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SUSTAINABLE INITIATIVES PROPOSAL FOR WINTERGREEN RESORT

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List of Acronyms

ALTATEC	ALTA Environmental Center
BLE	Low Energy Bluetooth
CMBR	Crested Butte Mountain Resort
HID	High-Intensity Discharge
LED	Light-emitting diode
MT CO_2e	Metric tons of carbon dioxide emitted
NSAA	National Ski Areas Association
REC	Renewable Energy Certificate
RFID	Radio Frequency ID
TWNF	The Wintergreen Nature Foundation
VGI	Voluntary Green Initiative
WARM	Waste Reduction Model

Executive Summary

The downhill ski industry contributes to global carbon emissions across many components of its operation, including transportation, snowmaking, and resort operations. Wintergreen Resort, a four season resort in central Virginia, may face significant sustainability challenges as a small ski resort at relatively low altitudes in the Southeastern United States. This report proposes initiatives to improve resort sustainability, through both emissions reduction and conservation efforts, based on on-site observations, interviews, and research.

In order to develop reasonable sustainability initiatives for Wintergreen Resort, a review of the current state of practice of emissions reductions across ski resorts was conducted to identify high impact emissions reduction strategies. Additionally, current research into the effectiveness of sustainability initiatives at resorts was evaluated. Identified high impact initiatives across resorts consistently included improvements to building operations and improvements in snowmaking efficiency.

Seven sustainability initiatives are proposed. Operations initiatives include replacing outdated outdoor lighting with energy-efficient LED lights, transitioning to digital lift passes to reduce waste and improve efficiency and using hydronic heat exchangers to maintain roads and reduce the need for plowing and salting. Waste reduction initiatives include implementing composting programs to divert food waste from landfills and reducing the use of single-use plastics and promoting reusable alternatives. Finally, conservation initiatives include enhancing the soil stability and plant diversity through native species reseeding and organic fertilization and monitoring and improving small mammal populations by maintaining natural habitats and minimizing disturbances.

Seven initiatives in progress are also proposed, which would require further development before implementation. These initiatives include implementing a gear donation program, further optimizing HVAC systems, utilizing wind power, utilizing energy from local cow manure, developing an incentive program for sustainability across the resort, introducing more education campaigns and increasing water reduction strategies across the resort and slopes.

It is recommended that initiatives be implemented through proposed small scale initiatives and gradually increasing scale as feasible. Future work may include refining proposed initiatives based on further feedback and upon completion of a full emissions inventory to better target reduction efforts.

1. Introduction

Wintergreen Resort is a four season resort located in Nellsyford, Virginia. Located at a relatively low altitude and considered a small ski resort, Wintergreen, like many other small-low altitude ski resorts, will likely have an outsized affect from climate change. The ski industry has attempted to incentivize and promote initiatives to improve resort sustainability, though their success can vary greatly depending on the needs, obstacles, and unique challenges of specific resorts.

This report seeks to provide several initiatives for implementation at Wintergreen Resort, including estimates of their impact on resort operations and emissions, recommendations for implementation, and examples of success at other ski resorts. Through on-site observation, interviews, and additional research, initiatives that were possible for Wintergreen were proposed.

This report is organized into the following chapters:

- Chapter 2 discusses the background of sustainability initiatives within the downhill ski industry. This includes a discussion of background research including trends and observations of ski resort emissions, a background to Wintergreen resort specific considerations, and a summary of current state practice integrating sustainable initiatives in resorts.
- Chapter 3 proposes initiatives relating to updating resort operations. This includes updating the outdoor lighting system, converting passes to fully electronic passes and updates to local roads and parking lots. Emissions reduction estimates, examples of successful implementation in other ski resorts, and implementation obstacles and recommendations for Wintergreen are also provided for these initiatives.
- Chapter 4 proposes initiatives to reduce waste produced at Wintergreen Resort. This includes reducing food waste provided by on-site restaurants and reducing the use of single-use plastic materials. Emissions reduction estimates, examples of successful implementation in other ski resorts, and implementation obstacles and recommendations for Wintergreen are also provided for these initiatives.
- Chapter 5 discusses environmental concerns of the resort impact on the larger ecosystem. This includes improving soil and plant diversity as well as considerations for improving species diversity. Examples of successful implementation in other ski resorts, and implementation obstacles and recommendations for Wintergreen are also provided for these initiatives.
- Chapter 6 provides multiple additional initiatives resulting from open brainstorming sessions and on-site observations. These are brief, initial suggestions and do not include emissions estimates and additional research from other resorts.
- Chapter 7 provides final recommendations for the resort and for future work.

2. Background

This chapter will discuss sustainability concerns, issues and initiatives relevant specifically to the downhill ski industry. This will include an explanation and discussion of the National Ski Areas Association (NSAA) annual reporting data and a synthesis of available data including specific relevant initiatives by reporting ski resorts. Additionally, current sustainable practices and specific considerations and needs relative to Wintergreen resort will also be discussed. Finally, an introduction to the proposed initiatives will be given.

2.1 Ski industry sustainability

Many components of the downhill ski industry contribute to global carbon emissions, including transportation, snowmaking, general resort operations and maintenance. Emissions can be measured as equivalent carbon emissions (measured in metric tons of carbon dioxide emitted, MT CO_2e), to provide a tangible measurement of the effect of the industry on global carbon emissions.

Currently, the largest effort to quantify carbon dioxide emissions across ski resorts has been conducted by the National Ski Areas Association (NSAA). Currently, 90% of ski areas in the United States are NSAA members. Since 2012, the NSAA has sponsored a voluntary climate challenge for ski resorts based in the United States and Canada. The results of this challenge, which include self-reported current emissions inventories, target emissions, and reduction initiatives for reducing carbon emissions, have been published annually since 2012 [1].

Emissions reporting for the NSAA climate challenge requires classifying ski resort emissions as Scope 1, 2, or 3 emissions. Scope 1 emissions includes any direct ski resort emissions, such as diesel required for the operation of grooming equipment. Scope 2 emissions includes indirect ski resort emissions, such as purchasing external electricity required for operations. Scope 3 emissions include any emissions required for operations not covered by Scopes 1 and 2, including food waste and solid waste. This framework can be helpful for targeting specific emissions reduction strategies.

In addition to directly calculated and reported carbon emissions, there are other, less tangible environmental effects from the ski industry. These impacts can include the effect of grooming, grading and manmade snow on underlying soil including negatively affecting pH, increasing erosion and negatively impacting local biodiversity [2]. Therefore, while it will be beneficial to quantify and discuss specific methods of reducing carbon emissions, the overall effect of a downhill ski resort on the local environment should also be considered when proposing sustainable resort improvements.

2.1.1 Implementation benefits and challenges

There has been significant study on specific methods of implementation, success, and economic implications of adopting sustainable practices in ski resorts. The success of implementation of sustainable initiatives at surveyed ski resorts could be attributed to three key factors: complexity, observability, and compatibility with employee and corporate culture [3]. Additionally, internal communication may help influence a positive opinion of sustainable initiatives among employees [3] and goal setting toward sustainability at all levels may ensure each level of employee understands the reasoning behind sustainability initiatives which can contribute to greater participation and support [4].

There may be some economic incentive to prioritizing environmentally sustainable initiatives as well, as customers may be attracted to resorts implementing sustainable initiatives and some resorts were shown to have outperformed stock goals due directly to the incorporation of sustainability initiatives. Additionally, incorporating sustainability initiatives in resorts has been shown to increase employee retention and overall satisfaction [4].

2.1.2 Ski resort emissions trends and challenges

A review of available NSAA data was conducted to observe key emissions trends over time and to identify planned reductions with high estimated carbon reductions [1], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16]. Reported emissions are given as Scope 1 (direct emission, such as fuel directly needed to run on site grooming equipment), Scope 2 (indirect, such as purchasing electricity for resort operations) and Scope 3 (other, such as food waste). Scope 2 emissions, which includes purchased external electricity, is a significant category for many resorts. To better understand the possible subcomponents of emissions in this category, the average of total electricity used based on source for NSAA reporting ski resorts is given in Table 1 below. While snowmaking and lift operations do account for significant electricity usage, building operations remain the most significant use of electricity at ski resorts.

***Table 1. Average electricity by end use, as self-reported by NSAA ski resorts** [1]*

Source	Average of total electricity
Buildings	43%
Lift Operations	27%
Snowmaking	15%
Uncategorized electricity	15%

During annual reporting, resorts estimate their annual emissions by type as well as propose reductions, including an impact estimate. The total number of Scope 1 and 2 emissions and proposed emission reductions is given in Figure 1.

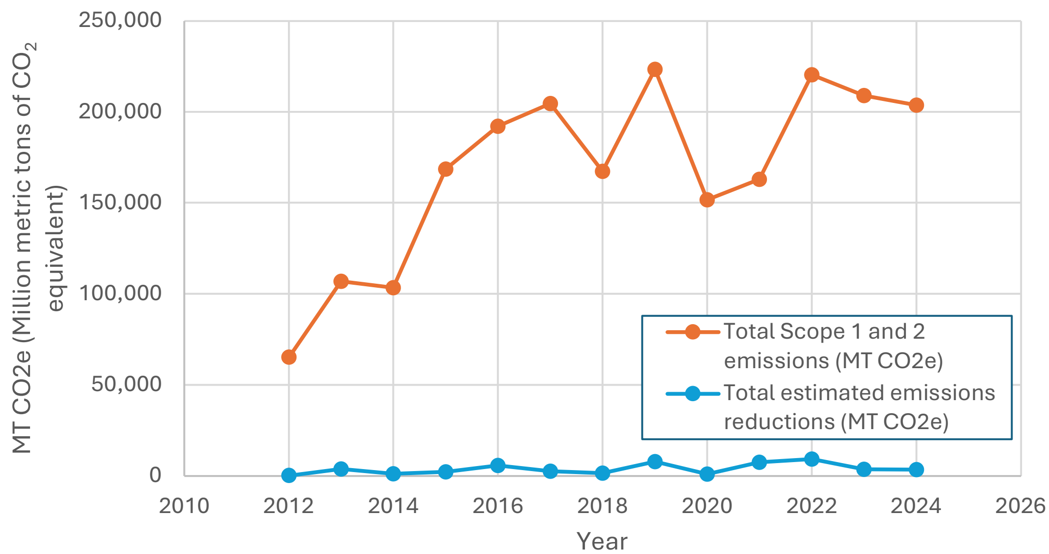

Figure 1. Total reported Scope 1 and 2 emissions and estimated reductions

The total amount of Scope 1 and 2 emissions has increased between 2012 and 2024, likely due to the increasing number of participating resorts. However, it can also be seen from Figure 1 that the estimated emissions reductions have remained relatively consistent, despite the significant increase in participating resorts and estimated emissions. A more accurate comparison is the average Scope 1 and 2 emissions per reporting ski resort, which is given in Figure 2 below.

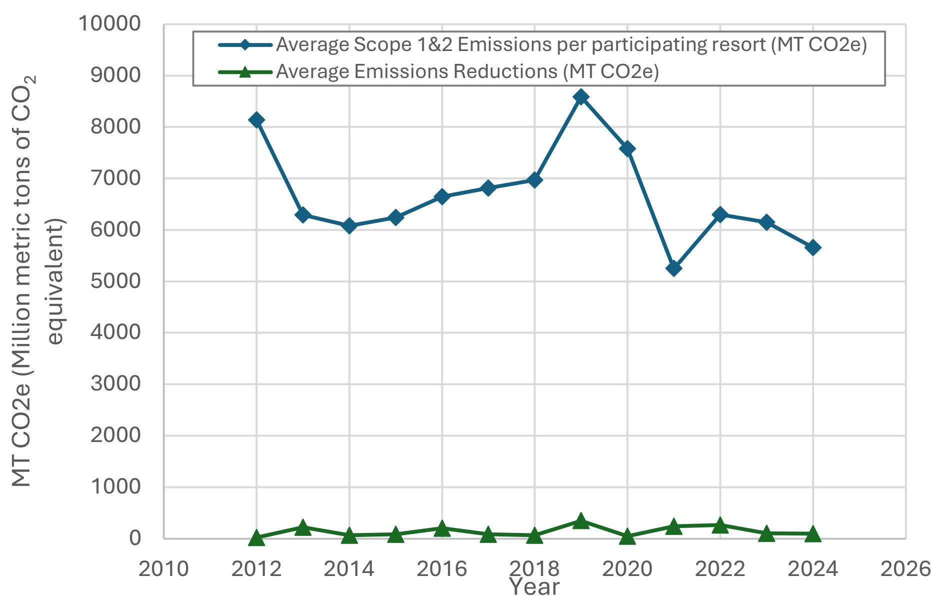

Figure 2. Average reported Scope 1 and 2 emissions and estimated reductions per ski resort

Figure 2 indicates that the average emissions reported per resort is generally trending downward, with a large disruption during the COVID19 pandemic and estimated emissions reductions per resort have remained relatively consistent. This downward trend of average emissions is most likely due to the implementation of planned initiatives to reduce resort emissions. Many resorts began reporting data for the challenge and proposed relatively straightforward reductions, including converting lighting to LEDs, replacing outdated heating systems or snowmaking guns with higher efficiency models. These gradual and incremental changes have worked to decrease the average Scope 1 and 2 emissions reported by resort. However, progress, while trending downward, remains relatively slow. Many ski resorts reporting for the challenge supplement their emissions estimates with Renewable Energy Certificate (REC) purchases and carbon offsets, as seen in Figure 3 below.

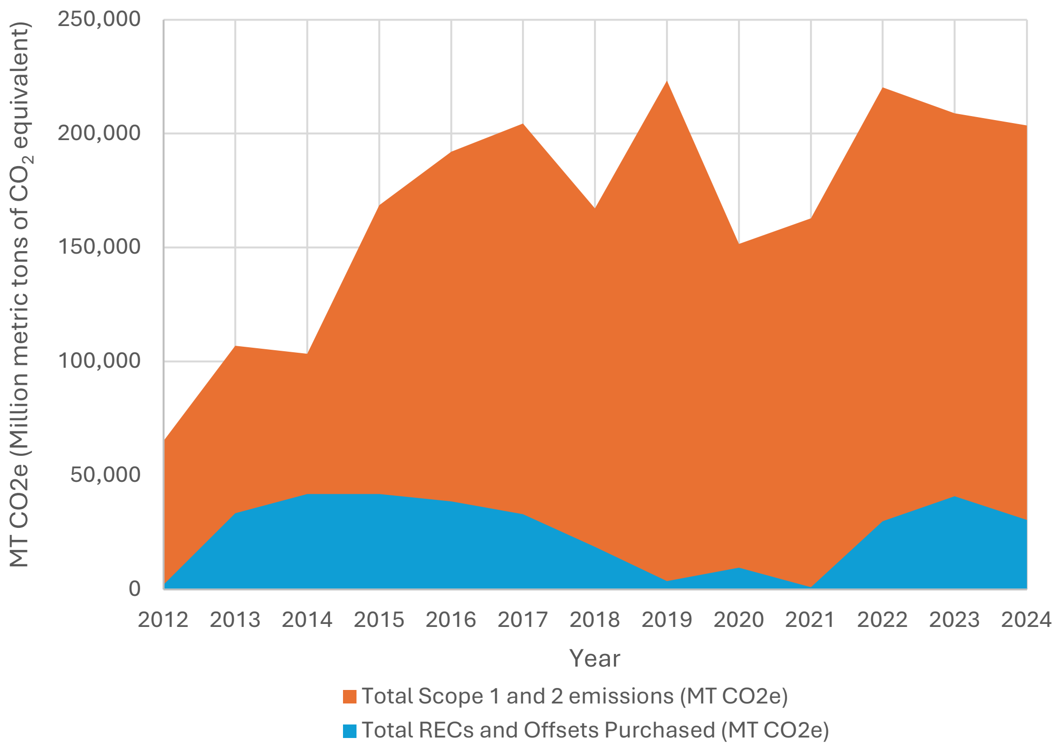

Figure 3. Total reported Scope 1 and 2 emissions and purchased RECs and carbon offsets

Figure 3 indicates that, as previously discussed, the total reported Scope 1 and 2 emissions have increased over time, likely due to the increase in reporting ski resorts. However, the amount of purchased RECs and carbon offsets has remained relatively constant, with a significant drop in 2019-2021 likely due to effects from the COVID 19 pandemic.

These trends have revealed that significantly reducing emissions has been challenging for ski resorts. Many have succeeded in purchasing RECs and carbon offsets but overall, there has been some struggle in significantly lowering overall ski resort emissions. The implementation of proposed initiatives and the purchasing of RECs and carbon offsets has shown an overall gradual decrease in emissions per reporting ski resort. However, significant emissions reduction remains challenging for many ski resorts.

2.1.3 Wintergreen Resort considerations

Wintergreen Resort is a four-season resort originally constructed in 1975 and includes an indoor/outdoor center, a spa, lodging, 45 holes of golf, 22 tennis courts in addition to 129 acres of skiable area specified for downhill skiing located near Nellysford, Virginia [17].

Wintergreen Resort currently enacts many different environmental actions and sustainability efforts. Most significantly, Wintergreen collaborates with The Wintergreen Nature Foundation (TWNF) for local conservation efforts and promoting environmental education. This includes donating $1 per night to each overnight guest's bill to TWNF which then matches this donation.

Current conservation initiatives enacted by Wintergreen include supporting Crawford's Knob Natural Preserve, a preserved wetlands space, reintroduction of the near-extinct American Chestnut, protection of 6,000 resort acres from further development, and the protection of endangered ecosystems to the Shamokin Springs Nature Preserve and the Allen Creek Nature Preserve.

Additionally, Wintergreen Resort currently excels in snowmaking related sustainable initiatives both from its water sourcing and snowmaking efficiency. Wintergreen Resort currently utilizes a closed loop water sourcing system for manufacturing snow, which includes the annual water collection of manufactured snow, which is stored for reuse. The automated snowmaking system, which ensures peak system efficiency of snowmaking equipment, results in a 10% reduction in energy.

In addition to snowmaking initiatives, building related initiatives include using low energy/motion sensor lights in public places and using low water use facilities in all public restrooms. [17]

Wintergreen Resort has unique considerations that may affect the proposal of certain initiatives, including size and geographic constraints. With only 129 skiable acres, Wintergreen Resort is considered a small ski resort and experiences specific issues of scale to resorts of this size. Smaller ski resorts experience economic issues when approaching larger sustainability initiatives and the cost effectiveness of some initiatives at larger scale may not apply to smaller ski resorts [18]. Additionally, higher altitude and larger ski resorts have been shown to more easily enact sustainable operations [19].

Wintergreen Resort also faces geographic obstacles, including being located at a relatively low elevation. It has been found that lower altitude resorts will exhibit increasing resource demand with climate change [2]. Additionally, Wintergreen Resort receives only 35" of natural snowfall per year [17] and relies completely on snowmaking for its ski resort operations. Wintergreen Resort is also located in the Southeastern United States. Scope 1 and 2 emissions as reported by ski areas by location are given in Figure 4 below [1]. Ski areas located in the Southeastern United States, including Wintergreen Resort, exhibit the highest overall emissions. More specifically, Southeastern United States ski resorts have significantly more Scope 2 emissions, indicating a significantly higher electricity use.

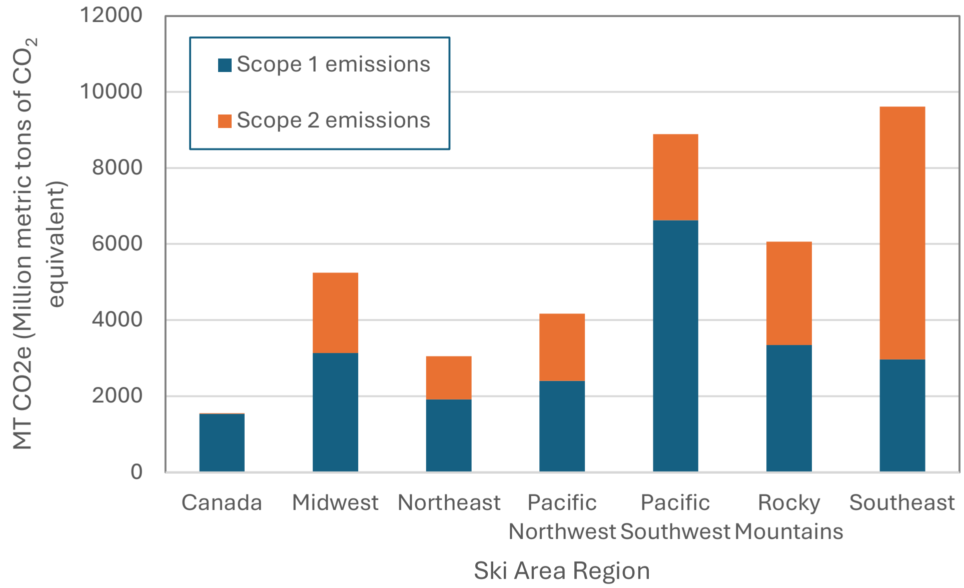

Figure 4. Scope 1 and 2 emissions comparison by ski area region

A significant obstacle for implementation of sustainable initiatives across Wintergreen Resort is the consideration of private property owners. Unlike many resorts, all lodging units at Wintergreen Resort are individually and privately owned. Sustainability initiatives may be proposed or suggested by the property management director but ultimately, the choice to adopt sustainable initiatives remains the decision of the individual private property owner. While Wintergreen Resort has implemented some significant building-efficiency initiatives, such as implementing LEDs, motion sensor lighting, energy efficient appliances, etc., these cannot be implemented on a larger scale throughout the entire resort property.

Therefore, proposed initiatives should consider the current industry recommendations, state of the industry challenges and obstacles, and opportunities that are unique to Wintergreen Resort.

2.2 Current state of practice

In order to effectively propose sustainability initiatives for Wintergreen Resort, a review of current state of the practice sustainability initiatives for downhill ski resorts was conducted. This included reviewing a selection of current research literature, current ski industry recommendations, and proposed initiatives from ski resorts with a high estimated impact on lowering carbon emissions.

There have been many research studies regarding the implementation and effectiveness of sustainability initiatives at recreational ski resorts. A study comparing sustainable initiatives across ski resorts in four Alpine countries found that several strategic initiatives were able to increase resort sustainability. Improvements to snowmaking, including increasing energy efficiency and water management systems critically improved snow production efficiency. Additionally, it was found that integrated energy management systems, specifically those that allow for real time monitoring, especially for monitoring ski lift energy consumption significantly reduced carbon emissions. The most strategic factors found to decrease carbon emissions included integrating renewable energy and digital monitoring systems and upgrading equipment for energy efficiency [20].

A different study, focusing on the sustainability of small, private ski clubs based in Ontario, Canada, found that key initiatives for these resorts included switching to light emitting diode (LED) lighting, prioritizing energy and water efficiency in lodges, buildings and within snowmaking and, for economic sustainability, diversification to other industries. Many resorts in this study focused on improving and automating snowmaking, which was found to have a large impact on emissions [21].

After a review of options for North American ski resorts, a different study synthesizing options for both economic and environmental sustainability suggested resorts obtain Leadership in Energy and Environmental Design (LEED) certification, apply for sustainability grant initiatives, hire a sustainability manager and consider using pass sharing between resorts [2].

2.2.1 Industry recommended initiatives

Several studies included recommendations of specific initiatives to lower resort emissions. In a study conducted by Goncalves et al [22] recommended sustainability initiatives were categorized into either “concerned citizen strategies” or “proactive initiatives”. A concerned citizen strategy. “deals with prevention and control measure such as reducing toxic emissions and waste, waste recycling, conserving energy and natural resources, or reducing the impact of the business on the ecosystem.” Proactive initiatives, by contrast, employ long-term processes to prioritize environmental improvement [22]. Profit increased when implementing voluntary green initiatives, VGI, categorized as either concerned citizen or proactive strategies, a list of suggested initiatives available to ski resorts included in this study are given in Table 2**Error! Reference source not found.** below.

Table 2. Voluntary Green Initiatives and Environmental Strategies *[22]*

VGI category	Environmental Strategies	Description
Transport	Concerned citizen	“Easy access”: access to the resort by public transport
		“Bus + ski pass package”: available at a discounted price
		“Sustainable mobility”: Alternative and environmentally friendly modes of transport
		“Incentives for car sharing”: Car sharing to get to the resort
Energy	Concerned citizen	“Wood heating”: the resort runs at least one wood-fueled boiler
		“Solar power”: Photovoltaic panels and/or a solar water heating system
		“Other sources of renewable energy”: Wind, micro hydroelectric, geothermal energy
		“Eco-consumption”: The local council and/or lift services take active steps to reduce energy consumption for the heating and lighting of offices/buildings and the resort

Table 2. Voluntary Green Initiatives and Environmental Strategies (continued) [22]

VGI category	Environmental Strategies	Description
Water, Rubbish, and Waste	Concerned citizen	“Recycling collection”: Recycling collection containers are in use within the Resort; and all houses and hotels/hostels within the area comply in sorting their waste, separating plastics and metals from general household rubbish
		“Information on recycling collection”: clear information is given concerning the local recycling possibilities and the whereabouts of these facilities
	Proactive	“Internal policies”: the local council, the lift services, or the tourist information office have an internal sustainability policy
Development and planning	Proactive	“Green building standards”: for the construction and renovation of new buildings
		“Incentives”: The local council encourages individuals to set up renewable energy systems by providing information and financial incentives to do so
		“Town planning”: the resort gives priority to refurbishing and renovation rather than extending the urban areas onto previously unbuilt land
		“Ski area management”: management of the ski area is exemplary and takes into account sustainability initiatives
		“Protected areas”: protected areas are present on the territory of the commune; they are enhanced by information

Most significantly, the International Ski and Snowboard Federation has published a guide, *Sustainability Guide for Ski Resorts* [23], which outlines fourteen key initiatives recommended for ski areas as they continue to enact sustainable initiatives. These include:

- Reducing energy consumption and carbon footprints of ski lifts
- Attaining 100% green electricity using a renewable energy mix
- Setting a net zero goal for 2050
- Adopting an effective piste management plan
- Conserving natural habitats
- Encouraging sustainable travel
- Introducing snow farming practices
- Implement snow pump technology with lower emissions and water use
- Achieve net zero waste
- Collaborate with key stakeholders
- Design more sustainable restaurants, cafes, and bars
- Design more sustainable accommodation (hotels, chalets and alpine huts)
- Conduct sustainable events
- Create a sustainability program

Altogether, it can be seen there are consistencies among the recommendations between resort study and industry analysis indicating there are distinct initiatives that can be effective for reducing carbon emissions at ski resorts.

2.2.2 High impact initiatives

In addition to emissions reporting, the NSAA annual report also includes planned emission reductions for participating ski resorts. Specific quantified reductions were reported for all resorts between 2019 and 2024 [1] [12], [13], [14], [15], [16]. To best identify trends reported, quantified emissions reductions were categorized into six broad categories based on type: building operations, electricity, on site fuel, recycling, snowmaking and transportation. Examples of types of proposed sustainability initiatives within each category are given in Table 3.

Table 3. Categories of Sustainability Initiatives and Examples

Initiative category	Sample initiatives
Snowmaking	Updating snow guns with higher efficiency models, installing automation systems for snowmaking operations
Building operations	Installing thermostat controls, installing energy efficient updates in buildings, retrofitting boilers and heating systems
On site fuel	Switching fuel types for heating, converting engines to biodiesel
Electricity	Installing solar arrays, generating alternative sources of energy, upgrading light efficiency
Transportation	Decreasing individual vehicle trips through shuttles and carpooling
Recycling	Implementing recycling or composting programs

Proposed high impact reductions were identified, defined as having an estimated reduction of greater than 80 million metric tons of CO_2 equivalent (MT CO_2e). The complete dataset of all high impact proposed initiatives proposed between 2019 and 2024 is given in Appendix A. A summary of the categorized high impact initiatives, including the cumulative estimated reductions by initiative category is given in Table 4 and shown in Figure 5.

Table 4. Cumulative reported emissions reduction, by type (2019-2024)

Initiative category	Cumulative reported reduction (2019-2024), MT CO_2e	Percent of total proposed high impact reductions
Snowmaking	2742	26%
Building operations	2622	24%
On site fuel	2174	20%
Electricity	1777	17%
Transportation	904	8%
Recycling	510	5%

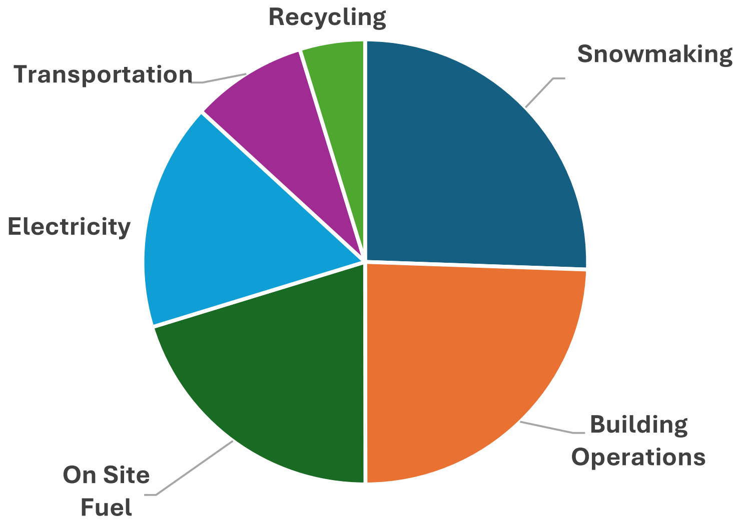

Figure 5. Proposed high impact sustainability initiative, by initiative category (2019 -2024)

Sustainable initiatives in snowmaking and building operations accounted for approximately half of all high impact proposed initiatives across resorts between 2019 and 2024. Snowmaking improvements most commonly included upgrading snowmaking equipment to newer, more efficient models, and automating snow production. Sustainable improvements to building operations were much broader and included updating ventilation and heating systems, boilers, compressors, and other improvements. On site fuel improvements also accounted for a large portion of high impact improvements, which included incorporating renewable diesel, biofuels, converting heavy equipment to electric vehicles, or incorporating more efficient fuel use into resort operations. Electricity improvements accounted for 17% of the total proportion of high impact reductions, most of which included updating lighting to LEDs, updating appliances or equipment to more efficient models, as well as incorporating renewable energy into operations. Transportation based initiatives, mostly comprised of carpooling incentives and initiatives, accounted for 8% of all high impact initiatives. Finally, recycling initiatives, including composting and improved recycling channels, accounted for 5% of all high impact initiatives.

2.2.3 Introduction to proposed initiatives

Following on-site observations, staff interviews, and discussions of current industry standards of sustainability initiatives, seven final initiatives were selected and proposed. Each initiative includes an emissions reduction estimate, a discussion of possible obstacles to implementation at Wintergreen, and examples of the successful implementation of this initiative elsewhere.

These seven selected initiatives are presented in three subcategories: operations updates, waste reduction initiatives, and broader environmental impact considerations. Operations update initiatives include updating the outdoor lighting system, using electronic based passes and updates to local roads and parking lots. Waste reduction initiatives include reducing food waste and reducing the use of single use plastics. Finally, broader environmental considerations include a discussion of the impact of Wintergreen on the local environment and improvements that could be made to increase soil and plant diversity as well as improving species diversity at the resort as well.

Following these initiatives, a final section of ideas in progress is presented. These ideas have not been fully developed, but are presented as ideas in progress that, with interest, could merit further development.

3. Operations Updates

This chapter presents proposed initiatives that increase efficiency of resort operations. This includes updating outdoor lighting systems, using electronic ski passes and updating the heating methods for local roads and parking lots. Emissions reduction estimates, examples of successful implementation at other resorts, and recommendations for implementation at Wintergreen are provided for each.

3.1 Lighting System Updates

This section will discuss the potential benefit from switching the exterior lighting at Wintergreen to LEDs. While this is a relatively simpler effort, successful implementation will create meaningful sustainable impacts at the resort.

Light-emitting diode (LED) lights are a more energy efficient and longer lasting alternative to commonly used high-intensity discharge (HID) lights that are used at various ski resorts. Compared to HIDs, LED lights have a longer lifespan of over 100,000 hours of usage compared to HID's span of 10,000-25,000 hours allowing for less frequent replacements [24].LEDs provide high quality lighting with minimal waste energy from infrared radiation and lighting towards unneeded directions. Additionally, the diodes do not need time to warm-up or cool-down given the nature of the semiconductor lighting device.

Wintergreen Resort has already implemented several energy-efficient initiatives involving LED lights and related energy efficiency. These include the use of low energy light and motion detectors, LEDs for the Christmas Grand Illumination display, and the use of LEDs in indoor spaces at the resort [17]. In contrast to this, there are still outdated lighting fixtures in terms of energy efficiency, which do not host LED lights, along various slopes at Wintergreen, as shown in Figure 6. There are also LED replacements that could be made to other outdoor lighting fixtures around the lodge such as at the ticket box, along sidewalks, and at some parking lots.

Figure 6. Light at Big Acorn ski-lift

Based on observations at Wintergreen Resort, there are approximately 8-10 light posts for each slope that is used for night skiing. And for each of these posts there are around 3-4 individual light units' position on these posts to illuminate a wide area of the slope around it. With this information and the understanding of the 13 areas of Wintergreen that feature slope lights, according to the Wintergreen resort map shown in Figure 7, it can be estimated that there are approximately 200 individual lights that are used to illuminate ski areas. This approximation will provide a reasonable baseline for subsequent energy consumption analyses and implementation considerations.

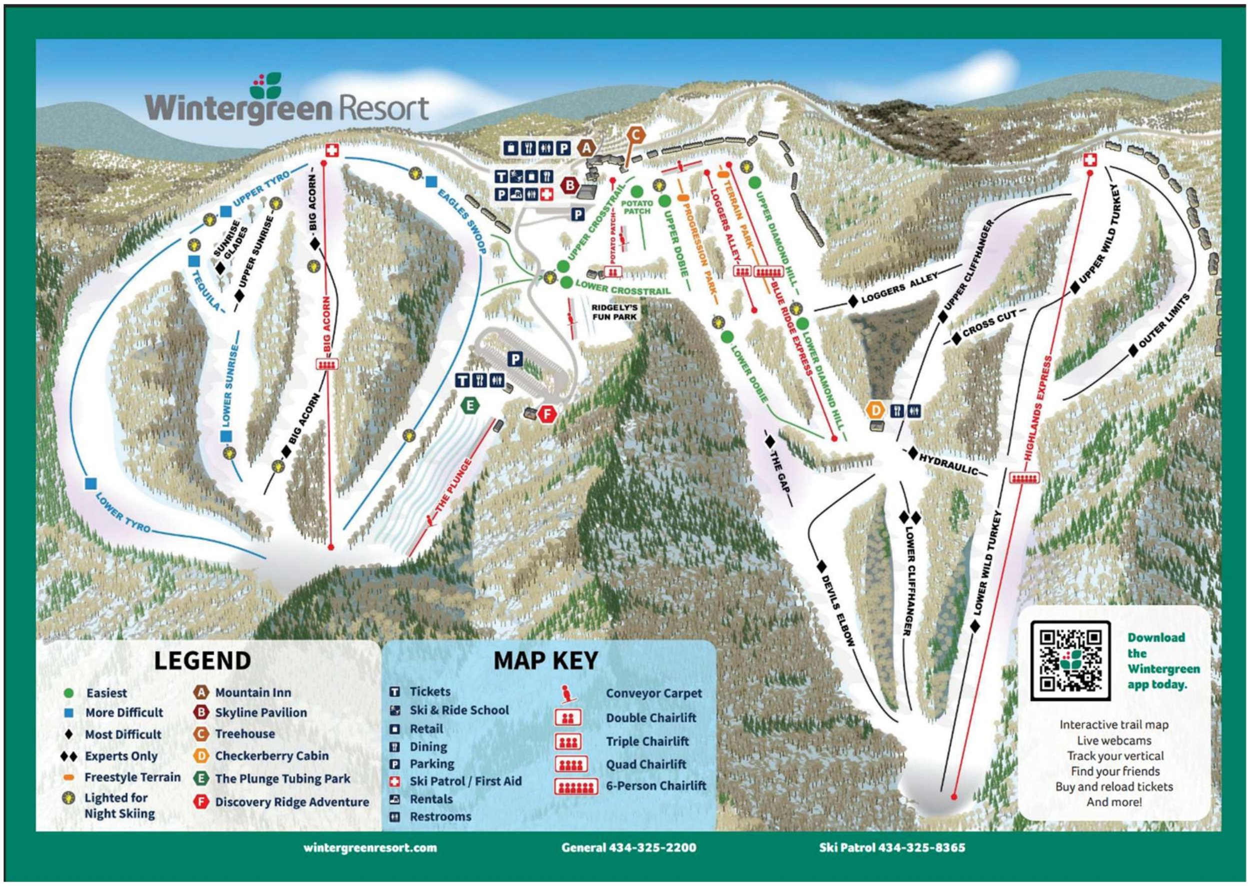

***Figure 7. Wintergreen Ski Trail Map** [17]*

3.1.1 Examples of successful implementation

A summary of examples of successful implementation of updating lighting systems at other recreational ski resorts is given in Table 5 below.

Table 5. Summary of successful implementation of lighting system updates

Ski Resort (Location)	Implementation	Impact/Notes
Massanutten Resort, VA	Resort is currently transitioning their metal halide lights to LEDs.	• They expect the switch to save them 41,000 kWh per year from the ski area lights alone [25]. • Massanutten has 82 acres of ski-able area as opposed to Wintergreen's 129 acres. • All the resort's slopes have night skiing lighting unlike Wintergreen which only has 54% night skiing lighting.
Boyne Mountain Resort, MI	Upgraded 800 fluorescent lights by retrofitting them with T8 LED tubes.	• Projected to provide approximately 70,000 kWh in annual energy savings. A estimated reduction of 37 metric tons of CO_2 equivalent (MT CO_2e) each year [1].
Crystal Mountain, WA	Upgraded all 23 of their night skiing light fixtures to LEDs.	• Provided an energy reduction of 85%. This provided improved lighting quality, energy efficiency, and less maintenance. [1].
Wachusett Mountain, MA	Converted from 1,000-watt HID lights to 400-watt LED lights in 2017.	• The cost of using the 500 metal halide lights at Wachusett Mountain ski trails contributes $100,000 to the resort's energy bill in 2016 [26]. • Energy costs dropped by 75%. Additionally, a local power company assisted in the retrofitting effort by offsetting their investment by $300,000. • The mountain is also able to digitally adjust the output of the LEDs since they are "smart" LuxTronic fixtures which communicate via wireless controller, allowing for greater energy efficiency.

3.1.2 Impact estimate

The intended benefit from this upgrade would be an increase in energy efficiency and a decrease in electricity consumption. To establish an accurate estimate, several variables for this equation need to be determined:

- Operating Hours, ***O***
  - For Wintergreen, night skiing starts at 4PM and occurs from 4PM-9PM on Thursday-Saturdays, or 5 hours per day. From Sunday-Wednesday, the slopes are only open until 5PM, and for those days, estimate 2 hours per day of lighting required. With these values totaled together, the weekly operating hours that require lighting are **23 hours per week**.
- Season Length, ***L***
  - Wintergreen ski season is from December to mid-March which is about **15 weeks** of operation.
- Number of Lights, ***n***
  - Will utilize the estimated **200 HID lights** from previous estimate based on site observations
- HID Energy Usage, ***HE***
  - Average consumption of **400 watts** [27].
- LED Energy Usage, ***LE***
  - Average consumption of **100 watts** for an equivalent brightness [28].

With these variables set, the weekly energy consumption can be calculated for both options at Wintergreen:

$$num\ of\ lights * light\ energy\ usage * operating\ hours$$

*(1) HID lights: 200 * 400 * 23 = 1,840,000Wh* ***= 1840kWh***

*(2) LED lights: 200 * 100 * 23 = 460,000Wh* ***= 460kWh***

Thus, the weekly energy savings achieved with LED lighting can be calculated:

$$HID\ weekly\ energy\ cost - LED\ energy\ cost$$

(1) 1,840kWh – 460kWh ***= 1380kWh*** *saved per week*

or

*Weekly energy cost * length of Wintergreen ski season*

(2) 1380 kWh 15 weeks* ***= 20,700kWh*** *saved per ski season*

Based on average Virginia commercial electricity rates, **9.05 cents** can be estimated as a cost per kilowatt hour [29]. The weekly cost savings should be:

$$weekly\ energy\ cost * cost\ per\ kWh$$

*(1) 1,380kWh * 0.0905 =* ***$124.59*** *saved per week*

or

$$Savings\ per\ week * Wintergreen\ ski\ season\ length$$

*(2) 124.59 * 15 =* ***$1,868.85*** *saved per ski season*

As shown, there are financial and energy incentives from implementing LED lighting on the ski slopes. This also does not count for various other LED lighting opportunities around the lodge and parking lots. Over the lifespan of an LED light (around 100,000 hours), the money saved over the lifespan of one installation of LEDs can be calculated:

$$\frac{LED\ lifespan}{operating\ hours} = LED\ lifespan\ (weeks)$$

(1) 100,000/23 = ~4,348 weeks

LED lifespan in weeks * savings per week = total savings over LED lifespan

*(2) 124.59 * 4,348 =* ***$541,717.32*** *total savings over LED lifespan*

By installing LEDs, Wintergreen can save just over half a million dollars in energy costs over the lifespan of one installation of LEDs.

3.1.1 Implementation considerations and recommendations

Given the number of lights used currently at the resort, updating to LEDs should be a simple operation. Regarding calculations done in the impact estimate section, the switch should pay for itself over the years, including light costs and labor. Furthermore, since Wintergreen is not a year-long ski resort location, it is recommended updates should occur during the summer and without the concern of snow during the process. Depending on the wiring within the current light fixtures, the LEDs may be able to be retrofitted to existing light poles. If not, new light poles or wiring may be needed. Alternatively, lighting may be updated as the lights are replaced regularly at the end of their service life.

3.2 Use of Electronic Passes

Every visitor to Wintergreen using the slopes currently needs a physical lift pass. In addition to the reusable physical lift passes, single-use lift tickets and rental/lesson tickets are also being used. The adoption of digital lift passes would increase convenience for visitors and reduce unnecessary waste and emissions from pass manufacturing and distribution.

Many ski resorts currently use Radio Frequency ID (RFID) cards for lift passes. At the bottom of the lift, skiers enter through an RFID scanner gate which opens on scanning their pass. A current major manufacturer of lift gates is Axess [30]. As can be seen in Figure 8 below, the pass scanner (orange) is located on the left side of the ticket gate. A skier will usually place the RFID card on their left side, either in a pocket or sometimes in a slot on their glove. When the pass comes in proximity to the scanner, around 45cm or less, it is detected, and the gate opens.

Figure 8: Axess AX500 Smart Gate NG Ski Lift Ticket Gate *[30]*

In addition to lift gates, Axess also manufactures compatible RFID cards [31]. These cards use ISO 15693 standard RFID chips, which are noted to have a range of around 45cm [32]. Axess manufactures several different types of cards; in addition to standard offerings of single and multi-use cards, they also offer more eco-friendly alternatives, such as the LITE CARD ORGANIC, which is made of recyclable paper [33]. The existence of these offerings demonstrates an awareness of the waste production of these cards and the value in finding alternatives.

A report by MasterCard outlines guidelines for creating sustainable cards - desirable materials include recycled PVC (rPVC), PLA, PETG, wood, and others. Materials like PLA are more sustainable since they can be derived from biodegradable and renewable sources, while materials like recycled PVC use existing material to reduce waste. The report also emphasizes the importance of considering full card lifecycle - certain materials can have negative impacts in a landfill or when incinerated [34].

Despite their effectiveness, these RFID gate systems have some drawbacks. Each visitor is required to have a physical pass, which results in a resort needing to purchase, format, and distribute many of these RFID passes. It would be environmentally and logistically beneficial to remove the necessity for these physical passes and would save money on purchasing RFID cards. Skiers would also be able to purchase and activate passes entirely digitally, so ticket window and pass distribution operations could become leaner and more efficient. Another drawback to RFID passes is that they are easily lost and potentially damaged by proximity to electronics like smartphones, so skiers must exercise caution in keeping track of their pass. Since most skiers will already have a smartphone, a digital pass would add no further burden of belongings to keep track of. For these reasons, it would be beneficial to implement a digital pass system at Wintergreen.

3.2.1 Examples of successful implementation

There are several examples of digital ski passes being successfully implemented, although their use is currently not very widespread. This presents an opportunity for Wintergreen to be a leader in a new direction of sustainability efforts for ski resorts.

Low energy Bluetooth (BLE) is the current most popular choice for digital lift passes. BLE is designed for very low power consumption, which is ideal for a mainly passive function like a digital pass. The technology also supports detection of device position and distance, which is useful for recognizing a skier passing through a gate [35].

Firstly, the widely used EPIC ski pass offers a digital pass solution as part of their mobile app [36]. This solution uses BLE technology to scan through the lift gate using a mobile phone. The digital pass is available for use at 37 Vail-owned resorts in North America.

Axess has also developed a digital ski pass solution, along with a compatible lift gate, as shown in Figure 9. The new gate allows for detection of both RFID and digital BLE passes. Their documentation for the gate emphasizes the benefits of secure digital pass storage and reduced cost through less use of RFID passes [37]. The digital pass is purchased online and stored on the Axess SKI WALLET app [38]. This solution is currently being used at Patscherkofel and Axamer Lizum ski areas in Austria [39]. Axess lift gates are currently used at Wintergreen, making this solution a strong contender for adoption.

***Figure 9: Axess AX500 Smart Gate NG BLE** [37]*

Another solution is offered by Skidata, also in the form of a mobile app [40]. This solution has been adopted by several resorts, including KitzSki, Saalbach-Hinterglemm, Levi, Sierra Nevada, Tatry Super Ski, and more [41], [42]. In their statement about the launch of this technology at their resort, Finland's Levi ski resort emphasized how the solution will help them reduce plastic waste significantly.

Finally, the popular Indy Pass is also rolling out a digital pass solution designed by Entabeni Systems, beginning at Magic Mountain, Beaver Mountain, and Bluewood resorts [43].

Overall, it is clear that ski areas around the world are pushing for more digital ski pass solutions, thanks to reduced waste, saved costs, convenience for skiers, and improved operations efficiency.

3.2.2 Impact estimate

The impact of implementing digital ski passes at Wintergreen will come in the form of reduced waste and increased operations efficiency. First, an estimate of the reduction in carbon emissions from phasing out physical RFID cards will be calculated. These estimates will be made in terms of reduction per 1000 visitors; exact figures can then be determined based on Wintergreen's visitation statistics.

Taking into account visitors with season passes, occasional visitors with single use passes, and recurring visitors with reusable passes, an estimated average of 1 pass distributed per visitor will be used.

Research on the emissions impact of plastic card manufacturing indicates that one plastic card results in approximately 150 grams of CO_2 equivalent greenhouse gas emissions [44]. Transporting the cards to Wintergreen would further increase the associated emissions. This produces at least 150kg of CO_2 equivalent emissions per 1000 visitors. If Wintergreen received 50,000 visitors in a single season, this would represent 8 tons of CO_2 equivalent emissions.

Assuming that Wintergreen began a gradual incorporation of digital passes, it should be possible to achieve a 50% adoption rate within 5 years. This would represent a 75kg CO_2 equivalent emission reduction per 1000 visitors per season within 5 years.

Wintergreen would also see benefits from improved operations efficiency. With many passes being digitally purchased and distributed, burden would be removed from ticket windows, and employees would be free to work in other areas of the resort to improve efficiency.

Additionally, RFID cards cost around $20 per 100 cards to purchase. A 50% reduction in physical cards distributed would represent a savings of at least $100 per 1000 visitors per season.

3.2.3 Implementation considerations and recommendations

Given that Wintergreen is already using lift gates manufactured by Axess, it would be easiest to use their existing digital pass solution for a seamless transition to digital passes. The backwards compatibility with existing RFID cards and familiarity to resort visitors should make for an easy transition.

Wintergreen will need to make an upfront investment in purchasing the new lift gates compatible with BLE technology. If there are any gates that are old or malfunctioning, it may be best to first replace only those gates with the new, BLE-compatible ones and run those gates as a pilot program. Wintergreen should perform a cost-benefit analysis based on their exact visitation numbers to determine the timeframe for payoff on the investment based on reduced costs from RFID pass purchase and the upfront cost of purchasing new lift gates.

Given that there will likely be guests who do not want to immediately switch to a digital pass, it would be beneficial to keep RFID cards for the near future, but swapping to a more sustainable offering like those by Axess would be best. Additionally, it could be effective to require a small deposit on each pass distributed, with the deposit returned upon returning the pass. This would make it possible for Wintergreen to maintain and reuse a much smaller number of physical passes. Wintergreen would also be able to ensure proper disposal of those passes for maximum sustainability.

Although the sustainability impact of this solution is relatively small compared to the resort's major operations, every incremental improvement will count in the end. This solution is immediately beneficial to the resort's visitors and presents long-term benefits for Wintergreen's operations, making it worth considering for implementation in the near future.

3.3 Local Road Maintenance

Road and pathway management is a necessary part of any operation and grows more important as scale increases. Ensuring that this infrastructure remains functional as it ages with minimal maintenance is preferred. Identifying materials or systems that can improve this infrastructure and implementing them could result in a meaningful reduction in both cost and carbon emissions.

Roads and pathways, especially in the parking lot area, were observed to be in poor condition. Freeze/thaw cycles and plowing have shortened the lifespan of asphalt that is already highly trafficked. Hydronic heat exchangers, which warm roadways from below the pavement surface, can increase the longevity of pavements in cold climates and reduce the need for plowing. This could also mitigate salting, resulting in environmental benefits. A hydronic heat exchanger is a series of pipes connected to a pump that circulates a warm liquid and is able to hold a surface just above freezing, preventing snow and ice from accumulating [45]. These systems absorb heat when it is available and store it in large underground reservoirs. The liquids chosen maintain heat very well and the pipes are insulated, resulting in warmth extending far past the energy being applied to the system. Figure 10 provides an example of a hydronic heat exchanger being used to warm a bridge using solar power. The reservoirs in the mountain contain warm liquid that is circulated.

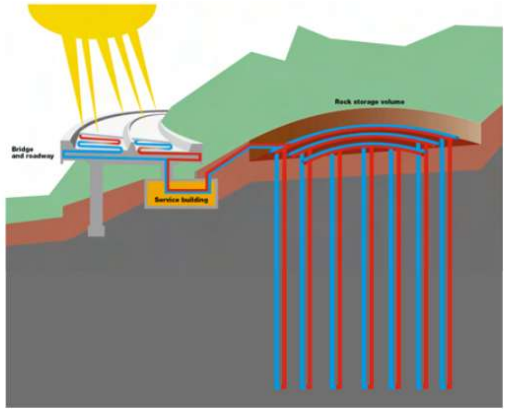

Figure 10. Example of a hydronic heat exchanger [46]

Possibilities for heating the liquid include an existing HVAC system, a geothermal unit, excess heat from other operations, or the sun [46]. The solution chosen depends on the existing infrastructure, with some resulting in almost no carbon footprint. Alternatively, electric coil systems can provide similar benefits, with the main advantage of warming instantly and independence from external factors [46]. Electric systems function by generating resistance in a lattice of copper wires [47]. Electric heating also has a lower thermal mass, which allows for quick heating, but also more energy required to maintain the heat. This solution is best used in smaller and more confined spaces. Figure 11 shows an alternative method of pavement heating, electric wiring.

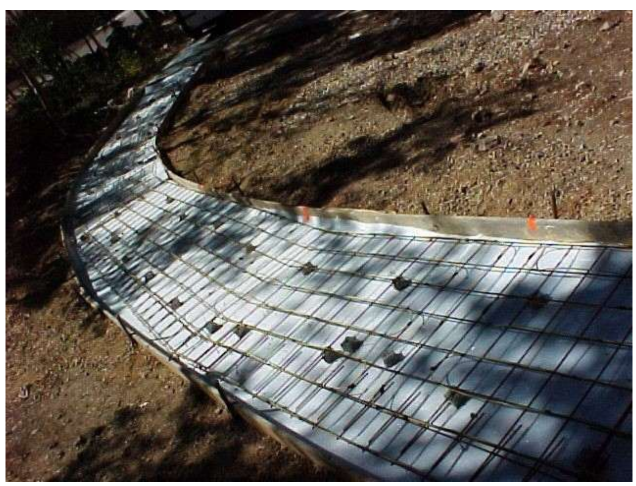

Figure 11. Implementation of electric heating in a sidewalk *[47]*

The most obvious drawback of a hydronic heat exchanger is that it is dependent on external factors for the warmth. If the system depends on energy from the sun to maintain heat throughout the winter, weather could affect the snow melting capacity. A system that relies on HVAC requires electricity but does not have this issue, although this alternative represents more CO_2e emissions.

The current solution at Wintergreen is to hire external plowing companies as well as using a company fleet to ensure that all roads within and leading to Wintergreen are properly salted and plowed. However, these vehicles take up space on the road and are unable to immediately remove snow, resulting in icing and traffic. This combination creates danger for motorists and pedestrians alike. By using a hydronic heating system, the snow can melt as it falls, mitigating accumulation in all but the most dangerous conditions.

Additionally, heavy salting is employed on pedestrian walkways that cannot easily be shoveled, resulting in slipping and damaging the insides of buildings, as well as severe environmental harm. It also requires a significant amount of manpower to track all sidewalks on the property and clear them off as snow accumulates. **Figure 12** is the result of current snow removal techniques.

Figure 12. Crumbling sidewalk crossing parking lot

3.3.1 Examples of successful implementation

Most notably, Vail Resorts has successfully implemented natural gas heated roads and pedestrian sidewalks [48]. This system maintains a road surface temperature of at least 32 degrees resulting in significantly reduced snow build up [48]. These heaters are implemented in locations that are expensive and inconvenient to clear with shovels or plows, while areas that are large are still manually cleared. The solution that Vail chose relies on a natural gas boiler due to the limitations of their system, causing the price to fluctuate with the natural gas market. Originally, the cost was the same as traditional plowing and salting, although in recent years the price of natural gas has increased, resulting in a slight imbalance [48]. However, the cost of plowing is dependent on the price of gasoline, so a tradeoff of fossil fuel prices will usually be the determining factor on price.

Initially, many people were opposed to melting all snow on the roads because it takes away from the majestic atmosphere of a resort [48]. Other benefits include easier deliveries and less mess resulting from the plows damaging roads.

Next steps that Vail plans to take include expanding the system to cover more roads and attempting to shift to a renewable energy source to heat the liquid. Proposals included solar energy, which was found to be most likely not possible [48].

Avon employs a similar heating system, with the notable exception being that they draw their heat from a wastewater treatment plant instead of a single-purpose boiler [49]. Originally, the proposal called for a large boiler, which drew criticism by the town council. The proposal was then amended to draw heat from the wastewater treatment plant, which was cited as the main reason the proposal was passed. This system melts snow that falls on downtown pedestrian walkways and not roads, resulting in a much smaller scope than the Vail operation. This project cost around $3 million to implement, with most of that coming from the heat-pump system. While the upfront cost is significant, the per year cost of upkeep is $350,000, while traditional snowmelt would have cost at least $513,000. In Avon's case, utilizing heat from an already existing source resulted in both longer-term environmental and economic benefits.

Deer Valley resort also has heated walkways between slopes and buildings, totaling over 2,000 square feet [47]. These sidewalks utilize the wire heating system, requiring constant power to function. They have lasted for 16 years, but are covered under warranty for 25. Wire systems fully rely on electricity, the sustainability of which is dependent on generation.

Each of these instances represents a way a ski resort implemented some form of road heating to prevent snow buildup in heavily trafficked areas, whether they are pedestrian walkways or windy roads. They represent three unique methods of surface heating, either by gas boiler, excess heat, or electricity. Each presents different benefits including consistency, cost, and speed respectively. Each solution has different downsides as well, which are market dependency, reliance on external factors, and emissions.

3.3.2 Impact estimate

Once installed, hydronic heat exchangers surpass alternative snow-melt operations with regards to carbon emissions. Hydronic heating systems produce 18% less MT CO_2e than road salts per square foot [45]. On top of that, plows burn an average of 1.5 gallons of fuel per hour, resulting in 30 pounds of CO_2e released [50] [51] [52] [53]. It only costs 11 pounds of CO_2e per square mile to construct a system that will last for 50 years [45] The operating costs of a hydronic heat exchanger with regards to carbon output is approximately 60 $lbs/mi^2/hr$, which is around twice a snow plow, however, typically more than one plow is necessary to keep an area clear [45]. This estimate assumes that all heat put into the system comes from existing sources, such as the sun, other machinery, or geothermal energy. The largest sources of CO_2 in a hydronic system are the road itself and the creation of the piping system [45]. Additionally, added construction emissions will be incurred, but the longevity of the system, which can be up to 50 years, will lengthen the lifespan of the road, reducing the associated emissions. Since the asphalt itself is the single largest contributor to emissions within the system, any action to increase the time it is functional vastly reduces the generated carbon emissions, all while making roads safer.

Cost associated with this estimate place hydronic heating systems at around $15 per square foot and the parking lot and access roads that can most directly benefit are about 0.001 square miles, resulting in roughly $25 to $60 million with additional landscaping costs [54]. Despite the high cost, repaving parking lots is also quite expensive at around $3 per square foot [55]. Many costs associated with plowing and salting will be heavily reduced by a hydronic heat exchanger, which typically lasts for up to 50 years. Installing a hydronic heat exchanger would result in savings over its 50-year lifespan if more than $1.2 million is spent on snow removal that would be mitigated by this new system. Current costs associated with frequent resurfacing, plowing, shoveling, and salting can be safely assumed to be at least $1 million per year, accounting for employee and contractor wages, equipment, and fuel. There are clear environmental benefits to implementing a hydronic heat exchange system at Wintergreen, while the economic benefits depend on the cost of the current system as well as the longevity of the hydronic heating system.

4. Waste Reduction

This chapter presents proposed initiatives that will reduce resort waste production, specifically Scope 3 emissions. This includes reducing food waste and reducing the use of single use plastics. Emissions reduction estimates, examples of successful implementation at other resorts, and recommendations for implementation at Wintergreen are provided for each.

4.1 Food Waste

While not specifically ski related, food waste can be a very unsustainable area of ski resort operations. Implementing new ways to decrease the amount of waste toward landfills would increase the overall sustainability of the resort.

Food waste breaking down in landfills produces methane gas – a harmful greenhouse gas. In contrast, food waste decomposed in a compost bin produces carbon dioxide due to the presence of oxygen. Unlike landfills where the food waste is buried under other waste, creating an environment lacking oxygen, compost bins allow for the flow of oxygen causing a different chemical reaction. Carbon dioxide is much better than methane for the atmosphere as evidenced by the high amount of heat methane gas absorbs and traps in the atmosphere compared to carbon dioxide, a ratio of 28 to 1 [56]. Reducing the amount of food waste Wintergreen sends to landfills will reduce the impact the resort has on the atmosphere and improve its sustainability.

Currently, Wintergreen Resort has a trash and recycling system that utilizes Nelson County's Collection Centers. The system allows for the collection and compacting of the resort's trash and garbage in addition to the recycling of certain waste. The county recycles the resort's, "corrugated cardboard, mixed paper, metal food cans (aluminum, tin, steel, or bi-metal), and plastic containers," [57]. Notably, the trash and recycling plan does not address food waste, implying it is managed in the same manner as non-recyclable waste—compacted and sent to a landfill. This assumption is supported by the absence of dedicated food waste bins at the resort during resort observation.

4.1.1 Examples of successful implementation

Other ski resorts around the United States have successfully, or are currently in the process of, implementing more sustainable food waste disposal programs.

Crested Butte Mountain Resort (CMBR) in Colorado has been working to achieve zero waste to landfills by 2030. Part of this involves introducing composting of food scraps and compostable packaging. The resort began this program in 2019 with composting kitchen scraps only, but now compost scraps from all food locations and events hosted at the resort. At cafeterias, the resort now includes compost bins along with the standard trash and recycling ones in addition to clear signage. For table service locations, employees are trained to sort waste based on whether it is compostable, recyclable, or neither. By 2021, the parent company of Crested Butte Mountain Resort, Vail Resorts, reported a 41.7% waste diversion from landfills and an overall reduced waste of 483 tons [58].

The ALTA Environmental Center (ALTAEC) working at ALTA Ski Areas in Utah has also worked to establish more sustainable waste management. In 2019, the resort had a temporary agreement with Wasatch Resource Recovery to process their food waste. Wasatch Resource Recovery is a facility that "...processes organic waste which includes food scraps, liquid waste and manufacturing food waste..." and turns the waste into biogas and fertilizers [59]. In 2021, the ALTAEC set up a second pilot program with a different facility that accomplishes similar processing of waste. Similar to Crested Butte Mountain Resort, ALTAEC set up new composting bins around the dining areas for guests to utilize and for the resort to collect the waste to be transported. Their staff was likewise trained to answer questions from guests about proper waste sorting [56].

Composting is a very common practice at many resorts to help reduce the amount of food waste ending up in landfills. Table 6 lists a few other resorts in the United States that also have composting programs, as well as the reductions in greenhouse gas emissions they have achieved.

***Table 6. Highlighted reduction reported by ski resorts implementing food waste composting** [12], [13], [14], [15], [16]*

Resort	State	Dates Tracked	Metric Tons of Carbon Dioxide ($MTCO_2E$) Reduction
Snowbird Ski and Summer Resort	Utah	Sept. 2022 – Oct. 2023	28
Sugarloaf Resort	Maine	May 2022 – April 2023	0.7
Solitude Mountain Resort	Utah	Aug. 2022 – July 2023	1.6
Arapahoe Basin Ski Area	Colorado	Oct. 2020 – Sept. 2021	<1
The Highlands	Michigan	Jan. 2021 – Dec. 2021	3

4.1.2 Impact estimate

The biggest impact estimator is the amount of food waste diverted from landfills. While the estimation process will be different depending on how Wintergreen decides to divert the waste, and where to, the weight of the waste would serve as a valuable metric for monitoring and evaluating waste management performance. Additionally, the reduction in waste transported to landfills could also make for an acceptable metric as the food waste is currently included in that total.

CMBR in Colorado, which implemented food waste diversion practices described earlier, recorded 10.11 tons (20,220 pounds) of food waste diverted from landfills in the 2020-21 ski season [58]. In 2021, Brighton Ski Resort in Utah implemented a similar program and in three months diverted almost 10,000 pounds of food waste. This program did not include public composting bins, only internal waste. According to the sustainability director at the resort, the resort could save $35 per pound of food waste kept out of its trash after establishing a more expansive system [61].

The amount of food waste Wintergreen resort produces is unknown, although the impact per ton can be estimated. The Environmental Protection Agency's Waste Reduction Model (WARM), "...provide[s] high-level comparisons of potential greenhouse gas emissions reductions, energy savings, and economic impacts…" [62]. According to WARM, for every ton of food waste landfilled, there is 0.5 metric tons of carbon dioxide ($MTCO_2e$) equivalent released into the atmosphere; while for composting the same 1 ton of food waste there is only 0.15 $MTCO_2e$ [62]. This results in a 70% reduction of greenhouse gas emissions for every ton of food waste that is composted instead of landfilled.

4.1.3 Implementation considerations and recommendations

One way Wintergreen Resort can work toward more sustainable food waste management procedures is by following steps other ski resorts and hotels have taken. Composting appears to be the most implemented food waste reduction technique according to the literature on the topic. To achieve this, Wintergreen should partner with local waste management or a composting company to utilize their services. One such company is Black Bear Composting in Crozet, Virginia. They provide collection equipment for business and collect waste at regular intervals to take back to their composting center [63]. In addition, new composting bins with clear and concise signage should then be installed around most guest areas (especially food and lodging areas) to collect food waste as well as any other compostable items. To track progress, the amount of composted waste, in tons, can be tracked from year to year to see how these changes, and future initiatives, impact the amount of waste being diverted from landfills.

4.2 Single Use Plastics

This section focuses on how Wintergreen can reduce single-use plastics and the alternatives they can implement instead. This can be through eliminating single-use plastics all together and implementing better recycling procedures. Emissions reduction estimates, examples of successful implementation at other resorts, and recommendations for implementation at Wintergreen are provided.

4.2.1 Examples of successful implementation

Other ski resorts have successfully implemented plans to reduce plastic usage and waste. Steamboat Ski and Resort Corp.'s is one resort that is committed to reducing single-use plastics in the resort. One way they did this was by shipping the plastic bags from their rental and retail locations to a company that recycles bag to bag in order to reduce their plastic waste [15]. Another plan they implemented was contacting their beverage partner, Coca-Cola, to switch from plastic bottles to either fountain drinks or aluminum cans [15]. Schweitzer's in Idaho, also contacted their beverage provider Coca-Cola to have them recycle their products as there is a lack of recycling facilities in their area. This has led to "approximately 15 large pallets of plastic and aluminum saved from the waste stream" [14]. In 2022, they continued their efforts to reduce single-use plastic. They focused their efforts on reducing single-use plastic water bottles. They added six new drinking fountains and bought 1500 reusable water bottles. These were given to all the passholders and employees to promote the use of the reusable water bottles. Another resort is Mount Washington Alpine Resort [13]. One idea they implemented was sorting out the recycling with proper bins and signage. In the early stages they also focused on education for the skiers. They planned to have educational signs behind their water bottle filling stations to promote the use of them rather than plastic water bottles thrown out after one use. Snowbird in Utah has been able to decrease their usage of single-use plastic water bottles by guests by 1.3% [12]. They have done this by increasing their sales and giveaway of their reusable water bottles by over 75% [12]. They have given out the reusable water bottles as an incentive for doing other sustainable practices such as ridesharing. Another change they made was switching the single-use plastic bags to reusable and paper bags in their retail stores. These ski resorts have set an example for how to implement sustainable initiatives to reduce the use of single-use plastic and dispose of plastic waste properly.

4.2.2 Impact estimate

The estimate of impact will depend on how Wintergreen chooses to implement the different ideas. The best way to estimate this is the carbon dioxide emissions from single-use plastic. According to the study by Di Paolo et al., the amount of carbon dioxide emissions from plastic water bottles in one month is 275.2 kg [64] for a weight of 0.0191kg. Therefore, if Wintergreen stops selling plastic water bottles, they can reduce carbon dioxide emissions by that much. Table 7 has been reproduced from this study and shows the breakdown of different single use plastics and their metrics such as initial carbon dioxide value and the new carbon dioxide values for different sustainable material alternatives. The products featured in the table are the main sources of single-use plastics. The water bottle category had the biggest difference in decreasing carbon dioxide emissions when compared with sustainable alternatives such as glass, tetrapak, or PLA.

***Table 7. Alternative materials for common plastic products** [64]*

Product	Category	Annual Consumption	Weight (kg)	Material	Initial CO_2 Value (kg)	Substituting Material	New Weight (kg)
Water bottle 0.5 L	Bottles	2252	0.0191	PET	275.2	Glass	0.0573
						Tetrapak	0.015
						PLA	0.01
Garbage Bags 30 L	Garbage Bags	70	0.043	LDPE	12.4	Paper	0.055
						Compostable	0.012
						Kraftpaper	0.15
Plate	Cutlery	1500	0.015	LDPE	77.9	Compostable	0.011
						Paper	0.011
Spoons, forks, and knives	Cutlery	1500	0.004	PP	18	Compostable	0.005
						Wood	0.0025
Pouch	Other packaging	1500	0.004	PP	18	Paper	0.0021
						Compostable	0.003

4.2.3 Implementation considerations and recommendations

Implementing the reduction of single use plastics can occur in phases ranging from relatively small and straightforward changes to larger system-wide implementation. For example, a small initial change to monitor impact could be reducing plastic straw use and increasing availability of recycling bins. Although there were many trash cans both inside and outside at the ski resort, according to observation, there were no recycling bins. These would help to dispose of plastic and other recyclable waste appropriately. Another idea for implementation is to not sell plastic, single-use water bottles. Wintergreen should encourage others to bring reusable water bottles by installing water bottle filling stations. Economically, Wintergreen could also promote selling their own reusable water bottles that can be used in the resort. However, single-use water bottles can still be sold as long as they are made of a different alternative to plastic such as aluminum. Additional initial implementation can also include adding educational signage around the resort to promote recycling, especially to clarify any recycling sorting requirements. Signage also provides an opportunity to share a QR code to provide more information to resort goers of Wintergreen's sustainability initiatives.

However, there are several obstacles present that Wintergreen faces when trying to implement more sustainable practices. The first is an economic obstacle. Switching from plastic to reusable materials can cost more. Promoting the use of reusable water bottles may decrease the sales of water at Wintergreen restaurants, but this is likely insignificant to total restaurant sales. The second is that the lodging at Wintergreen is privately owned, which would make implementing recycling across all lodging difficult.

In summary, single-use plastics in ski resorts are harmful to the environment, but implementing sustainable practices can help reduce the harm. Changes such as adding water bottle filling stations and reusable water bottles, not offering plastic straws, and promoting recycling with the use of proper bins can help reduce the usage of plastic and thus the effects of plastic on the environment. Educational signs around the resort can help skiers and resort-goers to join in on the sustainability mission. There are many aspects of the ski resort that Wintergreen can improve to be more sustainable and reducing their plastic usage and waste is one way in which both the guests and Wintergreen can participate.

5. Environmental Concerns

This chapter presents proposed initiatives that will affect the conservation efforts and biodiversity of the local environment. This includes suggested initiatives to increase the soil and plant diversity and specific initiatives to increase species diversity throughout the skiable acreage of the resort. Examples of successful implementation at other resorts and recommendations for implementation at Wintergreen are provided for each.

5.1 Soil and Plant Diversity Considerations

Ski resorts often cause significant environmental disruptions, particularly to soil and plant life. One of the primary consequences is the acceleration of soil erosion, which can lead to long-lasting degradation of ecosystems by changing the topography and soil thickness. This effects the shape and biodiversity of the slope by decreasing soil depth, which can lead to the exposure of bedrock and prevents plants with deep roots from thriving [65]. The mechanical disturbance associated with ski slope construction, such as grading, compacts the soil and reduces its ability to retain water, diminishing its capacity to support vegetation [66].

On machine-graded slopes, these disturbances further decrease the soil's hydrological functions, making less water available for plant growth [67]. This alteration of soil properties is compounded by practices like artificial snowmaking, which can exacerbate vegetation degradation by further altering soil moisture levels [68]. Research has shown that areas subjected to such disturbances often experience reduced plant cover and productivity, with little sign of natural recovery or vegetation succession [68], [69]. These changes not only affect the aesthetic and biological diversity of ski resort areas but also disrupt nutrient cycling and soil chemistry, leading to broader ecological consequences [68], [69].

On steeper slopes where erosion is already a concern, grooming accelerates soil loss which leads to reduced organic matter and a less fertile soil environment. These changes make it more difficult for native plants to establish and thrive [65]. As such, it is essential for ski resorts to implement sustainable practices that mitigate soil erosion and protect plant life, particularly in fragile alpine ecosystems where recovery is slow and difficult. Protection of soil composition and native plant biodiversity is also beneficial from a marketing standpoint. Native plants tend to be better adapted to environmental factors and can rebound more quickly than seeded plants. If native plants are propagated, the resort will need to spend less time replanting in the offseason. Native plants often have longer roots than what is in seeding mixtures, contributing to a more stable soil [65]. This will prevent erosion, preserving the slopes and reducing the amount of corrective work that needs to be done in the offseason to reconstruct slopes.

To address these challenges, ski resorts have adopted restoration measures aimed at promoting soil recovery and enhancing plant biodiversity. Machine-graded ski slopes typically cause short-term declines in vegetation cover and diversity. However, long-term restoration strategies have proven effective in stabilizing soils and encouraging the growth of native plant species. Techniques such as hydroseeding with local seed mixtures, topsoil storage and replacement, and low-intensity grazing have been shown to improve erosion control and foster a more self-sustaining plant community. When consistently applied, these measures lead to the establishment of protective plant cover and a significant increase in plant species native to the region [70], [71].

These findings highlight the importance of comprehensive, site-specific restoration strategies for mitigating the negative impacts of ski resorts on soil and plant biodiversity. Although recovery is a gradual process, resorts that implement such strategies show a clear path toward reducing soil erosion, enhancing plant diversity, and supporting the long-term ecological sustainability of ecosystems. Through these efforts, ski resorts can help restore soil health and contribute to the resilience of the ecosystems on which they depend.

5.1.1 Examples of successful implementation

At Monterosa Ski Resort in the Northwester Italian Alps, efforts have been made to address these challenges and improve soil and plant health. Ski runs at Monterosa were machine-graded between 1988 and 1996, followed by immediate hydroseeding with grass/legume mixtures and the application of mineral fertilizers. In the following years, upkeep of the slopes was maintained using topsoil from different parts of the slope and manure was applied to the runs in the off-season in lieu of mineral fertilizers.

Over time, low-intensity grazing and other restoration practices, including the storage and replacement of topsoil, have been used to help promote vegetation recovery [71]. Over a period of 17 years, soil aggregate stability, soil erosion, soil sampling, root traits, and vegetation surveys were taken at regular intervals. From the start of the study the surveys determined that the longer the slopes were left alone to recover from the initial plowing, the better the soil and plant biodiversity. This recovery can be attributed to the rebounding of native species after the reseeding. The vegetation survey shows a clear rebound in native species along with a decline in the species that were in the hydroseeded mix, reproduced in Figure 13 [71]. The soil mechanics and structure are further improved by the root structures present in the native species. The root trait survey paired with the soil surveys show this recovery, reproduced in Figure 14 [71].

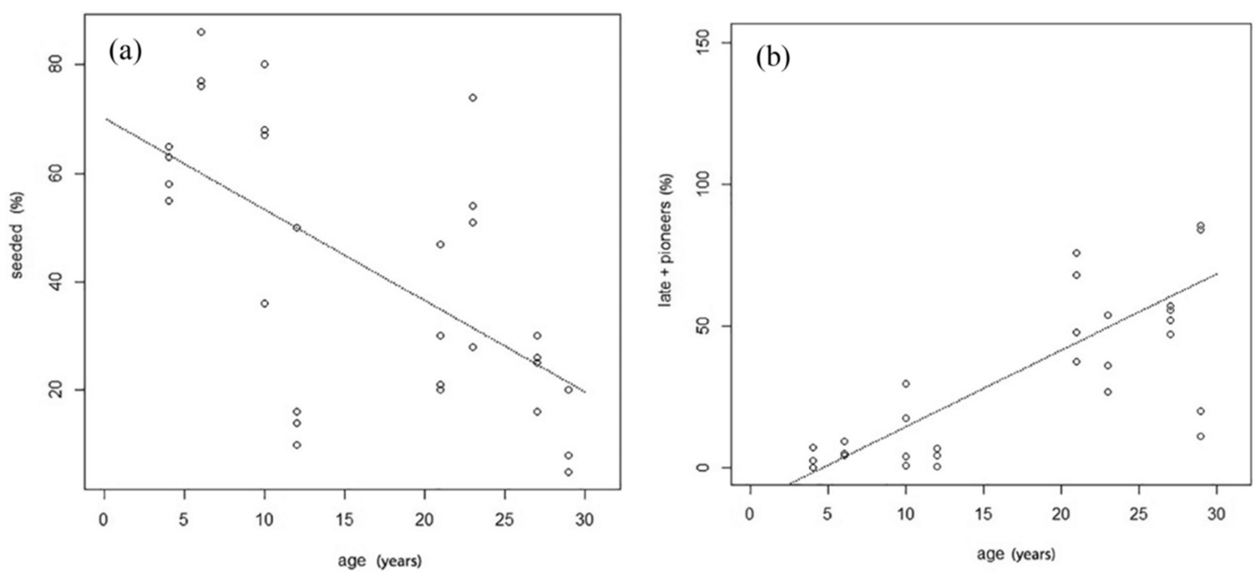

Figure 13. a) seeded species cover (%) and b) Native species cover (%), % change on ski runs correlated to years after seeding [71]

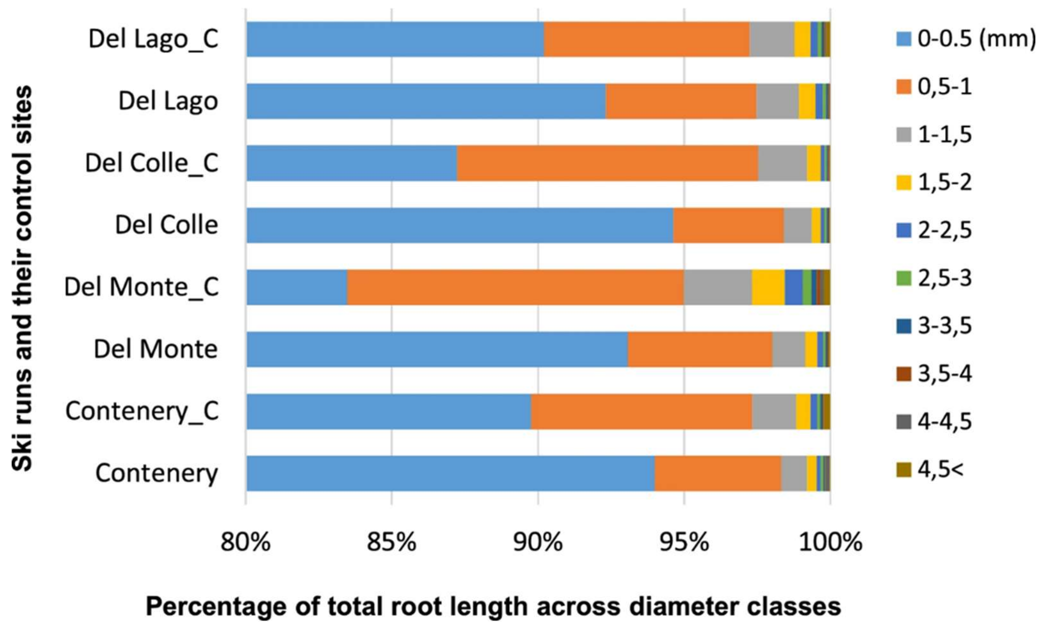

Figure 14. Root length distribution in different root diameter classes of four machine-graded ski runs *[71]*

At the end of the study, Monterosa had about a 75% vegetation cover, which is necessary to prevent erosion and a significant increase from the beginning of the study. This change in soil health is attributed to the combination of the introduction of native plant species through hydroseeding and reduced slope disturbance. These changes led to the re-establishment of a protective plant cover, helping to reduce soil erosion and promote the growth of native plant species [57] [58].

In summary, reseeding of native plant species, fertilization using manure rather than mineral fertilizers, storing and reusing topsoil, and less frequent re-grading/disturbance leads to an increased biodiversity of plant species and improved soil structures leading to better hydrolytic qualities and less erosion. These in turn provide better soil for native plants to grow in and the cycle continues, contributing to a more biodiverse ski slope which is beneficial for the other organisms that live near the resort. In addition to benefiting the ecosystem, this improved soil structure will allow the slope to maintain itself as soils with more root structures tend to be more resistant to disruptive forces, like layers of dense snow [71].

5.1.2 Impact estimate

Implementing soil conservation and native plant restoration at ski resorts provides significant environmental benefits, including reduced erosion, enhanced carbon sequestration, improved water retention, and decreased reliance on artificial snowmaking due to better thermal conductivity. Research shows that bare slopes can lose 100–200 tons of soil per hectare annually [66], while revegetation can reduce this loss by 70–90% [71]. Native vegetation also aids carbon sequestration, with alpine meadows storing 100–200 grams of carbon per square meter per year [72]. At Wintergreen's 52-hectare slopes, this equates to sequestering 5.2–10.4 metric tons of CO_2 annually, offsetting emissions from driving 13,242–26,484 miles [73]. Over time, deeper root systems and increased organic matter further enhance soil stability and carbon storage. By reducing soil loss, improving water retention, and supporting long-term ecological resilience, these strategies benefit both the environment and the sustainability of ski resorts.

5.1.3 Implementation considerations and recommendations

Wintergreen Resort can significantly improve soil stability and environmental sustainability by implementing a combination of erosion prevention, native plant reseeding, and soil restoration techniques. The most effective strategy to mitigate soil erosion is to minimize ski slope expansion and limit mechanical disturbances such as grading and excessive grooming. Expanding trails removes stabilizing vegetation and exposes soil to erosion, while frequent regrading compacts the soil, reducing its ability to retain water and support plant life. In the case of expansion, the following techniques should be employed.

A key component of restoration efforts should be reseeding with native plant species that are well-adapted to the area, as these species have deep root systems that enhance soil structure, increase organic matter, and provide long-term erosion control. Recommended species can be found in Figure 15 [74]. Using diverse native plant mixes for hydroseeding will ensure year-round ground coverage, strengthening soil resilience while also supporting local wildlife.

Contribution	Common name	Scientific name	Image
Slope Stability	Little Bluestem	*Schizachyrium scoparium* [75]	
	Purpletop	*Tridens flavus* [76]	
	Allegheny Spurge	*Pachysandra procumbens* [77]	
	Switchgrass	*Panicum virgatum* [78]	
Soil Retention	Firewheel	*Gaillardia pulchella* [79]	
	Shrubby St. Johnswort	*Hypericum prolificum* [80]	
	Lanceleaf Tickseed	*Coreopsis lanceolata* [81]	

Figure 15. Recommended species for reseeding at Wintergreen Resort to improve soil metrics and biodiversity.

To further enhance soil health, organic fertilization practices should be prioritized over synthetic fertilizers. Applying manure-based compost or biochar has been shown to improve soil microbial activity, increase water retention, and promote plant resilience [71]. Additionally, reapplying stored topsoil after construction or disturbances can help reintroduce native seed banks and beneficial soil microbes, accelerating plant recovery.

Finally, Wintergreen Resort could benefit from implementing a long-term ecological monitoring program to assess plant recovery and soil stability. By using vegetation surveys and soil testing, the resort can track erosion rates, plant survival, and organic matter accumulation over time, ensuring that restoration efforts are effective and adaptive. By restricting expansion, replanting native species, utilizing organic soil amendments, and implementing a monitoring program, Wintergreen Resort can drastically reduce erosion, enhance biodiversity, and improve the long-term sustainability of its slopes. These measures will not only protect the surrounding environment but also reduce maintenance costs and reinforce the resort's reputation as an environmentally responsible destination.

5.2 Species Diversity Considerations

Upon the construction of man-made systems, it is common to see a reduction in biodiversity. The same is observed at ski resorts around the world. While these problems appear difficult to address, some resorts have been able to implement tactics that raise their local species biodiversity. The restoration of the surrounding natural habitat adds value to the resorts, often successful due to natural beauty.

The purpose of this section is to explore the possibility that although efforts to conserve small mammal populations around ski areas are difficult, there is value in monitoring populations closely in order to maintain diversity that keeps the terrain and ecosystem resilient to other challenges posed by the resort.

There are several factors that hinder the survival and ability of species to thrive in ski areas including deforestation, removal of stumps and rocks, and grooming of soil in preparation for pistes [82]. Logically, the disruption of habitat and vegetation will decrease the numbers of species that rely on them. The wide expansions of runs also create barriers and change animal migration [83]. An additional consideration is the presence of consumers in these areas. Even though biodiversity of species is a draw for tourism, the presence of tourists often has a direct impact on populations [84]. A literature analysis from 2022 found that of 67 articles on the effect of mountain recreation, 91% found significant impacts, and 82% were predominantly negative [85]

At Wintergreen Resort, with 26 runs and a variety of recreational activities like hiking, mountain biking, and golf, the impact of human activity in the area is high. Figure 16 shows the extent of the 129 skiable acres available at Wintergreen [86].

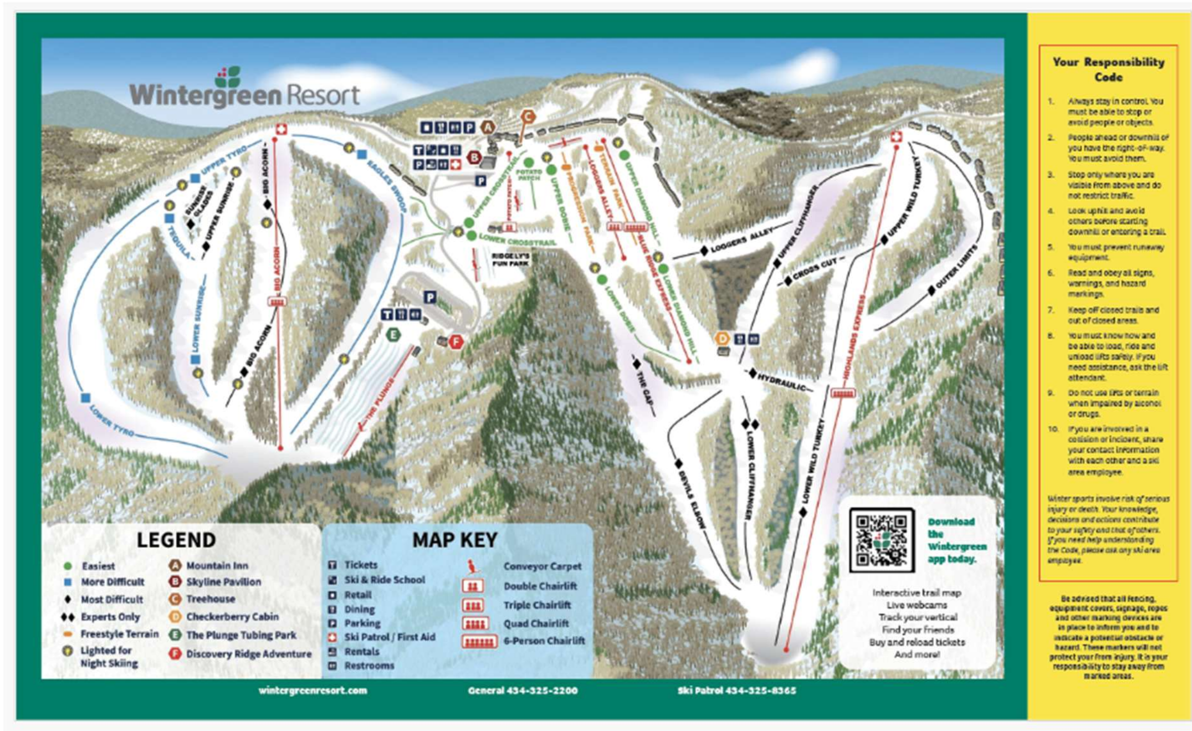

Figure 16. Total Map of the 26 slopes maintained at Wintergreen as of 2025 [86]

While Wintergreen, compared to other resorts, has maintained more undeveloped acreage and some tree cover, there has been no measure of the effects of development and human activity in the area. By monitoring populations in and around the resort as well as implementing new methods of maintaining habitats, Wintergreen will be able to more effectively preserve and grow their vertebrate biodiversity.

5.2.1 Examples of successful implementation

Successful implementation of strategies to increase mammal biodiversity can vary widely. The report will explore two routes of improvement: through monitoring of populations and the through ski piste construction and maintenance.

Monitoring of populations can take many forms, some more convenient and cost-efficient than others. A study published in 2013 sought to understand the effect of ski pistes and tourism on the migration of fat dormouse, common dormouse, pygmy shrew, bank mole, and yellow-necked mouse [83]. The approach included 5 experiments consisting of trapping and marking that measured spontaneous crossings, habitat use, ability to cross the pistes, and translocation of individuals [83]. Their goal was to determine whether small mammals used and crossed the pistes and if the pistes proved to be an “ecological barrier” [83]. The trapping component of their experiment found that mammals never spontaneously crossed the piste, while some crossed when translocated, proving that current ski-run design acts as an ecological barrier [83]. Another method of monitoring used by Ronja Risberg is following animal tracks on determined transects [84]. Tracks within 150 cm of the transect were counted in different areas with varying “activity” levels, linking increased human activity on the slopes to decreased animal tracks [84].

Standard ski piste development is usually centered around deforestation, removal of debris, and grading of the soil. All these methods destroy habitat real estate for small mammals, but there are ways to minimize this effect. In Vail, Colorado, a study found that leaving some “woody debris” and allowing islands of trees and undisturbed area in between pistes increased the population density of red-backed voles and allowed them to cross at a higher rate [82]. Another study proposes transplanted natural vegetation like shrubs to deter erosion of soil and provide more habitats on the piste while maintaining safety on the slopes [68]. By leaving the undergrowth on slopes rather than stripping it, a transition from forest to slope is maintained, reducing the harm to nearby ecosystems [68].

It can be seen that ski resorts have successfully implemented incremental changes to help increase mammal biodiversity. By increasing biodiversity, the value of the resort is also increased by restoring the natural beauty and by increasing ecosystem resilience to other degradation, previously discussed in Section 5.1.

5.2.2 Impact estimate

Unlike several other sustainability initiatives presented, increasing mammal biodiversity has a less tangible quantification for estimating its direct impact on sustainable operations. The benefit of monitoring species is particularly challenging to explain. For example, small mammals such as mice feed into the much larger ecosystem. Shrews, voles, and other local small mammal species should be monitored in relation to each other.

Part of the attraction of ski resorts is enjoying the outdoor experience, which relies heavily on the plant and wildlife biodiversity. The extent of ski resorts and pistes seems to be expanding, making this is an important sustainability consideration, though inherently difficult to quantify.

Previous efforts involving alternative construction of ski pistes have very rough estimates of the increase in populations. However, it is relatively easy for each individual resort to compute population density, basic statistical analysis, and chi-squared tests from trapping data [83]. Over time, trends can be easily found from the data, and if maintenance of changes overcomes the minimal benefits, efforts can be pivoted to focus on other populations or areas.

5.2.3 Implementation considerations and recommendations

This subsection will explore the possible complications and logistics of executing possible solutions to the problem.

The most glaring obstacle in the implementation of almost all the proposed solutions is the additional time expenditure and workforce required for these projects. In the cases of tracking populations by trapping, transects will need to be mapped and traps set and maintained with sustenance and bedding for warmth depending on the season as shown in Figure 17 [82].

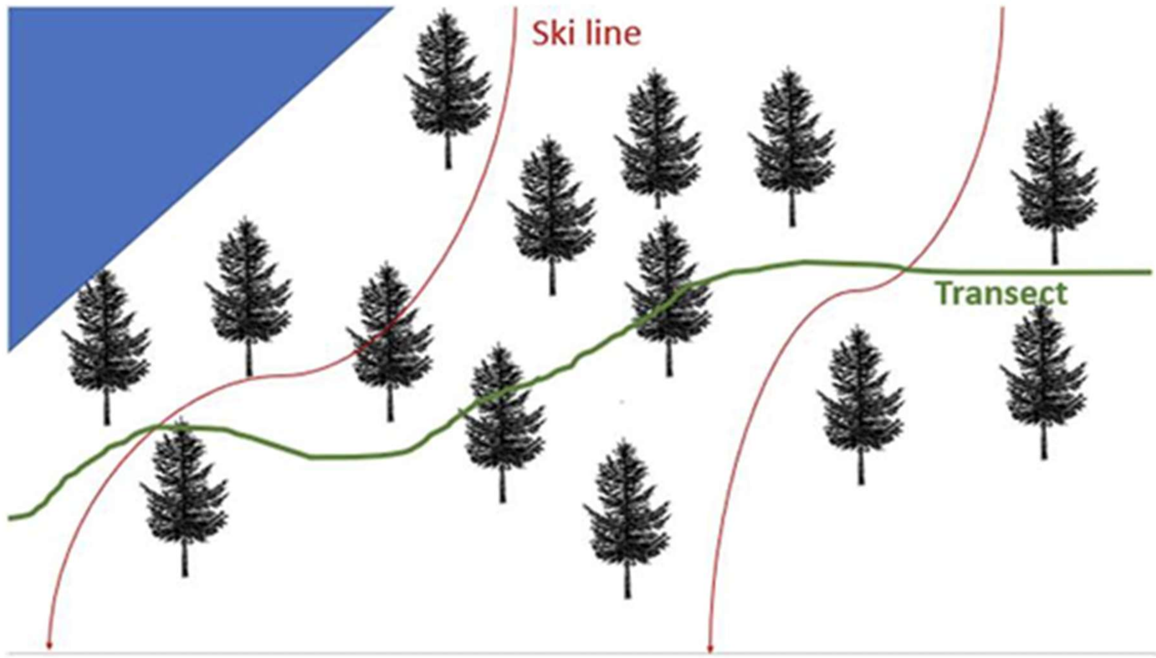

Figure 17. From Negro et al. as an example of how transects were mapped with respect to ski lines while measuring the number of spontaneous crossing across pistes. [83]

Wildlife professionals will need to be able to handle the animals for measurements. The design of the study will also take considerable thought to ensure proper methods and control populations. Traps will need to be set in the evening and checked at least once in the morning [82]. If the implementation involves reintroducing shrubbery or woody areas back into the pistes or adding forested islands, the cost of landscaping is added.

If the route of less invasive piste design is used, this will require less time and resources during piste development. There would be less excavating, grading, and removal of debris. This would however require a consistent snowpack to protect patrons from injury and to maintain a smooth slope. In the summer, the debris would allow for more small mammals to thrive until the ski season begins again and a gradual transition from forest to piste.

However, if this method is to be used or woody islands are created on already existing slopes, rocks will need to be brought in and secured in the topsoil as well as woody debris (perhaps from tree trimmings or maintenance landscaping scraps), or as mentioned before, the transplantation of shrubs.

In conclusion, the primary challenge of these implementations is the cost of hiring professionals or additional staff in order to properly implement and track any solutions. It is important to remember that biodiversity and the balance of ecosystems is delicate, and worth the additional time and work needed to care for it.

6. Initiatives in Development

In addition to the seven presented sustainability initiatives, additional initiatives were openly ideated and are presented here. Following resort observations and discussions, these ideas remain in-progress and currently do not include impact estimates or proven success at other resorts. However, these initiatives in development could be further researched with client interest.

- To supplant the resort's store of skiing gear and to minimize the amount of personal gear discarded after use, Wintergreen could adopt a donation-based program for used gear. Visitors can bring and recycled used gear in exchange for incentives such as a free lift pass, one free lesson for kids, or a free meal at the lodge per certain number of items donated. This program would allow expensive items to be accumulated by Wintergreen's rental facility and minimize clothing and plastic waste in landfills.
- Building climate control consumes a large amount of energy, so optimizing how lodges and residential rooms are heated and cooled could result in noticeable electricity use reductions. Currently, window AC units are used in lodge hotel rooms, which is a primary location for improvement. Shifting to a central HVAC system or even distributed systems that operate on a smaller number of buildings would save both money and carbon emissions in the long term. Additionally, landscaping around buildings can be used to contain heat, benefiting any climate control system. While the project may have high initial cost, the progress towards long term sustainability goals indicates that proper focus on HVAC systems is reasonable and beneficial.
- While examining options for sustainable energy solutions, it may be worth considering the possibility of wind power. Ski areas tend to experience strong winds on a regular basis, so strategically placed wind turbines could provide additional renewable energy. These could be integrated into light poles and lift pylons. However, snowy conditions could make turbines difficult to maintain and operate – conditions would have to be evaluated carefully. Since Wintergreen does not receive that much natural snow and is instead reliant on snowmaking, this may be less of a concern, making this a more plausible avenue at Wintergreen than at other resorts.
- Cow manure may be used to power a portion of the ski resort. This idea seems to be mostly unexplored by ski resorts but a prime example of this being effective is Killington Resort in Vermont. The resort uses methane gas from cow manure to power one of its lifts, their Peak lodge, and one of its restaurants. There are reportedly 215,000 cows in Vermont which is considerably less than Virginia's 1.32 million [87]. There is a great opportunity to work with local dairy and beef farmers to make use of cow manure and power a portion of the ski resort. This could also extend to energy sustainability outside of the ski area during the off season.
- An incentive program for the residents and resort goers could help to promote sustainability from the skiers themselves. One example is if they use a ride-sharing program or a form of public transportation or carpooling. Wintergreen could promote this by a coupon to the stores inside the resort. This could be expanded to the residents recycling and resort goers

bringing reusable water bottles. Wintergreen can only address a certain amount of the sustainability issues as the resort goers need to also contribute. A potential way to accomplish this is with this incentive program which should likely not incur additional costs for Wintergreen.

- Educating resort guests on sustainability is one of the most powerful and cost-effective ways to reduce the environmental impact of ski tourism. By simply informing guests—through fliers, posters, digital welcome messages, and email updates—resorts can promote more mindful behavior, from conserving energy in lodging to choosing eco-friendly transportation options. Guests are more likely to adopt sustainable behaviors and engage in sustainable actions like ridesharing, minimizing gear waste, or supporting local businesses when informed of the sustainability benefits. Other resorts have used education-based strategies to great effect, such as including sustainability tips in welcome packets or posting signage to encourage small, conscious changes. In addition to reducing negative impact, these simple tools build a culture of shared environmental responsibility.
- Reducing water consumption at Wintergreen is a step toward improving overall sustainability. Ski resorts typically use vast amounts of water for snowmaking, hospitality services, and maintaining facilities, which can strain local water supplies and ecosystems, especially in mountainous regions already vulnerable to climate change. By recycling wastewater and encouraging water-saving practices among guests and staff, ski resorts can significantly cut down on water usage. This not only helps preserve local habitats but also reduces the resort's energy footprint, since less water pumping and treatment are required.

7. Recommendations and Future Work

The downhill ski industry contributes to global carbon emissions across many components of its operation, including transportation, snowmaking, and resort operations. Following the development of proposed sustainability initiatives for Wintergreen Resort, several key recommendations have emerged for implementation, as well as several recommendations for future work.

First, it is highly recommended that for more accurate and efficient initiative estimates, Wintergreen Resort should conduct a full inventory of emissions. This should be similar in format to the specific Scope-based emissions inventory presented in the NSAA Climate Challenge reports. This will allow Wintergreen Resort to best identify the most efficient areas for emissions reduction.

Because the ability of Wintergreen Resort to realistically implement the proposed initiatives varies, the proposed sustainability initiatives were then ranked based by implementation difficulty. To consider this ranking, the relative cost, available materials, ability to implement on a small scale, and other obstacles to implementation were considered for each initiative. The relative difficulty of implementing each initiative at a small scale, as well as suggestions for small scale implementation for each are given in Table 8.

Table 8. Summary of proposed initiatives and implementation difficulty

Proposed initiative	Initiative type	Suggestions for initial small scale implementation	Relative difficulty of implementation
Lighting system updates	Energy Reduction	Replacing existing outdoor lights with LEDs as they require replacement	Very low
Food waste reduction	Waste reduction	Diverting food waste from standard waste, partnering with a composting company	Low
Single use plastics reduction	Waste reduction	Reducing availability of single use water bottles for purchase and expanding offering of water bottle refilling stations	Low
Increasing soil and plant diversity	Environmental concerns	Minimize further slope development and reduce excessive grooming	Moderate
Increasing species diversity	Environmental concerns	Creation of wooded islands along some ski slopes	Moderate
Use of electronic passes	Operations update	Replace existing pass readers with upgraded digital pass readers as they require replacement	High
Updating road materials	Operations update	Implementing heated road and sidewalk systems	Very high

While several initiatives have significant initial cost and may present more difficulty in implementation, several can be implemented with relatively low difficulty. It is recommended that initiatives be implemented through proposed small scale initiatives and gradually increasing scale as feasible. Future work may include refining proposed initiatives based on further feedback and upon completion of a full emissions inventory to better target reduction efforts.

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Appendix A: High Impact Initiatives

High impact reduction initiatives, defined as having greater than 80 million metric tons of equivalent CO2 as an estimated reduction

Year Reported	Resort	State	Estimated emissions reduction (MT CO_2e)	Reduction type	Additional details
2023	Massanutten	VA	914	Electricity	Installed 1500 kW solar array to produce 23% of electricity for water park
2021	Tremblant	QC	694	Building operations	Optimized building operation of heating, ventilation and air conditioning appliances
2024	Timberline	OR	661	On site fuel	Installed a bioreactor wastewater management system estimated to reduce 7,000 tanker truck mules hauling 584 tons of liquid waste annually
2024	Summit at Snoqualamie	BC	532	On site fuel	Converted grooming vehicles and heavy equipment to renewable diesel
2021	Loon Mountain	NH	511	On site fuel	Switched to propane for heating
2021	Big Sky	MT	427	Building operations	Installed new thermostat controls
2023	Boyne Mountain	MI	420	Building operations	Upgraded outdated thermostats
2024	Deer Valley	UT	394	Building operations	Added remote condensing units for walk-in refrigerators
2021	Boyne Highlands	MI	360	Snowmaking	Replaced older snow guns with energy efficient guns
2023	Sugarloaf	ME	328	Snowmaking	Replaced 121 towers and fan guns with new high efficiency models
2020	Eldora Mountain	CO	301	Electricity	Replaced 175 lighting fixtures during retrofit project
2022	Massanutten	VA	274	Snowmaking	Installed 50 new low energy guns and automated fans to upgrade snowmaking efficiency
2023	Snowshoe	WV	270	Snowmaking	Overhauled snowmaking system on beginner slope
2024	Snowbird	UT	250	Transportation	Increased vanpool and carpool options
2023	Timberline	OR	241	On site fuel	Boiler retrofit
2024	Sunday River	ME	228	Snowmaking	Installed 151 low E snow guns, hydrants and more
2022	Sugarloaf	ME	224	Snowmaking	Upgraded 23 snow gun nozzles and 90 high E snow guns
2023	Snowbird	UT	224	Transportation	3 fold increase in employee vanpool usage

Year Reported	Resort	State	Estimated emissions reduction (MT CO_2e)	Reduction type	Additional details
2022	The Highlands	MI	213	Electricity	Updated main lodge lighting: all LED retrofit throughout lodge and in golf areas
2022	Killington	VT	180	Snowmaking	Installed 80 new tower guns to replace old snowmaking equipment
2021	Alta	UT	170	Recycling	Increased general recycling efforts and reduced waste by 326 tons
2021	Steamboat	CO	162	Electricity	Retrofit exterior lighting on mountains for LEDs (replacing 4000 T8 tubes)
2022	Sunday River	ME	149	Snowmaking	Replaced existing snowmaking equipment with 131 HKD towers
2024	Palisades Tahoe	CA	142	Building operations	Added automation to three atmospheric boilers and 11 zone pumps to serve building heating system
2022	Cypress Mountain	BC	136	Building operations	Replaced 2 hot water tanks in main lodge
2022	Alta	UT	134	Recycling	Ongoing glass recycling program
2021	Blue Mountain	ON	123	Transportation	Cancelled summer shuttle service
2022	Taos	NM	122	Snowmaking	Added 7 additional HKD impulse snow guns
2022	Mammoth	CA	120	Building operations	Installed AquaRecycle's pure water recycling system in laundry facility to reduce water usage
2022	Timberline	OR	119	On site fuel	Installed new boiler HVAC system with 15% increase in efficiency
2024	Wisp	MD	116	Snowmaking	Installed new snowlances with onboard compressors
2023	Summit at Snoqualamie	BC	114	Recycling	Increased waste diversion efforts by purchasing industrial composting machine
2020	Big Sky	MT	113	Building operations	Renovated thermostat systems to increase efficiency by 15%
2022	Boyne Mountain	MI	113	Snowmaking	Updating snowmaking equipment to HKD guns
2021	Boreal Mountain	CA	109	On site fuel	Replaced lodge propane boiler with high efficiency propane system
2022	Boyne Mountain	MI	107	Electricity	Added VFDs to waterpark circulation pumps
2023	Eldora	CO	106	Transportation	Provided complimentary bus tickets to ski guests on weekends and holidays
2023	Boyne Mountain	MI	105	Snowmaking	Updated 50 total HKD snow guns

Year Reported	Resort	State	Estimated emissions reduction (MT CO_2e)	Reduction type	Additional details
2021	Big Sky	MT	105	Transportation	Built employee housing within walking distance to resort to reduce commuter footprint
2024	Boyne Mountain	MI	105	Snowmaking	Installed 50 HKD snowguns to replace older models
2022	Taos	NM	97	Transportation	Operated shuttle service from Taos
2023	Killington	VT	95	Building operations	Replaced air compressor
2024	Snowbird	UT	92	Recycling	Diverted 352,000 lbs glass from landfill
2022	Killington	VT	85	Snowmaking	Installed 80 tower guns to replace snowmaking equipment
2020	Steamboat Springs	CO	83	Snowmaking	Purchased Super Puma fan gun to replace older model
2024	Deer Valley	UT	80	Electricity	Updating florescent lights to LED lights
2024	Sun Valley	ID	80	Building operations	Installed new refrigeration system for indoor and outdoor ice rinks.