

Article

# How Can Ski Resorts Get Smart? Transdisciplinary Approaches to Sustainable Winter Tourism in the European Alps

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**Abstract:** Climate change and the call for reduction of greenhouse gas emissions, the efficient use of (renewable) energy, and more resilient winter tourism regions, forces ski resorts across the European Alps to look for “smart” approaches to transition towards a sustainable, low-carbon economy. Drawing on the smart-city concept and considering the different historical developments of Alpine resorts, the Smart Altitude Decision-Making Toolkit was developed using a combination of an energy audit tool, a WebGIS, and collaborative and innovative living labs installed in Les Orres (France), Madonna di Campiglio (Italy), Krvavec (Slovenia), and Verbier (Switzerland). This step-by-step Decision-Making Toolkit enables ski resorts to get feedback on their energy demand, an overview of the locally available sources of renewable energy, and insights regarding their potential for improving their energy efficiency by low-carbon interventions. The Decision-Making Toolkit is suitable for knowledge transfer between stakeholders within living labs and moreover provides the flexibility for tailor-made low-carbon strategies adapting to the unique assets and situatedness of ski resorts.

**Keywords:** mountain tourism; renewable energy; low-carbon economy; living lab; resort towns; transformation knowledge

## 1. Introduction

Across the European Alps, ski resort operators strive to meet increasing energy demands for running lifts, producing technical snow, grooming slopes, and heating buildings. At the same time, political, economic, and environmental drivers force ski areas to reduce greenhouse gas (GHG) emissions and save energy costs. In this context, improving energy efficiency, integrating renewable

energies, and valorizing endogenous resources, is seen as a potential and viable strategy. Since Alpine ski resorts share many characteristics with mountain cities [1], it is no surprise that mountain resort towns pin hopes on modernist smart-city approaches to handle the energy-related challenges of our time.

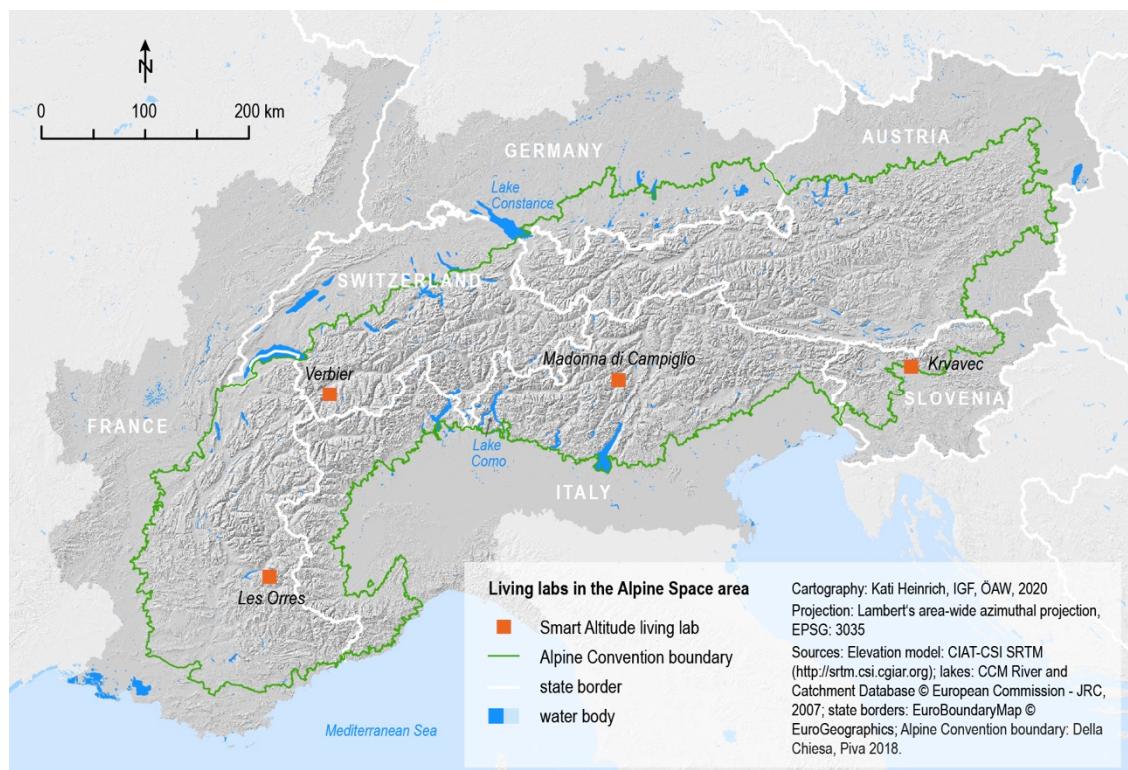
This paper reports on the novel approach developed within the three-year, transdisciplinary research and development project named “Smart Altitude”, co-funded by the Interreg Alpine Space Programme (through the European Regional Development Fund). A cross-sectorial consortium, including ski resort operators, regional development agencies, and research institutions, aims to create transformation knowledge by inductively developing a “smart” low-carbon approach, which identifies renewable energy potential and options for energy saving and offers a step-by-step toolkit for enabling transitions toward smart skiing in practice.

The inductively developed approach presented in this paper draws on experiences in four case study sites—the living labs—and can be used by ski resort operators and other key actors to answer the following questions of relevance: (1) How much energy and from which energy source is demanded by ski resorts? (2) Which sources of renewable energy are available locally and by which means can this information be communicated to stakeholders? (3) Which potential for improving energy efficiency exists locally and by which low-carbon intervention can this be achieved? The selection of both modernist and traditionalist resorts distributed over the western and the eastern European Alps—Les Orres/France, Madonna di Campiglio/Italy, Krvavec/Slovenia, as well as Verbier/Switzerland—shall guarantee a good replication potential across the Alpine arc and provide ski resorts with concrete steps to make “their” destination more future-proof. This paper focuses only on the ski resort operations and not on the associated GHG emissions from tourist travel to and from the ski resorts and from the tourist accommodations. We present the smart low-carbon approach for winter tourism areas by first describing the four study areas of the Smart Altitude project (Section 1.1) and discussing the different concepts that build the framework of our approach (Sections 1.2–1.4). Then, we introduce the building blocks of the low-carbon approach, which include energy audits, a web-based Geographic Information System (GIS), and living labs (Section 2), followed by the presentation and discussion of the practical application of the approach (Section 3), and close this paper with a conclusion and outlook (Section 4).

### 1.1. Study Areas

The study focuses on four areas in the Smart Altitude project (Figure 1; for key characteristics see Table 1): Les Orres, Madonna di Campiglio, Krvavec, and Verbier. Les Orres is located in the department Hautes-Alpes in Southeastern France. It is a typical mountain village in the French Alps made up of nine hamlets with a permanent resident population of 556 inhabitants [2]. The ski resort was created in 1970 with the historic center of Les Orres 1650. Les Orres 1800 was created in the 2000s by grouping together various tourist residences. Les Orres is a major resort in the French Alps, with a hosting capacity of 14,500 tourist beds. It is operated by Société d’Economie Mixte Locale des Orres, or SEMLORE, a local semi-public limited company that runs the ski lifts, snow making, snow grooming, the ice rink, the “espace rencontres culture” (a facility for events, congresses, forums, etc.), the tourism office, and a central online accomodation booking service.

Madonna di Campiglio is a village and a well-known ski resort in northeastern Italy. The village lies in the Val Rendena (Province of Trento) at an elevation of 1522 meters above sea level and has approximately 1000 permanent inhabitants. Madonna di Campiglio has been an important center for travelers and tourists for a long time; first for pilgrims and traders, then for the elite from Austria–Hungary and other central European regions, followed by mountaineers from Britain and Germany. Later on, Madonna di Campiglio developed into an important winter tourism center that attracts modern day tourists from all over the world. In the tourist area “Madonna di Campiglio—Pinzolo—Val Rendena”, there were 260,000 arrivals and 1,170,000 overnight stays in 2018 [3], of which 63% in the winter season (November–April). The private company Funivie Madonna di Campiglio is the local ski area operator.



**Figure 1.** Smart Altitude study sites in the Alpine Space cooperation area (shaded in dark grey). The Western and Eastern Alps are separated by an imaginary line from Lake Constance to Lake Como.

Krvavec is a Slovenian ski resort about 25 km north of the capital Ljubljana and was established in 1958 [4]. The ski resort is located some distance away from the closest settlement and operated by Rekreacijsko turistični center Krvavec, a private company. About 150,000 to 220,000 skiers frequent the ski resort each year, mainly as day guests. There is limited accommodation available in or near the ski resort; a total of 300 beds is divided equally between a hotel (run by the ski lift operator) and apartments/private rooms. Many guests stay in nearby cities like Ljubljana and make use of the various ski bus connections to Krvavec.

The Swiss ski resort Verbier, part of the municipality of Bagnes, is located in the southwestern Canton of Valais (Wallis). Verbier's development as a winter tourism center started in the early 20th century. The village grew rapidly with the start of mass ski tourism in the 1960s [5]. Currently, it has a residential population of approximately 3000 inhabitants and a significant number of second-home residents [6,7]. Operated by Téléverbier since 1950, Verbier is one of the gateways to the largest ski area in Switzerland, "Les 4 Vallées". In 2019, the municipality of Bagnes welcomed 61,828 arrivals and 175,043 overnight stays of which 73% were foreign visitors [8].

In sum, the four Smart Altitude case studies are very different in terms of historical development, size, number of tourist arrivals and skier days, the extent of the snow-making infrastructure, the amount of energy used, and the integration of renewable energy. All ski areas aim to transition towards a low-carbon economy with important steps to be taken within the framework of the Smart Altitude project. These steps are tailored to the needs of the resorts by taking all relevant environmental, economic, social, and political factors into account.

**Table 1.** Characteristics of the Smart Altitude study areas [9–11].

Characteristic	Les Orres	Madonna di Campiglio	Krvavec	Verbier <sup>3</sup>
Municipality	Les Orres (FR)	Pinzolo (IT)	Cerkle na Gorenjskem (SI)	Bagnes (CH)
Ski Operator Company	SEMLORE SAEM	Funivie Madonna di Campiglio S.p.A	RTC Krvavec d.o.o	Téléverbier SA
Altitudinal range (m a.s.l.)	1550–2720	1513–2501	1477–1973	1500–3300
Construction of first lift (year)	1966	1948	1973	1946
Winter season turnover (EUR)	11 million	25 million	4 million	44 million
Skier days per winter season (count)	510,000	1,222,872	205,508	1,161,554
Ski slopes (km)	48	60	30	200
Lifts (km)	15	28	13	43
Lift capacity (persons per hour)	22,398	35,533	14,121	45,980
Snow guns (count)	61	117	20	82
Snow lances (count)	125	629	90	278
Snow production per winter season ( $m^3$ )	600,000	1,140,000	200,000	720,000
Total energy consumption in winter season (kWh) <sup>1</sup>	6,887,686	15,094,773	5,267,260	16,223,786
Energy use for ski lifts (percentage of total energy use)	23	22	15	37
Energy use for snow production (percentage of total energy use)	27	30	34	6
Energy use for snow groomers (percentage of total energy use)	27	24	23	34
Energy use for operative buildings (percentage of total energy use) <sup>2</sup>	23	24	28	23
Renewable energy use (percentage of total energy use)	12	30	16	56

<sup>1</sup> Relates to the total energy consumption of the ski area operations. <sup>2</sup> Operative buildings are at the service of the ski slopes management (e.g., ski pass sale, warehouses, control room; does not include hotels or residential buildings). <sup>3</sup> Data are not validated by the Winter tourism Eco-energy Management Tool (Wi-EMT).

## 1.2. Alpine Resorts: Different Models

Tourism has a long tradition in the European Alps, which can be roughly divided into a western and an eastern part separated along an imaginary line from Lake Como to Lake Constance. Apart from a long-established religious tourism, tourists came to hunt, to mountaineer, to stay in one of the thermal spa resorts, or to enjoy the mountain scenery from the terrace of a Grand Hôtel since the early 19th century. A holiday in the Alps was only within reach of the elite and mainly took place during the summer months. The western Alps were a popular summer destination among foreign tourists, especially the wealthy English. The eastern Alps mostly attracted domestic tourists or tourists from neighboring states [12]. In the early phases of tourism in the Alps, tourists concentrated in a few resort towns, e.g., Interlaken, Zermatt, Chamonix, Kitzbühel, Meran, and Madonna di Campiglio, where they had vast economic, social, and environmental impacts [13–15]. The onset of winter tourism happened much later in the Alps, namely in the beginning of the 20th century. Like summer tourism, winter tourism was first concentrated in just a few resort towns, such as Davos or St. Moritz. The economic benefits dispersed to more regions and to a larger part of the local population with the start of mass winter tourism in the 1950s, when new ski resorts opened across the Alps (although this development was regionally uneven). At the same time, the diversity in the type of accommodations—hotels, apartments, guest rooms, vacation homes—available to tourists also increased with strong regional differences.

Bätzing discusses in his monograph “Die Alpen” [14] regional trajectories in tourism development, which are also significant for winter tourism. In western Austria and South Tyrol (Italy), tourism development has a highly decentralized character and, as a result, some degree of tourism infrastructure can be found almost everywhere in these regions. The development of tourist accommodations was often undertaken by the local population, which resulted in many small family-owned hotels and

the letting of guest rooms in residential houses. The latter was also stimulated by favorable tax measures. Second-home ownership in these regions is relatively low, although there are some notable exceptions, such as in popular Austrian ski resorts Kitzbühel and Seefeld. In Switzerland, on the other hand, tourism is spatially concentrated in relatively few towns with a great number of guest beds. These tourist towns have two configurations. The first is mainly composed of hotels with few second-home apartment complexes and the second solely of second homes. Tourism development in France has a highly centrally planned character, i.e., ski resort development plans have been steered by the central government with a strong emphasis on functionality until recently. This translated into spatially isolated and operationally integrated ski resorts at higher altitudes mainly made up of large hotels and apartment complexes, where cars are only necessary for the outward and return journey. In the Italian Alps, except for South Tyrol, tourism development was mainly ad hoc and without a planning component. Large capital injections from cities outside the Alps have led to a strong second home development in large complexes. As a result, tourism is concentrated in a few large resort towns. The local population does offer tourist accommodations in the form of private letting and small family-owned hotels in peripheral tourist towns, but they play a relatively small role in Italian tourism structures [13–16]. Slovenia represents a special case in tourism development in the Alps. When Slovenia was part of the Federal People's Republic of Yugoslavia, tourism infrastructure was relatively limited, and tourism only played a marginal role in terms of employment [17]. In the last 20 years, however, tourism has been a growing sector [18] and the winter tourism regions have experienced a transition towards modernization of the available tourism infrastructures [19].

These regional trajectories in Alpine tourism can be complemented with Barker's approach [13] to mass tourism in the Alps, in which she describes the regional development of ski resorts using two models, one for the western Alps (France, most of Switzerland, and parts of Italy) and one for the eastern Alps (easternmost part Switzerland, Austria, and parts of Italy, see Figure 1). According to Barker, ski resorts in the western Alps are characterized as high intensity, meaning that there is a minimum of one guest bed to five local residents. Furthermore, ski resorts are located at higher altitudes and therefore often not integrated in existing traditional settlements, which tend to be located at lower altitudes. We consider the Italian Alps more of a transition zone between the eastern and western Alps that does not easily fit in either of these two models [20]. In the eastern Alps, ski resorts are more dispersed with a lower intensity, i.e., in comparison with the size of the local population there are relatively fewer guest beds available. Also, ski resorts are located at lower altitudes and more often integrated in already existing village structures. Taking into account the models and patterns described above, together with the characteristics of the four case study sites, we can categorize the four living labs as either traditionalist—Madonna di Campiglio and Verbier—or modernist—Krvavec and Les Orres—based on their establishment as a tourist resort before or after the onset of mass ski tourism.

### 1.3. From Smart Cities to Smart Altitudes

The differentiation between traditionalist and modernist ski resorts can be useful in the context of smart skiing, a modernist notion representing a great confidence in technological progress. "Smart" has been a buzzword in EU policy documents for the last decades; smart growth, smart specialization, smart cities, smart citizens, etc. All these smart terms have in common a focus on innovation and intelligent solutions. Although different definitions of smart cities can be found in the literature [21], it is clear a smart city is made up of different dimensions, including transportation, ICT, more inclusive governance, and sustainable use of natural resources.

The European Commission defines a smart city as "a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business. A smart city goes beyond the use of information and communication technologies (ICT) for better resource use and less emissions. It means smarter urban transport networks, upgraded water supply and waste disposal facilities, and more efficient ways to light and heat buildings. It also means a more interactive and responsive city administration, safer public spaces,

and meeting the needs of an ageing population” [22]. Moreover, Caragliu et al. [23] (p. 70) define “a city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.”

Although most ski resorts are not located in urban areas, ski resort towns face problems (although often limited to the high season) that strongly resemble the ones experienced in cities, such as heavy traffic flows and high peaks in energy demands. The objectives of the Smart Altitude project overlap to some extent with the smart city concept, especially with regard to more efficient and sustainable energy management through innovation and intelligent strategies, such as establishing real-time monitoring of energy use, renewable energy integration, and smart grids, in order to realize a low-carbon economy. The Smart Altitude project is aware that a one fits all solution is not possible to achieve a low-carbon economy. Instead, low-carbon policies and strategies need to be based on regional and local assessments of strengths and weaknesses in terms of energy management, renewable energy potential, and investment in climate adaptation/mitigation and governance structures.

#### 1.4. Climate Change and Winter Tourism

Much has been written about the impacts of climate change on winter tourism in the Alps [24–26]. To deal with the impacts of climate change, ski resorts can implement various measures. In the climate change literature, often a distinction is made between adaptation and mitigation measures [27]. Adaptation is referred to as a change in response to environmental conditions that maintains or enhances the viability of a system [28]. The European Commission (EC) refers to adaptation as “anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage they can cause, or taking advantage of opportunities that may arise” [29]. Moreover, the EC points out that adaptation strategies are needed at all levels of administration, from local to the international level; however, “due to the varying severity and nature of climate impacts between regions in Europe, most adaptation initiatives will be taken at the regional or local levels” [29]. Adaptation measures that ski operators can take can be organized into two main types: (1) Technological (snowmaking systems, slope development, and operational practices) and (2) business practices (ski conglomerates, revenue diversification, marketing, indoor ski areas) [30]. However, the importance of collaborating with other stakeholders for achieving successful adaptation should not be underestimated, including the government and public administrations, the financial sector, and the final users. Mitigation measures are defined as those actions, implemented by a business and/or a policymaker, that reduce carbon dioxide emissions in the atmosphere [31]. The Smart Altitude project aims to demonstrate the potential of mitigation strategies such as energy efficiency, renewable energy, sustainable mobility, energy management, and smart grid across the Alpine region. Mitigation strategies set in place by a ski resort, as underlined by Lucena et al. [31], will have an influence not only on the GHG emissions, but also on the resilience of the business model and the energy system, which will be inevitably exposed to future impacts of both climate change and reduced availability of fossil fuels.

## 2. Materials and Methods

In order to develop the Smart Altitude approach that aims to support winter tourism regions in their transition towards a low-carbon economy and to design its step-by-step Decision-Making Toolkit that enables ski resorts to get (1) feedback on their energy demand, (2) an overview of the locally available sources of renewable energy, and (3) insights regarding their potential for improving their energy efficiency by low-carbon interventions, we have used three building blocks; energy audits, a web-based GIS application, and livings labs.

### 2.1. Energy Audits: Identifying Opportunities to Save Energy

In the 2012 Energy Efficiency Directive (EED) of the EU, energy audits are defined as “a systematic procedure with the purpose of obtaining adequate knowledge of the energy consumption profile of a

building or group of buildings, an industrial or commercial operation or installation or a private or public service, identifying and quantifying cost-effective energy saving opportunities, and reporting the findings” [32] (p. 1). Although the EED sets minimum requirements for energy audits, which are required for large enterprises, it does not provide recommendations or requirements regarding the audit processes, the input data, or audit report [33]. Instead of carrying out an energy audit every few years, large enterprises can also opt to establish an energy management system, which is a continuous process of looking for energy efficiency improvements. A well-known internal standard for energy management is the ISO 50001 Energy Management (EM) [34]. It provides a framework of requirements for organizations to develop more energy-efficient and environmentally friendlier policies [35]. It sets targets and objectives to meet these policies and provides tools to measure results. Overall, EM is a comprehensive framework taking into consideration technical, economic, and human resource aspects. EM follows the “Plan-Do-Check-Act” process for continuous improvement and is designed for any public or private sector organization.

Although energy audits are required for large enterprises, small and medium enterprises (SMEs), to which most ski resorts belong, are encouraged to perform energy audits or establish energy management systems, since much can also be gained in SMEs in terms of energy efficiency [33]. The importance of carrying out energy audits and adopting energy management systems has been fully implemented in the Smart Altitude approach. Indeed, the first step of the Smart Altitude approach is for ski resorts to participate in the “Winter tourism Eco-energy Management Tool” (Wi-EMT), based on a tailor-made questionnaire, which results in an evaluation report on their eco-energy-management efficiency and a comparison of their performance with other Alpine ski resorts. The Wi-EMT is inspired by the audit tool of the European CEEM project, called “3EMT”, adapting it to the peculiar characteristics of the “ski resorts industry” [36]. Moreover, establishing an energy management system, ISO 50001 certified or not, is advisable for ski resorts as they have many infrastructures with high energy consumption, including ski lifts, snowmaking equipment, snow groomers, and operative buildings. Within the Smart Altitude project, innovative Integrated Energy Management Systems (IEMS) are put in place in living labs.

## 2.2. WebGIS: Bringing Together Data on Renewable Energy Potential and Energy Performance

Part of the approach is the development and use of a web-based GIS application to visualize existing data on renewable energy potential and infrastructure for sustainable mobility, as well as key performance indicators (KPIs) on eco-energy-management efficiency in ski resorts, enabling users to calculate their own indicators and compare their area with other municipalities of the Alpine Space Programme’s area. A GIS is designed to capture, store, manipulate, and present spatial (or geographic) data [37]. It can display any type of data on a map as long as the data are geo-referenced, i.e., has a location component [38], and enable users to visualize and analyze different elements in order to understand how they relate to one another. A web-based GIS or WebGIS provides access to a GIS requiring only basic software [39], “allow[ing] users to call up geographical information via a browser and internet access, and to analyze and display it in line with their individual interests without having to purchase expensive geodata or costly GIS software” [40] (p. 176).

The Smart Altitude WebGIS (<http://webgis.smartaltitude.eu>) is one of the tools that support the prioritization of low-carbon operations. It is integrated into the Smart Altitude Toolkit for ski resort operators, policymakers, and other stakeholders. Some data sets integrated in the WebGIS have been developed through Smart Altitude activities (e.g., the KPIs), but most others have been identified through the screening of previous relevant projects and by searching the internet (e.g., renewable energy potential). For transnational Alpine-wide studies, such as Smart Altitude, both global and European data are potential sources of free information on renewable energy potential and infrastructure for sustainable mobility. Concerning the renewable energy potential, global geodata has several disadvantages, including data coarseness and data uncertainties due to measuring methods as well as all single processing chain steps. Nevertheless, they can serve as a first overview of renewable energy

potential values, especially for comparing purposes and for identifying regions with high potential within the Alpine Space area.

### 2.3. Living Labs: Enabling Collaborative Learning

Living labs are a novel approach to create collaborative learning and innovation [41]. Living labs, supported by a EU policy framework and funding mechanisms, have been widely adopted across Europe [42]. There is no clear definition available for living labs, but living labs have the following characteristics in common: They are flexible and user-oriented, represent a real-life environment, and support co-creation and collaboration between multiple stakeholders with various, sometimes conflicting, interests including citizens, researchers, industry, and policymakers [41,43–45]. This collaboration, the so-called “quadruple helix collaboration”, is a “process in which academia, industry, government and wider communities are engaged in order to create new knowledge, technology and innovation meeting both economic and societal need” [46] (p. 28).

The living labs in the Smart Altitude project, i.e., the four already-mentioned ski resorts, follow the constellation of the quadruple helix to come up with innovative solutions to achieve a low-carbon economy in response to climate change and to guarantee the economic viability of the ski resorts. The real-life ski resorts function as laboratories for creating and testing the Smart Altitude approach. Ski operators work together with public authorities, energy experts, researchers, tourism associations, and other stakeholders to achieve a low-carbon economy by using the Smart Altitude approach. Each of the living labs will implement innovative and high-impact low-carbon interventions in one of the following areas: Advanced energy efficiency, IEMS, renewable energy, and smart grid. The measures implemented are tailor-made for each living lab by considering the unique characteristics of each ski resort (see Section 3.3) and the needs of the stakeholders.

## 3. Results and Discussion

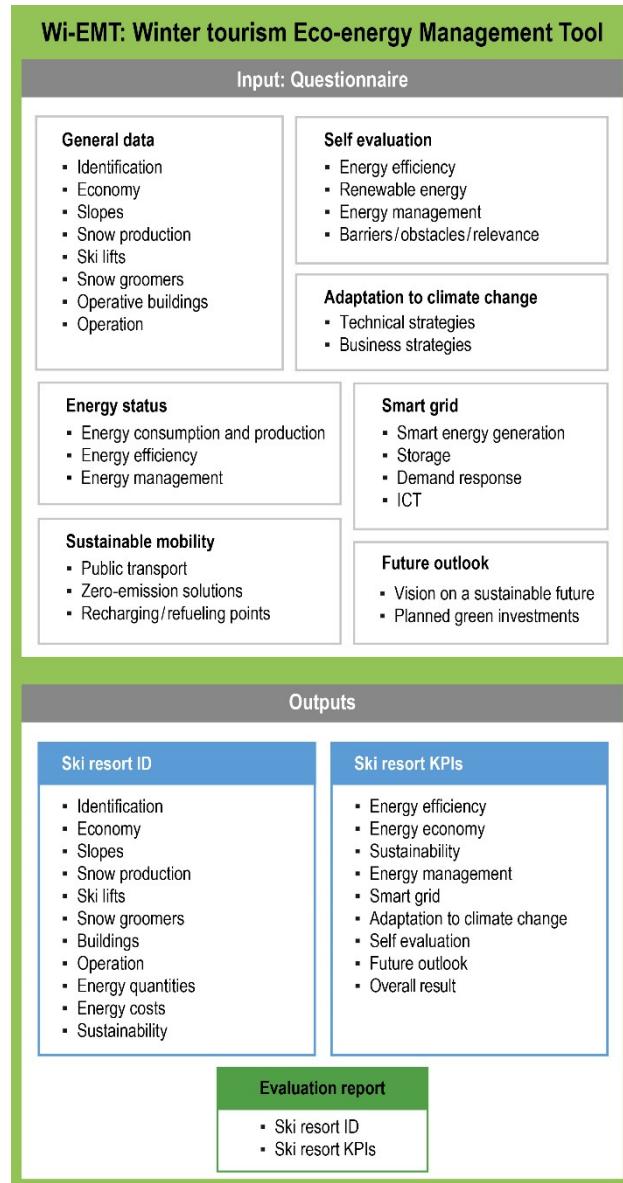
To reach the general aim of creating transformation knowledge by inductively developing a smart low-carbon approach, which identifies renewable energy potential and options for energy saving, and offers a step-by-step Decision-Making Toolkit (<https://smartaltitude.eu>) for enabling transitions toward smart skiing in practice, we:

- Designed a structured questionnaire, interviewed ski resort managers, and carried out energy audits in the study areas, to systematically identify energy consumption patterns and opportunities to save energy (or to systematically identify the ecologic, energetic, and management patterns);
- Developed an open-source web-based GIS to bring together and visualize existing data on renewable energy potential as well as Smart Altitude KPIs on eco-energy-management efficiency in ski resorts, enabling users to calculate their own indicators and compare their destination with other municipalities of the Alpine Space Programme’s area; and
- Implemented real-world laboratories for transdisciplinary collaborative learning, so-called “living labs”, including stakeholders from research institutes, the tourism industry, local and/or regional governmental institutions, and local communities—thus following the quadruple helix model of innovation.

### 3.1. The Wi-EMT Audit Tool

The Wi-EMT is an audit tool for ski resort operators to evaluate the ecological, energy, and management status and to identify the intervention priorities from a comparative perspective with other ski resorts. The input data are collected through a questionnaire that is filled out by ski resorts. The questionnaire is a self-evaluation and it is not validated by any third party. Ski resorts will not know the specific parameters of others, thus keeping the data confidential. The outputs are (1) a ski resort ID that includes the main characteristics, such as size, infrastructures, and operation of the ski resort, (2) ski resort KPIs that include measurable values that demonstrates how effectively the ski resort is

achieving key business objectives, and (3) an evaluation report that includes besides the ski resort ID and the ski resort KPIs also an overview of the energy efficiency, sustainability, and management level in the ski resort plus a comparison of its performance with the average of the other involved ski resorts in the Alpine Space. An overview of the Wi-EMT architecture is shown in Figure 2.

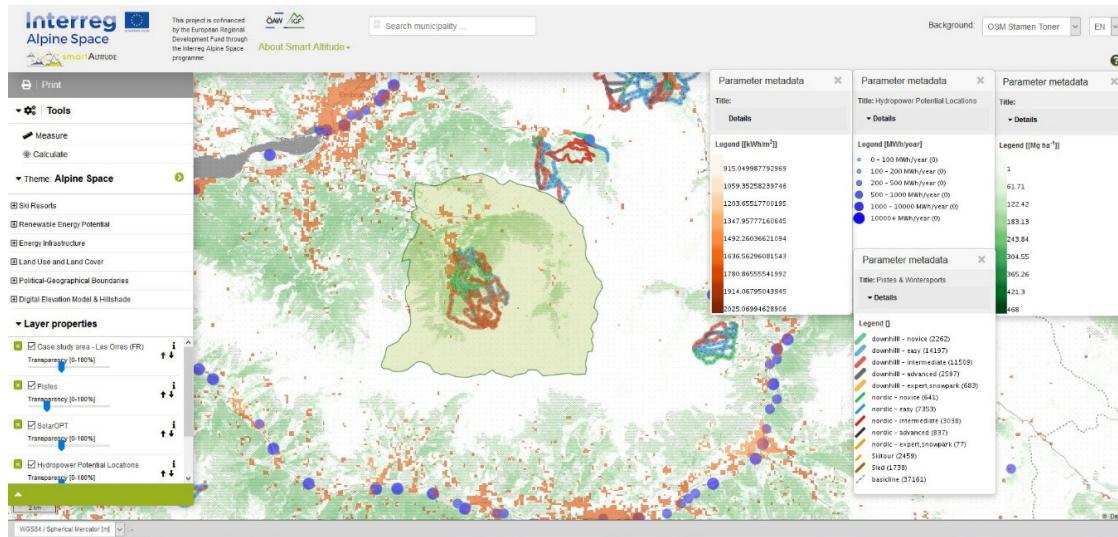


**Figure 2.** Overview of the Winter tourism Eco-energy Management Tool (Wi-EMT) design.

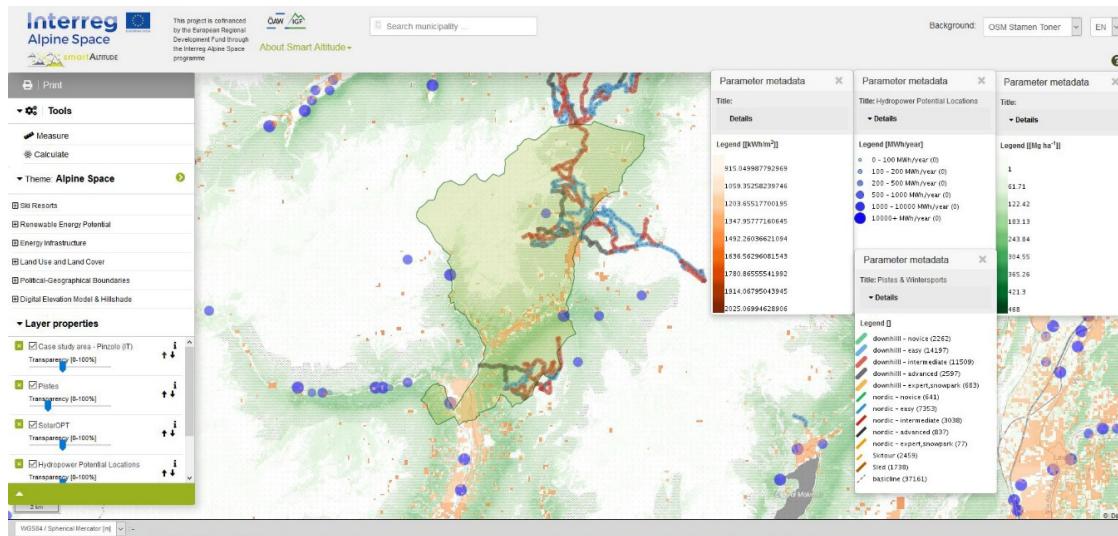
### 3.2. The Smart Altitude WebGIS

A WebGIS is a useful tool to communicate spatial information and more ambitiously to transfer knowledge to stakeholders [47]. In this project, the Smart Altitude WebGIS communicates spatial information and transfers knowledge concerning the potential of renewable energy and sustainable energy management in winter tourism to ski operators and other interested stakeholders. In order to move towards a sustainable energy management and thus a low-carbon economy, the living labs will need to increase the share of renewable energy use for the ski resorts' operations. In the Smart Altitude WebGIS, the potential of renewable energy sources can be visualized per pixel or per municipality (see Figures 3 and 4). These values only provide a preliminary overview of the potential. However, this information together with the status of living labs concerning energy efficiency

and sustainability and the possible mitigation and adaptation measures provide important input for decision-making processes towards a low-carbon economy. Moreover, the ski area operator or other interested stakeholders can request and visualize the renewable energy potential in the Smart Altitude WebGIS in combination with other relevant spatial data, such as energy infrastructure, land use and land cover, political-geographical boundaries, ski resort information, and elevation, to gain a more in-depth assessment of the ski area.



**Figure 3.** Screenshot of the Smart Altitude WebGIS with focus on living lab Les Orres. Shown are the solar energy potential, potential hydropower locations, and the above ground biomass, and the ski pistes.



**Figure 4.** Screenshot of the Smart Altitude WebGIS with focus on living lab Madonna di Campiglio. Shown are the solar energy potential, potential hydropower locations, and the above ground biomass, and the ski pistes.

### 3.3. Living Labs

#### 3.3.1. Study Area 1: Les Orres, France

The objective of the living lab Les Orres (see Figure 5) in Smart Altitude is the extension of its current IEMS by integrating additional major energy consumption areas and renewable energy production. The main consumption areas not taken into account by the current IEMS are tourist

accommodations, which are mostly heated with electricity, and other areas such as public lighting and public buildings. In 2012, fully aware of its high energy consumption from an environmental and economic perspective, Les Orres carried out a complete energy audit of its energy consumption (artificial snow making, snow grooming, ski lifts, technical buildings, and amenities) and set up an IEMS. These two operations were carried out as part of the European Interreg Alpine Space project ALPSTAR (2011–2014) [48]. They made it possible to reduce the electricity consumption by 20%, the electricity costs by 25%, and GHG emissions by 100 tons of CO<sub>2</sub> annually [49]. Since then, Les Orres has been continuously improving its IEMS by connecting additional equipment and premises to the system, optimizing the electricity grid and the management of power transformers, and improving the load shedding capacity. It has also been working as part of the Smart Altitude project on the implementation of a mountain microgrid approach (a microgrid is a mini version of the traditional power grid that can be controlled independently from the main energy network [50]).



**Figure 5.** (a) Groomed pistes and accommodations (Les Orres); (b) accommodations and pistes (Madonna di Campiglio); (c) reservoir lake for snow production (Krvavec); (d) ski lifts (Verbier). Credits: Studio Berthier/Les Orres; Funivie Madonna di Campiglio; RTC Krvavec; Téléverbier.

The installed electrical power of the SEMLORE electric grid is 3 MW, to be compared to 8 MW for the public electric grid that supplies tourist accommodation, shops, and the village. The total electrical energy consumption of Les Orres municipality and resort is around 26 GWh/year. Les Orres is currently developing hydroelectric and photovoltaic production projects with a total capacity of around 23 GWh/year, thus approaching energy autonomy within 5 to 10 years. The goal of the smart-grid approach is to build a model integrating firstly the resort operations, tourism housing, public lighting, and other consumption endpoints and secondly the local green energy production, which is managed by a Local Energy Pilot system. This system must also be able to take into account the local production of renewable energies, as well as real-time and predictive external data such as meteorological data, data on the level of stress exerted on the public power supply network, and other data.

In the limited time allowed by the Smart Altitude project, it will not be possible to implement a fully operational smart grid in Les Orres, due to several reasons. First, some photovoltaic systems are being deployed, including the pilot deployment of bifacial photovoltaic panels, but the main 280 to 320 kW (of peak power) system will not be ready before the end of the project. Second, the major local renewable energy project is hydroelectricity with a potential of 23 GWh/year, but the implementation of such a project takes 5 to 10 years. Third, integrating tourism housing into the system is complex because most of the consumption comes from timeshare or multi-owner properties. So, any energy consumption reduction or monitoring system takes time to be implemented, requiring the agreement of the owner associations. Finally, the current French legislation and regulation are not well adapted to collective self-consumption, local energy communities, or peer-to-peer energy, although the situation is evolving. For all these reasons, Les Orres and EDF work at building a simulation model through a limited set of components: Three pilot tourism housing units and limited photovoltaic production units. The goals are to measure how the current IEMS and the new endpoints can be integrated in a common Local Energy Pilot system and to model the system capacity for energy consumption reduction, electrical load shedding, and local balance between production and consumption.

### 3.3.2. Study Area 2: Madonna di Campiglio, Italy

The main goal of the Smart Altitude project in the living lab Madonna di Campiglio (see Figure 5) is the testing of a new IEMS to improve energy efficiency, optimize the use of water, integrate renewable energy, and reduce CO<sub>2</sub> emissions in the ski area. Starting from the Smart Altitude project, the ski area aims to achieve zero CO<sub>2</sub> emissions by 2026, the year of the XXV Winter Olympic Games hosted in Italy, through mitigation and compensation interventions (e.g., reforestation). This decarbonization strategy is supported by an increasing number of customers interested in environmental and climate change issues. Moreover, Smart Altitude activities result from a collaborative learning among multiple stakeholders, such as the local ski resort operator (Funivie Madonna di Campiglio), a local research center (Fondazione Bruno Kessler), a local development agency (Trentino Sviluppo), and local policymakers (APRIE).

The new IEMS monitors the plants' operations, consumption of energy and water, and local renewable energy, in order to support eco-sustainable decisions. Moreover, the new IEMS integrates data from both existing and new monitoring systems. The latter include the artificial Lake Montagnoli (used for snow production), four ski lifts (with different characteristics of both the lift and the engine), local photovoltaic potential, and snow groomers warehouses. Overall, the IEMS data come from 14 different platforms and can be grouped into seven categories:

- Weather: Monitoring of temperature, precipitation, and solar radiation (with photovoltaic potential estimate), and forecasting of weather conditions;
- Skier data: Data on the skier days;
- Ski lifts: Data on energy consumption and number of entrances;
- Snow production: Data on water and compressed air usage, snow production, and energy consumption;
- Snow grooming: Data on operation, diesel consumption, snow-depth, and warehouses heating;
- Electric grid: Data on energy consumption from the medium voltage grid;
- Lake monitoring (Lake Montagnoli): Data on water temperatures at different depths and water surface level.

The new IEMS provides integrated data and information on the entire ski area and the mountain environment that can support ski managers in taking eco-sustainable decisions. The advantages of an integrated platform include the use of a single dashboard to display all the monitoring parameters, the possibility to generate KPIs by cross-referencing data from different systems, the possibility to identify complex forecasting algorithms to optimize snow production, snow grooming, and ski lift operations, the possibility to set up alarms, and the possibility to produce periodic reports. Despite

the increasing complexity of the ski resort's infrastructure, advances in monitoring systems, such as a smart IEMS, bring sustainable energy and water consumption within the reach of ski area operators.

### 3.3.3. Study Area 3: Krvavec, Slovenia

The Krvavec ski resort (see Figure 5) aims to reduce energy consumption for snowmaking, operating ski lifts and heating. This can be achieved by installing energy efficient systems and equipment for snowmaking units, cableways, and heating generators, and by smart monitoring the energy consumption. So far, a system to increase the energy efficiency of snowmaking units has been installed plus weather-controlled regulators for increasing the efficiency of heating the lift stations. In 2021, the Slovenian living lab will construct a large reservoir lake of 100,000 m<sup>3</sup> that will be used for snowmaking. The advantage is that the new lake will reduce the amount of water that needs to be pumped up from the valley for snowmaking purposes and thus will lower the energy consumption. Also, energy-consuming snow guns will be replaced with more low-carbon friendly ones. For the Krvavec ski resort, driving factors for planning or implementing the above-described innovation are (1) the need to adapt to the changing local climate, (2) to be better able to compete with other skiing resorts, (3) promotion of innovative solutions by partner companies, (4) the pressing need to address global climate crisis, and (5) to comply with local and regional policies and targets. One barrier that is hampering the transition towards a low-carbon economy in Krvavec is that the region and the country do not co-finance investments in ski lift infrastructure, as is the case in some other Alpine countries. Ski resorts fund 100% of these investments on their own, except for investments supported by EU funds. According to the operators of the Krvavec ski resort the main benefits of the planned low-carbon innovations are (1) reducing operational costs especially the costs for electricity and gas, (2) improving ski resort's image for marketing purposes, and (3) improving visitor's experience.

The ski resort has closely and continuously interacted with the suppliers of the equipment that has been or will be implemented as part of the Smart Altitude project. The suppliers have shown to be knowledgeable and interested in the innovation developments, providing ideas and listening to the needs of the ski resort.

### 3.3.4. Study Area 4: Verbier, Switzerland

In the living lab Verbier (see Figure 5) the aim is to work on the ISO 50001 certification and to advance together with the municipality of Bagneres towards the "energy city" gold label. The ski resort Verbier has already taken important steps towards a low-carbon economy in the last years and will build upon existing systems and expertise to make further increase energy efficiency and renewable energy use.

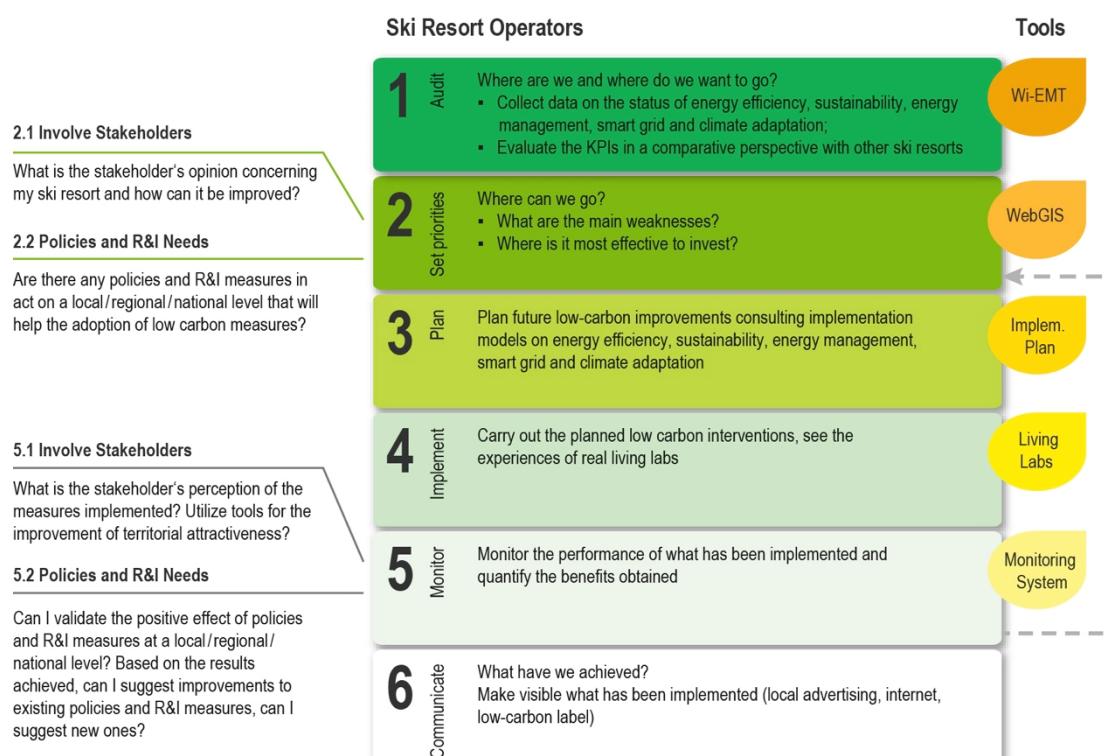
In 2016, Téléverbier introduced a strategy that promotes sustainable development, finds solutions to reduce environmental impacts, and promotes wise use of resources [51]. This strategy resulted in the implementation of a platform named OBSERV during the Smart Ski Resort project [52]. The platform provides extensive real-time monitoring of the buildings and ski lifts energy consumption for the entire ski resort. It also allows interactions if necessary. The platform is a valuable tool to identify problem areas and subsequently implement measures reducing energy consumption and increasing renewable energy use [53]. The platform also creates a data history such as hourly passages and energy consumption of lifts, which facilitates the analysis of data for effective actions. In collaboration with local actors, Téléverbier consequently introduced various energy saving measures such as lifts speed regulation, snow groomers motor optimization, replacement of electric or fossil heating system by renewable solutions, or sustainable public transportation solutions. This real-time, multi-source, and multi-fluid platform allows Téléverbier to optimize its energy efficiency. OBSERV is a valuable tool to support decisions on energy efficiency measures, identify issues, and promote renewable energy development. Since lift companies operate a multitude of energy-powered processes scattered over a large area, developing such a platform is challenging. The ski resort's electric consumption of around

8 million kWh/year is supplied exclusively by local hydroelectric production. Téléverbier further develops renewable energy production solutions on its territory, such as solar energy.

Additionally, in 2014, the municipality of Bagnes received the label “European Energy Award” for their commitment to efficient use of energy, climate protection, and renewable energies. In 2018, Bagnes implemented 66% of the scope of action and needs to implement an additional 9% of energy activities and policies to be awarded the “European Energy Award Gold” [54]. The objective within the project Smart Altitude is to harmonize the energy saving actions across Bagnes’ territory and Téléverbier. Thus, coherent and important steps toward a low-carbon, energy-efficient economy can continue to be taken in close collaboration with the municipality, the local energy utility company, and Téléverbier.

### 3.4. Decision-Making Toolkit

Given the dependence of ski resorts on natural conditions, adaptation to climate change is a topic of vital importance for ski operators and tourism policymakers: The sector is indeed required to rapidly respond, taking into account all the different implications that a decision might entail [55]. In order to remain competitive in a changing climate, operators need to take into account their strategic direction, considering each possible option for action and trying to bridge the gap between their needs and regional and local policies [55–57]. The aim of the Smart Altitude Decision-Making Toolkit (DMT) is to provide ski operators with a step-by-step approach for the selection and implementation of low-carbon measures (see Figure 6). For this reason, the DMT is designed as a toolkit outlining steps and decision-making factors that ski operators should go through for a successful implementation, taking into account the key elements and tools developed through the project and tested within the project’s living labs. The structure of the DMT is designed within a management cycle perspective for continuous improvement of the strategy set in place by the ski operators.



**Figure 6.** Smart Altitude Decision-Making Toolkit (structure).

The DMT’s first step is an audit process regarding the status of the ski area. The Smart Altitude tool called Wi-EMT enables the users to report data describing the current situation of energy efficiency, sustainability (renewable energy, mobility), energy management, smart grid, and climate adaptation of

the ski resort. The tool also allows for the evaluation of the KPIs of the area. The second step asks the operators to set the priorities and future investments, through an analysis of the available potential for renewable energy and energy efficiency in the ski resort. During this step it is suggested that operators consider both local and regional policies as well as the tourists' perception of potential adaptation measures to be implemented. Throughout this phase, a participatory method with the involvement of local and regional stakeholders will allow ski resorts operators to bridge the gap between policymakers and the implementation level, which involves, as an example, the local community, the transport system, and the overall territorial asset [58–60]. Following the audit analysis and the priority setting, ski resort decision makers can start with the Implementation Planning of future mitigation and adaptation improvements, by consulting specific implementation models on climate change adaptation, energy efficiency, sustainability, energy management and smart grid provided by the Smart Altitude partners. After step three, the implementation of planned measures can begin in step four. Monitoring the performance of what has been implemented and quantifying the benefits obtained is crucial, as in any management cycle, in order to ensure continuous improvement. The Smart Altitude Monitoring System is the step five tool that allows for monitoring the effects and impacts of implemented measures; impact evaluation allows to start the process again by setting new goals and targets and continue with implementation of further adaptation and mitigation options. During this step, a direct involvement of the stakeholders identified during step two should be considered. As underlined in previous literature, this could assist ski operators and policymakers in forming an integrated policy plan thus increasing the ability of the ski area to adapt to a changing climate and to attract tourists [58,61]. The involvement of policymakers is of uttermost importance since the increase of GHG emissions due to tourism has important policy implications [62]. The final step involves marketing and communication of the results: It is crucial to make what has been implemented visible to stakeholders also in terms of estimated effects and benefits. This will allow to be accountable towards local/ regional stakeholders and to maximize attractiveness towards the wider public and final users, including tourists.

#### 4. Conclusions

Ski resorts across the European Alps are facing challenges related to climate change, greenhouse gas emissions, and the efficient use of (renewable) energy for running ski lifts, producing technical snow, grooming slopes, and heating buildings. To increase the sustainability of Alpine ski resorts, operators are increasingly looking for new "smart" strategies. The implementation of the novel and transdisciplinary Smart Altitude approach offers a step-by-step approach for transforming sustainability research into practice. Drawing on the smart-city concept and considering the different historical developments of Alpine resorts, the Smart Altitude Decision-Making Toolkit was developed using a combination of an energy audit tool, a WebGIS, and collaborative and innovative living labs installed in Les Orres (France), Madonna di Campiglio (Italy), Krvavec (Slovenia), and Verbier (Switzerland). This step-by-step Decision-Making Toolkit helps ski resorts and other stakeholders to answer the following questions: (1) How much energy (and from which renewable energy source) is demanded by ski resorts? (2) Which sources of renewable energy are available locally and by which means can this information be communicated to stakeholders? (3) Which potential for improving energy efficiency exists locally and by which low-carbon intervention can this be achieved?

The Wi-EMT evaluation tool in combination with the Smart Altitude WebGIS and the Decision-Making Toolkit are suitable for knowledge transfer between stakeholders within living labs and moreover provide the flexibility for tailor-made low-carbon strategies depending on the unique assets and situatedness of ski resorts. The Wi-EMT audit tool provides a well-structured analysis of the energy demand by ski resorts and offers possible paths towards eco-energy efficiency and a low-carbon economy. In the WebGIS, the locally available renewable energy can be looked up by ski operators and other interested stakeholders for a spatial overview and comparison purposes. Using a living lab approach ensures that the eco-energy efficient and low-carbon solutions are tailor-made, user-oriented, and supported by the stakeholders.

Transdisciplinary approaches to sustainable winter tourism in ski resorts are a promising step towards achieving a low-carbon economy. Some challenges remain though that hamper the implementation of low-carbon interventions by ski operators, including financial, legislative, and time constraints. Furthermore, to achieve a more encompassing low-carbon economy in winter tourism resorts, the impact of tourist travel and the accommodation industry on GHG emissions has to be considered. Paradoxically, becoming a low-carbon winter tourism resort might attract more tourists with associated environmental costs. Also, low-carbon interventions only have a long-term impact on climate change. These issues are not considered within the Smart Altitude project. A more in-depth, multi-scale, and temporal examination of these considerations in terms of wider governance structures and socio-economic settings in which the living labs are embedded is therefore merited. In this respect, an analysis of the transition towards a low-carbon economy in traditionalist and modernist ski resorts would be an interesting topic for future research.

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