Ski Tourism and Climate Change: The case study of Sogndal Ski Centre

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Master Thesis in Climate Change Management

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Høgskulen på Vestlandet

Western Norway University of Applied Sciences

Ski Tourism and Climate Change:
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Master thesis in Climate Change Management

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Any finally, to the terrible 2018/19 winter season, which made this thesis have a backbone and show why it is necessary to have a discussion on climate change within ski tourism in Sogndal.

Høgskulen på Vestlandet

Abstract

Ski tourism in Norway, a highly snow-dependent industry may be seriously affected by climate change. This thesis shows that Sogndal ski centre (Western Norway) will become a victim from climate change impacts whilst at the same time contributing to those impacts through releasing greenhouse gas emissions. A ski season simulation model SkiSim2.0 was applied to Sogndal ski centre alongside analysing the carbon inventory of their 2017/18 winter season. The model shows that climate impacts under a low emission scenario are negligible, with the ski centre still ensuring over a 100-day season until 2080. Under a high emission scenario, with warming towards 4˚C there is a severe reduction in ski season length with the ski centre hovering around the 100-day threshold towards 2080. The Christmas holidays will become particularly sensitive, and after the year 2050, the ski centre may become economically unsustainable. The carbon inventory analysis showed that customer commuting represents 62% of the total 232,889 kg/CO_2 emitted for the 2017/18 winter season. SkiSim2.0 model is very good illustration of changes in ski season length but is not reality, therefore the results should be seen as an indicator. The carbon inventory is limited due to the quantity and quality of the data but represents a building block to expand from. Sogndal, a ski centre that specialises in off-piste skiing cannot apply traditional adaptation techniques of snow production to increase season length. This thesis provides an attempt to recommend a preliminary climate change action plan for the ski centre. That uses the theory of sustainable development to introduce short- and long-term strategies that would reduce the carbon footprint of Sogndal ski centre to be in align with Norway's reduction targets of 40% by the year 2030. It also recommends that a climate change sector is established within the Alpinanleggenese Landsforening (ALF) helping to implement climate change action plans and emission reduction targets throughout all ski centres in Norway.

Samandrag på norsk

Skiturismen i Norge er svært snøavhengig, og kan bli kraftig påvirket av klimaendringer. Denne oppaven viser at alpinanlegget i Sogndal vil være blant ofrene for klimaendringer, samtidig som anlegget selv bidrar til disse endringene gjennom klimagassutslipp. Fremtidige skisesonger i Sogndal ble simulert ved hjelp av SkiSim2.0, samt at det ble utarbeidet en oversikt over anleggets klimagassutslipp i 2017/18-sesongen. Modellen viser at klimapådriv som i et lavutslippscenario har liten påvirkning. Anlegget vil fortsatt ha skisesonger på over 100 dager frem til 2080. I et scenario med høye utslipp, med oppvarming opp mot 4°C, vil sesongen bli drastisk redusert og variere rundt 100 dager frem til 2080. Juleferien vil være svært følsom, og fra 2050 og utover vil anleggets økonomiske levedyktighet bli påvirket. Oversikten over klimagassutslipp viser at besøkende star for 62 prosent av det totale utslippet på 232,889 kg karbondioksid i 2017/18. Modellen fra SkiSim2.0 gir et godt bilde av skisesongenes potensielle varighet, men er fortsatt en modell. Virkeligheten kan være annerledes, derfor må resultatene fra modellen anses som en indikator. Klimagassregnskap har også begrensninger grunnet både kvanttiet og kvalitet på datagrunnlaget. Det er likevel en grunnmur det kan bygges videre på. Sogndal, som er et skisenter som spesialiserer seg på off-piste, har ikke anledning til å benytte seg av tradisjonelle tilpasningsteknikker med snøproduksjon for å utvide sesongen. Denne oppgaven foreslår en foreløpig klimaplan for alpinanlegget. Planen bruker teorier fra bærekraftig utvikling som grunnlag for strategier på kort og lang sikt. Disse strategiene vil redusere anleggets utslipp slik at de er på linje med de nasjonale målene om 40% nedgang innen 2030. Oppgaven anbefaler også opprettelsen av et forbund for norske skisteder som kan bidra med å implementere klimaplaner og mål om utslippskutt for alle norske skianlegg.

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A. Introduction

Tourism is considered to be one of the largest global economic sectors but is still one of the least prepared for the impacts from climate change (Scott et al., 2012). This has led to the statement from (UNWTO, 2008) that “tourism contributes to global warming, and, at the same time, is a victim of climate change”. Today, contributing 8% of the global greenhouse gas emissions, tourism industry is projected to grow in the future (Lenzen et al., 2018). One of the first tourism sectors to be impacted from climate change is ski tourism. The winter seasons will be shortened with warming temperatures resulting in a reduced quantity of natural snow. Making ski areas who once had correct climatic conditions for snow, start to suffer from an increase in precipitation falling as rain. Supply side adaptations, such as artificial snow production, have been implemented to deal with this shortening of the ski season length. Thus allowing ski centres to open under unfavourable natural snow conditions to meet the 100-day ski season economic threshold set out by Abegg et al (2007). However, snow production is implemented greenhouse gas emissions can increase, (Aall et al., 2016) and have consequences on the surrounding environment and biodiversity, (Rixen et al., 2003). For ski centres that specialise in off-piste skiing like Sogndal ski centre, implementing these techniques is not possible, as the conditions needed for off-piste skiing can only be satisfied with natural snow. To reduce the consequences of a reduction in snow depth, ski centres should implement a climate action plan with the theory of sustainable development as a backbone; where climate change impacts are interlinked and a reliance on technology is seen to create larger problems into the future (WCED, 1987). This thesis will focus on ski tourism within Norway, a country where ski culture is deeply rooted and currently has over 7.5 million skier visits spread over 200 ski centres (Vanat, 2018).

During the last two years, it has been observed that Sogndal ski centre specialises in off-piste skiing and that a ski centre with this focus is particularly vulnerable by not having a climate change action plan.

This thesis looks into how Sogndal ski centre will become a victim of climate change impacts and to what extent the ski centre has a role in adding to these impacts through their greenhouse gas emissions. Two research topics will be investigated.

1. The change of ski season length by the year 2080 for Sogndal ski centre

While there have been two similar studies on what will be the reduction in ski season length in Norway and the necessary increase in snow production to compensate for the natural snow depth loss, Gildestad et al., 2017; Scott et al., 2019) Both did not address the issue that

Sogndal ski centre specialises in providing lift based off-piste skiing, failing to address this issue can result in the ski centre believing they are less sensitive to the impacts than they really are. This initial part of the thesis will provide the potential change in ski season length for the off-piste area and follow the same methodology as the literature using SkiSim2.0 model to predict the change in ski season length.

2. **Assessing Sogndal ski centres carbon footprint and strategies for reduction.**

This section aims to provide a carbon inventory of Sogndal ski centre's 2017/18 winter season and highlight the sectors that contribute the most. A comprehensive carbon assessment was beyond the scope of this thesis. The inventory was chosen for two reasons, first to provide an estimation of the baseline emissions that are incurred in a normal winter season. Secondly to provide a starting point to bring in a climate action plan with adaptation and mitigation strategies to reduce the volume of emissions released. The climate action plan will be associated with the theory of sustainable development.

1. Background

1.1. The development of ski tourism

Commercial ski tourism evolved into downhill skiing (Alpine) from the low technological cross country (Nordic) skiing which was developed from mountaineering techniques. The growth of skiing was dampened during the Second World War but after, ski tourism began to grow with the international ski tourism boom throughout the 1960's and 1970's. This led to many new ski areas being established and smaller areas started expanding to deal with the tourism boom (Hudson & Hudson, 2015). Ski lifts were technologically simple meaning a low entry barrier into the market. With significant economic growth at the time and more emphasis on leisure time together with snow abundant winters in both Europe and North America this led to a large increase in demand for alpine skiing (Steiger et al., 2017). Markets began to mature slowing the growth of the number of ski visitors and centres in the 1980's and 1990's with ski areas beginning to attract skiers from having a focus on comfort from new types of lifts (chairlifts, gondolas) and snow quality (grooming) and length of the season (snowmaking). Leading to increased competition between the ski areas. Operating costs started to increase with these investments along with the requirement of large capital investments, many small ski areas were forced to close. The snow deficient winters of the 80's and 90's led to snow making being introduced allowing resorts to produce snow and satisfy the increasing demand for better quality skiing from customers. The economic loss of low snow years can be crippling for ski resorts with large capital investment and more resorts started to evolve into four season destinations to support the investments and continue the attractiveness of the area for accommodation owners in the non-winter months (Steiger et al., 2017). To date ski tourism continues to play a large and important role in lifestyle, culture and economic benefits to different regions and countries with the participation over 350 million skier visits worldwide at over 2000 resorts. Traditional markets in North America and the Alps have matured but still secure a large dominance of distribution of skier visits and lifts available with resorts in the Alps sharing 43% of the market and North America at 21%. The dominance of major destinations which exceed 100,000 visitors per year is still apparent, with 20% of the resorts worldwide accounting for 80% of the skier visits worldwide. This can be linked to that resorts in the Alps being early adaptors to low snowfalls and investing heavily in artificial snow production allowing themselves guaranteed skiing from the start of the season, securing economic viability especially from international tourists (Vanat, 2018).

Japan experienced an abnormal boom that peaked in 1994, where it was common to wait in queues for over an hour for lifts during weekends or holidays. However, during this boom, a winter sports culture was not formed due to resorts not investing into accommodation areas resulting in mainly single day visits. Due to the large concentration of leisure skiers instead of tourism, this led to Japanese snow resorts experiencing a remarkable decline to date compared to all other matured markets (Macearth, 2015).

Only Japan within the area of Asia and the Pacific has experienced a declining market. China on the other hand, built 57 new ski areas in 2017 to satisfy their own ski tourism boom. The future trends within the market will be affected from the growth within the Asian and Eastern European markets which currently provide 35% of skiers worldwide, but currently only have 24% of the skier visits. With new lifts expanding or building new ski areas confirms that Eastern Europe and Asia will start to grow skier visits into the future decades. Where these skier visits choose to go will play an important part in which markets will experience growth or decline into the future. The vulnerability of ski tourism will play a large role in how the industry continues into future, leaving winners and losers between continents, countries and regions (Vanat, 2018).

1.2. Ski tourism within Norway

Alpine and cross-country skiing plays a fundamental role within the Norwegian lifestyle and more importantly continues the cultural heritage of Norwegians ‘’being born on skis’’. Throughout the middle-ages Scandinavian farmers, hunters and warriors regularly used skis as a form of transportation. This later developed into the roots of commercial ski tourism which began in the early twentieth century with cross country skiing (Nordic) as the precursor to commercial downhill ski tourism. The area of Telemark, Southern Norway revolutionised the ski shape and developed the first cambered skis, allowing them to become lighter and more flexible. In 1868, Sondre Norheim demonstrated the first Telemark ski and helped to popularize the benefits of a stiffer binding. Allowing himself and a small group of friends to develop dynamic turning which evolved skiing into the multi-disciplined sport it is today (Lund & Masia, n.d.).

The development of the Oslo to Bergen train line indirectly helped in establishing and facilitating the start of Norway’s first ski centre in Geilo, situated in the Hallingdal valley in 1935, documenting the start of modern ski tourism. With ski tourism demand growing, Geilo became the first ski centre in Norway to focus on comfort by introducing a chair lift and piste machine in 1954 and 1972 respectively (Norway, n.d.). To date there are over 200 ski centres in Norway with over 650 lifts (figure 1), ranging from local centres with one lift to international renowned all-season destinations including summer glacier skiing. Skier visits average around 6.9 million and has started to increase with the winter of 16/17 being the largest to date with over 7.5 million skier visits. Norway has an inbound market as 47% of visits are from international skiers (Vanat, 2018). The high participation of Norwegian skiers shows the importance economically and culturally for small, rural mountainous ski centres to exist (Scott et al., 2019).

Figure 1 - Location of alpine ski areas in Norway - (Scott, et al., 2019)

Nordic skiing is considered to be more popular due to the cultural history and skiers currently have access to over 30,000 km of trails with 2500 km of these being illuminated at nights, demonstrating the popularity of the sport (Vanat, 2018).

Even with a small population of over 5 million citizens, internationally Norway is recognised as the most dominant country ever within skiing competitions, especially the Winter Olympics. Where they have the largest medal count of 368 medals to date, and 132 of them are gold. With a large percentage of these medals coming from cross country skiing. Two Winter Olympics have taken place there, Oslo in 1942 and Lillehammer in 1994.

In general, tourism and travel within Norway in 2017 had a direct contribution in 2017 of NOK122.4bn, (3.7% of GDP) and is forecasted to rise by 2.2% pa and employed 172,000 jobs, 6.5% of the national employment. Leisure travel spending is 80.8% of the GDP contribution, with domestic spending at 70.1% within this sector (Council, 2018).

1.3. Climate Change within the Tourism industry

The recent publication from the International Panel on Climate Change (IPCC, 2018) 'special report on the impacts of global warming of 1.5 degree above pre-industrial levels…' illustrates the most up to date knowledge on current impacts from climate change across all sectors. It states that in 2017, human-induced warming reached approximately 1˚C above pre-industrial levels and is projected to increase by 0.2˚C per decade. Moving the world away from the relatively stable Holocene period, into a new unknown geological era known as the Anthropocene. The profound changes in human and natural systems, including increase in floods, droughts, sea level rise and loss of biodiversity losses from the temperature rise to date. Causing unprecedented risks and challenges, increasing the vulnerability of populations and global sectors (IPCC, 2018). The report by UNWTO (2008) United Nations shows that climate change will have an adverse effect on the global economy and have profound changes within the global tourism sector.

On the other hand, tourism is also a driver of climate change from directly producing 8% of the global greenhouse gas emissions with transport as the biggest contributor. With the rapid increase in tourism demand, the contribution to climate change from the tourism industry is projected to grow (Lenzen et al., 2018). Conflictingly, this increase in demand will also increase the impacts that the industry faces from climate change.

1.4. Climate Change within the Winter Tourism Industry

Scott et al. (2016) reviewed the IPCC Fifth Assessment report on the implications for the tourism sector. They highlight that ski tourism, a sector of nature-based tourism is one of three most at climate risk within the tourism sector. This is due to the high dependency on correct weather and climate conditions as skiing is dependent on snow. Snow is a very climate sensitive resource and will be negatively affected by the rising temperatures and changing precipitation patterns having an effect on the availability of this resource (Steiger, 2011)**.** The basis of this problem is that snow cover can respond rapidly to small changes in temperature due to the melt/freeze ratio of water being 0˚C. This means that ski tourism areas that once had stable snow relating conditions find themselves having periods of far more unstable ski conditions. These changes could lead to significant social and economic impacts through decreasing the viability and sustainability of winter tourism such as the ski industry. These effects increase the vulnerability of the ski destination to offer skiing as an activity and also the travel decision-making process of the tourists. Where weather and climate are key factors considered by tourists influencing travel planning; the destination choice and the timing of their travel (Scott et al., 2012).

Literature regarding ski tourism and climate change started to appear in the 1980's with climate impact assessments, and has now grown and diversified and has been thoroughly reviewed by Steiger et al., (2017). The impacts on ski tourism can be broken down into both supply and demand arguments. Supply side impacts are categorised as the assessment of climate change vulnerability at either ski regions or individual ski resorts. Giving the changes in snowfall, ski season length and economic revenues from the result of increased snowmaking requirements and costs (Dawson et al., 2011). With the introduction of SkiSim by Scott et al., (2003) a model that can simulate specific changes in opening days of ski resorts under future greenhouse gas (GHG) emission scenarios. Demonstrating an individual resort's response capacity through increasing snowmaking production to deal with natural snow depth loss, see North America – (Scott et al., 2003), Austria – (Steiger & Stötter, 2013) and Norway – (Gildestad et al., 2017, Scott et al., 2019).
It is also important to understand what the demand-side responses are to the known supply side assessment. For instance, what will be the changes in skier's behaviour with a reduction of opening days? Their own demand for skiing can either decrease or choose to ski at other destinations with more favourable conditions either regionally or globally (König 1998; Dawsen et al., 2011; Demiroglu et al., 2018).

The response capacity currently to deal with supply and demand side changes has been through the implementation of adaptation techniques. Focussing heavily on snowmaking (supply-side adaptation) as the best adaption technique and has been a focus of the majority of literature available. However, neglecting the problem of rebound effects that are attributed with the increase energy demand and GHG emissions from snowmaking (Aall et al., 2016). There is a potential for consumer adaptation of chasing for snow (demand side response), which leads to an increase in transportation emissions. This leading to the term mal-adaptation, where the benefits of the adaptation technique (snow making) are offset by the increase in GHG emissions (Aall et al., 2016). Resulting in a potentially greater impact from climate change onto ski areas, resulting in a stronger decline in snowfall from increased GHG emissions. Unless, challenged and changed this becomes a perpetual machine slowly increasing GHG emissions in the future.

Currently with a large percentage of ski areas and literature focussing on adaptation techniques there has been little focus on implementing mitigation techniques to reduce individual ski centres GHG emissions. Literature within Island tourism, where the threat from climate change is as strong as ski tourism has been more progressive with promoting synergies between adaptation and mitigation techniques (Becken, 2005).

1.5. Sustainable Development

The potential for ski resorts to bring in policies with the concept of sustainable development at the core instead of increasing economic growth is large. The term sustainable development was introduced by the Brundtland Commission in their report 'Our Common Future' in 1987 and encompasses environmental, social and economic issues (WCED, 1987). Today the definition is widely accepted as;

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- The concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and
- The idea of limitations imposed by the state of technology and social organisation on the environment's ability to meet the present and future needs", (WCED, 1987, p. Chapter 2).

Within the two key concepts, the first refers to social and economic aspects with the latter focussing on the environment. In giving priority to the environment by creating climate change policies in the sector of ski tourism it allows a synergy of adaptation and mitigations techniques to be implemented successfully. By stating that natural snow depth is the basic environmental need that meets the needs for ski tourism to operate. Then there can be a shift on policies to maintain the adequate depth of natural snow instead of focussing on purely producing artificial snow to fill the deficit. This concept should be more prioritised at ski centres that specialise in off-piste and tree skiing terrain, such as Sogndal ski centre where artificial snowmaking cannot be applied to an off-piste terrain.

The report by WCED (1987) elaborates further saying that, "The direction of technological developments may solve some immediate problems but lead to even greater ones." This is true with the expansion of the term environment to include areas such as natural water course and biodiversity. Snowmaking is a very water-intensive technology, In Davos ski area (Switzerland), the water consumed for snowmaking is around 600,000m^3 which represents 33% of the entire drinking water consumption of the Davos region (Jong, 2015). Further, when water is withdrawn from natural water bodies (rivers and lakes), lowering water levels at critical times of the year (Scott & McBoyle, 2006). Due to the high density of artificial snow, the melting period is extended by up to 2-3 weeks compared to natural snow, causing plant growth delay and biodiversity productivity minimised (Rixen et al., 2003).

By having sustainable development as a core principle and by looking at ski resorts from a systems perspective allows a different approach to show that ski centres operate within a whole system made up of different boundaries shown in figure 2.

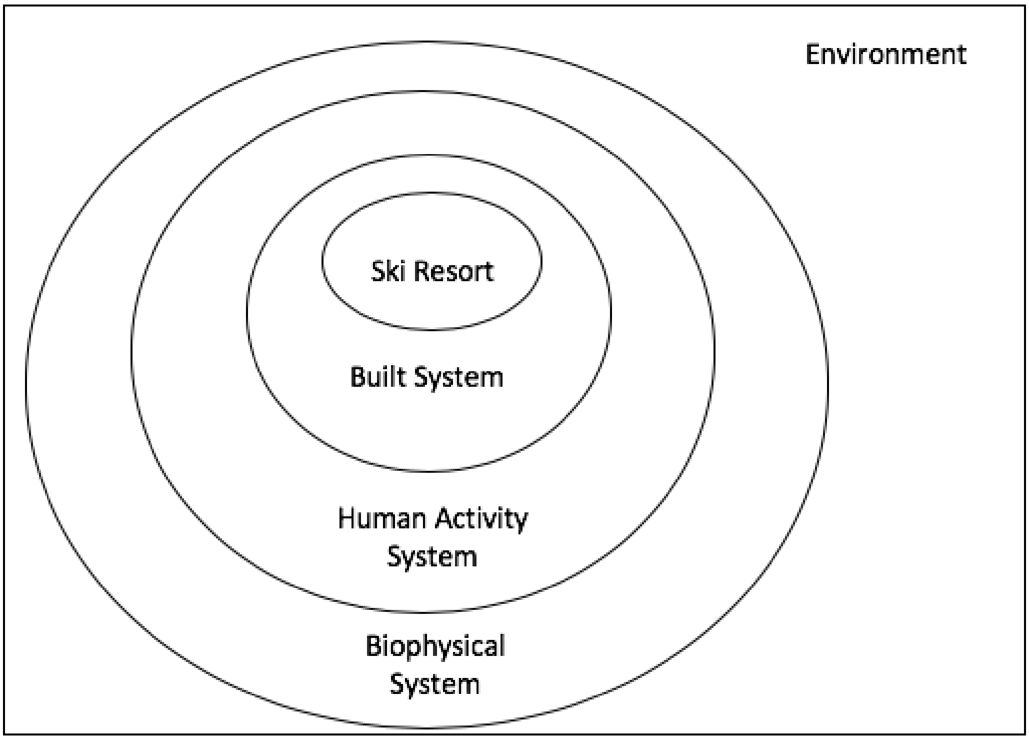

Figure 2 - Systems diagram - (Del Matto & Scott, 2009)

This system diagram shows in basic form how ski centres are a part of a complex set of biophysical and social systems, and to operate are reliable on them (Del Matto & Scott, 2009). Bringing in policies that have no adverse effects outside the system boundary that it was implemented in should be prioritised. The built system represents the physical infrastructure such as buildings and ski trails, highlighting that the materials come from the biophysical system and the waste produced leaks through all boundaries to the environment. Human activity system encloses the host community and guests and the main activity is through income generation. The biophysical provides the materials, energy and water for the inner systems and also contains flora and fauna. The environment is described as the resource area for temperature and precipitation (rain or snowfall) along with atmospheric gases (Del Matto & Scott, 2009). Changes in either one of these resources will have leaching effects through all of the systems with the greatest on the ski centre. Within this context, it becomes clearer that the most important system boundary is the environment, where the basics needs of the ski resort, snow is created. Thus, putting emphasis on maintaining a healthy environment that has the strongest influence on maintain a healthy ski resort.

One of the few ski resorts to focus on this perspective is Whistler ski resort located in Canada. Their comprehensive sustainability plan "Whistler 2020" which focussed on reducing their GHG emissions along with putting emphasis on the importance on maintain and protecting the natural environment around them (RMOW, 2007).

1.6. Off-piste skiing

The conditions needed for off-piste skiing are found and created within the environment sector and are highly sensitive to changes from either temperature, precipitation or atmospheric gases. Off-piste skiing typically requires a larger snow depth to cover natural terrain than resort ski trails (alpine skiing) with the most ideal conditions being powder snow.

The neglection of snowmaking within climate change risk assessment as illustrated by Scott et al., (2019), would communicate misinformation on the future of climate change risk at ski centres.

However, this cannot be fully applied to ski areas that specialise in lift based off-piste or tree skiing such as Sogndal ski centre as snowmaking cannot fulfil the deficit of natural snow within these areas. A consumer research study from the Ski Club of Great Britain (2016) showed that off-piste skiing represented 39% of the British market and where snowboarding represented 12%, off-piste snowboarding represented 6% of the participation numbersthis high participation shows that there is an increasing trend in skiers moving away from the conventional resort ski trails and are focussing on off-piste. Either ski resorts with lift-based access or moving into ski touring and splitboarding where no lift infrastructure is needed. (Scott, et al., 2019), mentioned that the popularity of skiing could decrease within Norway with decreasing natural snow depth. The study by Damm et al., (2014) showed that under future climatic conditions in Austria, there will be a decline in the ski areas seasonal visitor numbers of 22-64% has to be expected when taking into consideration only natural snowfall.

Therefore, suggesting ski areas that specialise in off-piste ski terrain can increase the number of opening days through snowmaking could be communicating misinformation to stakeholders and customers. For these individual areas, the main focus should be to show the change in opening days from declining natural snow under global warming scenarios as this best informs the changes that will be seen in the off-piste area. Allowing the ski area to communicate these effects and why it is important to implement reduction targets in place to lower GHG emissions to the lowest global warming scenario. Reducing the decline of natural snow and improving overall conditions for that resort. This is as especially important at Sogndal ski centre where such a large focus of their customers and marketing is for off-piste and tree skiing from the ski lifts but also the local area of Sogndal which specialises in providing ski touring terrain for everyone.

1.7. Research Questions

The aim of this master thesis is to assess the impacts from projected climate change on Sogndal ski centre, a small ski area situated in Western Norway. This thesis looks to answer the following two research questions:

1. What are the projected climate change impacts on the weather conditions needed for off-piste skiing at Sogndal ski centre to open by the year 2080?

2. How can the ski centre implement a climate action plan to reduce the climate change impacts?

2. Background and terminology

2.1. Greenhouse gases (GHG)

Greenhouse gases are found in the atmosphere, they absorb and emit wavelengths that are emitted by the earth's surface, creating the greenhouse effect leading to global warming. Water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the most common found greenhouse gases and all appear naturally in the atmosphere. The concentration of these gases is strongly affected by anthropogenic activity (Burkett, 2014). Throughout this thesis, concentration will be on carbon dioxide.

2.2. Representative Concentration Pathways (RCP)

Representative concentration pathways are used to highlight the range of possible climate scenarios. The four different scenarios are labelled as RCP2.6, RCP4.5, RCP6.0 and RCP8.5. They show the trajectories of GHG concentrations and climate forcing's and are labelled by their approximate radiative forcing (W/m^2) which can be reached during or towards the end of the 21st century. The different scenarios are based upon changes within socioeconomic pathways, human activities and GHG emissions (Burkett, 2014, p. 178).

Throughout this thesis, concentration will be on RCP4.5, 2˚C warming by 2100 (Paris Agreement) and RCP8.5, 4˚C+ warming by 2100 (Business as Usual).

2.3. Climate change within Norway

It is known that the northern hemisphere is projected to warm faster than the southern hemisphere (IPCC, 2013). Norway has observed a changing climate and will experience significant changes by the year 2100. The mean annual temperature, 1971 – 2000 has increased by 1.3˚C with largest increase in the spring and winter months Hanssen-Bauer, et al., (2017).

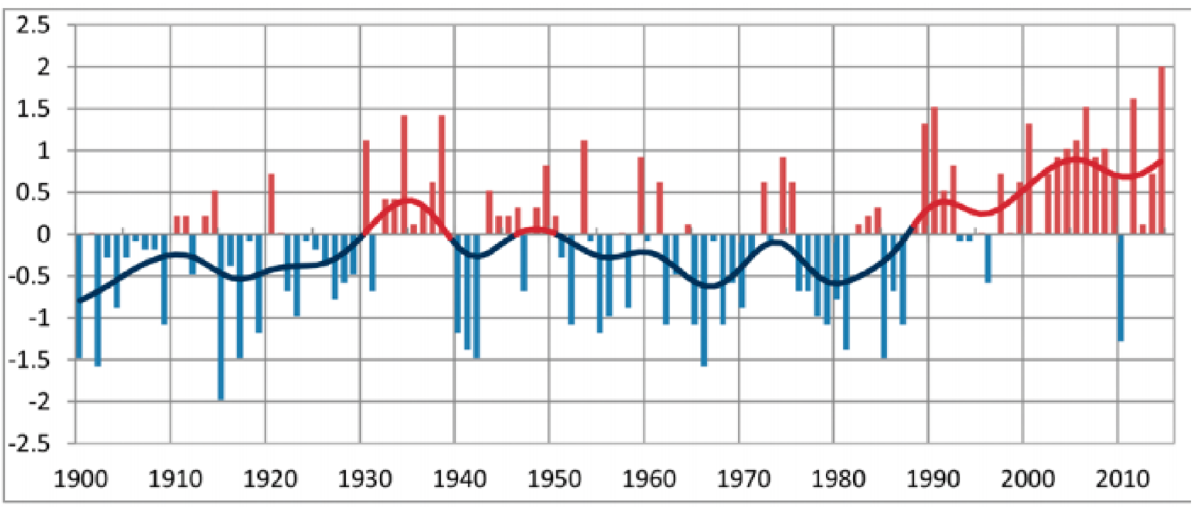

Figure 3 - Annual temperatures for mainland Norway - (Hanssen-Bauer, et al., 2017)

Under the highest RCP scenario (RCP 8.5) the following changes which are critical for the conditions for winter sports are estimated to be observed by the end of the century Hanssen-Bauer, et al., (2017).

- Annual temperature will increase by ca 4.5˚C (interval 3.3 to 6.4˚C)
- Annual precipitation will increase by ca 18% (interval 7 to 23%)
- Length of snow covers is projected to decrease all over the country.
- The number of glaciers will be reduced, the largest glaciers area and volume will be reduced by up to a 1/3

With the combined effects of increasing temperatures and precipitation an increased snow water equivalent (SWE) has been observed throughout Norway. A higher SWE indicates a melting snowpack and throughout Norway there is a general trend of later snow accumulation and an earlier snowmelt (Dryydal & Vikhamar-Schuler, 2009). With a reduction in area and length of glaciers, the ability of summer skiing will be affected and has already been observed at Galdhøppigen summer ski area. Where the glacier has retreated 8m resulting in the centre needing to move the lift structure further up the glacier to compensate (Johansen & Lusæter, 2019).

2.5. Climate change projections in Sogn og Fjordane

This section details the climate projections within Sogn og Fjordane (figure 4) for both temperature and precipitation to the year 2100.

Figure 4 - location of Sogn og Fjordane county area - (Losnegård, 2018)

2.5.1. Temperature

Figure 5 shows the future winter (Dec-Feb) temperature rise in Sogn og Fjordane under the two different RCP scenarios.

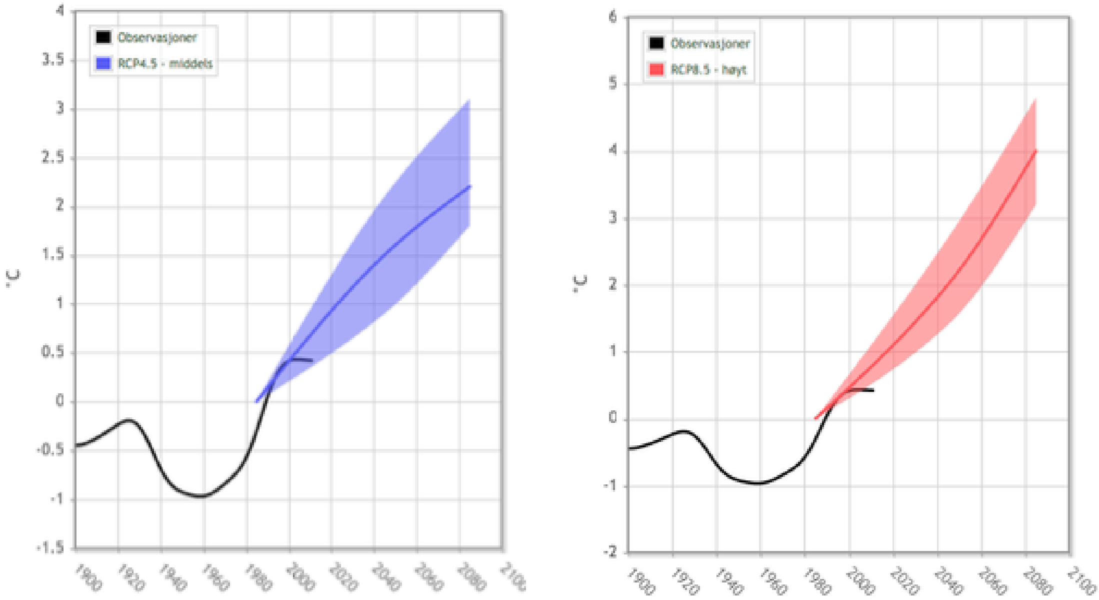

Figure 5 - Sogn of Fjordane temperature rise under two RCP scenarios - (KlimaserviceSenter, 2019)

The low emission scenario (RCP 4.5), shows that by 2030 the winter temperature has increased between 0.6˚C and 1.6˚C, increasing further by the year 2050 with between 1.0˚C and 2.3˚C and finally rising to 1.7˚C and 3.0˚C by 2080.

The high emission scenario (RCP 8.5), by the year 2030, there will have been a temperature increase between 1.0˚C and 1.8˚C, increasing further by the year 2050 with between 1.6˚C and 3.0˚C and rising to 3.0˚C and 4.5˚C by 2080.

2.5.2. Precipitation

Figure 6 shows the future changes in winter precipitation within Sogn og Fjordane under the two different RCP scenarios.

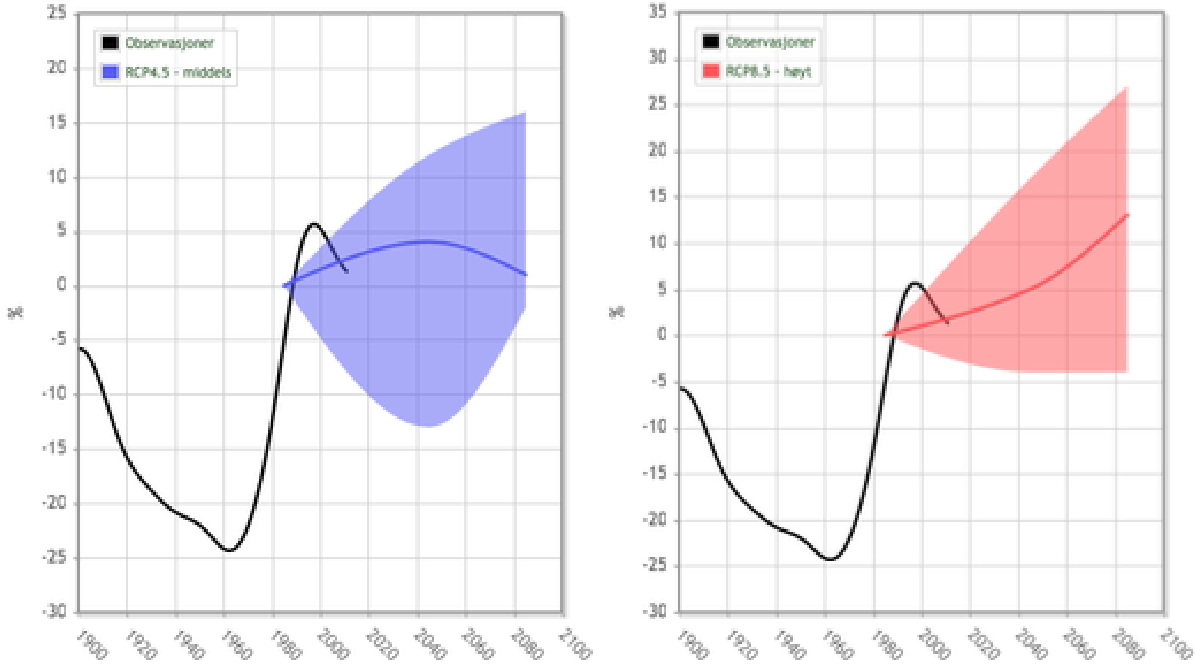

Figure 6 - Sogn of Fjordane precipitation changes under two RCP scenarios - (KlimaserviceSenter, 2019)

During the winter months there is expected to be both a decrease and increase of precipitation in individual years but with a general increasing projection to mid-century before decreasing. Low emission scenario highlights by the year 2030 precipitation patterns have changed within the range of -12% and 8%, by 2050 the difference in ranges widen more with -13% to 13% and reducing to -4% to 15% by 2080. Within the high emission scenario, precipitation has a more increasing linear trend line. 2030 will see changes ranging from -3% to 12%, by 2050 changes are between -4% and 17% and increasing further with 2080 seeing a range between -4% and 25%.

2.6. Natural snowfall sensitivity.

With the temperature increase for both emission scenarios there is a strong link to a shift of earlier snowmelt and declining snow accumulation. Where a change in snowpack dynamics being a consequence of the sensitivity of snow to temperature increase. Resulting in a decrease proportion of snowfall relative to rainfall, increasing the energy for snow melting. These changes will not just have impacts on snowpack accumulation but changes to the surrounding environment with the prospect of hydrologic changes to local rivers increasing ecological stress from reduced summer stream flows (Rood, et al., 2008).

3. Case study - Sogndal ski centre

I chose to use a case study so I could research the application of the two research questions in 'real-life events'. The focus was placed on Sogndal ski centre situated outside of Sogndal, (figure 7). Currently the ski centre has no carbon inventory, climate action plan or reduction goals, meaning this case is of great relevance. The case study research method is used in many situations where there is an interest in gaining knowledge from a specific individual, group, organisational, social and political related phenomena (Yin, 2014). It allows the researcher to focus on a case and acquire a comprehensive and real-world perspective and only represented by chosen variables.

Figure 7 - location of Sogndal ski centre

3.1. Background

Sogndal ski centre situated 15km into Sogndalsdalen was officially established in 1979 with the installation of their first ski lift, however skiing was recorded in this area from 1956 with frequent slalom races being held. After a few poor economic years, Sogndal Kommune (council) invested into the centre becoming the largest shareholder in 1999. The ski centre expanded further in 2014 with the addition of Rindabotn and Kalvavatni lifts opening up a new area specialising in off-piste and tree skiing. Currently providing skiers with the option of 5 lifts (2 children's lifts) and 6 groomed pistes, (figure 8). There has been a further expansion with the availability of nearby cabins to purchase for holiday homes with the sales from cabins directly financing the operations and future expansions of the ski centre. Alongside ticket sales, the centre has many sponsors from both local companies and international companies, example the Toyota Children's lift. Currently the centre employees 4 full time staff and approximately 20 part time/weekend staff throughout the winter. Skier visits were approximately 18,000 for 2018/19 winter and experiences a long winter season with a normal season opening from late November to early May, (private communication with Sogndal staff).

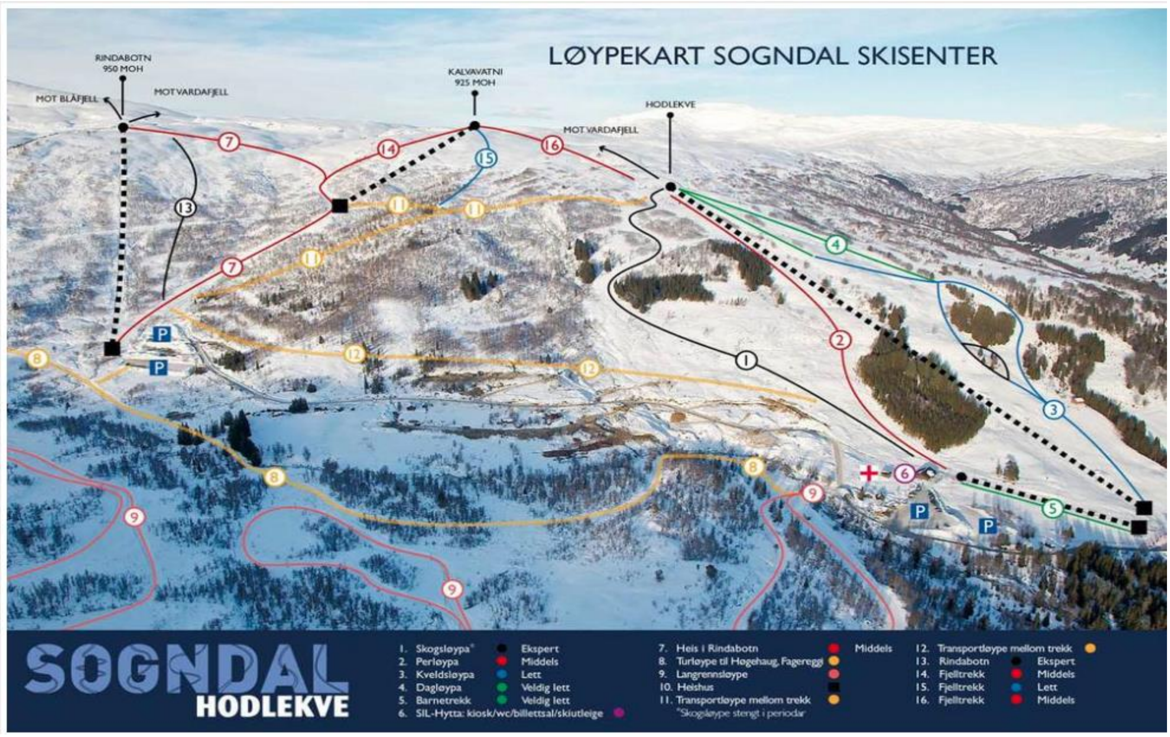

Figure 8 - Piste map - (Centre, 2019)

The ski centre is the closest to Sogndal, which has a local population of 8000 inhabitants, of which 3200 are students (Kommune, 2018).

The ski centre plays an important role within the community providing ski lessons for the local schools, holds several ski/snowboard competitions and has links to two local companies, SGN Skis and Furberg Snowboards who test their products at the centre. They also play an important role with one of Norway's largest winter festivals, Fjellsportfestivalen, held there every February since 2009. The terrain available from the lifts has received praise from national (Friflyt) and international magazines (Powder) for providing reliable world class tree skiing conditions. In 2019 Dalaloven (base building) located at the bottom of Rindabotn lift was opened giving an area for cantina, apres ski and ski shop for the customers. Alongside a workshop area for piste machines and snow-mobiles. Sogndal ski centre has expansion plans to install a new lift into higher elevated terrain, (private communication with Sogndal staff).

4. The impacts on ski season length at Sogndal ski centre from climate change.

4.1. Method - SkiSim2.0

Scott et al. (2003) developed the SkiSim model and it has been utilised to show climate change risk at individual ski centres globally. It has been used extensively in North American markets by (Scott et al., 2003), Austria (Steiger & Stötter, 2013) and in Norway by (Scott et al., 2019). For this study, the latest model Ski Sim 2 (Steiger & Stötter, 2013) was applied. From reading Scott et al., (2003) and Steiger (2010) more information regarding the methodologies and other details within the model can be found.

The climate data (daily temperature, precipitation and snowfall) were collected from the National meteorological service in Norway. Climate change scenarios were provided by The Norwegian Climate Service Centre, (Hanssen-Bauer et al., 2017) and are based upon the (IPCC, 2014) GHG emission pathways. These data projections are downscaled based upon the Euro-CORDEX regional climate model.

SkiSim2.0 models the results of the natural snow pack depth that is calibrated with observed daily snow depth measurements over a 30-year period (1981-2010) from the nearest weather station to Sogndal ski centre. The data is extrapolated to the most vulnerable altitude, for Sogndal this is the base station situated at the bottom of the lowest ski lift. With the parameters of 0.65˚C/100m and 3%/100m for precipitation. Meaning that every 100m increase in altitude the average temperature will decrease by 0.65˚C and the precipitation will increase by 3% every 100m increase in altitude.

Snowfall and degree-day factor are the two important parameters when calibrating the model with the weather station data. The upper and lower temperatures of when there is either 100% snowfall or 100% rainfall are defined and in between these two temperatures, the snow-rain is linearly interpolated. Snow depth is modelled through the degree-day factor which states the snow-water equivalent that has melted per 1˚C temperature change along with the accumulation of snowfall. Retuning the result of snow depth calculated from snowfall and snow melt (Scott et al., 2019).

Results are produced for the two different warming climate scenarios of RCP 4.5 and 8.5, across different 100m altitude bands over the desired time periods of 2030 (2021-2050), 2050 (2041-2070) and 2080 (2071-2100). The depth of natural snow available can be compared to the depth required to open Sogndal ski centre. When true, this provides a result of one opening day available and the total number of opening days available over the season, showing the ski season length.

A second output result is the probability of Sogndal ski centre being open during an economically important Christmas holiday period (2 weeks). It is defined as the percentage of years over a decade that skiing is possible on all days over the 2 weeks during a 30 -year period. If skiing is possible on all days through the Christmas period, the year is treated as 1 and if no days are possible it is treated as 0.

Arguably the most important aspect for a ski centre is to have 100-days of skiing (Abegg et al., 2007) with having 75% or more probability of being operational during the economically important Christmas-New Year holiday period for all winters (Scott et al., 2007). The use of SkiSim2.0 can provide an illustration of if this is possible in the future for Sogndal ski centre.

4.1.2. Previous research results of SkiSim2.0

There have been two research studies that have used SkiSim2.0 model as a methodology on the future ski season length for ski centres situated in Norway, (Gildestad et al., 2017; Scott et al., 2019). However, the model incorporates the ability of snowmaking to increase ski season length along with only needing 30cm of snow to provide sufficient snow depth for skiing. These results do not best represent the characteristics of Sogndal ski centre's ski season length in the future due to needing larger than 30cm of snow depth due to the topography of slopes and off-piste area and currently having no snow making infrastructure. Through private communication with Robert Steiger, SkiSim2.0 was ran again for Sogndal ski centre but with different input parameters. The natural snow depth needed was set to 60cm and the ability of snowmaking was turned off to give a more accurate result of the change in opening days in the off-piste area.

4.2. Generic model

As with every model, reality is simplified. SkiSim2.0 been designed with the ability to be applied to any ski resort chosen that has the correct weather data. The model gives a generic application of how weather systems work regarding altitude, longitude and height of where the ski resorts is based allowing it to be used in multiple different areas. And currently for Sogndal ski centre, cannot include how local factors can influence the surrounding area, ie the effect on the local climate from glaciers and the changes occurring from these melting. The following section provides different examples of different weather patterns that may influence weather patterns into the future that cannot be modelled.

4.2.1. Data

Temperature

Fjærland was chosen due to having the furthest back catalogue of temperature, (maximum, mean and minimum) and precipitation (snowfall and rain). Fjærland's weather is influenced by both Jostedals glacier and being situated at sea level, thus giving it a slightly different climate compared to where the ski centre is based, (figure 9). These small changes in temperature, may lead to deviations within the results of SkiSim2.0 that may return snowfall when there is actually rain falling in the ski centre.

Figure 9 - Locations of data collection and ski centre

The downscaling of data for the temperature and precipitation changes within regional areas from national models can lead to errors which may affect the final outcome of the model.

Precipitation

The distribution of rainfall and precipitation in Norway is directly influenced by the direction of the moving weather fronts because of the topography. It is exposed to weather systems from both the Atlantic Ocean and the Norwegian Sea along the west coast. The mountains near the coast force the warm maritime air upwards causing heavy rainfall in western Norway. The north Atlantic oscillation index has a major part in determining the weather patterns, a positive index brings in warm moist air across the Atlantic and is associated with winter floods, (Roald, 2008).

Figure 10 shows the different storm trajectories, determining the precipitation events over Norway. If these storm trajectories start to deviate or some become more dominant, this may have large scale effects on the precipitation events within Norway and Sogndal.

Figure 10 - Van Bebbers classification of storm trajectories in Europe - (Roald, 2008)

Summary

With the stated local variables that can lead to uncertainties within the SkiSim2.0 model to return values of season length. The model produces one variable for the chosen time period, however with these limitations it would be probable that the returned value would lie in-between a range of higher and lower values. The range of these values are not known and therefore the results should be taken as an illustration of what is the potential future.

4.3. Results – SkiSim2.0

Two main types of impacts are illustrated here, the projected ski season length and the Christmas indicator of two lifts situated at Sogndal ski centre for both emission scenarios.

4.3.1. Location of lifts at Sogndal ski centre.

As explained in chapter 3.1, the ski centre comprises of five ski lifts. However, within this thesis the results of the SkiSim2.0 will only be for Hodlekve and Rindabotn lifts, see figure 5 for reference.

4.3.2. Hodlekve lift

The average ski season length from the calibrated baseline period from SkiSim2.0 for the opening days at Hodlekve lift with a minimum of 60cm of natural snowfall is 157 days and is 11% higher than the actual opening days of winter 17/18 of 140 days.

RCP 4.5

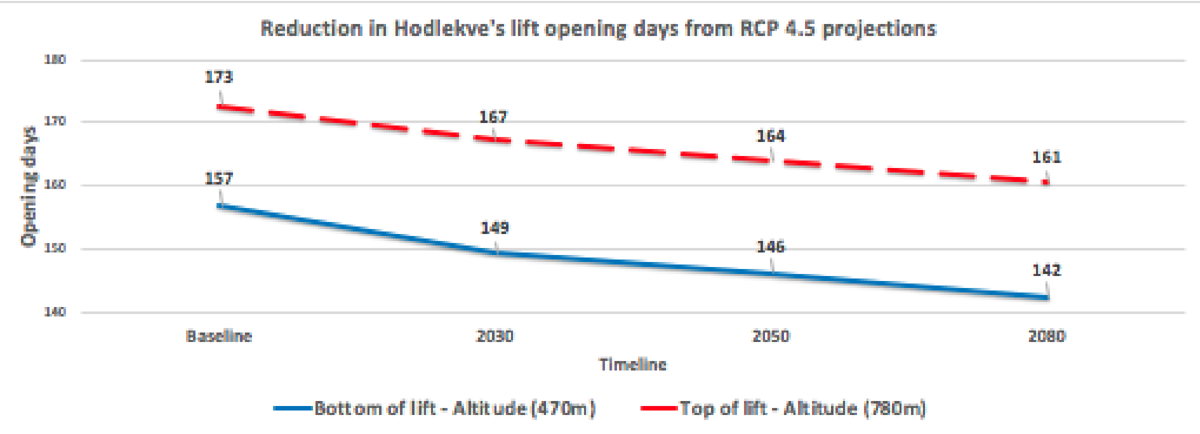

Figure 11 - SkiSim2.0 results - Hodlekve lift RCP 4.5 scenario

The change in opening days with a world warmed to RCP 4.5 are shown in the figure 11 It shows that by the year 2030, Hodlkeve lift will experience a reduction of 8 days at the bottom of the lift, whilst the top station will have a reduction of 6 days. The year 2050 follows a less steep gradient of decline, reducing the opening days of 3 at both top and bottom. From, 2050 to 2080, the bottom lift has a reduction of 4 days and reducing 3 days at the top station. Hodlekve lift experiences a faster reduction in opening days towards the year 2030 compared to the latter half of the century and this can be linked to a reduction and negative emissions.

By the year 2080, the percentage of Hodlekve lift having sufficient skiing conditions over the Christmas period is 77% for RCP 4.5, expecting closures in two or three years in every decade.

RCP 8.5

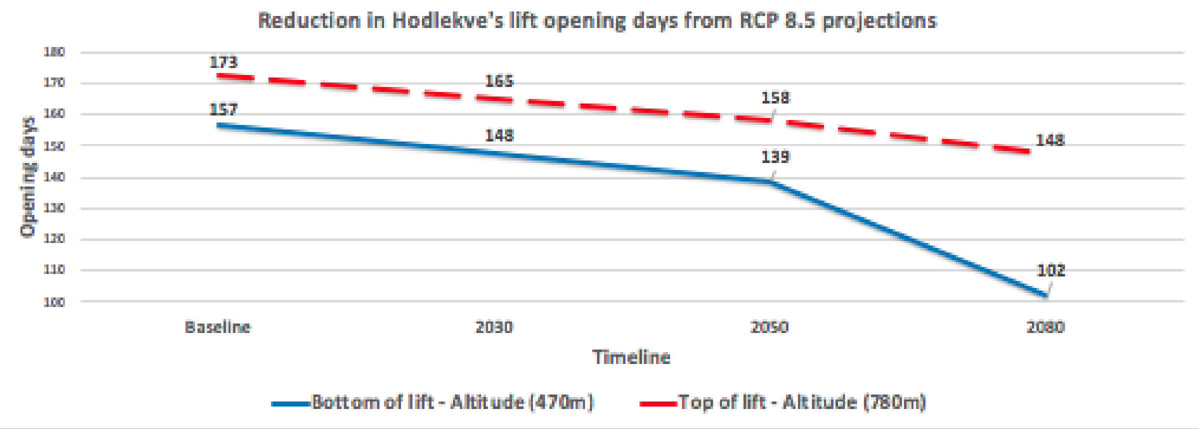

Figure 12 - SkiSim2.0 results - Hodlekve lift RCP 8.5 scenario

There is a dramatic change in opening days under the RCP 8.5 scenario (figure 12). By the year 2030, the difference in opening days compared to the baseline line at the bottom of the lift is 9 days, and a reduction of 8 days at the top of the lift. By the year 2050, both the top and bottom experience similar reduction, with 7 and 9 days respectively. Towards the year 2080, the gradient of the line steepens indicating an abrupt decline in opening days, resulting in the top of the lift experiencing 10 days and the bottom losing 31 days. This results in 1 lost day per year.

By the year 2080, the percentage of Hodlekve lift to have sufficient snow on all days over the Christmas period drops to 40%, expecting closures over the Christmas period to be more common than the lift being open.

4.3.3. Rindabotn lift

The average ski season length from the calibrated baseline period from SkiSim2.0 for the opening days at Rindabotn lift with a minimum of 60cm of natural snowfall is 162 days and is 5% higher than the actual opening days of winter 17/18 of 155 days.

RCP 4.5

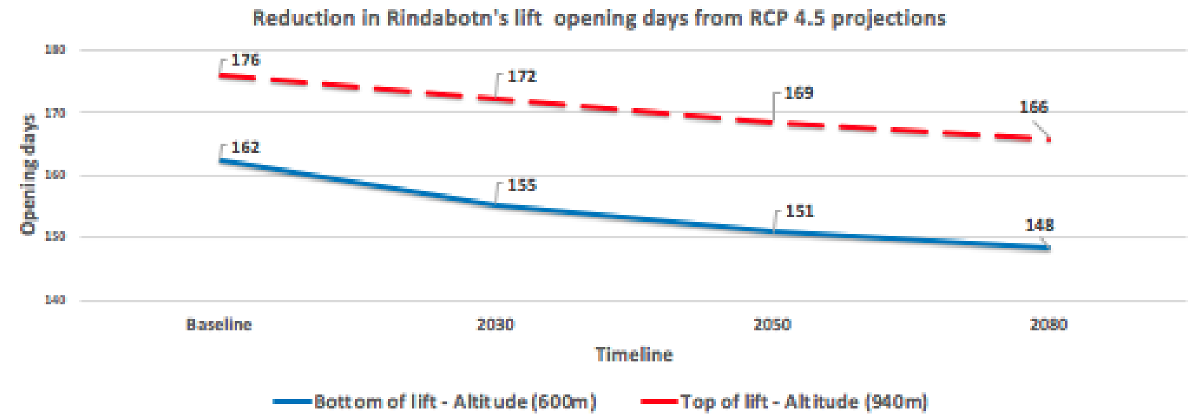

Figure 13 - SkiSim2.0 results - Rindabotn lift RCP 4.5 scenario

The change in opening days within a RCP 4.5 warming for Rindabotn lift are shown in figure 13. By the year 2030, the top of the lift will experience a reduction of 4 opening days, whilst the bottom will have a reduction of 7. The gradient of the line reduces to the year 2050, with both the top and bottom having a reduction of 3 and 4 respectively. Towards the year 2080, reduction slows down with the top and bottom both experiencing a reduction of 3 days.

By the year 2080, the percentage of Rindabotn lift to have sufficient snow on all days over the Christmas period drops to 87%, expecting 1 year being closed in every decade over the Christmas period.

RCP 8.5

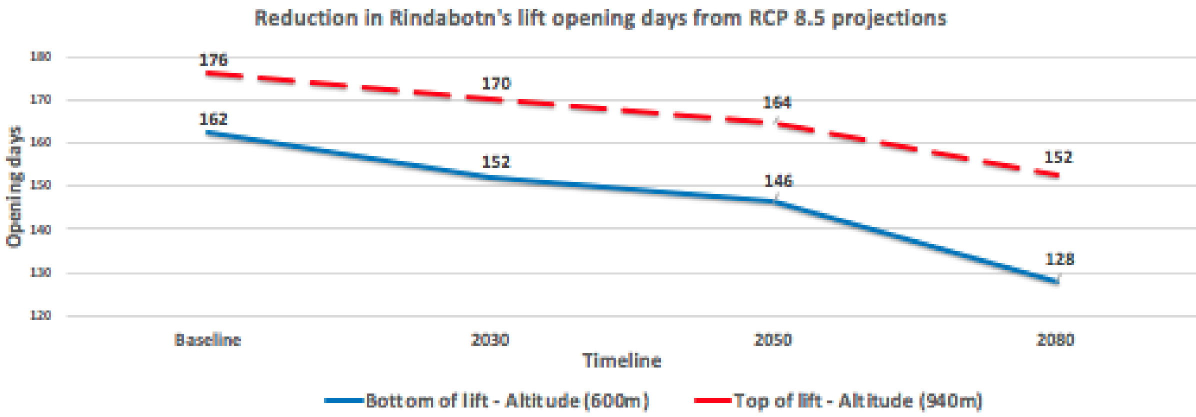

Figure 14 - SkiSim2.0 results - Rindabotn lift RCP 8.5 scenario

The change in opening days within a RCP 8.5 warming for Rindabotn lift are shown in figure 14.

Compared to the baseline, by the year 2030 the top of the lift will have a reduction of 6 opening days and the bottom having a reduction of 10. Both the top and bottom have a reduction of 6 days to the year 2050. The gradient of line becomes steeper towards the year 2080 for both lifts. The top will have a reduction of 12 days whilst the bottom has 18 days reduction.

By the year 2080, the percentage of Rindabotn lift to have sufficient snow on all days over the Christmas period drops to 57%, expecting under half of the years to be closed over a decade.

4.4. Discussion of the results

The following section summarises the changes in opening days for both lifts (table 1 and 2). This is presented for the most vulnerable altitude (bottom station), as correct snow conditions are needed here for the lift to be open.

Table 1 - Ski season length

		RCP 4.5			**RCP 8.5**		
Lift	**Baseline**	**2030**	**2050**	**2080**	**2030**	**2050**	**2080**
Hodlekve	157	149	146	142	148	139	102
		-5%	*-7%*	*-10%*	*-6%*	*-12%*	*-35%*
Rindabotn	162	155	151	148	152	146	128
		-4%	*-7%*	*-9%*	*-6%*	*-10%*	*-21%*

Under RCP 4.5 by the year 2080 there will be a 10% reduction in opening days for Hodlekve Lift and 9% for Rindabotn. RCP 8.5 shows a dramatic change for Hodlekve by 2080 with a loss of 35% opening days and Rindabotn experiencing a 21% change. The results also show that there is a big difference in opening days from climate change between the top and bottom of the lifts.

The results from the model show that each lift under the high emission scenario have over 100 days of potential opening days. This is a threshold that is often used as a rough indicator to show the profitability of the ski centre with snow reliability. By using this threshold, Hodlekve would be profitable by the year 2080 under both emission scenarios. The 100-day rule provides a general view but there is the possibility of the 100 days being situated from January to mid-April and not considering important economic periods such as the Christmas holidays.

Table 2 shows the probability of each day having enough snow for the lift to be open over the Christmas holidays.

Table 2 - Probability of Christmas period

		RCP 4.5			RCP 8.5		
Lift	**Baseline**	**2030**	**2050**	**2080**	**2030**	**2050**	**2080**
Hodlekve	1	0.9	0.87	0.77	0.87	0.77	0.4
Rindabotn	1	1	0.93	0.87	0.97	0.87	0.57

The reliability of the ski centre to be open over the Christmas period is severely reduced with RCP 8.5, which in aspect could be crucial for cabin sales and usage. Cabins that have been designed with ski in ski out with the use of Hodlekve lift would be affected by 2050 and onwards declining from every 2 years being closed per decade to every 6 by the year 2080. Rindabotn Christmas period drops below the economic threshold towards the year 2080 with an opening percentage of 57%.

The 100-day rule stated by Abegg et al., (2007) is just satisfied for the bottom of Hodlekve lift station under RCP 8.5 by year 2080 but does not satisfy the 75% Christmas period rule set by Scott et al., (2007). Sogndal ski centre may satisfy the 100-day rule but with a current long winter season approximately 140 days the loss of these days would reduce the reliable reputation and with projected decline in opening days over the Christmas period showing that there is a greater chance of ski season change at the start of the season. The results are similar to the projections of early snowmelt and declining snow accumulation stated by Hanssen-Bauer et al. (2017) in chapter 2.5.

On the other hand, alpine skiing at Sogndal ski centre may be more reliable in terms of opening days over the season as less snow is needed and their ability to push snow and groom slopes with piste machines. The ski centre may need to invest in snowmaking machines to satisfy the customer demand over Christmas period on low snow years and provide the necessary snow depth on Rindabotn lift for the access to lifts into higher terrain. The relatively small size of the ski centre may hinder the necessary investments in snowmaking technology and may lose revenue from customers that choose to ski at larger resorts where there is a larger capital resource to install and operate snowmaking. The ability of customers to change their travel plans of destination choice and the timing of their travel from changes in weather is still unknown and may result in customers becoming less loyal to that destination from consecutive bad snow years and choosing either to change destination or stop skiing and engage in a different sport, Demiroglu et al., (2018); Dawson et al., (2013). This may become more apparent when the reliability of Sogndal ski centre to be open over the Christmas period reduces, which may lead to skiers travelling abroad over this time period.

4.4.1. Comparison to other national ski centres.

The results show that the ski season length in Sogndal ski centre in a warming climate is not as badly affected compared to other ski centres either nationally or internationally. The report by Scott et all., (2019), who ran the SkiSim2.0 model for 110 alpine ski centres within Norway concluded that there is a wide regional difference for ski centres profitability in a warming climate. Even within Western Norway, they showed a decline of 34% (RCP 4.5) and 71% (RCP 8.5) in ski season length by the year 2080. Sogndal ski centre could be seen as a winner compared to other centres. But with such a large percentage of customers using the centre for the off-piste terrain where the centre might have 100 days of the ski season to open but unfavourable snow conditions (wet snow) for off-piste skiing could see a reduction of customers on days that are available for opening.

4.4.2. Comparison to international ski destinations

The findings from the SkiSim2.0 models show that Sogndal ski centre will have the correct length of season of over 100 days but will suffer over the Christmas holiday period with RCP 8.5 scenario. However, when comparing against other ski areas that have had SkiSim2.0 model simulations show a larger change in opening days and need a large increase in snowmaking to cope with this loss. Studies within Austria/Italy, Steiger & Stötter (2013), showed that ski areas in the Northern and Southern Tirol range will have a snow reliability percentage of 14% and 9% respectively by the year 2070 under high emission scenario. Whilst, Scott et al., (2017) show that the system capacity of ski resorts in Ontario Canada with high emission scenarios by mid-century will be severely disrupted with losses between 28% and 73% even with the ability of snowmaking.

However, with both the Alps and North America having large percentages of ski areas already have snowmaking technology implemented, they can have a faster demand side response to the projected changes.

The results from SkiSim2.0 are similar to the study by Damm et al., (2016) who analysed and modelled the impacts from a 2˚C temperature rise on natural snow depth and overnight stays in Europe. The report showed a decrease in ski season length from natural snow depth in Western Norway to be in a range of 40-50 days. They also highlighted the fact that natural snow depth has a direct response on the number of visitor’s stays, where a reduction in snow depth correlates to a reduction in visitor days for that region.

4.4.3. Comparison to 2018/19 winter

The winter of 2018/19 had one of the lowest snow years in the previous 20 years and could be said to show what is expected of snow conditions in the future. This low snowpack resulted in the ski centre having a significant reduction in season length for both lifts. Hodlekve lift having 92 days and Rindabotn lift having 95, both shy of the 100 days open threshold. Over the Christmas period, the ski centre was closed with the first lifts running from the 3rd of January. This year Christmas period and opening days are already lower than the projected changes under the RCP 8.5 by the year 2080. Compared to the previous winter season 17/18 having there has been a reduction of opening days of 48 for Hodlekve lift and 60 days for Rindabotn lift.

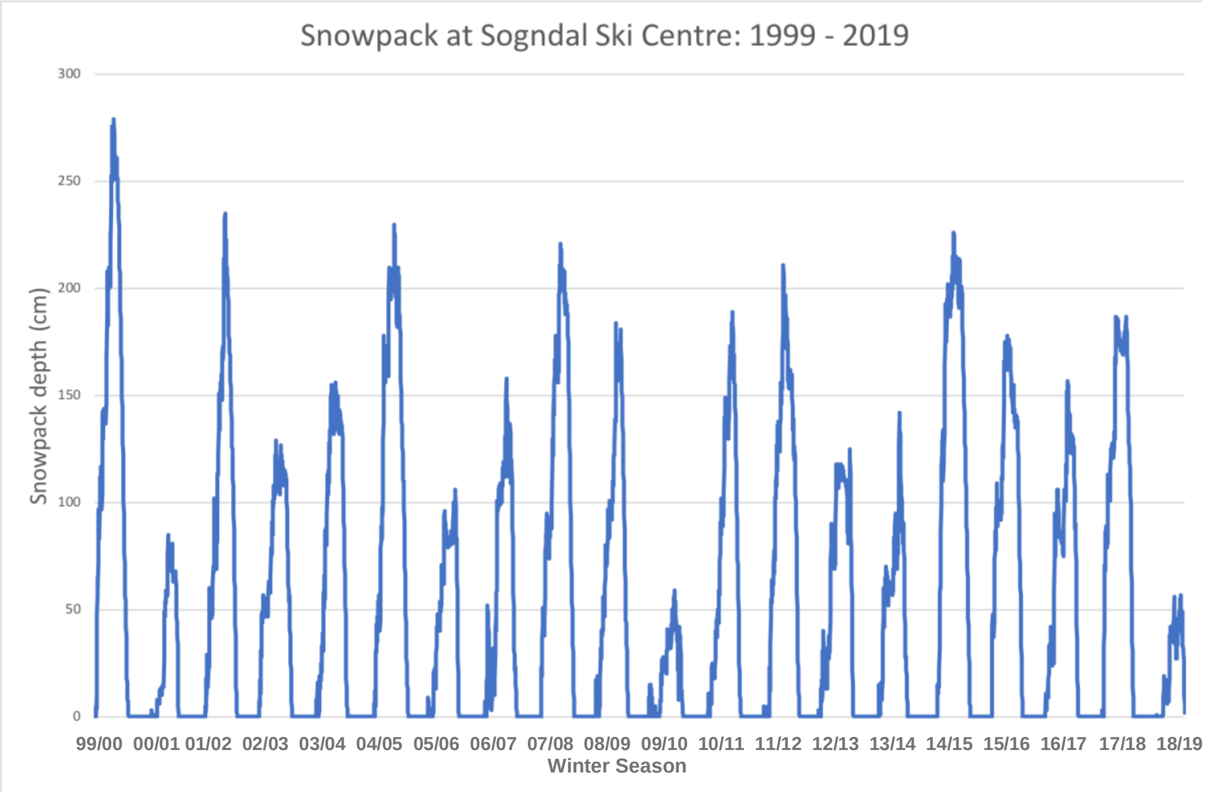

Figure 15 - Seasonal snow pack at Sogndal ski centre - plotted from (NVE, 2019) data

From figure 15, it is clearly seen that there are extreme snowpack patterns over a 10-year period, with certain years having 3-4 times reduction of snowpack compared to others. In future scenarios these low snow years will play a large role in how economically viable Sogndal ski centre will be in terms ski season length. It is still uncertain how sustainable low snowpack years will be into the future with both projected GHG emission scenarios.

5. Development of a climate change action plan for Sogndal Ski Centre

As stated in the previous chapters, the impacts from climate change on Sogndal ski centre will lead to a decrease in season length for both emission scenarios. However, Sogndal ski centre has the ability to help chose which one of those emission scenarios it sees as best for the future development/longevity of the centre. This section aims to provide inspiration and recommendations for the management of Sogndal ski centre to begin to implement a climate change change action plan which will lead to the ski centres emissions being aligned to the low emission scenario of RCP 4.5. Some recommendations might lead to a reduction of income/increased operating costs, but the potential benefits of these would be returned in the later years with an increase in season length. An example may be to encourage customers to travel by public transport to the centre, reducing income collected through parking tickets but having a larger impact further into the future from emission reductions. Therefore, it is important to weigh the costs and benefits of each recommendation. On the other hand, the above example might lead to new synergies such as creating a behaviour change within their customers, encouraging them to use public transport more. Reducing their own transport emissions which in time benefits Sogndal ski centre.

To bring around this change, it needs to be viewed from a holistic approach where actions don't necessary focus on every aspect within the ski centre at once but are set out over 10-year time frame. This allows prioritises to be set for sectors that contribute the highest emissions and also areas of easy and quick solutions, (low hanging fruits). The holistic view will also include looking at the centre from the system perspective (figure 2) and also bringing in actions that prioritise the surrounding environment and biodiversity. The following chapter will show why I assessed the carbon footprint of Sogndal ski centre through a carbon inventory to show what sectors contribute the most emissions. And finish with recommendations of different strategies that may be implemented in both a 5 and 10-year time period.

5.1. Method - Carbon Inventory.

Carbon inventory is often referred to as the process of making such estimations of the volume of carbon dioxide released from different sections. Inventories can be done for a product, a service, a person or a company and there can be different scopes of carbon inventories, from its basic form of only using two variables to complex systems with multiple variables. The variables are made up from a quantity and an emission factor (Upham et al., 2009).

To bring in correct strategies to limit the future impacts on Sogndal ski centre, an assessment of their emitted greenhouse gasses was completed. The completion of the audit will help with raising awareness for both management, stakeholders and the customers of the areas within the ski centre that contribute the most emissions. The act of doing the inventory and if creatively communicating the results can show that everyday leisure activity even with current technology nearly always has implications on climate change and the surrounding environment.

A general approach was undertaken for the carbon inventory to be in align with the scope of this research project and provides an applied practical method which estimated the baseline emissions of Sogndal ski centre for the 17/18 winter season. Further improvements can be made to this baseline to improve its accuracy into the future.

5.2. Data collection

Primary data collection occurred between November 2018 and March 2019 through a combination of different ways. To collect data regarding the quantity variables was gathered through private communication with different actors and judgement has been used to select the different categories that are most significant. The categories were

- Ski lifts electricity consumption
- Slope maintenance fuel consumption
- Customers transportation to and from the ski centre
- Employees transportation to and from the ski centre

Sogndal ski centre provided the data on the ski lifts electricity usage, fuel consumption and number of employee's, Sogndal Kommune provided the number of car parking tickets sold and Widerøe provided the volume of plane tickets purchased with a ski bag for the 17/18 winter season.

The emission factor data was gathered through a variety of sources from national and international organisations for electricity and transportation emissions and scientific literature for fuel emissions.

The data collected is limited to first-order carbon dioxide emissions, which are attributed to the ski centre being there and would not have occurred otherwise. This allows the audit to only include the emissions released from the consumption of the variable and not the whole life cycle analysis (Upham et al., 2009).

5.3. Emission factors

The following section describes each individual emission factors chosen to complete the carbon inventory from the different chosen sectors.

5.3.1. Road transportation emission factor

Knowing which type of car, the age or performance of engine is difficult unless you perform a thorough and detailed counting of visitors to Sogndal ski centre. To overcome this problem, average emission factor of cars manufactured in 2012 produced by the European Environment Agency (EEA, 2012) of 130 g-CO_2/km was used. This allows the emissions per vehicle to be calculated within a margin of error that is acceptable to produce the carbon inventory. Of course, there are vehicles which drive to the ski centre which have a lower or higher emission factor, the drivers driving style is also not considered. In the future a more in-depth analysis could be used to register the type of car used leading to more accurate results.

The bus emission factor was taken from the category of heavy-duty vehicles of 964 g-CO_2/km in 2015 from the report (The Norwegian Environment Agency, et al., 2017).

All emission factor for surface transportation are per km driven instead of per passenger km which is normally used and is easier when doing direct comparisons when looking into reduction strategies through mitigation techniques.

5.3.2. Aircraft emission factors

Aircraft emission estimations are calculated on the basis of assumptions relating to the load factor, type, age and capacity of the aircraft. It becomes difficult to account for these different factors on a per-flight basis Upham et al., 2009). The International Civil Aviation Organisation (ICAO, 2019) uses a distance-based approach to estimate the aviation emissions per passenger trip. ICAO uses industry averages for the above factors alongside the passenger's origin and destination airports and average flight distance. Sogndal airport is a domestic airport only and the emission factor calculated per passenger kilometre for short haul flights which was approximately 400 g-CO_2/km.

There are more than just emissions released from burning fossil fuels with aviation, there are specific effects from these emissions in high altitude which lead to aircrafts having a higher impact than initially thought from direct CO_2 released. The global warming potential (GWP) from aviation should include Nitrogen oxide (NOx), stratospheric water, contrails, sulphate aerosols reflecting sunlight and soot aerosols absorbing sunlight (Jungbluth & Meili, 2019) Currently the exact relevance of emissions from aviation is the subject of many scientific debates as some of the relevant emissions have a short lifetime. Which makes using the GWP methodology harder as it has been developed for long lived emissions. Also, the effect of aviation emissions is dependent on the exact location and timing of the emissions released. This is affected by the difference in water vapour experienced in the troposphere and stratosphere, the ozone formation at that exact location and the overall engine efficiency (Boucher, 2008); (Jungbluth & Meili, 2019)**.** The multiple publications of different emissions effects from aviation per passenger along with missing scientific knowledge on applying GWP to aviation emissions can lead to multiple different emission factors. This can become an important shortcoming when comparing different emission factors between the transport sector and leading to car and plane emission factors being similar (Jungbluth & Meili, 2019). The emission factor applied from ICAO does not include the GWP meaning that the estimation of CO_2 emissions per passenger could be higher or lower by several factors.

5.3.3. Electricity

The generation of electricity within Norway has a relatively low emission factor due to the large installed hydropower capacity found throughout Norway. However, Norway is part of the Association of Issuing Bodies (AIB) which must provide information of the origin of electricity generation (GO). With countries signing up to the GO agreement it allows the country to calculate their respective energy mix. This is required due to countries who buy and sell electricity through the European Attribute Mix (EAM) where electricity is provided in multi forms from renewables to fossil fuels. This suggests that even though the power production in Norway is from 98% renewable sources the electricity used in Norway can be from the EAM where the carbon footprint is much higher. At any one time it is difficult to say where the origin of electricity consumed in Norway has come from, concluding that the emission factor is difficult to calculate (NVE, 2019); (Association of Issuing Bodies, 2019).

To assess the impact of the electricity consumption, three assessments were considered. The three assessments include, the Norwegian Power production emission factor (NVE) from 2017, the EAM emission factor and the emission factor used by the Building Research Establishment Environmental Assessment Method (BREEAM, 2019). The different emission factors are shown below

- NVE - 16.4g-CO_2/kWh
- EAM - 345g-CO_2/kWh
- BREEAM - 132g-CO_2/kWh

The results section is calculated using the BREEAM emission factor of 132g-CO_2/kWh which bests represents the electricity emission factor in Norway, (recommendation from a SVECO consultant). The difference in emissions across each electricity emission factor is discussed further in chapter 7.1.

5.3.4. Fuel

Diesel fuel is a mixture of hydrocarbons which during the combustion process of an engine produces gas emissions. The emissions are a mixture of water vapour (H_20), Oxygen (0_2) and particulate matter (PM) with the largest percentage as carbon dioxide (CO_2). From this process it is known that 1 litre of diesel fuel will release 2.7kg/CO_2 emissions and therefore can be used to calculate the volume of CO_2 emissions released from a known volume of diesel burnt (Davies, n.d.)

5.4. Estimation of the quantity of each sector.

The following sector describes the way that the estimation of each sectors quantity was collected.

5.4.1. Estimation of transportation numbers

Customer

Car return trips were estimated from available parking ticket data. Parking tickets can either be day parking passes or parking season cards purchased. Day ticket numbers is precise, as one day parking card represents one vehicle return trip. The season cards are more difficult, card holders are assumed to drive an average of 3 times per week over the length of the 22-week winter season.

- Day ticket numbers – 6061
- Season ticket numbers – 410

From these numbers, this gives a yearly customer return trip estimation of 33,121

To estimate aviation numbers the assumption of only plane tickets that have purchased an additional ski bag on the flight will count towards aviation numbers. Obviously, this can underestimate the number as a customer can fly into Sogndal and rent equipment or not ski at Sogndal ski centre. But this information is not known without a detailed survey. Widerøe, which operates the airplanes flying into Sogndal quoted a total of 85 ski bags purchased over the winter season giving 170 return plane trips.

Employee

Employee return trips were estimated through assuming that a full-time employee has 5 return trips per week and part-time employees having 3 trips per week over the 22-week season.

- Full time employees – 4
- Part time employees – 20

From these numbers, along with season length gives 1826 return trips.

5.4.2. Estimation of Transport distance and mode

Ideally, estimation of transport distances requires knowledge from the origin of every participant. This information is difficult to obtain for each individual car, however for aviation the distance from airports is approximately known.

- Oslo – 480km return trip
- Bergen – 284km return trip

Car return trip distance was estimated through choosing the four closest towns and applying a weighting factor to each one representing the size of population.

- Songdal – 26km return trip – 75% weight factor
- Kjørnes – 32km return trip – 10% weight factor
- Kaupanger – 50km return trip – 10% weight factor
- Leikanger – 70km return trip – 5% weight factor
- Average distance travelled – 32km

Nevertheless, this area has the highest possibility for potential error as estimating an incorrect transport distance with this value being multiplied over such a large quantity number, small errors can result in a large final difference. As the ski centres operating emissions are constant, the assumed transport distance and participation can substantially affect the contributions to emissions. In future years, these source categories should be prioritised to give more accurate results.

5.4.3. Electricity and fuel emission factors

These emissions relate to the ski centre winter season operations only. This consists of operation of the 4 ski lifts and the fuel used for slope maintenance from both piste machines and snow scooters. For electricity usage, the ski centre provided the hourly kWh consumption of the four ski lifts allowing a value of electricity consumption to be gathered over the winter season. The annual lift electricity consumption was 121,578 kWh and fuel consumption were 25,100 litres.

6. Results - Carbon Inventory

The following chapter summarises the results from the carbon inventory calculations. The chapter will be divided into two sections of direct and indirect emissions from Songdal ski centre, and a further breakdown of the different sectors that contribute to these. While the scope of the carbon inventory provides accuracy to the nearest kg/Tonne, the results are rounded due to the quality of data and the limitations within the calculations. It also provides an ease of reading and comparing. Percentage values are given in whole percent, due to the uncertainty of results. Due to the rounding and data input, the total emission values do not represent the exact sum of all the different sectors for the 2017/18 winter season.

6.1. Total emissions from Sogndal ski centre

Figure 16 presents the volume of emissions released from the chosen sectors at Sogndal ski centre with direct emissions in blue and indirect in red. The percentage of each individual sectors contributions is shown in figure 17.

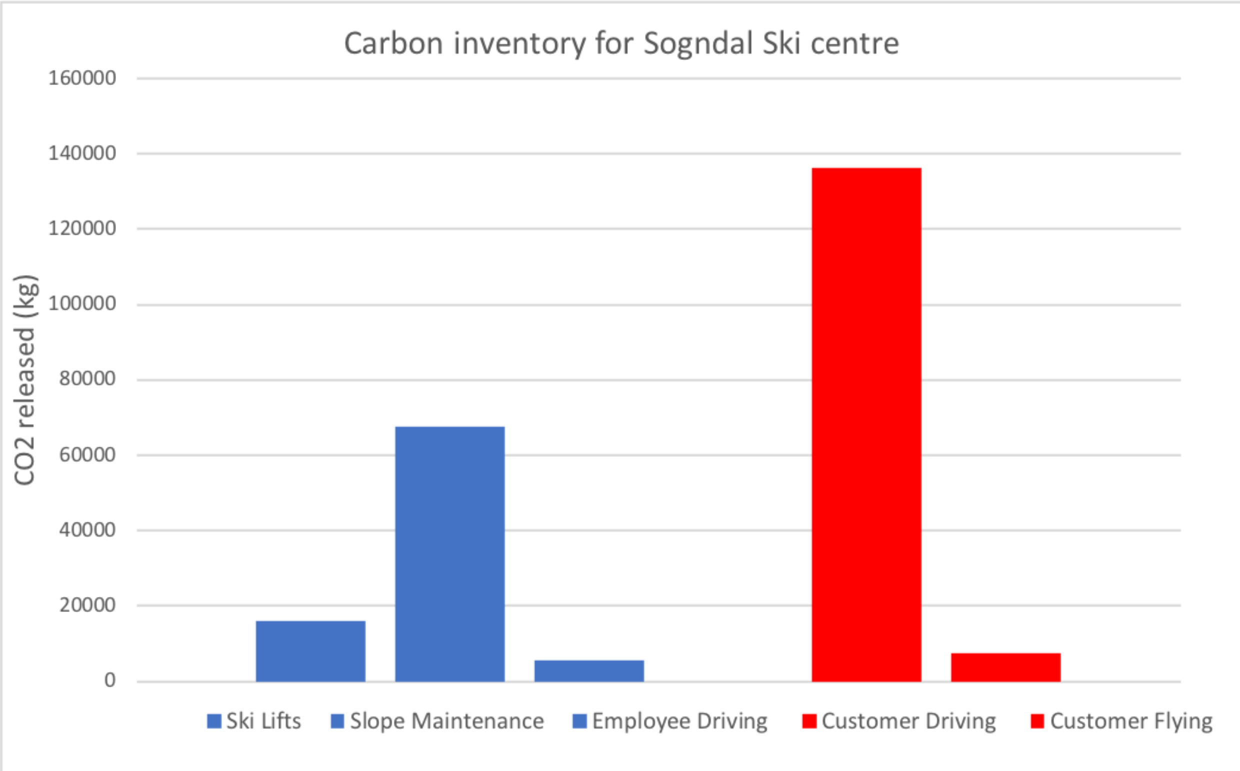

Figure 16 – Sogndal ski centres individual sector emissions

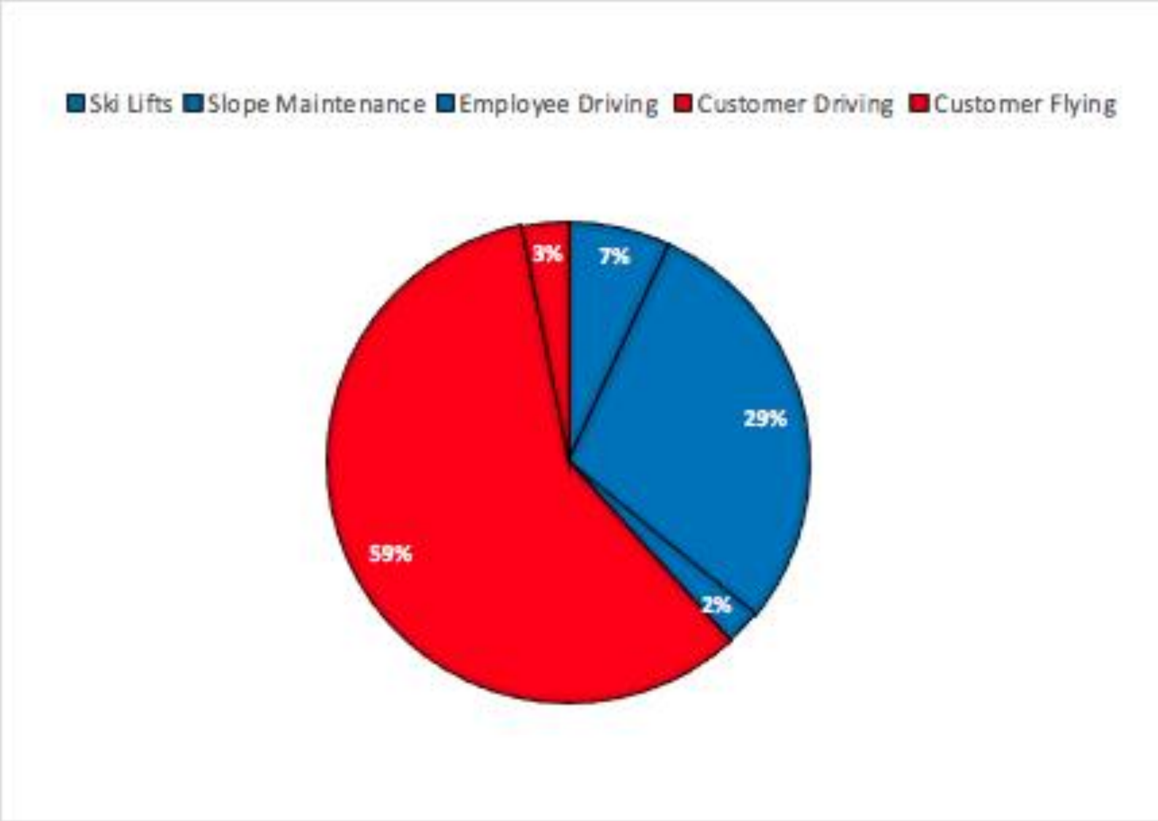

Figure 17 – Each individual sector percentage of total emissions

6.2. Direct

Sectors that fall under direct emissions are directly related to the daily operations and maintenance that allows Sogndal ski centre to be open for the winter season. The different sectors chosen were, the emissions from ski lifts, slope maintenance and employee driving due to the data that was available to the author.

Emissions from slope maintenance and operations

The ski centre purchased 25,100 litres of fuel for the winter season to be used for all machines that are necessary in the daily operations of the ski centre. These include, piste machines, snow-removal trucks and snowmobiles, together provide operations in slope maintenance, snow removal of the road and carparks and safety and lift maintenance. The volume of emission released from fuel usage is ca. 67,500 kg/CO_2 and represents 29% of the total carbon inventory and 76% of the total direct emissions.

Emissions from ski lifts
Management provided an excel spreadsheet showing each individual lift's electricity consumption over the winter season. The total emissions amount to ca. 16,048 kg/CO_2. The biggest contributor in this sector is Rindabotn lift contributing ca. 47%. Hodlekve is the second largest contributor with 35%, children's lift with 12% and Kalvavatni is the smallest contributor with only 6%. The Toyota children's lift was built at the end of the season and was not counted. The 17/18 winter season total lift emissions represent ca. 7% of the total carbon inventory and 18% of total direct emissions.

Emissions from staff commuting.
This sector only accounts for the number of full and part time staff that was is employed during the winter seasons and does not include any ski patrol members. The total emissions amount to ca. 5,703 kg/CO_2. Full time staff members contribute to ca. 32% of emissions and part time staff are the largest contribution of ca. 68%. Staff commuting is responsible for 2% of the total carbon inventory of the ski centre and 6% of the total direct emissions.

6.3. Indirect

Sectors that fall under indirect emissions are described as emissions that are produced by the ski centre being open over the winter season. The chosen sector of customers travel behaviour was chosen by the author as the only data available and travel behaviour is based on either driving or flying. Emissions from food and ski equipment are left out due to either being negligible in the final result or the data for calculations is out of the scope of this project.

Emissions from car travel.
Data on commuting behaviour is based on the volume of car day and season parking tickets sold and the frequency of use. The total emissions amount to ca 136,276 kg/CO_2. With the biggest contributor being the season card holders contributing 82% of the emissions. Day parking passes contribute the remaining 18%. Customer car travel behaviour amounts to 59% of the total carbon inventory and 95% of total indirect emissions.

Emissions from plane travel.
This sector only accounts for the volume of customers who have flown in from either Oslo or Bergen to Sogndal and have purchased a ski bag on the plane. The total emissions amount to ca. 7,362 kg/CO_2. Customer flying behaviour amounts to 3% of the total carbon inventory and 5% of the total indirect emissions.

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6.4. Summary.

The total emissions released from Sogndal ski centre for the winter season of 2017/18 from the sectors calculated was approximately 232,889 kg/CO_2. The direct sectors contributed 38% and the indirect sectors contributed 62%, with customer commuting the largest individual sector with 59% of the total emissions. With accurate data around the ski centres spending and waste would produce a more accurate carbon inventory alongside estimations of emissions released from the construction of Dalaloven and the nearby cabins. Further research would give more accurate data for the estimation of parking season card holder's volume of trips per season to the ski centre and their return trip length. However, this simplified carbon inventory provides a valuable insight into the size of each individual sectors carbon footprint and provides the beginning of more accurate inventories to come and the starting point for bringing in strategies to lower the ski centre's carbon footprint.

7. Discussion of Carbon Inventory

The following section will explain any limitations in each sector previously described and will also explain the logical theory behind the chosen parameters of each section.

7.1 Limitations based on data

Customer commuting

As explained in the earlier chapter getting accurate data is very challenging and requires in depth research and a lengthy timeline. With the known car parking data and the ski centre being open 7 days a week; cross country skiing is every day and lift access 6 days a week. It was assumed that on average a season parking card holder would drive 3 times per week. This number is heavily dependent on personal choice and weather dependencies. Further research should look into getting more accurate data for commuting.
The calculation of distance is unknown for each customer and was assumed for the closest four towns and given a respected weighting factor. This does not reflect the distance driven by customers and getting the correct distances is difficult.

Customers who choose to fly into Sogndal has limitations because of Widerøe stated that a total of 85 ski bags have been booked from Oslo and Bergen combined. Due to population sizes I assumed that 65 return trips are from Oslo and 20 return trips are from Bergen. To account for customers flying, it was assumed that all customers who flew to Sogndal, (1) booked a return flight and (2) went skiing at Sogndal ski centre. This assumption is not correct as flight data could be of residents flying to Oslo/Bergen for an international ski holiday or flying into Sogndal to go on a ski tour trip and not ski at the centre. However, to know the behaviour of each individual customer is difficult and for the scope of this thesis the behaviour can be assumed.

Employee commuting

It is unknown the exact number of return trips each employee does during each week or the season as it can be dependent on their work position. An example of the above, an employee who is responsible for clearing snow from the road can make multiple return trips a day throughout a heavy snowfall and also go multiple days in a row of not commuting due to no previous snowfalls. I have assumed that each full-time employee had 5 return trips per week and part time had 3.

The same entails for customer commuting as each employee are stated to have an average driving distance. To get more accurate data would be easier with employees as they could state their average distance driven alongside the number of days employed over the season.

Electricity

With the difficulty of knowing the exact emission factor from the electricity network, the comparison between them is shown in figure 18 below.

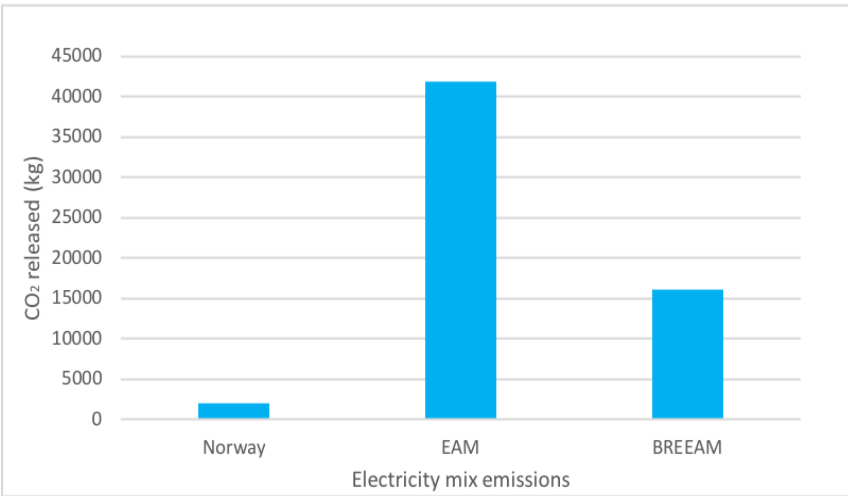

Figure 18 - Comparison of electricity generation emissions

If Sogndal ski centre uses electricity that is generated from the Norwegian power production emission factor of 16.4g/kWh, their annual emissions would have been 1,994kg/CO_2 a reduction of 88%. If the electricity usage was from EAM with an emission factor of 345g/kWh, there would have been an emission increase of 261% emitting 41,944kg/CO_2. Any further carbon inventories at Sogndal ski centre should take into consideration of not using the power production emission factor as this would represent a false reality and should use the emission factor from BREEAM.

7.2. Recommended improvements to the methodology.

The customer and employee commuting behaviour are arguably the most difficult categories to calculate, due to requiring extensive information on each individual commuting behaviour (quantity and distance) each week over the winter season. However, certain actions could be implemented to improve the accuracy of the calculations in this area. Firstly, season card holders could be asked to record the number of trips over the season and register this with Sogndal ski centre. This would give a better indication of the average trip per week and can link it up to what were those specific snow conditions over that season. Secondly, season card holders could register their trips in more detail stating the number of trips over the season with their average distance driving, thus improving the accuracy of the emissions released. The ski centre employees can state their average driven distance and the days employed over the season to give more accurate results over a short period of time.

Sogndal ski centre should register the volume of fuel that is used on each of their machines; piste machines, snowmobiles and machinery to understand what percentage of the slope maintenance each machine contributes. Thus, done over a long period of time (5-10 years) would give them a judgement of how much fuel is used when comparing good and bad snow seasons and what could be the reductions in fuel usage with replacing machines for more efficient models.

8. Climate Change Action Plan

The aim of this assessment and the following chapter is to provide some initial inspiration and recommendations to identify areas to introduce strategies that can have (1) emission reductions and (2) promote sustainability of the surrounding environment. This area should be used as a preliminary climate action plan and be developed further. It will mainly focus on providing recommendations from literature (Bizikova et al., 2008; Del Matto & Scott, 2009) or other ski centres environmental plans; (RMOW 2007; NSAA 2016) which can be implemented at the ski centre either in the short (5-years) or long term (10+ years). It will also provide recommendations for ski centres in Norway to work together.

The carbon inventory showed areas with the biggest contributions and it is recommended to focus on this area. Strategies should not disregard areas with low contributions or areas not included in the carbon inventory such as future expansion plans for both ski lifts and cabins. As these can have further impacts not just from increase in emissions but on the surrounding environment and biodiversity through land use changes to build the infrastructure.

8.1 Importance

It is important to implement a climate action plan which contains the correct strategies and techniques to reduce the carbon footprint of the ski centre as well as maintaining the surrounding biophysical system and the environment explained in the chapter 1.5. It is also important for the rich culture of skiing to maintain within small ski centres and having a correct climate system in the future could be the best possible way to maintain the high participation. With the Sogndal Kommune has already implemented a climate change action plan for 20% GHG reductions by 2020 (Kommune, 2009), reductions from the ski centre can help with these goals. Also, with Sogndal Kommune being one of the largest shareholders, reductions at the ski centre should be of best priority to them for the longevity of the centre and their investments with also keeping the rich ski culture within Sogndal. By creating and implementing a climate change action plan will be symbolic for other ski centres within Norway who are of similar size to do the same. Reducing emissions, resulting in reducing the severity of ski season changes may be one of the best strategies to deal with unknown behaviour changes into the future. The importance of creating a climate change action plan that supports and protects the surrounding environment and biodiversity, reducing the loss of nature is now even more apparent. The report by IPBES (2019) highlights that nature is declining globally at unprecedented rates, killing the foundations of our likelihood and states that through transformative change, nature can still be conserved.

8.2. Recommended actions

The following chapter aims to provide inspiration to bring in policies in the short and long term that will help with lowering the emissions of Sogndal ski centre to that of the Paris Agreement (RCP 4.5) with both adaptation and mitigation techniques. When comparing the difference in loss of operating days from chapter 4.3, it is in the interest of the ski centre to have a lower emission scenario into the future, providing economic stability compared to the ski season reduction with RCP 8.5. It is also necessary that being situated within Norway to help with the national reduction targets set out by the Norwegian Government when signing the Paris Agreement in 2016. All reductions will help with Sogndal's local GHG reduction targets of 20% by the year 2020.

8.3. Norway and the Paris Agreement.

Norway was among one of the first countries to ratify the Paris Agreement in 2016, (Norway.No, 2019). The Paris Agreement consists of lowering GHG emissions in the atmosphere to stabilise the average world temperature by 2˚C (RCP 4.5) by the end of the century. Norway has set two reduction targets:

- Unconditional - 40% below 1990 by 2030
- Conditional - carbon neutrality by 2030

Unconditional targets represent what Norway can do "on its own" to reduce their GHG emissions. Conditional target is set to show what can be achieved with the help of other countries.

However, with current reduction policies to date, Norway's emissions are projected to decrease by only 7% by the year 2030 (Tracker, 2019). A far cry from the 2030 reduction strategy of 40% or carbon neutrality.

8.4. Sogndal ski centre and the Paris Agreement

With the results from the SkiSim2.0 model showing the large potential differences between both the emission scenarios, it would be in the ski centres interest to reduce their own emissions to be in accord to Norway's Paris Agreement reduction targets.

In regard to why it is necessary to reduce emissions to maintain an adequate natural snow depth there are other potential indirect areas may be effected. This could see property values around the area decline due to the ski centre having a decreasing trend in natural snow cover and opening days. The report by Savills (2018) have started to provide information to clients of which ski resorts have the highest resilience to future climate change and promoting which resorts are implementing climate plans. If Sogndal ski centre closed from insufficient snow depth, with the known behaviour demand of skiers chasing snow there is potential for an increase in energy use from local customers either driving to resorts further away or taking international ski holidays by plane trips.

8.5. Why the Integration of Adaptation and Mitigation?

The reason for choosing to do both adaptation and mitigation is that integration of the two needs to take place to avoid negative feedback mechanisms between them.

Adaptation is considered the response capacity to anticipate and cope with impacts that cannot be avoided under the different GHG emissions scenarios. Mitigation is seen as a way of keeping climate change moderate rather than extreme by reducing emissions (IPCC, 2014). By integrating adaptation and mitigation with sustainable development reduces the damage to the environment. Figure 19 presents an overview of the importance knowing how techniques on their own either mitigation or adaptation could lead into emission and vulnerability increased. Showing how the linkages between adaptation and mitigation with sustainable development leads to a reduction in both vulnerability and emissions. By creating policies that have a reduced vulnerability it allows the ski centre to become better prepared for unknown or unseen changes such as a shift in weather patterns from climate change or the change in behaviour of skiers.

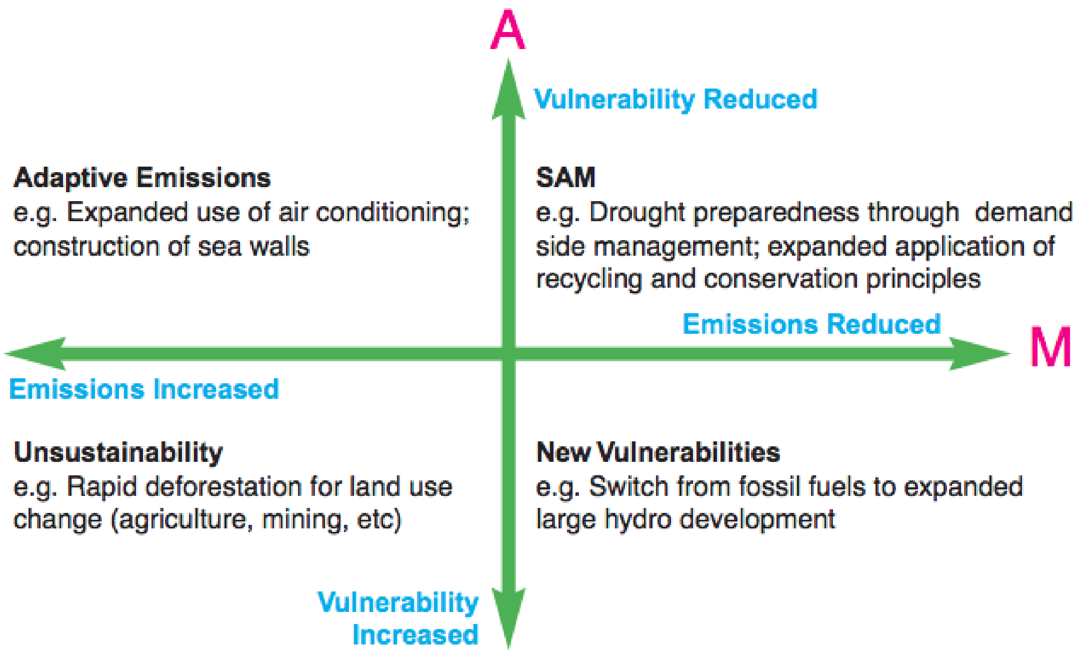

Figure 19 - linkages between adaptation and mitigation, in the context of sustainable development - (Cohen & Waddell, 2009)

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By creating strategies that are focussed with sustainable development, adaptation and mitigation (SAM) mind-set, this reduces the ability of mal-adaptive and mal-mitigation to be present. Where mal-adaptation could be seen as only using snowmaking to adapt to reduced snow depth leading to increase in GHG emissions. And mal-mitigation waiting for technology fixes with increase efficiencies, which tightly couples the ski centre into waiting for technologies to reduce their carbon footprint and increasing their vulnerability if these take too long to be deployed. An example would be waiting for their customers to have an uptake of electric cars, reducing the customer commuting emissions. Currently Norway has 52% of new cars sold in 2017 were electric (Tsang & Libell, 2018) making them a world leader. However, it still only represents 7% of the registered cars within Norway (SSB, 2019).

9. Discussion

9.1. Short term strategies

The following section will recommend a selection of possible actions to be implemented within a 5 year time frame with the aim to have a 15% reduction of GHG emissions by 2025.

Education and information

Sogndal ski centre can become a media platform in providing the correct education and information to their customers and staff. Shaping their perception and awareness regarding the impacts of climate change and the ability for reduction measures. Dalaloven can play an important role of being the location to provide this information. The following are a list of recommendations under different sections:

Climate change impacts - strategies under this section refer to either techniques that would adapt the ski centre to the impacts from climate change. Or education, with a focus being on the management and customers becoming “climate change educated” and being aware of available research showing these impacts through a decrease in ski season length.

Emission reductions – Strategies under this section refer to reducing the emissions of the ski centre.

Sustainability – strategies under this section refer to prioritising and protecting the natural environment and biodiversity surrounding the ski centre as well as becoming a sustainable actor within the Sogndal County.

Climate change impacts:

- Show the change in opening days for both Hodlekve and Rindabotn lifts under both emission scenarios. Educating customers’ why it is necessary that there is an RCP 4.5 warming instead of RCP 8.5. Show why it is important to bring in a climate change action plan.
- Remove large rocks and tree stumps that are situated in the slope and off-piste area, reducing the volume of snow needed to open. Add fences or trees on areas that are vulnerable to snow drifting from the wind.
- Learn about potential behavioural change of skiers and how this could impact or benefit the ski centre.

Emission reduction:

- Promote the use of public transport for traveling to Sogndal and to Sogndal ski centre. No longer promote high emission transport such as flying to reach Sogndal. 85 return flights produced more emissions than the all of the employees commuting emissions for the winter season.
  Create a car sharing platform on social media for customers to organise, reducing the volume of customer commuting emissions. Show what the average emissions from each mode of transport are.
  Promote car sharing with employees
- Work with Sogndal Kommune and local bus companies to provide bus transportation on high demand days, (weekends, holidays etc) to and from the ski centre. With one bus full of skiers can have an approximately 70% emission reduction.[1]
  Also helps to fulfil local climate plans of reduction in transport emissions.
  Understand that waiting for electrification technologies for transport will take GHG levels beyond the planetary boundary to reduce the severe consequences of climate change.
- Reduce unnecessary electricity and energy usage. Record a baseline level of electricity and energy to show a realistic view of how, where and what level of energy is being used. Reduction in electricity usage can allow a country with high electricity emissions to purchase electricity through the EAM from Norway.
- Inventory the fuel usage for each machine, thus given the savings when upgrading.
- Re-use and repair work clothes from the previous season and purchase clothes with the smallest environmental impact. Recycle clothes when no longer in use.
- Re-plant a native tree for every tree that is removed for the expansion of either ski slopes, ski lifts or construction of buildings/cabins.
- Serve organic/local food in the restaurant in Dalaloven, with priority on low emission food with multiple vegetarian options.
- Purchase electric snowmobiles when replacing old models.
- **Implement GHG reduction targets to reduce emissions by 15% within 5 years.**

[1] Based on one full bus at 45 capacity reducing 22 cars, based on 2 customer per car driving the same distance.

Sustainability

- Protect local wildlife areas such as peatlands and local river courses.
- Have no waste or chemicals polluting surrounding areas or watercourses. All waste is treated correctly.
- Restore natural areas such as biodiversity and ecosystem integrity, protecting areas from being overused and have no net habitat loss.
- Bring in recycling bins, food bins for composting.
- Limits to growth are understood and respected in terms of the built system. All new buildings should meet correct environmental standards in Norway and have lowest energy use.
- Become an actor with pushing for better environmental policies within Sogndal and Sogn og Fjordane region. Support candidates who priorities environmental policies.
- Support environmental organisations such as Protect Our Winters Norge, have an area where customers can support and become a member.
- Understand that snow making can be seen as a mal-adaptive technique by increasing emissions from electricity use and the damaging ecological effects it has. When bringing in snow making machines work to local land use planning regulations on the impacts on local ecology and Sogndal ski centre should aim to have larger emission reductions to compensate for the increase from extra electricity use.

9.2. Long term strategies

The following section will recommend a selection of possible actions to be implemented by 2030 and continue afterwards with the aim of the strategy to have 40% reduction of GHG emissions by 2030.

Climate change impacts

- Continue to be educated on future climate trends and changes in natural snowfall for Sogndal region and how this will affect Sogndal. Engage with any new research about climate change impacts.
- Highlight why it is necessary for other ski centres within Sogn og Fjordane to also reduce emissions to RCP 4.5 or below.

Emission reductions

- Increase the availability of public transport to and from the ski centre, more frequent buses for night skiing and weekends. Aim to have larger percentage of weekend customers using public transport rather than private, large student base where low priced public transport would be better for them.
- Holistic view of energy and electricity consumption so there is no extra usage.
- Purchase or apply for grant funding to purchase electrical or more fuel efficient piste machine when replacing old models. Can experience large volume of emission reduction due to being the second largest area in the carbon inventory.
- Purchase most energy efficient snowmaking technology.
- Install electrical car charging stations.
- **Reduce carbon footprint by 40% and be in according to Norway's reduction targets for RCP 4.5 for 2030.**

Sustainability

- Energy efficiency of snowmaking machines – understand the need to avoid snowmaking becoming a mal-adaptation technique where the use of snowmaking machines increases the total GHG emissions from the ski centre.
- Sogndal ski centre is planning lift expansion, the instalment of this lift should be under correct land use plans, have the smallest impact of the surrounding environment and be built with resource consumption in mind.
- Produce a detailed carbon inventory.
- Push for the creation of a Norwegian ski areas association.
- No peatlands drained.
- Continue to prioritise the local environment.
- Expand and update the climate change action plan when necessary.

9.3. Norwegian ski centres in general.

The Creation of a climate change section in the ski area association.

Impacts on ski tourism from climate change within Norway is not as serious compared to The Alps or Northern America. However, with current weak or no policies from the national government focusing on ski centres within Norway. Ski centres and environmental organisations (POW) should advocate for the creation of a climate change sector within the Alpinanleggenes Landsforening (ALF), the industry association for the alpine industry in Norway. With the establishment of this sector similar to the 'Sustainable slopes' in the National Ski Areas Association (NSAA) in North America, who represents over 300 alpine areas as their trade association. The association created the environmental charter in the year 2000 to address the environmental concerns within the ski industry, normally referred to as "Sustainable Slopes", endorsing for lowering of environmental footprints (NSAA, 2016). The creation of a similar association, this can advocate for better local national policies for ski centres to members of the local Kommune and national government. It can also set standards for the emission reductions within ski centres and help with providing/finding funding to bring around these changes when necessary.

Green certificates

Currently there are some ski destinations that have environmental plans, most notable, Trysil, situated in South East Norway. They were awarded a Bærekraftig Reiseliv (sustainable tourism) certificate and celebrate this with a few other destination resorts in Norway. To achieve this, the main goal of Trysil was reducing energy costs from decreasing internal air temperature in the buildings and replacing the light fittings with more efficient versions (Trysil, 2019). However, what is failed to be mentioned is the new airport that was established within 1 hour drive from Trysil ski centre in 2017, with the goal of increasing international tourists, (Nærlingsliv, 2017). Trysil should consider a more aggressive and transformative climate change action plan, similar to the recommendations for Sogndal ski centre which has a larger focus on the surrounding environment rather than increasing the economic growth of the resort, which ultimately resulting in an increase of GHG emissions.

This award should then be focussed on giving it to the local municipality instead of a tourism destination where marketing is key. This will allow a better transformative approach to where they include all forms of transportation, biodiversity impacts and land use changes into account. Minimising the ability of a singular destination being branded as a sustainable destination but located in a region that has increasing emissions per annum.

Transportation within Norwegian tourism

Strategies for tourism within Norway, including the ski industry should be focussing on policies that reduce the biggest sector of emissions: travel from aviation. Currently tourism accounts for 20% of Norway's GHG emissions and aviation contributing 65% (Gössling et al., 2011).

If the ski tourism wants to contribute to Norway's reduction goals set out in the Paris agreement of 40% by 2030 then there needs to be strong policies to bring around this change and should focus on aviation as the biggest area to reduce. Currently the thinking is from electrification of airplanes however this is not in a realistic time frame for the needed reductions measures by 2030, with the first being introduced into Norway in 2032 (Christensen, 2017). The same applies for wishing for emission reductions in the transport sector to come from electrical cars as explained in chapter 8.5. To feel the remedies of these solutions would be beyond 2030 where the IPCC has stated IPCC has stated to avoid the serious effects of climate change; large scale reductions need to be implemented by the year 2030.

Summary

Ski centres should understand that they cannot be sustainable on their own, all centres are a part of a local municipality that has developed a climate change action plan to contribute to the Norwegian government's reduction targets. Which currently are far shy of their goals. Therefore, there should be a constant dialogue and information sharing platform of how each ski centre can help with the municipality's reduction plan and vice versa. From the establishment of a climate change sector within the ALF that produces a yearly report with the current emission target goals of all ski centres within Norway and how they plan to achieve them.

The best advice for Sogndal ski centre, would take the preliminary climate change action plan stated in this thesis, collaborate with the two local institutes of Vestlandsforsking (research institute) and HVL (university) on how best to implement these strategies. Then present this to Sogndal Kommune to establish Sogndal as a Bærekraftig Reiseliv certified destination, which covers all local businesses, transportation, hotels and most importantly Sogndal ski centre.

10. Conclusion

By examining the climate change impacts on ski season length at Sogndal ski centre, as well as showing how the ski centre contributes to those impacts. This thesis has provided new insights into how small ski centres with a focus on off-piste skiing cannot maintain season length through best practice techniques such as snowmaking. The increase in capital and operation costs could result in small ski centres going into financial difficulty, and instead should prioritise the surrounding environment with implementing strategies for emission reductions. Which in terms of off-piste skiing it is the only way to stop a decrease in season length and meet the needs of the future generations.

If the emission reduction goals of the Paris Agreement (RCP 4.5) are met, then losses of opening days will be between 10% for Sogndal ski centre by late century (2080) compared to a baseline of 157 days. When focusing on the economical Christmas period, there will be stronger impacts with a reduction of 23% of opening days by 2080. These would not severely disrupt the viability of the ski centre as ski season length is still over the 100 day threshold and 75% Christmas openings, set out by Abegg et al., (2007) and Scott et al., (2007).

The ski season length would be disrupted further with the high emission scenario (RCP 8.5) with Sogndal ski centre experiencing a ski season shortening of 35% with 102 days available for opening by late century. The once economical period over the Christmas holidays is severely reduced to 40% of the years having correct snow depth, with a reduction from the year 2050. However, when comparing this study to literature with similar methodology (SkiSim2.0), ski tourism at Sogndal ski centre is not as severely impacted compared to the others. Nationally, within Western Norway the average decrease in ski season length is 56% with only natural snow depth by 2080 (Scott et al., 2019). In contrast, international destinations with a large increase in snow production would see resorts in the Northern Tyrol range, Austria will have a snow reliability rate of 14% (Steiger & Stötter, 2013). Due to Sogndal ski centre specialising in providing lift based off-piste terrain the behavioural changes that could be witnessed with poor snow conditions are unknown. Where most studies point to customers substituting their local ski centre to other areas with more favourable conditions (Damm et al., 2014). With further research and improving the limitations and uncertainties of the SkiSim2.0 model would provide more accurate results.

With these known impacts and the not having the ability to increase snow depth with snow production in off-piste terrain, Sogndal ski centre should prioritise themselves with emission reduction targets to be align to the Paris Agreement. As this is the best way to maintain an adequate ski season length. For the 2017/18 winter season, Sogndal ski centre produced approximately 232,889 kg/CO_2, with 62% coming from customer transportation. The purpose of the second half of this thesis is to create a climate change action plan that links the strategies for both short-and-long term perspective to sustainable development. Where the environment's ability to meet the present and future needs are not limited from imposing technology. Bringing in strategies that increase the local bus service, reducing emissions from private cars is a good place to start.

This thesis provides a building block for Sogndal ski centre to bring in a climate change action plan before the winter season of 2019/20 begins. Thus, putting them in good position to help others do the same and push for the start of a climate change sector within the ALF that only has the focus on providing support for all ski centres within Norway with their uphill battle with climate change impacts.

Climate change is likely to effect and destabilise the winter tourism system in the future decades. The uncertainties of how much it will be change are still relatively unknown due to the influence of potential international mitigation policies such as increase energy prices or a sudden increase in GHG from a melting permafrost. But, one way to strengthen the resilience of ski tourism within Norway and more importantly Sogndal ski centre is to prioritise climate strategies that focus on the surrounding environmental with introducing emission reductions that are in align to the Paris Agreement. This will provide the adequate snow depth needed for the future needs of customers.
But maybe the greatest thing Sogndal ski centre could contribute is to ask their largest shareholder, Sogndal Kommune to collaborate with them to not only make Sogndal ski centre a sustainable destination but Sogndal area as a whole to become one.

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