplied to Edinburgh by 2050, as made evident by the UK government's late 2023 decimation of the HS2 proposal. That will become a barrier to investment and jobs in important sectors of the Edinburgh economy. The study evidence reported in Chapter 3 confirms the significance of flights to and from Edinburgh as shapers of current incomes and future prosperity across the airport's economic 'handprint'. *Such economic effects, and significant wellbeing costs, of a flight demand/supply reduction strategy do not seem to have received any explicit consideration in the Just Transition and Economic Strategies and the Scottish Government should urgently revisit this question for all the cities with reliance on aviation for long distance UK connectivity.*

Interviewees, and policymakers, in overseas case studies (and many in Edinburgh) had decided against short-term demand reductions and looked more towards new technologies, because they considered jobs and income growth as critically important. They were surprised that Scotland, and several had senior UK work experience, regarded itself as accessible across the UK, and to Europe, by rail and they remarked on the absence of Scottish attention to a vigorous expansion strategy to connect remote places and dispersed towns more effectively. These are places that could well atrophy without air access, by potentially more efficient, low cost, fuel efficient small and regional sized aircraft. *The Scottish government should undertake, and publish, a serious assessment of patterns of time and travel cost to destinations in the rest of the UK and Europe by air and alternative travel modes, both for tourist and business travel. Edinburgh business and policymakers need to know their real isochrones.*

There is not, in Scottish approaches to aviation, at either national or municipal levels, much attention to accentuating the positives of aviation. Complex economic negatives and positives need to be more carefully considered in strategic choice of the transition path/ strategy.

IV. Although much work is now going to flesh out strategy and delivery plans for Scotland's

energy and business sectors there is as yet no concrete, deliverable strategy for the aviation sector. That has implications not just for economic accessibility issues and GHG emissions, but for having in place the skills, businesses and infrastructures that will drive innovation and change in the aviation industry. Scottish policymakers may not be fully informed about the real prospects of technological change in fuels and aircraft and by unduly focussing on demand reductions to attain emission reduction targets, may miss important opportunities to place innovative firms in the fuel and engineering sectors at the forefront of production for the new green economy.

Clear linked strategies for energy, industry and aviation urgently need to be put in place if Scotland is not to choose an emissions limiting path that destroy prosperity.

These omissions apply particularly to the development of adequate supplies of synthetic SAF, both in the short term as SAF is used as a 'drop-in' fuel with existing propulsion systems, and in the longer term if green hydrogen fuelled propulsion does not completely remove GHG emissions. Extensively available clean electricity represents a significant commercial and competitive advantage for Scotland in the production of both SAF and green hydrogen aviation fuels.

With the loss of jobs at Ineos (Grangemouth), reflecting a potential failure to plan for green jobs to replace ending fossil fuel processing, there is a strong case for Scotland's 'industrial/economic' strategy to immediately establish the Scottish potential for major SAF production.

More widely, with the diversity of technological changes, which are increasingly seen as probable rather than merely possible, the emphasis of aviation strategy should be on maximising technological change led reductions in GHG emissions. Foreclosing aviation options before 2030 may miss the wave of innovations that could produce the decarbonised plane and leave Scottish aviation, businesses, and households with 'early mover regrets'. Rushing to net zero now, by diminishing aviation demand strategies, does not seem the best strategy for the next decade at least. 2030 should be the date at which demand

reductions strategies are contemplated should technological change not deliver the expected results. It is important to note that waiting for certainty about a feasible new technology is different from deferring policy to speed adoption of 'green' car and domestic heating systems that are already working technologies. Policy needs to address how to transform the aviation-GHG dilemma to one of supportive synergies.

V. Many governments quickly espoused net zero GHG targets after the Paris Agreement of 2016. The City of Edinburgh embraced a net zero target for 2030, the Scottish Government 2045 and, more in line with international aspirations, the UK set 2050 as the target date. Such date diversity makes little practical sense within a multi-level but highly centralised country.

Scotland, as a small, open economy, operating in globally competitive markets is a 'price taker' in most activities. Similarly, it is not, self-assessed, moral leadership apart, a 'zero carbon' maker for the globe. Unless Scots are to be satisfied simply by being 'moral leaders' facilitating an eventual net zero, we may be disappointed by the outcomes from global warming as zero carbon is essentially a global 'public good' and 'until it is enjoyed by everybody it will be enjoyed by nobody.'

However faster emissions progress here is, at the very least, slowing wider warming. **At COP 28 much disappointment was expressed as many governments had failed to deliver the reduction strategies and targets offered from 2016 onwards. The UK Climate Change Committee, and Committees of the House of Commons and the Scottish Parliament have also expressed disappointment that Scotland has failed to meet its emission targets over the last 5 years and, more worryingly, failed to conclude and publish a net zero strategy with early stage deliverables set out.**

This report reaches the same conclusions, and specifically in relation to a strategy for emissions reductions and net zero in the Scottish aviation sector. There needs to be a clear explanation as to why strategies have not appeared to achieve what governments have embraced.

One explanation is adverse context. This millennium has become an increasingly difficult time for

policymakers as negative shocks of financial crises, pandemic, and wars have exacerbated an already difficult set of long run, neglected policy issues such as old-age care, pensions, housing, infrastructure, and health sector reforms that have been 'kicked-down the road' for decades. Moreover, the nature of the net zero attainment problem involves such a fundamental change of ways of living, working, and travelling, with complex, recursive change systems required.

There is also a sense emerging that, by the occasion of COP 28, governments may have the will to change but neither the conceptual framings to deliver net-zero in ways compatible with fairness and prosperity goals nor the governance capacities to construct and deliver credible strategies for change. Given their consistent failure to deliver clear strategy for change to net zero, Scotland, and Edinburgh City, have to assess whether missed emission targets, and missing strategies and delivery plans are simply a matter of fiscal resources or whether governance competences and systems existing in Scotland match the difficulty of the problems on hand.

VI. The research for this report suggests that there is continuing failure, relative to other cities and nations, in Scottish governments and Scotland's major city regions, in this study Edinburgh, to think about the effective futures of their airports as strategic economic infrastructures that have major effects on household prosperity and fiscal capacity for Scotland.

As the Just Transition Energy Strategy (2023) and published advice to Scottish government (Element Energy, 2021) float ideas about reducing flights by 30 percent by 2030, have the Scottish Government actually estimated the potential loss of fiscal revenue and household incomes, and have they matched job losses to new skills opportunities for emerging green economies? We do not know but no such loss appears in the sound budget-forecasting work of the Scottish Fiscal Commission (2023) or indeed the Budget plans of the Scottish Government! The presently diverse, unlinked, and unclear government thinking about what the 'green, blue, wellbeing, inclusive, fair, with community wealth building and productivity' (GBWIFCWP) economy is, how it operates, and what it is for, has left significant sections of the public, workers, firms, business leaders, and a few academics unsure of which is the priority narrative applying in different

settings. Airports, and other businesses, with triple bottom line targets that they are required by Boards and investors to meet, now have a growing sense of unease not about choosing net zero, nor about the imperative of decarbonising as quickly as possible, but about the lack of clarity about the path for change, and where it will lead in terms of prosperity and wellbeing as well as net zero and 'justice'.

Scottish economic policy, including aviation strategy, is truly 'up in the air' and it urgently needs a well-made landing path. *The Scottish Government need to develop a coherent single narrative and framework for economic decision taking, albeit with multiple goals and different explicit redistribution aims but without the implication that some new economic system has been invented to deliver the GBWIFCWP agenda.* And it needs to be able to articulate and assess 'high' and 'low' pathways to net zero.

That start should be made immediately by firming-up and publishing the overall Scottish transition plan to deliver net-zero that should be explicit on how emission reduction targets are to be met and the associated costs, investment, employment, wellbeing, and distributional effects of proposed measures. Scotland should not tend towards zero wellbeing growth by default.

Governments in Scotland need to set their transition strategy within, and be part of, a coherent economics narrative for policy making in Scotland that investors and policy decision takers (including some of their own officials) can interpret with clarity. The MacPherson review has highlighted how the opacity of Scottish economic, and related, policies now both deters inward investment and loosens the location ties of businesses already located in Scotland. How Edinburgh businesses, investing now, will be connected to the wider world beyond the metropolitan area after 2030 is more uncertain than for major cities in England. These issues need to be reviewed and acted upon now.

VII. All the research for the report made clear the complexity of understanding then changing multiple 'wicked systems' to choose and move forward on a path towards timely arrival at net zero GHG. That process has to be designed and delivered by collaborative governance approaches, as multiple orders of government affect outcomes in all localities and also requires interaction with citizens, communities,

business, and investors to maximise the synergies and reduce the uncertainties for all in the change processes. The feasible paths to decarbonisation, for places and sectors as well as Scotland as a whole, have to be explored for their costs, benefits, and potential risks.

Carbon descent paths will require multiple missions to be constructed for each of the major goals of public policy (the green, the inclusive, the wellbeing and the productivity aims), their strategy overlaps identified and managed, and the resources and capabilities to deliver change identified.

Regular monitoring of progress in relation to a clear national performance framework as each phase of delivery is completed should allow strategic recalibration of change as the efficacy of different policy actions is identified and as changing technologies and behaviours transform from possibilities to probabilities to realities. In regard to aviation and Edinburgh, the sectoral strategy for aviation needs to overlap with the mission for Edinburgh.

This is a demanding array of challenges of how governance has to evolve and transition to a net zero carbon path. **There was much evidence in this study that having made enlightened choices of visions for future goals, Scotland has, in many areas, but particularly the future of aviation and the economy, set out on an opaquely chosen and dimly illuminated forward path.**

The final three conclusions below highlight how limited progress has been made on these issues to date and opportunities for change.

VIII. Good policymaking for complex, evolving, system change needs to use all the available evidence to assess how systems function, including their structures and connections, and the known factors that drive change. The recognition that a system is at play requires multi-sector models, of different kinds that recognise random and self-organising effects. These models require significant interacting economy-environment sectors, and they need to be developed spatially, at national and metropolitan scales and for sectors. These models are missing for Scotland and its major cities.

Models provide information to inform decision choices, they do not calculate 'answers,' and they

are of limited applicability beyond informing 'the next move' forward. They need to be recalibrated as path progress is carefully monitored in a national, or metropolitan, or sectoral performance framework.

The findings from this study are that the Scottish Government have undertaken partial modelling of the effects of the 'just transition,' and that is welcome. Some metropolitan areas try to develop coherent modelling of regional scale economic changes. Scottish cities, and the regional partnerships that serve metropolitan areas, have rarely devoted significant resources to understanding their metropolitan economies (although Edinburgh City have in recent decades and Glasgow City Region have markedly stepped up their capacity in consequence to the city deal process). The City of Toronto has modelled the major effects of different pathways to net zero and the Greater Cities Commission (now reintegrated back into the government of New South Wales) have strong capacities to understand and articulate the consequences of major infrastructure decisions on the metropolitan economy.

At both Scottish and metropolitan scales, there have been no attempts, at least found in this research, which undertake the GHG-economy-technology modelling of paths to net zero, for the economy as a whole, let alone for aviation. In essence, neither side of the policy dilemma aviation GHG- regional economic prosperity has been modelled at all in relation to future aviation strategies for Scotland or the Edinburgh city-region.

Further, there is currently limited capacity in Scotland to actually model the 'just transition' or different scenarios for understanding airport/aviation changes and the outcomes for regional economies. Given the long duration of the transition process and the likely need to adapt strategies there needs to be a significant step-up in Scottish capacities, and especially in the two major cities, to understand, track and model the interactions of environmental (GHG) and economic change.

Good climate science has illuminated the global warming dangers. Impressive engineering science is seeing Scotland contribute impressively to the 'green innovation swarm.' However, Scottish policymaking seems to have neglected the

economic, social and management sciences in developing new modelling for selecting the transition path. Scottish economic and infrastructure policy making, especially for the larger cities, needs more analysis and fewer adjectives.

For instance, can Scotland, and its major cities estimate the volumes and broad patterns of aviation that the city-regions and Scotland will require 5, 10, 15 and 20 years from now to support their intended population, income, and wellbeing and how the intended net zero path will embed the changes to green economic employment. And to do so for different assumptions about the prevalence of decarbonised fuels. If not, how do governments explain the paths they are choosing and is demand limitation in aviation simply the lazy solution necessitated by absence of smart policy thinking?

To accelerate the development of quality modelling of transition to net zero for Scotland, the Scottish government should usefully take advice from leading scientists, economists and social scientists (perhaps using the network and convening powers of the Royal Society of Edinburgh), and establish, with the aviation industry, an expert environment-economy-aviation group that could emulate the aims of the important modelling studies reported in Chapter 4 and remedy the dearth (noted in Chapter 3) of econometric and other modelling of the economic effects of aviation and external connectivity on Scottish and metropolitan economic prosperity and productivity.

Clear, agreed, evidenced, and modelled, first steps route maps to GHG reductions become essential for well-designed collaborations. These evidenced paths for aviation reduction do not exist for Edinburgh. What about other aspects of collaborative governance?

IX. Officials in governments airports in all the case study settings are well aware of the profound complexity of the changes required and that collaborative strategic, informed action for change is required. The review concluded that the idea is much more espoused than practised.

Governing complex, geographically dispersed systems, such as interregional and international mobility, is always challenging. They involve multiple areas of government action. Governments are primarily organised into, sectoral silos

of policy, strategy, delivery, and Ministerial responsibility. Spatial systems also are influenced by, and influence, the actions of multiple layers of government with different policy autonomies, preferences, and resources.

The aviation sector requires coordinated actions by all levels of government associated with aviation and airports (and numerous governance entities as well). The UK government (though strategically disinclined to impose demand limitations) will set the schedule for, and regional allocation of, category 3 emissions (*and disconnected by national policy from access to high speed rail, the Scottish Government should be arguing strongly to have to meet a lower share of Category 3 GHG emission reductions that similar cities closer to London and Europe*). Critically, the UK government are significantly involved in the research and industrial policies that will shape new fuels, such as support for SAF production and CCUS sites and green hydrogen production, and aircraft components. They will also set key aspects of the tax regimes that will influence choices by airlines, including carbon taxation as well as infrastructure and regional development programmes that have some traction in Scotland, post-Brexit.

The Scottish Government has environmental and emissions policies, infrastructure investment decisions that impact the development of airports and transportation to them, and has the major powers in relation to skills, industrial and spatial policies within Scotland.

The City of Edinburgh has significant planning and land powers as well as local service activities that shape airport activities and GHG reductions. And operating within the wider region of the Edinburgh and South-east city Deal, and other multi-authority governance entities, it has significance in skills and local infrastructure projects.

The different orders of government operate more or less collaboratively in different spheres of activity and in Scotland versus England there has been a stronger tradition of community collaboration and weaker connection with business.

In relation to a collaborative intergovernmental approach to the 'just transition to net zero' collaboration falls at the first hurdle. At present, all 3 governments have different dates set to

achieve net zero, 2030 for the City, 2045 for Scotland and 2050 for the UK. Different intra Britain connectivity and initial, implicit, aviation decarbonisation strategies are apparent. There is no regular, frequent, cross order of government dialogue, between the UK government and devolved administrations, on the decarbonisation strategy for metropolitan and devolved regions in the UK. That speaks to an unwillingness to put aside difference of interests to pursue solutions to the common problem.

Clearly, the different time scales declared must imply a failure to connect the time paths of the different measures to be deployed by different governments. *Given the significance of the issues involved there should be regular recurrent intergovernmental meetings of policy officials on major elements of transition strategies, including aviation and interregional connectivity, with an annual cross-government summit of relevant Ministers and other leaders (from the major sector providers and users) ensuring good ideas are shared, plans aligned and blockages to progress removed.*

At a more general level, Scottish discussion of the GHG transition path is fragmented across academic institutions and disciplines, divided across different business sectors, think tank interest is peripatetic, does not always include community views and is still split across sectoral and professional silos within governments. *There may be a case for a national thought leading institution to put in place a sustained conversation, perhaps linked to the required modelling effort noted above, on 'Scotland's progress to Net Zero.' For at least the next decade years that could function as a 'transition' knowledge broker and mobiliser and would contain a strong stream of discussion on infrastructure, aviation, the economy and GHG emissions.*

Within governments the selection of the transition path and then movement along it requires strong inter-departmental collaboration. Economy, Transport, Energy, Infrastructure (and especially for connectivity and aviation) have to be intricately connected in decision taking. For instance, the Scottish energy transition review, at the heart of the drive towards net zero, exemplifies this imperative for cross-sector coordination, in noting that:

Through accessing global markets, Scotland can realise vast growth opportunities, including exporting our skills and knowledge in offshore energy and decommissioning... that will require co-operation and action at a UK-level to facilitate smooth international trade... To ensure we deliver climate-friendly, affordable, and secure energy supplies here in Scotland, we must look to collaborate with others, particularly our neighbours around the North Sea (Scottish Government, 2023).

This makes perfect sense, but how is it linked to the economy, aviation, and skills strategies? It is not clear; there is no designed map for forward change steps. Policy integration across different sectors remains opaque.

The 'just transition' mission has to be expanded to explicitly embrace all the major goals of Holyrood. A multiple 'missions' approach needs to be developed that connects cross sectoral actions and they need to be designed (or vice versa) to mesh with a revitalised National Performance Framework that government actually uses.

The Scottish Government should strengthen their own National Performance Framework, not least by spelling out the evidence and underlying theories of change and causal linkages underpinning it. When they have done so they should cascade the approach downwards to their Regional Economic Partnerships so that there is some national to local coherence in framing economic and infrastructure policies and understanding their outcomes. The measures in the framework, and the areal basis on which it is used, should reflect the spatial nature of the economy, and that would emphasise key mobility outcomes, including aviation, and how they connect to economic and other changes.

Mobility and Physical Connectivity have to be the focus of a major sub-Mission and within that the future of aviation and economic roles of airports clearly considered.

If aviation at Edinburgh, and for Scotland, are to be decarbonised effectively a credible, published, transition strategy, expressed in a linked set of missions framed within the National Performance Framework has to be developed. Currently the intended decarbonisation path for Scotland and the Edinburgh 'metropolis' the city is unclear and there is an almost systematic avoidance of discussion of

how the net zero path to 2030, let alone for 2045, will impact the airport and the economy.

A much more coherent coordination of strategic policy initiatives is required if net zero and other objectives are to be simultaneously achieved. It was noted above that a multi-faceted, but unclear economic policy narrative, obfuscates the relationship between economic progress and net zero GHG emissions. There is also a multiplicity of relevant strategic statements on relevant issues since, say, 2016. At the Scottish level these have ranged across infrastructure (the Scottish Infrastructure Commission Reports), enterprise, building back better, cities, major infrastructure projects, the transport review, social inclusion, and the energy transition as well as national spatial planning, see below.

These strategies are not always linked to the National Performance Framework, nor each other. Policy strategists interviewed in Edinburgh noted in Edinburgh that over the last decade a different style of strategic statement has become commonplace in Scottish policymaking. Introductory chapters typically spell out a compelling vision for dealing with major Scottish challenge government wishes to address. There is then often a limited evidence base for change presented and major strategies are left devoid of delivery plans and required resource commitments for progress. The Aviation section of the Scottish Transport Strategy makes it clear that officials are aware of many of the policy dilemmas and possible routes to resolution but then, without resource commitments, defer a decarbonisation strategy for aviation somewhere down the, unspecified, path to net zero.

Aviation policy, both literally and metaphorically, has to be grounded in actions for airports. **Spatial planning policies in Scotland, and perhaps the planning profession, have big ideas for small places and have developed much, useful, thinking for expanding service and infrastructure choices within neighbourhoods. Planning, appropriately, has taken a major interest in questions of environmental sustainability and achieving net zero. However, there is at national and local levels, limited thinking, arguably much diminished since a decade ago, regarding strategic regional and metropolitan planning within Scotland.** Statutory spatial structure plans are no longer required

and neither of the city regions focussed on Edinburgh and Glasgow now have a spatial development strategy. This report echoes the recent Our Scottish Future report on 'Rewiring Scotland' (Dickson and Barnes, 2024) in making a case for stronger local government but in seeing the governance of linked, strategically important strategy and delivery in economic policy, skills, and infrastructure to be reframed at functional regional levels. Scotland needs strategic regional economic thinking and action. Disappointingly, diminution of the significance of bigger spatial thinking is apparent in the 4th National Planning Framework (Scottish Government, 2023). **It is strong on sustainability and place principles, largely for others to develop, but has no clear sense of the economic geography of Scotland (drawing ad hoc regions for action) and an odd selection of national priority locations. No airports, and especially, Edinburgh Airport, are regarded as strategic locations for Scotland, let alone the Edinburgh focussed metropolis. The NPF 4 should be the template for strategic policy actions for the big internal and external connection geographies for Scotland.** This omission, of spatial planning to support efficient zero carbon interregional and international connections is such a stark contrast with how planning, infrastructure, the economy, and net zero issues are connected in the context of Sydney, and parts of Ontario. Half a century ago, the Scottish Office and the emerging Scottish regions were regarded as being at the forefront of international expertise in strategic spatial planning and economically oriented infrastructure investments. It would be difficult to make that claim now just when such skills are required to shape the economic geography of 'Just Transition'.

Not one of 25 leading Edinburgh-based economic actors interviewed for this study agreed with the National Planning Framework's priority for Edinburgh of developing housing in North-East Edinburgh (whilst recognising the imperative for increased supplies of affordable housing in the city-region) ahead of developing a thriving, integrated decarbonised, infrastructure to connect Scotland to the wider world that involved Edinburgh airport. This seems, given the nature of Edinburgh's economic base, which requires fast travel over long distances, a potentially serious omission in economic development strategy for the city and the nation.

And in a similar vein, there is no sustained discussion of creating a significant aerotropolis possibility close to the airport, and possibly a major mixed tenure non-profit housing to employ airport staff in homes heated by surplus, currently wasted zero carbon solar energy. Why not

There is a sustained unwillingness to identify potential productivity and employment growth points, where Scotland's economy might be in 2030 and 2045, in high-level infrastructure and spatial planning policies. Whether that arises from a lack of spatial awareness within the bureaucracy or persistent unwillingness to prioritise places in planning and resource allocations, the result is that the Scottish government fail to provide the 'indicative planning' and place leadership that is so critical to spatial development in periods of major economic change. The Scottish administration does not seem to take Marianna Mazzucatto's (2011) notion and roles of the 'entrepreneurial state' at all seriously in shaping our future geography.

It is clear that the consolidated finding of this report is that, **whilst recognising the difficult policy making times, and the complexity of meeting the net zero imperative by taking 'the high road', there are key features of effective governance for net zero, including intergovernmental collaboration and coordination, missing research and modelling, unintegrated sectoral policy actions, major strategies weak on evidence and delivery plans and an approach to spatial planning and major infrastructure provision that seems, at best, loosely related to where and what a prospering, net zero Scotland will be. It is exceptionally difficult to see how Edinburgh Airport, and the high accessibility space it creates, fits into strategic thinking for Scotland**

Key spatial nodes for the future, such as Edinburgh Airport, may not have been best supported to achieve, collaboratively, our longer term goals. Good spatial and infrastructure planning has to go beyond Scottish government and its agencies outlining 'place principles' and downloading the task of implementing them to more local levels (often with minimal planning service and infrastructure budgets). It has to implement these principles for the big geographies and big infrastructures, and not just well-served neighbourhoods, that will serve Scotland in the future. There is a case for restarting the strategic

planning debate for Scotland with consideration of how to effectively connect our cities, regions and airports to the wider world of 2035 and 2045.

X. Many of the points made above in relation to policy and strategy formation for attaining net zero with prosperity that apply to the Scottish Government also apply at the municipal scale and are influenced by national infrastructure, planning, and economic policy decisions. In contrast to the experiences noted in Sydney and Toronto, Edinburgh Airport has a more distant and less collaborative relationship with local governments. Tensions seem to arise over short-term niggles such as parking charges and taxi access rather than collaboration on big challenges for future aviation change and the impact on the city and the region.

That absence of purposive collaboration, and the missing research on how the airport drives and is driven by city growth, is indicative of how the city, and the regional economic partnership fail to take sufficient substantive account of the strategic economic roles of the airport. This could mean a failure to recognise the immediate negative economic impact of flight restrictions on the metropolitan economy and the much deeper, longer-term productivity effects from lost connectivity within Scotland, the UK, Europe, and the wider world.

The City of Edinburgh, and the appropriate collection of surrounding municipalities, need to update their understanding of how employees who need to travel work to the Airport, either to work onsite or pass through the terminal as passengers travelling to work in the rest of the UK, are distributed around the Airport. There is a presumption in much discussion of how Edinburgh functions that it is almost entirely a city-core focussed city. Not now, it is an expanding polycentric metropolis with complex travel to work patterns. The City dismissed early aerotropolis ideas in planning discussions in the 1990's and with the growth of the airport and the westwards spread of the functional city, it may be that the airport provides a potentially important employment growth pole for the western suburbs that could comprise alternative, longer term growth locations. These options need to be more fully explored in strategic and local area plans.

The city, and metropolitan partners, need to take a lead role, with others in spelling out what economic activities might arise from decarbonising aviation through technological change. Seeking to induce the UK government, perhaps through the new Framework and geography of the Green Freeport, and with levelling-up and similar Scottish support, to immediately assess the possibility of developing one of the SAF production centres intimated by the UK government, to be immediately developed with or as a replacement for Ineos at Grangemouth. This is a potentially pivotal element in aviation decarbonisation and new green job development for Scotland.

The new Greenport, that may be a useful geographic and governance framework for metropolitan economic development over the next decade, as the city deal has been for the last, could usefully look at major connectivity infrastructure for the city-region. In New South Wales, through investment to connect ports, airports and by zero carbon rail network developments across the Sydney metropolitan area, is aiming to have a well-developed intra metropolitan transport system connecting with the key connections to the wider world. With the Edinburgh city-region growth momentum of the last 20 years maintained into the future then such a connected infrastructure network would be a major competitive advantage for the metropolitan economy.

Business leaders in Edinburgh spoke highly of the current version of the city economic plan, shaped as the city deal emerged. Perhaps this is the time for the City and other authorities in the metropolitan region to grow beyond their recent, successful, focus on skills and innovation and begin to rethink how major infrastructure projects could better connect the airport not just to the city core by low carbon travel (as it has already substantially done) but to the functional region growing around the airport.

Just as there has been a proliferation of strategies for change, there has also been a growing number of economic development and transition agencies with overlapping remits and non-aligned boundaries. This can only hamper effective development of the green economy with zero carbon connectivity. The city and the other participants in the metropolitan area need to convince the Scottish Government,

existing agencies, and other municipalities to create an integrated entity that will deliver the infrastructure, green industry transitions and skills to power prosperity, and to maximise the use of green finance and land value capture to minimise the public capital costs of change, as the city region moves towards net zero with prosperity. New governance has to emerge for new times.'

It is not clear, currently, how Edinburgh Airport plays into any policy thinking at national (or Scottish Government agency) and City government levels regarding Scottish, regional, metropolitan and neighbourhood economic changes or wider changes that impact measures in the National Performance Framework.

That observation can also be made in relation to understanding the ways in which Edinburgh Airport, as a major Scottish infrastructure and global connection point, plays into the achievement of metropolitan and Scottish goals for the environment, inclusion, and the economy. Edinburgh Airport, the City and the Green Freeport partners could rectify that omission by establishing a working party to audit how activities at and through the airport contribute to local goals and those of Scotland's National Performance Framework or, alternatively, UN's Sustainable Development Goals. A preliminary review for this project suggests that airport activities and consequences have positive implications for the majority of SDG policy goals. The Airport, the City and metropolitan partners could usefully undertake such an exercise and identify ways in which the Airport's contribution to the City, the Region and Scotland can be maximised over the next decade.

In policy discussions in Scotland there was recognition that decarbonising aviation required reductions of GHG emissions in flight, still to be done, in the operations within the airport, largely completed, and in the development of carbon free ground transportation (partly done). There was less recognition that an airport constitutes a site of peak international/interregional connectivity that can be used both to generate metropolitan jobs in the vicinity of the airport but also reduce the future carbon footprint of such developments for a city (one of the central arguments for the new West Sydney airport). Nor is consideration given to how an airport can be a significant generator of clean energy if its lands and structures are used intelligently, and indeed more attention given to the development of mixed neighbourhoods for airport based employees within active travel distance.

Last Word

There is a positive discussion to be had to about how to keep aviation from Edinburgh 'up in the air', to 'land timeously at net zero' and 'not crash but grow the Edinburgh economy' through stronger connections for better growth. The aim has to be, for the city, the metropolitan region and Scotland, to 'take the high road to 2045'.

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