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Spaceport Operator Carbon Impact – A Life Cycle Analysis

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Contents

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Acronyms & Abbreviations

CG	Cosmic Girl
CIoS	Cornwall and the Isles of Scilly
CO_2e	CO_2 equivalents
GHG	greenhouse gas
GWP	global warming potential
L1	LauncherOne
LCA	life cycle assessment
nm	nautical miles
RF	radiative forcing
RFI	radiative forcing index
RP-1	Rocket Propellant-1
t CO_2e	tonnes of CO_2 equivalent

1. Executive summary

This report provides a holistic assessment of the life cycle greenhouse gas (GHG) emissions from planned launches and ancillary activities associated with launch missions at the proposed Spaceport Cornwall between 2022 and 2027, using an attributional life cycle assessment (LCA) methodology. The radiative forcing (RF) effects due to emissions at high altitude are also quantified given their importance in climate impacts of aviation activities and space missions.

Annual total life cycle GHG emissions of Spaceport Cornwall were estimated to grow from 1,250 t CO_2e in 2022 to 1,559-1,563 t CO_2e between 2023 and 2027 when RF effects of emissions at high altitude are excluded. When RF effects are considered, annual total life cycle GHG emissions increase by 73% and would grow from 2,164 t CO_2e in 2022 to 2,700-2,705 t CO_2e between 2023 and 2027. These emissions are 30-56% higher for 2022 than those in a previous assessment as a more comprehensive range of activities, indirect emissions and a reasonable probability of launch failure are considered in order to have a more complete understanding of the emissions. However, they are 16-36% lower for 2027 as the number of launches per year remains at 2 during 2023 and 2027 while this number rises gradually to 8 by 2027 in the previous assessment.

When RF effects are excluded, annual life cycle emissions associated with launches at Spaceport Cornwall would be between 0.033% (year 2022) and 0.041% (year 2023 onwards) of total territorial GHG emissions for Cornwall and the Isles of Scilly (CIoS) in 2019. When RF effects are considered, annual life cycle emissions associated with launches at Spaceport Cornwall would be between 0.057% (year 2022) and 0.071% (year 2023 onwards) of total territorial GHG emissions for CIoS in 2019. These percentages would be higher when total CIoS GHG emissions reduce in the future. However, caution is needed when interpreting these percentages as the 2019 CIoS emissions available were calculated using territorial based accounting methods that did not capture the full life cycle emissions. The actual scale of Spaceport Cornwall life cycle emissions as a percentage of total CIoS life cycle emissions in 2017 could potentially be 2.3 times lower at 0.014-0.018% without RF effects and 0.025-0.031% with RF effects.

It should be noted that results including RF effects are highly uncertain as the science base for the RF effects of emissions at high altitude still needs to be improved. Further research is also needed to evaluate the net GHG emissions of planned launches at Spaceport Cornwall from a consequential LCA perspective and to identify ways to reduce the emissions based on findings from this assessment.

2. Introduction

A horizontal launch spaceport at Cornwall Airport Newquay has been proposed and is currently under development. This would become the world's first horizontal launch capability where small satellite launch and aviation passenger services are fully integrated. It is expected to bring a wide range of benefits to Cornwall, including, for example, jobs and economic growth. However, these benefits will need to be weighed against potential environmental costs. One of the key environmental costs is the contribution towards anthropogenic (human impacts) climate change given the greenhouse gas (GHG)-intensive nature of space launches. In light of the continuing global drive to address climate change and the recent declaration of a climate change emergency by the UK government and Cornwall Council, it is crucial to have a clear understanding of the GHG footprint of the proposed Spaceport Cornwall activity. This could help identify ways to reduce the climate impact of Spaceport Cornwall in the future.

This report was commissioned by Spaceport Cornwall and aims to perform a holistic assessment of the GHG emissions of planned launches from the proposed Spaceport Cornwall between 2022, when the first launch mission is expected, and 2027, after which the number of annual launch missions is expected to stay the same. In particular, a previous GHG assessment of Spaceport Cornwall [1] will be updated to cover a more comprehensive coverage of emissions from ancillary and upstream supply chain activities. The next section will explain the method and data used to estimate the GHG footprint. Section 4 presents and discusses the results and finally Section 5 draws conclusions.

3. Method and Data

The main components of the horizontal launch technology developed by Virgin Orbit include the carrier aircraft, Cosmic Girl, a modified Boeing 747-400 (41R) passenger aircraft manufactured in 2001 now in freighter configuration and no internal fittings, and a two-stage rocket LauncherOne to provide Low Earth Orbit deployment service for small satellites. Both direct and indirect GHG emissions from the launches and ancillary activities associated with launch missions will be calculated annually. The attributional life cycle assessment (LCA) methodology [2] is used to provide a comprehensive coverage of all upstream processes related to the launches and ancillary activities. LCA is an internationally standardised method to quantify the environmental impacts over the entire life cycle of a product system or activity and has been widely applied in many sectors such as energy, water, food, raw materials and waste. The LCA software SimaPro (version 9.3.0.3) and the Life Cycle Impact Assessment method ReCiPe 2016 are used to calculate the emissions, with all relevant GHGs such as CO_2, CH_4 and N_2O covered and converted into CO_2 equivalents (CO_2e) based on their global warming potential (GWP).

The system boundary for the LCA model is shown in Figure 1. Although abortive launch missions and launch failures are expected to be minimal for horizontal launches, an increase of 5%, the overall failure rate of space launches between 2000 and 2019 [3], is applied to the GHG emission results in order to account for a reasonable probability of launch failure and abortive missions. General test programme and transport in the US that are not directly linked to launches in the UK are excluded. Rocket retrieval is also excluded as the second stage will burn up in the atmosphere upon re-entry following payload deployment while the first stage will fall within a designated hazard area in the North Atlantic Ocean with its retrieval depending on circumstances (such as weather, environmental cost and availability of assets to retrieve it). Fuel and electricity consumed in ground operations such as payload integration and rocket mating activities are covered in this assessment.

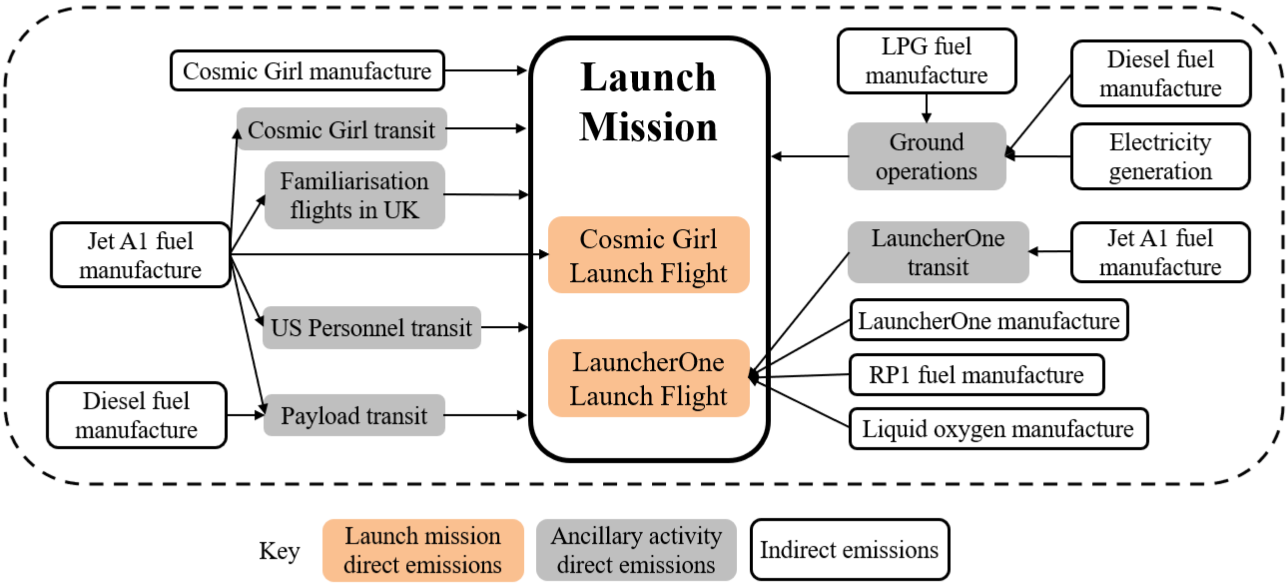

Figure 1. System boundary for the LCA model

The Ecoinvent life cycle inventory database (version 3.8) is used for the background datasets in the LCA. The following foreground data and information are used in the LCA model:

- The planned number of launches would be 1 in 2022 and 2 annually between 2023 and 2027.
- **Cosmic Girl mission Jet A1 fuel burn**: the range for Cosmic Girl per launch mission at 35,000 feet launch altitude is 800 nautical miles (nm) with an expected Jet A1 aviation fuel consumption of 34,927 kg;
- **LauncherOne RP-1 fuel burn**: the rocket used, the LauncherOne system, has an expected RP-1 rocket fuel consumption of 7,150 kg per launch;
- **Cosmic Girl transit**: round-trip transit distance for Cosmic Girl is assumed to be 11,000 miles between Long Beach, USA and Cornwall Airport Newquay. Launch missions will be programmed together to minimise transit flights, resulting in 1 round-trip transit per year;

- Jet A1 fuel consumption rate of Cosmic Girl (no payload) for the transit between Long Beach, USA and Cornwall Airport Newquay and familiarisation flights in the UK is estimated to be 11.6 kg/km based on information available in the technical specifications of Boeing 747-400ER with General Electric engines and a 240,310 L fuel capacity [4];
- **Cosmic Girl familiarisation flights**: UK familiarisation and training flight range is assumed to be 200 nm (two 100-nm flights) per launch programme;
- **LauncherOne transit**: each mission will involve an import of a US (Long Beach facility) manufactured rocket transported by air. Rocket import is a medium-term plan ahead of a long-term option of rocket manufacture in UK, which is not considered here. Rocket transit is assumed to be 5,500 miles from Long Beach to Cornwall Airport Newquay. The number of rockets transported in a given year equals the number of launches in that year. Rockets will be empty when transported and weigh 2.9 t each. The Ecoinvent dataset "Transport, freight, aircraft, long haul {GLO}| transport, freight, aircraft, dedicated freight, long haul" is used to model this process;
- **US personnel transit**: for each launch programme there will be 4-5 air crew that will fly with Cosmic Girl from US and a further 20 personnel, some of which will be UK based. It is assumed that 10 people will use commercial scheduled airlines to fly from Long Beach (LAX Los Angeles USA) to Cornwall. The Ecoinvent dataset "Transport, passenger aircraft, long haul {GLO}| transport, passenger aircraft, long haul" is used to model this process;
- **Payload transit**: LauncherOne has a total low Earth orbit payload capacity of 500 kg and a Sun-synchronous orbit payload capacity of 300 kg. The first launch in 2022 will have 6 payloads with a combined weight of ~300 kg, 4 from the UK (3 from Harwell, 1 from Cardiff), 1 from Poland and 1 from the US (Washington DC) with an assumed weight of 50 kg each. UK payloads will be transported by road and the Ecoinvent dataset "Transport, freight, light commercial vehicle {Europe without Switzerland}" is used to model this process. Payloads from Poland and the US will be transported by air and the Ecoinvent dataset "Transport, freight, aircraft, long haul {GLO}| transport, freight, aircraft, dedicated freight, long haul" is used to model this process. As the geographical distribution of future payloads is expected to be similar to the 2022 launch, the emissions from payload transit in future launches are assumed to be the same as those of the 2022 launch;
- **Fuel manufacture**: as RP-1 is a more refined version of Jet A1 fuel and is chemically very similar, the Ecoinvent dataset "Kerosene {Europe without Switzerland}| market for" is used to model the manufacture and delivery of both Jet A1 and RP-1;
- **Liquid oxygen manufacture**: 15,800 kg of liquid oxygen is estimated to be used as oxidiser by LauncherOne. Ecoinvent dataset "Oxygen, liquid {RER}| market for" is used to model the manufacture and delivery of liquid oxygen.

- **Cosmic Girl manufacture**: the manufacture of Cosmic Girl is modelled using the Ecoinvent dataset "Aircraft, passenger, long haul {GLO}| aircraft production, passenger aircraft, long haul". This dataset is modelled based on the production of an aircraft representative of the global aircraft fleet operating in 2016 and is linearly extrapolated to reflect the 160 t weight of Cosmic Girl. It is assumed that 0.00091 piece of Cosmic Girl is required for every launch mission based on a lifetime of 30 years for Boeing 747-400 aircraft and a 10-day use of Cosmic Girl per launch;
- **LauncherOne manufacture**: as there is no data available for the manufacture of LauncherOne and there is no dataset in Ecoinvent for rocket manufacture, the Ecoinvent dataset "Aircraft, passenger, long haul {GLO}| aircraft production, passenger aircraft, long haul" is also used to model the manufacture of LauncherOne. Again, this dataset is linearly extrapolated to reflect the 2.9 t empty mass of LauncherOne;
- **Ground operations**: this include the integration, rocket mating and aircraft servicing activities, with emissions incurred through stationary energy consumption by the related buildings and facilities as well as fuel consumption by ground support equipment and onsite transport vehicles.

In addition to direct emissions, radiative forcing (RF) effects due to emissions at high altitude have also been quantified. RF is the net change in the energy balance of the Earth system due to some imposed perturbation, usually expressed in watts per m^2 averaged over a particular period of time. It is effectively a measurement of the capacity of the emitted GHG, and/or other forcing agents, to affect the energy balance and thereby defines the contribution of the activity to climate change. The GWP methodology used to convert emissions of GHGs into CO_2e is based on the RF of GHGs relative to that of CO_2. More details of RF and GWP can be found in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [5].

It has long been recognised that emissions at high altitude in the stratosphere have higher RF (and hence GWP) than emissions at lower altitudes or ground level and therefore need to be appropriately accounted for given the expected increase in aviation and space launch activities [5–9]. However, there are significant uncertainties in the magnitude of these effects for different emissions such as CO_2, water vapour and black carbon soot at high altitude. In order to take into account this RF effect, different studies calculated the so-called radiative forcing index (RFI) factor that can be multiplied by the direct CO_2 emissions at high altitude (e.g., from aviation). The UK Government GHG Conversion Factors [10] applies a RFI factor of 1.9 for aviation CO_2 emissions, i.e., a 90% increase to the direct CO_2 emissions. A recent study [11] systematically reviewed the state of the art approaches to the accounting for RF effects of aircraft emissions and recommended a RFI factor of 2 for total direct aircraft CO_2 emissions or 5.2 for emissions in the higher atmosphere.

This report will adopt two different approaches. The first approach is to only account for the actual GHG emissions from the Spaceport activities excluding the RF effects at high altitude. The second approach is to apply a RFI factor of 2 to the total direct aircraft CO_2 emissions from Cosmic Girl transit and mission flights and the air transit of LauncherOne and US personnel (Jet A1) as the split between emissions at higher and lower atmosphere is unavailable and a RFI factor of 5.2 to the total direct CO_2 emissions from LauncherOne (RP-1) as they will only be at higher atmosphere. The RFI factor of 2 is not applied to direct aircraft CO_2 emissions from the Cosmic Girl UK familiarisation flights as these would be entirely in the lower atmosphere.

4. Results

The results for annual GHG emissions from different activities related to the space launches are presented in Tables 1 and 2. When using Approach 1 where RF effects at high altitude are excluded, annual total life cycle GHG emissions grow from 1,190 t CO_2e in 2022 to 1,485-1,489 t CO_2e between 2023 and 2027 as the number of launches increases from 1 to 2 (see Table 1).

Table 1. GHG emissions from different activities related to space launches at Spaceport Cornwall without the inclusion of RF effects of emissions at high altitude

Tonnes of CO_2 equivalent (t CO_2e)	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
Launch missions	1	2	2	2	2	2
Cosmic Girl mission Jet A1 fuel burn	109	218	218	218	218	218
LauncherOne mission RP-1 fuel burn	22	45	45	45	45	45
Total launch mission direct emissions	**131**	**262**	**262**	**262**	**262**	**262**
Cosmic Girl transit Jet A1 fuel burn	639	639	639	639	639	639
Cosmic Girl familiarisation flights Jet A1 fuel burn	13	27	27	27	27	27
LauncherOne transit Jet A1 fuel burn	15	29	29	29	29	29
US personnel transit Jet A1 fuel burn	15	15	15	15	15	15
Poland & US payload transit Jet A1 fuel burn	0.2	0.5	0.5	0.5	0.5	0.5
UK payload transit diesel fuel burn	0.1	0.2	0.2	0.2	0.2	0.2
Ground operations direct emissions	55	55	55	55	55	55
Total ancillary activity direct emissions	**737**	**765**	**765**	**765**	**765**	**765**
Production of Cosmic Girl	7	14	14	14	14	14
Production of LauncherOne	98	195	195	195	195	195
Production of Jet A1 fuel	124	145	145	145	145	145
Production of RP-1 fuel	3	7	7	7	7	7
Production of diesel fuel	0.02	0.03	0.03	0.03	0.03	0.03
Production of liquid oxygen	9	17	17	17	17	17
Production of fuel & electricity for ground operations	82	82	82	81	78	80
Total indirect emissions	**322**	**461**	**462**	**460**	**457**	**459**
Total life cycle GHG emissions	**1,190**	**1,489**	**1,489**	**1,488**	**1,485**	**1,487**

When using Approach 2 where RF effects are taken into account, annual total life cycle GHG emissions are 73% higher than without RF effects, growing from 2,061 t CO_2e in 2022 to 2,572-2,576 t CO_2e between 2023 and 2027 (see Table 2).

Table 2. GHG emissions from different activities related to space launches at Spaceport Cornwall with RF effects of emissions at high altitude

Tonnes of CO_2 equivalent with RF (t CO_2e)	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
Launch missions	1	2	2	2	2	2
Cosmic Girl mission Jet A1 fuel burn	218	435	435	435	435	435
LauncherOne mission RP-1 fuel burn	116	232	232	232	232	232
Total launch mission direct emissions	**334**	**667**	**667**	**667**	**667**	**667**
Cosmic Girl transit Jet A1 fuel burn	1,278	1,278	1,278	1,278	1,278	1,278
Cosmic Girl familiarisation flights Jet A1 fuel burn	13	27	27	27	27	27
LauncherOne transit Jet A1 fuel burn	29	58	58	58	58	58
US personnel transit Jet A1 fuel burn	29	29	29	29	29	29
US payload transit Jet A1 fuel burn	0.5	0.9	0.9	0.9	0.9	0.9
UK payload transit diesel fuel burn	0.1	0.2	0.2	0.2	0.2	0.2
Ground activities direct emissions	55	55	55	55	55	55
Total ancillary activity direct emissions	**1,405**	**1,448**	**1,448**	**1,448**	**1,448**	**1,448**
Production of Cosmic Girl	7	14	14	14	14	14
Production of LauncherOne	98	195	195	195	195	195
Production of Jet A1 fuel	124	145	145	145	145	145
Production of RP-1 fuel	3	7	7	7	7	7
Production of diesel fuel	0.02	0.03	0.03	0.03	0.03	0.03
Production of liquid oxygen	9	17	17	17	17	17
Production of fuel and electricity for ground operations	82	82	82	81	78	80
Total indirect emissions	**322**	**461**	**461**	**460**	**456**	**459**
Total life cycle GHG emissions	**2,061**	**2,576**	**2,576**	**2,575**	**2,572**	**2,574**

When a 5% launch failure/abort rate is considered, annual total life cycle GHG emissions of Spaceport Cornwall were estimated to grow from 1,250 t CO_2e in 2022 to 1,559-1,563 t CO_2e between 2023 and 2027 without RF effects and from 2,164 t CO_2e in 2022 to 2,700-2,705 t CO_2e between 2023 and 2027 with RF effects (see Table 3). To put these results into context, annual Spaceport Cornwall life cycle GHG emissions as a percentage of total territorial GHG emissions for Cornwall and the Isles of Scilly (CIoS) in the year 2019 (3,811,696 t CO_2e [12]) are also shown in Table 3. This percentage is between 0.033% (year 2022 – Approach 1) and 0.071% (year 2023-2027 – Approach 2). These percentages are expected to increase when total CIoS emissions reduce in the future. However, caution is needed when interpreting these percentages as the total CIoS emissions used were calculated using territorial based accounting methods that did not capture the full life cycle emissions. Emissions calculated using consumption-based accounting methods are more comparable to life cycle emissions but are difficult and time consuming to estimate. An earlier study shows that the consumption based GHG emissions for CIoS in the year 2008 was 11,353,196 t CO_2e [13], 2.25 times that of the territorial based estimate (5,035,230 t CO_2e [12]). Therefore, the actual scale of Spaceport Cornwall emissions as a percentage of total CIoS life cycle emissions could potentially be 2.25 times lower at 0.015-0.018% without RF effects and 0.025-0.031% with RF effects.

Table 3. Life cycle GHG emissions from horizontal launches at Spaceport Cornwall considering potential launch failure and abortive missions as percentages of total CIoS emissions in 2019

	2022	2023	2024	2025	2026	2027
Spaceport Cornwall life cycle GHG emissions considering a 5% probability for launch failure						
Without RF effect	1,250	1,563	1,563	1,562	1,559	1,561
With RF effect	2,164	2,705	2,705	2,704	2,700	2,703
Spaceport Cornwall emissions as a percentage of total CIoS territorial emissions in 2019						
Without RF effect	0.033%	0.041%	0.041%	0.041%	0.041%	0.041%
With RF effect	0.057%	0.071%	0.071%	0.071%	0.071%	0.071%

It should also be noted that there are uncertainties with the results and therefore they need to be interpreted carefully. The key uncertainty is the RF effects in Approach 2. This is an area that is still under extensive scientific research and lacks consensus. Although this report has adopted the most appropriate multiplication factors in the current literature [11], they could potentially change as the scientific understanding of the RF effects of emissions at high altitude advances. Some parameters such as the fuel consumption rates are supplied directly by Virgin Orbit or estimated based on the best available information such as rocket manufacture. These could potentially be refined in the future when actual operation data becomes available.

In addition, this assessment represents an attributional LCA perspective, which focuses on describing the environmentally relevant physical flows to and from a product system life cycle [2]. This perspective produces an estimate of how much of the global environmental burdens should be attributed to the product system studied and is most appropriate for evaluating an established product with relatively large environmental impacts. To estimate the net GHG emissions of Spaceport Cornwall, it is more appropriate to use the consequential LCA methodology, which evaluates how global environmental burdens will change in response to possible decisions [2]. However, this would require an estimate of not only emissions incurred by launch activities at Spaceport Cornwall but also emissions incurred in a business-as-usual scenario, where the same launch services would be provided by vertical launch facilities in countries like the US, India and Russia.

5. Conclusions

This report presents findings from a holistic assessment of the GHG footprint of planned launches from the proposed Spaceport Cornwall between 2022 and 2027, using an attributional life cycle assessment (LCA) methodology. Annual total life cycle GHG emissions were estimated to grow from 1,250 t CO_2e in 2022 to 1,559-1,563 t CO_2e between 2023 and 2027 when RF effects at high altitude are excluded. When RF effects are considered, annual total life cycle GHG emissions increase by 73% and would grow from 2,164 t CO_2e in 2022 to 2,700-2,705 t CO_2e between 2023 and 2027. These emissions are 30-56% higher for 2022 than those in a previous assessment [1] as a more comprehensive range of activities, indirect emissions and a reasonable probability of launch failure and abortive missions are considered in order to have a more complete understanding of the emissions. However, they are 16-36% lower for 2027 as the number of launches per year remains at 2 during 2023 and 2027 while this number rises gradually to 8 by 2027 in the previous assessment.

When RF effects are excluded, annual life cycle emissions associated with launches at Spaceport Cornwall would be between 0.033% (year 2022) and 0.041% (year 2023 onwards) of total territorial GHG emissions for CIoS in 2019. When RF effects are considered, annual life cycle emissions associated with launches at Spaceport Cornwall would be between 0.057% (year 2022) and 0.071% (year 2023 onwards) of total territorial GHG emissions for CIoS in 2019. However, caution is needed when interpreting these percentages as the 2019 CIoS emissions available were calculated using territorial based accounting methods that did not capture the full life cycle emissions. The actual scale of Spaceport Cornwall life cycle emissions as a percentage of total CIoS life cycle emissions in 2019 could potentially be 2.25 times lower at 0.015-0.018% without RF effects and 0.025-0.031% with RF effects.

It should be noted that results including RF effects are highly uncertain as the science base for the RF effects of emissions at high altitude still needs to be improved. Further research is also needed to evaluate the net GHG emissions of planned launches at Spaceport Cornwall from a consequential LCA perspective and to identify ways to reduce the emissions based on findings from this assessment.

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