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Paris-compliant emission reductions for Sweden:
heuristic narratives for guiding energy policy

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1. Introduction

1.1 The Global Carbon Budget

The scenarios developed in this report are aligned with the IPCC's latest global carbon budget for an 83% chance (or better) of 2°C (i.e. 740GtCO_2 from the start of 2024). This value is subsequently downscaled to Sweden following the method outlined in the Carbon Budget report (Stoddard & Anderson 2023), which itself is borrowed from the peer-reviewed Factor of Two paper (with its Swedish and energy-specific focus) (Anderson, Broderick & Stoddard 2020).

It is important to be cognisant of how the 2°C Swedish scenarios developed in this report align with the lowest ambition level of the Paris Agreement (i.e. "well below 2°C") rather than the much more demanding level of "pursuing … 1.5°C". Since the drafting of the Paris Agreement in 2015 (ratified in 2016), there has been considerable work across the scientific community to understand the difference in impacts between 1.5 and 2°C of warming. This work alongside empirical evidence of significant and accelerating impacts at the current level of warming (around 1.2°C), underpin the view that 1.5°C is now the "dangerous" threshold to which signatories of the 1992 UNFCCC agreed to avoid.

According to the IPCC's 2020 carbon budgets, this higher 1.5°C ambition of the Paris Agreement equates to a global carbon budget (updated to the start of 2024) of just 340GtCO_2, or around eight years of current global emissions. For the purposes of this report, we judge that such a small budget (for a 50% chance of 1.5°C) is no-longer viable (i.e. political, social and technical inertia put the 1.5 °C budget beyond reach). However, it is in important to understand that this assumption does not, necessarily, put 1.5°C beyond reach. The IPCC carbon budget for an 83% chance of 2°C (the focus of this report) is the same value as the budget for 17% chance (1 in 6) of not exceeding 1.5°C. However, this weaker interpretation of the Paris Agreement does come with significantly elevated risks of much more damaging impacts, including to life and the viability of many communities.

The IPCC's analysis, on which this report is based, relies on academic papers typically published in the years running up to 2020. However, since then, there has been a growing concern amongst many analysts that the budget values in AR6 overestimate the levels that actually remain. The most recent assessment reduces both the 1.5 and 2°C carbon budget by around 130GtCO_2 (Lamboll et al. 2023); this represents a reduction of almost 40% for the 1.5C budget and a little under 20% for the 2°C value used here.

1.2 The Swedish Carbon Budget

Before proceeding with the development of the scenarios, it is important to briefly reiterate just how challenging the mitigation rate (cuts in energy-related CO_2 per year) are for "well below" 2°C and from the start of 2024. As detailed in the Carbon Budget report, an optimistic reading of Sweden's remaining Paris-compliant carbon budget is 285MtCO2. Extrapolating from official statistics, we estimate Sweden's territorial emissions (i.e. not including imports and exports, but including international bunkers) for 2023 to be in the region 45MtCO_2. Should this level continue, then Sweden will consume all of its fair contribution to staying "well below 2°C" within seven years. Another way to view this, is that a straight line descending from Sweden's current level of emissions to zero emissions, would see full decarbonisation being completed by 2037. However, any shortfall in the rate of emissions reduction (from the start of 2024) would, other things being equal, see the zero-date come closer still. The rate at which Sweden chooses to reduce its emissions in the immediate to near term dictates whether Sweden abides or reneges on even a weak 2°C interpretation of its Paris commitments. If Sweden were to abide by its 1.5°C commitment, and following the above logic, the emissions would need to reach zero by 2027.

In practice, the necessary acceleration of mitigation rates from current level to that required to stay within Sweden's 285MtCO_2 carbon budget will inevitably be constrained by political, social, technical and economic inertia. Consequently, post this 'acceleration' period the actual reduction rate will need to exceed the theoretical exponential rate, so as to stay within budget. It may be that removing the final few

$MtCO_2$ from the energy system will also prove more challenging than during the main period of rapidly declining emissions. Should this be the case, then, again, the mitigation rate (post acceleration) will need to be higher still. In short, the sooner inertial constraints can be overcome, and the faster final residual emissions can be removed, then the lower the rate during the principal period of mitigation (though it will still be at an unprecedentedly high rate).

1.3 Background to the Scenario narratives

Set against the downscaled and Paris-compliant carbon budget for Sweden, the illustrated scenario narratives (hereafter scenario/s) developed in this report are expressly intended as a political heuristic. They are not intended to provide a blueprint for action, but rather offer a sense of the pace and level of political, social, technical and economic change now necessary to deliver on Sweden's 2°C commitment. The scenario is informed quantitatively by both the carbon budget framework and the latest energy and emissions data from the Swedish Energy Agency and Statistics Sweden. However, whilst there is a quantitative basis to the scenario, it is deliberately developed and presented as a more qualitative narrative.

Before engaging with the scenarios, it is important to reiterate the key reasons why such a fundamental and rapid transformational change is necessary if the Paris commitments are to be honoured; change that would have profound impacts on many facets of Swedish society and norms.

1) The cumulative nature of carbon dioxide in the atmosphere (a characteristic shared by several other key greenhouse gases) means that only when emissions are brought to zero will the concentration of CO_2 in the atmosphere stop rising. Consequently, a cut in emissions only reduces the rate of *increase in temperature*, it does not stop temperatures rising. This will only occur when fossil fuel emissions cease and residual GHG emissions are balanced by uptakes. Even then the temperature will very likely continue to rise for some time to come before reaching a new stabilisation level and subsequently falling slowly over the following centuries. However, it is important to understand that when the temperature ceases to rise many impacts will continue to escalate, not least sea level rise, but also, and in more complex ways, the ongoing disruption to ecosystems.

2) International leaders have presided over an ongoing annual rise in global emissions, despite repeatedly signing international agreements to cut such

emissions (since the ratification of the UNFCCC in 1994). Today, global emissions are over 60% higher than they were at the time of the first IPCC report in 1990, and are still rising (Stoddard, Anderson et al. 2021). During this time Sweden, a wealthy industrialised nation, has only reduced its territorial emissions (including international bunkers) by a little under 0.7% p.a.[1] (this falls to just under 0.5% p.a. on a consumption basis). Had leaders delivered action commensurate with the commitments they made, the situation today would have been very different. There is a salutary lesson here. The physics, and therefore the impacts, only responds to delivered actions; in isolation fine words and protocols are meaningless. The failure, by repeated leaders in Sweden and Globally to acknowledge this, is a key factor in pushing today's action to completely unprecedented levels. *Som man bäddar får man ligga.*

2. Aligning Sweden with its climate commitments

2.1 There are no non-radical futures

With Sweden's 2°C carbon budget equating to just over six years of current emissions we are under no illusions that a timely transformation is going to require a fundamental reshaping of societal values, political norms and power structures. Given this, there is a clear danger of Sweden forfeiting its 2°C carbon budget and thereby directly or indirectly choosing to renege on it 2°C commitment. This is similarly true for most nations, and consequently there is now a high possibility of the Paris Agreement's weaker 2°C commitment going the same way of its stronger 1.5°C obligation. However, we must also be under no illusion that the choice of Sweden's leaders to fail on 2°C is a choice to accept much greater climate impacts, with a very real prospect that 2°C will be a transient temperature on a pathway to still higher levels of warming across coming decades. All of this risks socio-political destabilization initiated by climate induced impacts, ranging from migration to food scarcity, disease to conflict, and flooding to droughts.

Although the energy scenario developed here will be judged as implausible by some readers, such a conclusion risks misunderstanding the rapidly evolving physical reality with which we are now confronted; the time has long gone for non-radical futures. The effort required and disruption created in transforming the energy system (and indeed wider society) to align with Paris, is now nothing short of revolutionary. Perhaps here a statement from the IPCC (Working Group II) best captures just how revolutionary the transformation needs to be: *"Targeting a climate resilient, sustainable world involves fundamental changes to how society functions, including changes to underlying values, worldviews, ideologies, social structures, political and economic systems, and power relationships."*

There is a temptation to assume that such a radical transformation is simply too detrimental to our cultural and socio-economic norms to be worth pursuing. But this view inadvertently embraces the tenets of climate denialism. As already made clear, failing to make the requisite changes through organised and fair mitigation, will hasten chaotic, highly destructive and deeply unfair levels of accelerating climate change; all highly detrimental to the majority of citizens. Not least, as climate impacts escalate there is a very real risk that reduced crop yields and disrupted transportation [Kornhuber et al 2023] could lead to levels of migration and interrupted food supplies sufficient to destabilise already fragile political agreements between, and even within, nations. As recent history has demonstrated, undemocratic and more nationalist governments can arise under such pressured circumstances, risking heightened tensions and reducing cooperation between nations. Such a situation could rapidly escalate to intensified friction between groups within society, with the potential for substantial loss in civil liberties as governments endeavour to maintain order.

In contrast an organised and Marshall-style transformation, with fairness embedded as a key criteria, could yet deliver a 2°C-compliant transformation that supports an improvement in wellbeing and quality of life for the majority of Swedish citizens.

Set against the rhetorical political dialogue that dominates the mainstream debate and the sobering repercussions of such ephemeral politics, this report now turns to what it would take for a country, such as Sweden, to follow an energy pathway consistent with its Paris temperature and equity commitments. Just to restate, the Swedish budget of 285MtCO2 (from the start of 2024) used to guide this analysis is commensurate with a weaker interpretation of Paris. Consequently, and demanding though it is, the broad composition of action described here should be viewed as the minimum now necessary if Sweden is to deliver on its Paris commitments.

2.2 Focussing in on Energy

This scenario report works from an approximate level of energy supply, demand and sectoral make-up for 2023. As this data is not yet available, it is assumed that the 2023 data is very similar to that of 2022. However, one area that is likely to have changed relates to international bunker fuels, particularly those for aviation, but also, to a lesser degree, shipping. Here, the values of 2019 are taken to most closely relate to those of 2023, with the values in 2021 and 2022 still likely subdued or fluctuating as a legacy of Covid. This blend of the latest data certainly lacks a high degree of precision, but nevertheless it offers an adequate level of accuracy for the post-2023 energy scenarios developed here.

It is important to understand that Sweden's energy system exhibits several key characteristics distinct from many of its European partners. Per capita Sweden is a very high energy-consuming nation, at around 50% above the EU mean, and even 35% higher than the manufacturing powerhouse of Germany. However, whilst most EU nations have energy systems still dominated by fossil fuels, the past several decades have witnessed Sweden make a significant shift toward alternative energy sources, Today, around one third of both Sweden's total primary energy supply (excluding exports of electricity) and its final energy consumption (taking account of losses, etc.) is met by fossil fuels (on a territorial basis). This is less than in many developed nations, and puts Sweden at around the global average per capita in terms of their fossil fuel related carbon dioxide, at a little under 5 tonnes per person (including aviation and shipping bunkers). For national comparisons, and on a territorial basis, the EU is nearer 7 tonnes, China 8, India 2 and Kenya around 0.5 tonnes per person. Turning to a consumption basis (taking account for imports and exports, and international aviation and shipping emissions) Sweden's per capita level rises to almost 7 tonnes, just slightly less than those for China and well above the Global average.

Whilst being cognisant of the systemic merits of consumption-based emissions accounting, in conducting this analysis and report the focus has been specifically on territorial emissions, including international bunkers (i.e. aviation and shipping).

3. Key criteria for the scenario narratives

3.1 Sectors as one way to divide the pie

In developing energy scenarios compliant with Sweden's "well below 2°C" carbon budget (285MtCO2), it is clear that the timeframe of delivery is key. In this regard, the core focus of the narratives needs to be two-fold. First, they need to address those sectors that represent a large proportion of Sweden's current emissions. And second, they have to consider those sectors that look set to grow in size and for which few if any technologies are sufficiently mature and readily available to compensate for the accompanying growth in emissions. However, this is not to say that the other sectors are unimportant; as the UN and many climate scientists repeatedly note, "every fraction of a degree matters".[2] Moreover, within a real-world economy, sectors are never stand alone, but rather are intimately connected to each other at multiple levels. Nevertheless, in developing the heuristic scenarios for this report, the two criteria identified above provide the guiding focus for the analysis.

What is evident from the Energy Agency data, is how, from an emissions perspective, the two sectors of domestic transport and industry dominate. Collectively, they represent almost two thirds of Sweden's territorial emissions (including international bunkers), with domestic transport just a few percentage points higher than industry. However, whilst these sectors dominate emissions, they both consume less energy than 'buildings and services', with, in 2020, domestic transport (the highest emissions sector) consuming just 41% of the energy of the 'building and services' sector. Superficially the relatively low carbon intensity of the energy used in this sector, suggests it is of little importance when considering the challenges of decarbonising higher emitting sectors. However, any low-carbon energy used within the 'building and services' sector, is low carbon energy not available elsewhere.

Set against the emergency scale of action required if Sweden is not to renege on its 2°C and equity (CBDR-RC) commitments, it is key that a triage approach guide the appropriate use of limited low-carbon energy sources and constrained access to resources. Under such a triage regime, the very high energy use by the 'building and services' sector (despite its relatively low emissions) becomes a key element of Sweden's decarbonisation agenda.

Within much of the literature on mitigation, little attention is paid to the practical requirements and constraints of rapid decarbonisation. On the face of it, technology substitution offers a ready opportunity for swift change. Switching from cars, vans and trucks powered by internal combustion engines (ICE's) to electric vehicles (EVs); from private cars to trams, buses and trains; retrofitting homes to reduce energy consumption; substituting to zero-carbon electricity from fossil fuel use in industry; etc. However, rolling out, at scale, such technologies to broadly halve emissions by 2030 will demand levels of construction and manufacturing simply not accounted for in official scenarios. Whilst services now constitute two thirds of Sweden's GDP, it still has a thriving engineering and industrial base. Nevertheless, delivering the

Marshall-style transformation dictated by Sweden's Paris commitments, will require both a retooling of much of industry and rebalancing of the economy, particularly towards construction. Such rebalancing from 'services' with their relatively low energy-intensity to more energy-intense manufacturing and construction will see a substantial (though temporary) rise in total energy demand. The actual increase will depend on the specific choices, for example, weighting changes in personal transport in favour of EVs or public/active transport. However, whichever choices are taken, a short-term rise in industrial energy demand is unavoidable. Set within the unprecedented emission constraints accompanying 2°C, this industrial renaissance has fundamental repercussions for non-industrial energy use. Stylistically, this relationship between industrial and non-industrial energy demand, within Sweden's 2°C carbon budget and emissions pathway, is illustrated in Fig 1.

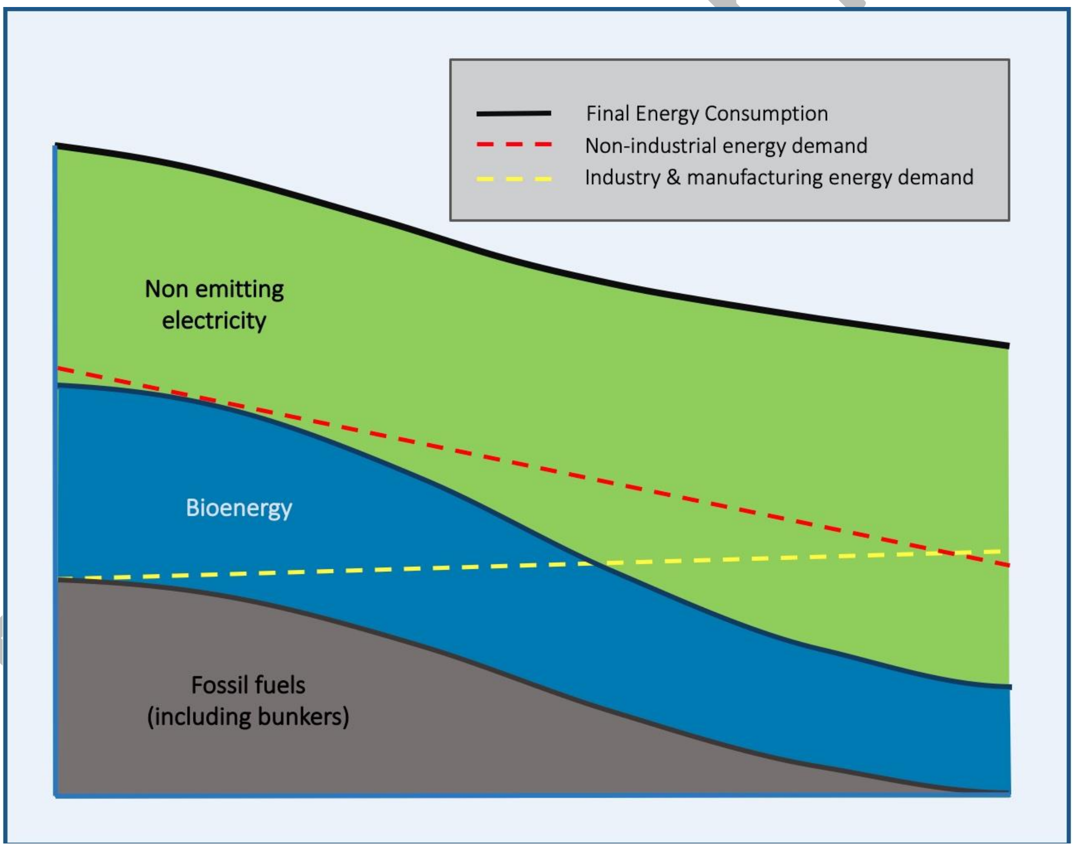

Figure 1. This series of plots and lines are purely stylistic, reflecting a Paris-compliant and energy-only decarbonisation pathway for Sweden (for a high chance of ≤ 2°C and a low chance of ≤1.5°C). Energy supply is represented by the solid colours (these are stacked area plots). The overlaid dashed lines are of final energy consumption, with red being for industrial use, and blue domestic and services. The grey and purple plots illustrate existing and falling fossil fuel use, constrained, from the start of 2024, to stay within 285MtCO_2, Sweden's fair share of the remaining global emissions budget for a high chance of not exceeding 2°C.

Key to understanding Figure 1, and therefore the energy challenges facing Sweden, is the distinction between final energy consumption (i.e. once loses due to thermal conversion are subtracted from primary energy consumption), and final energy services (i.e. the function that the supplied energy satisfies). Final energy services range from powering manufacturing processes, through to travel to and from work and on to meeting demand for domestic space and water heating. From the perspective of the users, provided these energy services have similar physical infrastructures and levels of control, the actual form of energy supply is of little relevance. For example, in terms of a decarbonised service provision, a local bus could be powered through sustainable biogas or renewable electricity. However, from a more systemic perspective, the more efficient the delivery of energy services, the smaller is the need to reduce the overall level of services. Typically, the electrification and structural improvements to the energy system (e.g. EVs for ICEs) brings significant efficiency improvements, delivering the same energy services but with much lower energy consumption. Going further, public or active travel may also provide the same 'travel' service (e.g. a child travelling 4km to school) as an EV, but with still further reductions in energy consumption. However, whilst from a user perspective the EV and ICE are almost one-for-one substitutions, a switch to active or public transport (for the same 'travel' service) involves other less tangible and diverse forms of change.

3.2 An engineering and industrial renaissance

To completely decarbonise Sweden's energy system with around fifteen years is an immense engineering and industrial challenge, with those services served by fossil fuels today, typically having to switch to zero-carbon electricity or potentially sustainable bioenergy.[3] This will involve not only a rapid ramp up of zero carbon electricity supply, but simultaneously the manufacture of end-user appliances able to use such electricity, the expansion and upgrading of the transmission grid and distribution networks, the electrification of much of the public and private transport equipment and vehicles, and a major programme of retrofitting Sweden's domestic, commercial and industrial buildings. Recognising this, the scenario constrains final energy supply to a level broadly capable of supplying a similar aggregate level of final energy services as Sweden currently experiences, though with a significantly different make-up. The one key exception to this is aviation. For technical and safety reasons there are no major decarbonisation options available for deployment across medium and long-haul flights within Sweden's 2°C carbon budget timeline. Across the wider energy landscape, the scenario assumes improvements in system-level energy efficiency exceed historical norms (typically ~2% pa.) with this continuing, in part, as a consequence of rapid electrification of those services currently reliant on fossil fuels. Typically, powering services through electricity is much more efficient than through various combustion processes. For this reason, the final energy consumption in Figure 1 is assumed to fall at around 2% pa. whilst still broadly delivering the same the level of services as is provided today. An important issue in considering efficiency gains, is that the very tight carbon budget (and hence energy supply in the near to medium term) imposes substantial reductions on what any energy/financial savings can be used for. In other words, Paris-compliant constraints severely limit opportunities for economic and consumption 'rebounds' that typically accompanying efficiency gains.

A further important issue captured within Figure 1, is the energy repercussion of the 'industrial renaissance' necessary to deliver the rapid programme of decarbonisation described above. This will unavoidably see a rise in absolute final energy consumption by the industrial and manufacturing sector, at least in the short to medium term. Improved energy efficiency in manufacture and supply chains can certainly help constrain any rise, but the sheer scale of raw materials and industrial output will inevitably impose a substantial energy burden. It is also important to note here, that if Sweden is not to renege on its climate commitments, this industrial renaissance would need to begin more or less immediately. As such, the pathway in Figure 2 really starts to bite from 2025 onwards. Consequently, in the early years, much of the energy demanded by industry will be met through fossil fuels, levels of which, at least initially, are set to rise with an accompanying increase in emissions. The upshot of this is that the final energy consumption (and hence emissions) of non-industrial sectors will need to reduce. Fortunately, the much greater efficiency of some energy services (active and public transport) and technologies (EVs) lessens the reduction in absolute final energy consumption for individuals and wider service sectors; i.e. the reduction in aggregate services is less than the reduction in final energy consumption.

3.3 Income & wealth inequality as a proxy for emissions

Study after study points to the huge inequality in energy use and emission between income groups in every country (IEA 2023). However, for many decades the Nordic nations have prided themselves on a model with much higher levels of equality and welfare. Whilst relative to most nations this remains the case, the Nordics have nevertheless seen an increase in health inequality (a good maker of wider inequality) sufficient for the region to have lost its advantage over other European nations. Turning to Sweden, the situation looks to have deteriorated much faster than in its Nordic neighbours, with some arguing "Sweden has actually seen the sharpest increase in income inequality in the world"(Nordforsk 2022). Other research reinforces this view, with Sweden's Statistics Authority (Statistikmyndigheten 2023) noting how in recent years Sweden's Gini coefficient (an index of inequality) has fallen to 0.333, the lowest level since the metric was first used in 1975. Providing more detail, the Authority points to how the highest income decile now have approximately 28% of Sweden's total disposable income, almost the same as that held, in total, by the five decile groups comprising Sweden's lower incomes. Similar conclusions are reached by other organisations(World Equality Database: the Lancet 2023). Focussing on emissions, but not specifically on Sweden, the 2022 World Inequality report (Chancel et al 2022) concludes that in recent years the richest groups within developed nations have seen a rise in emissions /capita, whilst the same measure across low- and middle-income groups has actually fallen.

It is absolutely clear from a depth and breadth of research that there are huge discrepancies in energy use and emissions across income groups. The sheer scale of these discrepancies, allied with the tight and rapidly shrinking timeline to hold emissions within 1.5-2°C carbon budgets, places equity high amongst the priorities of any Paris-compliant policy agenda.

A consequence of successive governments favouring weak climate legislation over such a quantitatively robust agenda, is that regulations targeting the highest energy users are now a prerequisite of Sweden meeting its international climate commitments. Simultaneously, the capacity of zero-carbon electricity generation, transmission and distribution need to be doubled, if not more, in just ten to fifteen years. Still greater and more profound levels of change are required of public and active transport, alongside the retooling of much of industry and its switching power sources away from fossil fuels. On top of all of this, efficiency and sufficiency measures need to be urgently rolled out across all energy end user sectors, including the built environment.

The essence of this rapid and system-level decarbonisation agenda is perhaps best characterised through the policy lenses of 'fairness', 'infrastructure' and 'technology'.

It is these three characteristics that are now used to frame the proposed Paris-compliant scenarios. Just to reiterate, these scenarios are constructed to broadly align with rate of emission reductions imposed by Sweden's 285GtCO2 carbon budget for 2°C. This commitment is taken at face value, and is 'the' key priority overriding any ephemeral political concerns or wider social or economic sensibilities. As 2023 draws to a close, and the Swedish Government warn of a short-term rise is emissions, the opportunity for non-radical responses has long gone.

4. Sector narratives of a Paris-compliant Sweden

4.1 Pre-amble

The scenario developed here comprises a *selection* of sector-based narratives. Whilst any such reductionist division inevitably omits important synergies, conflicts and crossovers, the following sector narratives do offer a sense of the profound scale of mitigation now required, whichever way the energy system may be divided. A key consideration in developing the narratives, and touched on earlier, is a recognition that labour and resources are limiting factors to delivering change. This consideration weighs heavily across all three of the key characteristics: *infrastructure*, *technology* and *fairness.* The narratives avoid specifying precise policy mechanisms. Instead the language of legislation is typically used as the driver of change, but this could extend to financial instruments as well as standards, regulations and even voluntary agreements. However, whatever the instruments chosen, they would need to pass a stringent consideration of fairness. Finally, the sector narratives are written in an active tense; i.e. the necessary changes are described as being already underway.

4.2 Housing

Infrastructure: Housebuilding undergoes a sea change, away from ever-expanding towns and cities to a much more ingenious use of urban space. This is facilitated by the almost complete shift towards active and public transport, and away from the private car. On so many levels this relinquishes valuable space for higher-density and high-quality apartments and town houses; the expansion of urban parks and ecosystem corridors, alongside wider communal facilities (from swimming pools to cafés, libraries to sports fields). In the rural areas, small communities are encouraged in preference to dispersed and isolated dwellings, opening up opportunities for improved public transport and some shared facilities.

Given the unprecedented rise in the need for labour and resources, policies are introduced to decrease the now over 600 thousand second homes that have become so popular in Sweden. There is much more emphasis on shared cottages (for example, so-called "andelsstugor"), local hotels, B&Bs, etc., all of which contribute to a thriving local economy as Swedes from more prosperous urban areas spend more money within the local rural communities. Depending on circumstances, some of the second homes become available for local residents reducing the labour and material demand for new homes.

Technology: Through a major programme of retrofit, following a priority order based on household energy ratings (with some consideration of household income), the energy requirement of residential thermal comfort of Sweden's almost 5 million homes is significantly reduced. In the early 2020s, households represented almost one quarter of Sweden's total final energy consumption, with over 70% of that arising from heating and hot water. In isolation this major reduction in energy consumption had a much smaller impact on direct emissions, as most of the energy was, ostensibly at least, from low carbon energy sources. However, with every kWh of low carbon energy not required to heat homes, so a kWh becomes available for the rapidly rising energy demands of the industrial renaissance. Accompanying the retrofit is the installation of solar panels on structurally suitable and appropriately oriented roof areas; consideration is given to the mix of solar electric and solar thermal. Tight legislation is introduced to rapidly convert the relatively small number of remaining and inefficient oil and solid fuel heating systems to much more efficient heat pumps. This both reduces emissions from fossil fuels and increases the availability of biomaterials for other purposes.

Legislation on new houses is significantly tightened in terms of thermal quality and the use of sustainable materials. Whilst this is initially unpopular with the senior executives of building companies, given the rules apply to all of Sweden's counties and municipalities, companies quickly change their practices and deliver in accordance with the legislation. Despite early concerns, this is rapidly seen to only marginally increase construction costs, with a still smaller percentage rise in the market price of properties.

Given all new properties meet passive house standards, as a minimum, alongside the inclusion of grey water systems and solar panels, the energy and water services feeding new estates and developments is substantially reduced. Furthermore, and following on from well-established Swedish practices, wherever practical, communal laundry and storage facilities are included; this has the effect of both reducing the overall size of apartments, and consequently materials and labour, as well as ensuring long-lasting industrial quality equipment is preferred over lower quality domestic appliances.

Early anxieties about the cost burden of delivering on both high-quality retrofit and passive house standards quickly fades as the cost savings from the significant reduction in the need for energy and water services is realised.

In the rural environment, where space is less of a constraint, all new properties are not only built to passive house standards, but, wherever possible and practical, include significant power generation. Collectively these combine to produce local micro-grids that make a major contribution to the relatively high energy demands typical of rural living, particularly in terms of transport.

Overall, from an operational perspective, these measures collectively deliver a progressively rapid reduction in the operational energy demands of Sweden's domestic energy stock, from current levels of ~85TWh, towards a little more than 30TWh. This is primarily from a reduction in heating demand, but also from far more efficient and judicious use of appliances.

***Fairness*:** Key to all legislation is a focus on fairness. One core element of this is that the retrofit programme prioritises those poorer households already struggling to meet existing energy costs. Moreover, the legislative structure driving the retrofits ensures that lower income households can afford any installation costs that are passed on to them, and that the quality of work undertaken on their properties is the same as for households with higher incomes. The second key element, that initially caused some consternation amongst wealthier citizens, was that all new dwellings are limited to a maximum size of 150m2. The primary reasons for this is to reduce the demand for material resources, labour and land. This is achieved both by the size constraint itself, but also indirectly by reducing the need to furnish and equip much larger properties. The choice of size constraint was the subject of a lot of debate, with many arguing it should be much lower, and others that there should be no such limit. In the end, 150m2 was chosen as an adequate compromise, able to house a large family yet also providing a very clear social signal that "we are all in this together" – an ethos universally judged essential to maintain social cohesion during the relatively long disruptive process of decarbonisation.

4.3 Surface passenger transport

Infrastructure: The central ethos guiding the decarbonisation of surface transport is the shift to "moving people" and away from "moving vehicles". Within towns and cities a sea change in planning and legislation has delivered a frequent and affordable public transport network, with a high level of integration between different modes. Alongside this, active travel is now a key and completely normalised means of covering distances up to 15km. Initially there was some reticence to embed active travel within local and regional travel strategies. However, through various packages of support for e-bikes and other forms of assisted cycling (owned and rented), opposition rapidly dwindled. Urban planning has required all new apartments and houses to be located near to essential services and amenities. Car parking space is limited to occasional loading and unloading, with many urban roads now, at least in part, repurposed through programmes of 'urban greening', street markets and cafes. Previous concerns about the dangers of cycling and walking are a thing of the past, and with clean and frequent buses, trams and local trains, urban car travel is all but eliminated. The exceptions to this are the loading of rented EVs in preparation for longer trips and small urban EV taxis for those whom active and public transport are not viable. What were initially intangible economic benefits have become increasingly evident, with lots of citizens who previously spent many 1000s SEK annually on private car travel (with proceeds going to distant car and oil companies), now spending their money within the local economy.

For longer travel between urban centres, reliable and relatively quick trains and buses have become the mode of choice, driven by price, convenience and increasingly lower journey times. A moratorium on new roads and road widening schemes, and preferential lanes and priorities for buses, has further catalysed a change from the twentieth century mindset of 'car is king'. Today cars are primarily rented EVs for longer distance trips with the family or friends; either picked up from rental hubs on the outskirts of cities, or, for an extra fee, delivered to your home for pre-trip loading. Despite their being access to EVs, the majority of medium and longer length journeys within Sweden are made by trains and buses, with ticketing structures designed to make family travel by public transport more affordable than travelling by car.

Within the rural regions of Sweden a somewhat different model has emerged. Here buses and efficient small EVs (or biogas cars) are the key transport modes, though the appeal of e-bikes has increased to a level where they are now a common site even away from the cities. As with the cities, many fewer households own a car, instead rental schemes and taxis have become the new norm, helped by the return of E-van deliveries of food and other essentials. All that said, in more remote rural areas private EVs (sometimes in carpools) are more common, though legislation has reversed the previous trend from ever-larger cars to much more appropriately sized EVs, charged for much of the year from local solar generation and micro-grids.

Technology: Petrol and diesel fuelled cars are being rapidly phased out; new sales of such cars were banned from 2025. The weight and size of new EVs is tightly regulated, with no more high-energy consuming SUVs, other than strictly controlled exceptions for work and farm vehicles. The supply of petrol and diesel is all but phased out by 2030 (with limited biofuel available after then), driven by a mix of legislation and a growing second-hand EV market. In the mid 2020s, with the growing recognition that car travel really is not appropriate within urban areas, there was a shift from installing evermore charging facilities in cities to EV rental hubs on the outskirts. In contrast, the rural areas saw an increase in charging facilities, including within some homes, particularly those with domestic power generation.

With the rapid rise in the popularity of E-bikes, so they have evolved into numerous forms, some even with three wheels. Bus technology is mixed, with electric vehicles being typical in the cities and larger towns, but in suburban and rural areas biogas vehicles are also common.

A big 'technology' advance in public transport has been the ease with which multi-mode journeys can be organised and tickets bought. Add to this, that it is now easy to reliably track the progress of all buses and trains, with alternatives provided in case of delays, etc. Moreover, changes in plans are also accommodated, with much greater flexibility across the ticket options. In many respects the conscious and careful effort to make travelling by public transport so easy was key to reducing the inevitable backlash of relegating the private car to the ranks of an historical anomaly.

Fairness**:** The levels of car ownership and distances travelled had previously been higher amongst higher socio-economic groups, with almost one fifth of households not owning a car. The wholesale shift from private car travel to various high-quality and reliable public transport modes has significantly increased fair access to travel. After a brief period in the early 2020s experimenting with rapid increases in inequality, Swedes had returned to the more typical Scandinavian model of relatively high levels of equality (with a low gini index). This 'fairness' ethos had been another key element in Sweden's new transport system. No longer was transport a means of companies and shareholders extracting profit, but rather the view of transport had changed to it becoming a service. This was central to the Government's popular 'fair fares' policy, whereby prices were affordable to all. The idea behind this, was that accessible and affordable transport supported a thriving society and economy. With many nations still battling to reconcile their competing, fragmented and costly transport systems, Sweden's integrated and clean public transport network has become a symbol of national pride.

With the virtual elimination of all combustion-powered vehicles in towns and cities, so the local air quality has improved. This is particularly relevant to those, typically poorer, citizens living beside previously busy roads. The wealth of evidence linking local air pollution with bronchial and asthmatic conditions was a real issue for children, with further evidence how such conditions impacted educational attainment. This indirect and almost hidden inequality embedded in the previous 'car is king' society is all but eliminated by the new transport model.

A final and important implication of Sweden's transport model, had been a notable reduction in the animosity toward the Government often felt in more rural areas of the country a long way from the capital and other big cities. Directly facilitating and funding local low-carbon travel in rural communities, alongside subsidised high-quality travel for longer journeys has helped foster a less fragmented nation. Allied with the economic merits of the shift away from 'second homes' and towards homes-away for home (B&Bs, small hotels, time-shared cottages, etc) within rural communities, the new twenty-first century transport system has also encouraged more staycations, further improving local economies, whilst at the same time as reducing emissions.

4.4 Industry and manufacturing

***Infrastructure*:** This sector, often held to be a cause of many of the climate and wider ecological problems, really has been a lynch pin to delivering a timely and sustainable response to the climate agenda. Through an ongoing and sometime fractious relationship between civil society, Government and industry, progressive and carefully crafted legislation has led to Swedish industries not only rapidly re-tooling but also successfully reconfiguring their role in society. Certainly, the profit motive is still there amongst some firms, but it is held in check. At the same time others have developed different business models more directly commensurate with progressive and sustainable decarbonisation agenda promoted by successive governments since the mid-2020s. The socio-technical transformation of much of Sweden's built environment and physical infrastructure is at a scale reminiscent of the post-War reconstruction under the Marshall Plan. Thankfully, many of the lessons learnt, retrospectively, from Sweden's the *Miljonprogrammet* have helped ensure that both retrofits and new physical infrastructure are more sympathetic of local geographies, socio-economics, cultural norms, etc. Where mistakes have been identified, there has been a process of rectifying them early on rather than just continuing regardless. This more dynamic and evolving vision of progress would not have fitted into the previous model of short-term economic optimisation. Recognising the merits of more tailored approaches, Government legislation has sort to favour Sweden's vibrant 'small and medium' (små och medelstora foretag) businesses as a key part of this re-energised and sustainable Sweden. Where scale is important, larger companies remain central to the economy, but here the legislative environment has contributed to an ethos guided more by partnership and stewardship than competition and short-term profit.

***Technology*:** The key technical change has been the rapid shift towards electrification and away from reliance on fossil fuels. This was relatively straightforward for manufacturing, but was much more of a challenge for steel and cement production. Nevertheless, both the sectors had made rapid strides away from fossil fuels by the late 2020s, and with government support are now demonstrating how the rich stream of carbon dioxide *process* emissions can be successfully captured and stored. Another notable transformation is what is actually being manufactured. The retooling and reskilling of the mid-2020s saw a surprisingly quick shift from producing one quarter of a million cars to a more mixed portfolio of vehicles, driven in large part by the burgeoning demand for active and public transport. Electric and bio-fuel buses, various small electric passenger vehicles, including diverse e-bike designs, small EVs to assist with accessibility, etc. There remains a market for conventional cars, though now electric and with a return to modest (more appropriate) horsepowers. Importantly, the move from private ownership to various rental schemes has increased significantly the typical use levels of cars, so far fewer cars need to be produced.

Two other critical areas of industrial change have been the programme of retrofits and rapid rollout of renewable electricity supply. The first of these has helped ensure high-skilled, high-quality and secure local employment, often through regionally-based *små och medelstora foretag*. To some degree, the same has been true of the renewables agenda, though with a clear split between domestic solar (installed locally) and the very large scale deployment of both onshore and offshore wind farms, which has tended to involve large national firms, though with some local ownership and oversight.

Fairness: The new industrial renaissance started in the 2020s had, from the outset, a strong thread of fairness and equity running through it. There was a clear understanding that if the decarbonisation agenda was to be successful it had to be an agenda for all. Consequently, in designing the programme of work, careful consideration had been given to the inclusion of local policy makers and citizens, providing at least some sense of local ownership rather than an imposed diktat from Stockholm. This inclusion had been key in transforming local industries, and had brought about a cultural shift in norms, rebalancing how society valued white-collar (typically skilled and manual) and blue-collar (often more office-based) employment. The decarbonisation agenda raised the profile and importance of crafts and skills, essential to the high-quality work characterising much of the agenda and which, in the 2010s and early 2020s, was increasingly being undervalued.

4.5 Electricity supply

Infrastructure: A much larger and fully decarbonised electricity sector is at heart of Sweden's zero fossil fuel future. In the early 2020s electricity met a little under one third of Sweden's final energy consumption. This is now rapidly rising and by the close of the 2030s will likely be over 75%, all of it zero carbon. In terms of the infrastructure demands there have been three are key that have seen considerable activity throughout the 2020s, and still continues today.

First of these was a major build programme of zero carbon supply options. Given the incredibly tight timeline for this, the key focus has been on rolling out wind power. It has become mature industry, offering relatively high capacity factors from reliable designs and able to generate electricity cheaper than most other modes. Initially there were discussions of expanding both hydro and nuclear, both low carbon and reliable options. However, both have very high upfront capital costs, long lead times and impose high labour requirements at a time when such labour is in short supply and high demand. In addition hydro brings with it a lot of localised siting and environmental issues, which, to a lesser extent, is also true of onshore wind farms. In addition to large scale supply, more distributed supply is being provided through the rapid rollout of domestic solar; such installation had become the new norm by the mid-2020s, and is now already making an important contribution to overall supply. A final key contributor to supply remains that from nuclear stations. It was decided in 2025 that no nuclear station would be decommissioned if it could continue to operate safely. Whether expansion of the existing fleet should be pursued remains an open and still contentious question. From a lifecycle approach it is certainly a low-carbon means of generation, but it clearly comes with major social and economic challenges, that repeated governments have failed to resolve or get sufficient agreement on. Nevertheless, new nuclear remains an possibility, though the ongoing fall in the cost of renewables, storage and demand management continues to work against its adoption.

The second element of infrastructure where there has been the significant expansion is in the high voltage transmission grid and the lower voltage distribution network. This has entailed substantial disruption and a change in some of the legislation on acceptable operation conditions and loads. By 2040 electricity looks set to provide around 200TWh, all of which needs to be supplied reliably to a breadth of industrial, commercial and domestic customers. The final issue that took some time to resolve was the conversion to electricity of those sectors previously reliant on fossil fuels. This has not proved possible everywhere, and where challenges were not overcome, bioenergy has provided an alternative form of low carbon supply. However, given the huge demands on Sweden's land to provide materials for bio-refineries, plastics, pharmaceuticals, etc., as well as for building material, there remains, post-decarbonisation, pressure to move away from using biomaterial for energy production.

Technology**:** This has and continues to prove relatively straightforward as the key low/zero-carbon generating technologies Sweden is rolling out are already tried and tested, i.e. wind turbines and solar panels. Even the large offshore wind farms now operating in the Baltic are of an existing mature design. Certainly, there is room for improvement, the capacity of offshore designs continues to rise (now reaching 16MW) and programmed maintenance offshore is not easy. But reliable and affordable supply is now the norm from Sweden's wind farms, and is set to grow significantly throughout the 2030s There is also a nice symmetry with Sweden returning to HVDC to bring the power ashore, a technology pioneered in Sweden back in the 1930s. The one area where technology remains dynamic is the balance between storage and demand management. However, as more of societies energy demands have been electrified, so the scope for demand management has increased. Despite this, both of these means of system-management (i.e. supply and demand) remain areas where further change is likely in the coming years (with hydrogen produced during periods of surplus electricity looking promising).

Fairness**:** With Sweden becoming almost self-sufficient in energy supply, so energy price spikes such as those following Putin's 2022 invasion of Ukraine and the 1970s and 80s 'oil price shocks' are things of the past. Energy supply is affordable to all, with the bands of rising tariffs as more energy is consumed (introduced in 2027) both helping control demand and maintaining stable prices for most customers. Where major sites of generation impact local communities, so there is some degree of control by and financial return to those communities. This mechanism, introduced by the progressive Government of 2025, has proved particularly popular in many rural communities, where a significant proportion of Sweden's electricity is generated.

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[1] Including Sweden's official bunker data and adding this to CO2-only values from the Global Cardon Atlas. This estimate is for the 30 years from and including 1990; a typical starting year for comparing national emissions data. The latest year in this estimate is 2019, with 2020 and 2021 not included as the data suggest these are anomalous (following Covid).

[2] Eg. UNEP 2022, both in the foreword and main body of the report. https://www.unep.org/resources/emissions-gap-report-2022

[3] Given the tight timeline for 2°C and, even more so, 1.5°C, the emissions from any increase in the use of bioenergy must not, at least theoretically, see a rise in emissions over the period between now and 2050 (i.e. by when 2°C is likely to be reached). However, burning biomass guarantees emissions of carbon dioxide at the moment of combustion, whereas planting new trees or other bioenergy crops, does not guarantee an uptake of CO2. The risk that such planting will fail to take up the requisite quantity of CO2 increases with time. Consequently, any prudent use of bioenergy should really see emissions from combustion being captured within just a year or two of that combustion. Even then, perhaps a multiplication factor should be included to help address escalating risks with increasing time from combustion.