A New Challenge for Spatial Planning: Light Pollution in Switzerland

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Abstract

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Artificial light is usually not considered as a source of pollution and actions to tackle the problem are applied seldom, although its impact on the natural environment and human health are well documented. In this paper I provided a review on existing regulations and policies, as well as mitigation measures to minimalize light emissions (LE) in Switzerland. There is no light pollution (LP) dedicated law in Switzerland (with exception of USG Art.2, Art. 7, Art.11). The engagement of cantons is not homogenous and is usually limited to recommendation and guideline documents to support municipalities in acting against LP.
In search for alternative methods of lowering the emissions I reviewed the regulations on the governmental level in the neighboring countries and at the EU level. Although in many countries there are no specific LP regulations, similarly to Switzerland, there are also examples, where hard regulation works well (France and Italy) and do not interfere with safety and security of the inhabitants. With use of LE data it was possible to prepare a qualitative analysis of certain types of measures applied at the municipal level and to find out, which work best. Mitigation measures implemented by municipalities differ technologically, and their efficiency differs greatly too, with the best results being obtained for night curfew and intelligent lighting control systems.
The relationship between the population density and the emission values were tested in order to examine whether the excessive and increasing emissions are related only to urban areas. In fact, the results showed, that less than 0,05% of the population lives under naturally dark skies. The relationship between population density and LE is strong, but LE is not limited only to highly urbanized areas. Naturally dark areas make 19% of Switzerland's territory, mostly in remote alpine regions.
A spatial analysis where data on areas sensitive to light pollution was used was aimed to distinguish "hot spots" where the best measures to avoid excessive emissions should be applied in the first place. The areas chosen for this analysis were National Parks, BLNs (Federal Inventory of Landscapes and Natural Monuments of National Importance), Moorlands, Migratory Waterbirds Imoportant Areas, and bird migration corridors. The result of this analysis showed, that 253 areas of national importance are impacted by excessive artificial lighting and in order to reduce the negative impacts on the nature, 603 municipalities should implement measures in order to limit LE. Finally, I discussed solutions for regulations and measures possible to implement in spatial planning in Switzerland. Possible solutions involve actions at the federal level (creating a new category of BLN areas: Area of Protected Dark Skies, and including LP maps in the Federal Office for the Environment map service), as well as at cantonal and municipal levels (e.g. consideration on the new category of BLN in structure plans, or implementing a LE zoning within the municipality).

Keywords

Light pollution, ALAN, mitigation measures, spatial planning, dark skies, nature conservation, Ortsbild, Landscape conservation

1 Introduction

1.1 Light pollution

1.1.1 The origins of artificial light

Artificial light (AL) is light generated to serve human purposes. The main reason of AL since ancient times was to increase safety of human beings, whether by repelling wildlife, illuminating the topography, or avoiding attacks and aggression of other humans. To increase safety on the streets of London, in 1417 the inhabitants of the city were obliged to hang a lit lantern on every front door. A similar obligation was put on Paris inhabitants by Ludwig XI. The first modern illumination system in the urban environment reaches back to 1662 when in London the first oil (mostly whale oil was used) lanterns were installed. Just in a couple of years, other big cities followed: Paris, Berlin, Copenhagen, Vienna (KROP-BENESCH 2019: 24).

Since then, the street illumination evolved rapidly, and already in 1808 in London oil lamps were replaced by gas lamps of brightness that had never been experienced before. The invention of an arc lamp by Humphry Davy at the beginning of the 19th century marked a big change in the subject of artificial illumination. Since then, cheap and efficient electric light was gradually introduced to virtually every street and every household (SUSSMAN 2009: 124).

It was not until the beginning of the 20th century when the first skeptic voices could be heard opposing the continuous illumination and a loss of the night sky. In the law "Ortspolizeiliche Verordnung zum Schutze des Stadtbildes" established in 1911 in Berlin, the authors objected to the distortion of the city- and landscape through excessive commercial illumination (MEIER ET AL. 2014: 112-113).

1.1.2 Can light be "pollution"?

Until now, light is not always considered a serious source of pollution because of the esthetic and safety components of its presence in daily life. However, light together with emissions such as noise and waste gas belong to environmental pollution, as long as it is emitted in an excessive, misdirected, and hence, harmful way. Depending on the source it is referred to as light pollution (LP), ALAN (artificial light at night), or LAN (light at night) (BEDROSIAN AND NELSON 2013: 751; FALCHI ET AL. 2016: 1; FOBERT ET AL. 2019: 1). According to the international nonprofit organization Darksky.org, there are four main components of LP (DARKSKY 2020):

- Glare; explained as an excessive direct light, that causes visual discomfort to which animals and humans react with squinting
- Skyglow; brightening of the sky (Figure 1.1)
- Light trespass; light penetration to unwanted or unintended areas
- Clutter; bright, excessive and unnecessary illumination

Although in many definitions the term "light pollution" refers to outdoor light as a source of emission only, light shining through clear glass facades coming from the inside of buildings (for example display windows) is also considered as LP (BAFU 2017: 65).

The first step to quantify any pollution is to measure the related emission. LP is rather simple to monitor and the measurements are based on satellite images. The units that are used to describe the light-related values are:

- Lux (lx): surface illumination intensity, 1 lx equals 1 Lumen/m^2,
- Candela (cd): luminous intensity of a light source, often used as light density (cd/m^2)

But in order to assess how bright is a night sky in the city, the best is to put it into perspective by comparison with, for example, a moonless night in the countryside.
Table 1.1 presents values of objective brightness measured in Lux of several situations with different lighting settings.

Table 1.1. Illumination values for different lighting settings and environments.

Lighting setting	Illumination intensity [lx]	Light density [cd/m^2]
Summer, noon, full Sun	129 000	8 000
Cloudy day	100 – 2 000	32-640
Office lighting	<500	
Footbal field with lighting	1 600	
City sky at night, cloudy, no Moon	0,03-0,55	0,009-0,17
Countryside sky at night, cloudy, no Moon	0,0007-0,009	0,00025-0,0027
City sky at cloudless night, no Moon	0,007-0,065	0,0023-0,021
Countryside cloudless night no Moon	0,0007-0,003	0,00025-0,0008

After (KROP-BENESCH 2019: 242), changed

Figure 1.1. Skyglow over Schaffhausen (SE direction). Photograph parameters ISO 800; f=3,5; 3,0 sec. © Liliana Schönberger

1.1.3 Impacts of light pollution on nature and human health

There are many studies confirming the negative impact of LP on the environment and on human health. One of the most important impacts that affects organisms regardless of the taxonomic affiliation is a disruption of the circadian rhythm (light-related day/night cycle). Key feature regulating to the circadian rhythm in vertebrates is melatonin production, a sleep-regulating hormone whose release is stimulated by the 24-hour solar cycle (BEDROSIAN AND NELSON 2013: 751).

A disruption in melatonin production was observed in bird species (RAAP ET AL. 2015: 4; DA SILVA ET AL. 2015: 7). In many nocturnal primates (lemurs, bats, and rodents) a decrease in nocturnal activity was linked to higher light exposure at night (BOLDOGH E AL. 2007: 528-530; ROTICS ET AL. 2011 164-165; LE TALLEC ET AL. 2013: 7). The LP impacts also aquatic organisms (light trespassing) and interferes with melatonin production in fish (BRÜNING ET AL. 2015: 520; KUPPRAT ET AL. 2020: 6). The implications of disturbance of the biological rhythm can lead to increased stress levels, lower breeding success, lower hatching success, lower foraging activity as it is stated in the quoted literature. LP disrupts also plant circadian cycles causing for example reduced flowering, lower photosynthetic rates, altering in the metabolic fluxes, impairment of the pollination process (BENNIE ET AL. 2016: 615-618; SINGHAL ET AL. 2019: 194).

Light attracts organisms. It is estimated that one single street lamp causes the death of 150 insects per night. According to the findings of Rotta, in the city of Zürich alone every night over 7,5 million insects die this way (ROTTA 2011: 38).

Figure 1.2. Firefly males during mating dance in Waldfriedhof in Schaffhausen. 13.07.2020. LP affects fireflies and interfere with their mating behavior (NATURSCHUTZ.CH, 2019).
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But not only insects are lured by artificial light to their doom. Twice a year billions of birds are migrating between their breeding and wintering grounds in spring and autumn. It was estimated, that on the flyways between Europe and Africa 2,1 billion songbirds move every year. A big portion of the birds are nocturnal migrants and move at night in order to avoid predators (HAHN ET

AL. 2009: 625). Although a specific explanation, why birds are attracted to the artificial light, does not exist, it is a well-known phenomenon that has been observed worldwide. Some scientists claim, that birds during their migration may adjust their flight path to the source of artificial light as they misidentify it for their natural navigation clues (Stars, Moon or Sun) (GAUTHREAUX AND BELSER 2006: 69; CABRERA-CRUZ ET AL. 2018: 5). As an example of this phenomenon could serve the so-called Light Tribute. Every year since 2001 on 11 September in New York, in order to pay a tribute to the victims of the World Trade Center terrorist attacks, two beams of light are directed up in the sky. The light is visible from up to 95 km, and according to the Audubon Society, can pose a threat to 160,000 birds on a single occasion. The birds lured by the light are disoriented and cannot find a way out of the light stream. Since 2013 there are mitigation measures applied, and every time when the number of birds trapped in the beam of light exceeds 1,000 individuals, the light is turned off for 20 minutes in order to give the birds a chance to escape (AUDOBON SOCIETY, 2020).

The artificial light has also implications for human health, starting with disrupted circadian rhythm and sleep disorders. An indirect impact of LP was documented for diseases such as depression (BEDROSIAN AND NELSON 2013: 754; SALGADO-DELGADO ET AL. 2011: 7), obesity (RYBNIKOVA ET AL. 2016: 819; WYSE ET AL. 2011: 1140), as well as breast and prostate cancer (HAIM AND PORTNOV 2013: 111; KIM ET AL. 2016: 363). The higher risk of disease was observed in populations living under higher values of light pollution at night, linking the higher disease risks to disrupted sleep regime.

1.1.4 The efforts to minimize light pollution

Although the negative impacts on nature and human health are well documented, artificial light is usually not considered to be a serious source of pollution, therefore, the implementation of regulations and measures to mitigate its effects is a slow process having rather secondary priority to policymakers (KYEK 2019: 24; SCHULTE-RÖMER ET AL. 2019: 12). According to both the experts on light pollution and lighting professionals, one of the biggest challenges in creating a successful framework for LP policy is the unawareness of the end-users (e.g. general public but also municipalities) (SCHULTE-RÖMER ET AL. 2019: 15). Nongovernmental organizations devoted to the subject, such as Dark-Sky with local branches in many countries (including Switzerland, www.dark-sky.ch), Die Helle Not (Austria, www.hellenot.org), Cielo Buio (Italy, www.cielobuio.org), or Loss of the Night Network LoNNe (Europe, cost-lonne.eu), to name a few, are of big importance in raising awareness and supporting initiatives against artificial light at night.

The approaches to tackle the problem are manifold. Depending on the country, they vary from non-binding recommendations and norms to strict and binding regulations implemented at the national level. Although the specialists in the matter believe that the better road is through raising awareness and non-binding recommendations, there are examples, where strict regulations and laws (restricting personal freedom as a side effect) are implemented and have been accepted by society. Nonetheless, there is no evidence so far proving the superiority of one approach over the other in order to minimize LE (KROP-BENESCH 2019: 169; SCHULTE-RÖMER ET AL. 2019: 17).

It is believed that with improvement of the awareness and higher accessibility to new technologies, LP can be tackled down (SCHULTE-RÖMER ET AL. 2019: 14). In practice, the spectrum of implemented factual (in contrast to policy or regulatory) measures is quite broad. It includes solutions such as switching off unnecessary lights at night (building illuminations, street lights), shielding the light sources, installing adjustable lighting with dimmers, smart lighting with motion detectors, changing the light source to nature- and human-friendly amber LEDs, establishing dark-

sky preserves and star parks, and, in particular following the principle ALAR: "*As Low As Reasonably Achievable*" (DONATELLO ET AL. 2019: 6, 10, 17).

However, the measures mentioned above have not been a subject of any evaluation and therefore, until now, it is impossible to assess which of these measures are providing the best results in fighting LP.

1.2 Hypotheses

Worldwide, LE is continuously increasing (approximately 6% per year (SINGHAL ET AL. 2019: 191)). In Switzerland, in the years between 1994 and 2009, LE increased by 70% (WARTMANN ET AL. 2019: 210). The increase of LE is connected to the population growth and expanding of settlements, which was the incentive for the initiative to stop the progressing urban sprawl into the landscape in 2019 (German: Zersiedlungsinitiative) and for the federal Concept of settlement development to the inside (German: Siedlungsentwicklung nach innen, (ARE 2009: 6; Wartmann et al. 2019: 209). Swiss spatial planning with its goals of sustainable settlement development, careful approach to land (a scarce resource in Switzerland), protecting the landscape and natural environment, faces a new challenge - light pollution.

The increase of light emissions is mostly observed in urban areas however brightening of remote alpine regions with lower population densities (for example alpine valleys with small settlements) is observed as well (SCHULER AND SCHATZ 2016: 1, Wartmann et al. 2019: 207). Given the above, it should be expected that particularly strong and effective actions should be implemented in the urbanized areas, where the levels of emissions are extremely high, whereas in remote areas the subject would not gain much of attention and therefore, little if any measures would be considered. The same would apply to e.g. natural reserves, protected habitats, parks of national importance - although those places are also under LP pressure, not many measures are expected to be applied. It is also expected that the effectiveness of applied measures in reducing LE will vary. In order to test the hypothesis, this paper will focus on the following research question:

What does the situation in regards to mitigation measures and regulatory work related to LP look like in Switzerland and how can the new challenges arising from LP be effectively addressed by means of spatial planning instruments?

How do LP levels relate to the level of urbanization (expressed by population density) and to documented mitigation measures spatially? How do the implemented measures perform?

Are there any places in Switzerland where LP has its "hot spots" with possible adverse effects on the environment and where immediate implementation of mitigation measures would be advisable?

2 Methods

2.1 Literature review

The aim of the literature review is to identify the implemented mitigation measures and to identify what are the best practices regarding regulating LP. The structure of the literature review is presented in the Table 2.1.

The literature review is divided into two categories. The main category refers to LP mitigation measures, policies, and enforcements of existing laws in Switzerland at the level of municipalities, cantons, and at the federal level.

The primary source of information for the review at the federal level were governmental websites of the Federal Department of the Environment, Transport, Energy and Communications (German: UVEK) and Federal Office for the Environment (German: BAFU) (BUNDESAMT FÜR UMWELT BAFU 2020; EIDGENÖSSISCHES DEPARTEMENT FÜR UMWELT, VERKEHR, ENERGIE UND KOMMUNIKATION 2020). The governmental websites were also the first source of information for actions implemented at the cantonal level. Further, I searched for adequate information on the official cantonal websites. The research at the municipal level included surveying local newspaper articles, municipal websites, and interviews with municipal officials. An additional source of information was the website of the organization Dark-Sky.ch (darksky.ch 2020).

The difficulty in gathering representative information for all 2202 municipalities in Switzerland lays in the fact, that not all documents are available online and to some extent, the implemented measures are not regulated in an official way in relation to LP, therefore it must be emphasized, that the review on the municipal level may not be complete.

The second category includes a review of the situation in the EU on the example of the neighboring countries: France, Austria, Germany, Italy, and Lichtenstein. In this part of the review I focused on the national level regulations and legislative frameworks at the level of European Union, as well as other non-binding measures undertaken at the level of the EU. To gather the literature in that matter I searched through the European Commission's online resources. For information on legislation in neighboring countries I searched the online resources of non-profit organizations active in the given countries (e.g. Helle Not in Austria, Cielobuio in Italy), as well as national reports on LP (ARONOVITZ ET AL. 2015; RENAT AG 2008).

All the online resources were last accessed in July 2020.

Table 2.1. The structure of the literature review

Main categories	Subcategories	Types of literature included
Switzerland		
	Municipality	Decrees, Ordinances, Guidelines, Technical mitigation measures
	Canton	Cantonal constitution, Richtplan (Aiming Plan), Guidelines, Recommendations
	Federal level	Constitution, Environment Protection Law, Spatial Planning Law, Building Law, Federal Recommendations, Norms

European Union (France, Austria, Germany, Italy, and Lichtenstein)	Federal level	Constitution, Environment Protection Law, Spatial Planning Law, Building Law, Norms, EU Directives, Projects, Procurements

2.2 Spatial analyses

Spatial analyses were conducted in order to assess the LP situation in Switzerland, its spatial relationship with the population density, as well as to study the spatial distribution of the implemented measures against LP, their relation to the levels of emissions in Switzerland, as well as to identify LP "hot spots" where implementing given measures would be advisable.
All spatial analyses were carried out in ArcGIS 10.5. As the background dataset for all the analyses I used LE values from 2010-2012 and LE trends expressing the changes in LE levels in years 2014-2018.

For the following areas an LE assessment was done (Zonal Statistics tool: mean, max and min LE values), in order to find out whether those areas are impacted by the elevated LE (LE higher than radiance value: 100, which is approximately 1/5 of the maximum radiance experienced nowadays in Switzerland (KYEK 2019: 16)):

- Parks of national importance;
- Federal inventory of landscape and natural monuments (BLN areas);
- Wetland areas of national importance;
- Water and migrant bird reserves;
- Bird migration corridors.

Those areas were chosen because of their importance for maintaining local, regional and global species populations and supporting biodiversity (BRUDERER 2017: 86, WETLANDS INTERNATIONAL 2020). Based on the obtained results, relevant (under LP pressure) areas were distinguished ("hot spots"), where it is advised to implement effective measures against LP (selection of municipalities that overlap with impacted natural areas).
Datasets on population density and LE values were used in order to investigate the relationship between LP and the level of urbanization. In order to test the relationship, a geographically weighted regression was conducted (Esri 2020), where average LE values (radiance/ha) were set as a dependent variable and population densities (average per municipality, N/ha) as an explanatory variable.
To present the relationship visually, a light emission index map was prepared by multiplying rasters (population density and LE). The higher the returned value, the higher population density and/or LE, while zero value locates areas, where LE=0. Null values are returned for uninhabited areas (no data on population density). The map was prepared with the Raster Calculator Tool.
Additionally, all the gathered information on implemented mitigation measures at the municipal level were mapped in order to assess their effectiveness by comparing with the values from datasets on trends in LE.

Data acquisition

Original data on LE in the form of satellite imagery was sourced from the American Defense Meteorological Satellite Program (DMSP). The processed datasets for a period 1992-2012 for Switzerland were retrieved from the Swiss Federal Institute for Forest, Snow and Landscape Research

WSL and were prepared by M. Weiss and F. Kienast. The resolution of the raster datasets is 1 km^2, and the LE values are presented in the radiance unit:

$$L = \frac{W \times sr^{-1}}{m^2}$$

Where:
L – radiance
W – watt
sr – steradian
m^2 – square meter.

Data on the LE trends in the tie frame 2014-2018 were kindly made available by Lukas D. Schuler, Dark-Sky Switzerland. The dataset was reclassified (tool: "Reclassify") into 5 categories:

1. Reduced LE
2. No changes in LE
3. Slight increase of LE
4. Moderate increase of LE
5. Substantial increase of LE

Population density data for 2018 (N/ha) was obtained from the Federal Statistical Office (German: Bundesamt für Statsistik, BFS). Data on the federal inventories and protected areas were retrieved from Federal Office for the Environment FOEN. Bird migration corridors were designated based on the available literature (Bruderer 2017).

3 Results

3.1 Mitigation measures in Switzerland

In Switzerland, there are three political levels having legislative and executive power, where different aspects of LE can be regulated (FDFA 2020). The next sections provide an overview of the available legislation related to LP starting with the federal level, where laws and parts of the constitution, as well as non-binding documents issued by the government, are presented. The second section presents an overview of available legislation at the cantonal level, and the last section presents findings at the municipal level.

3.2 Legislation at the federal level

Although at the national level there are no self-standing regulations, that refer explicitly to LP, there are certain articles in the Swiss Constitution as well as in the Environmental Protection Act, Water Protection Act, and Nature and Cultural Heritage Protection Act, that can be interpreted as an obligation of the Swiss Federation, Cantons and Municipalities to act upon the excessive lighting at night.

Federal Constitution

In section 4 (Environment and Spatial Planning) of the Federal Constitution (BV), Article 74 mentions the protection of human life and the natural environment against actions causing harm

and disturbance and defines the responsibilities (executions and legislation) (Article 74 BV). Since, as shown above, LP is a cause of harm and disturbance to both human health and natural environment, arguably the said article generally applies to any measures trying to address LP.
Article 78 BV refers to the protection and preservation of natural and cultural heritage. It calls out the protection of landscapes, cityscapes, oldtowns, natural, and cultural monuments (Article 78(2) BV), as well as fauna, flora, habitats, and biodiversity (Article. 78(4) BV), which allows addressing concerns about LP and its negative impacts on the elements listed above. Additionally, mitigation measures against LP fall within the scope of Article 118 BV, which deals with health protection (Article 118(2c) BV).

Environment Protection Act

The Environmental Protection Act (German: Umweltschutzgesetz: USG) lays out a general strategy of environment protection, which is the precautionary principle (German: Vorsorgeprinzip, Article 1(2) USG), which states, that all actions, that supposedly can cause harm to the environment should be limited or restricted precautionary, in order to avoid negative impacts, what can be translated in terms of lighting to "as much as necessary, as little as possible". Regarding different types of emisisions (noise, waves, vibrations) the USG sets a ground-rule to follow – to reduce the emissions at the source (German:Verursacherprinzip) as set out in Article 2 USG (which can be also be applied to the LE). A very important part of the USG, which potentially offers a statutory basis for mitigation measures against LP are the sections on emissions (Articles 11-12 USG) and ambient pollution levels (Articles 13-15 USG). Light consists of electro-magnetic radiation and as such is covered by Article 11(2) and 12(2) USG, even though there are no maximum emission values as confirmed by the Swiss Federal Court in its decisions BGE 140 II 33 and BGE 140 II 214.

Waters Protection Act

The Waters Protection Act (German: Gewässerschutzgesetz, GSchG) sets several goals, among them a few could potentially serve as a valid legal basis for measures taken to regulate LP issues. The said goals are: to protect human health, animals, and plants, to preserve natural habitats for fauna and flora, and to preserve waters as an element of a landscape (Articles 1a, 1c, 1d, 1e GSchG). Article 19 GSchG gives cantons the competence to create water protection areas in relation to the risk of pollution. The pollution type in this article is not specified, therefore it could potentially address the LP issues (Article 19 GSchG).

Federal Act on the Protection of Nature and Cultural Heritage

The Federal Act on the Protection of Nature and Cultural Heritage (German: Natur- und Heimatschutzgesetz, NHG) in a broad sense deals with the protection of landscape, sites important for local identity, and historical monuments, as well as biotopes and species (Article 1 NHG). Within the scope of this provision, all of the mentioned elements can be a subject of negative LP impact, therefore the angle of the text allows supporting measures against LP. Articles 18 and 23 NHG specifically refer to biotopes, species protection (Article 18 NHG), wetlands of national importance (Articles 23a, 23b, 23c, 23d NHG), and national parks (Articles 23e, 23f, 23g, 23h, 23i, 23j, 23k NHG), underlining the federal and cantonal obligations to protect those areas.

Spatial Planning Act

The Spatial Planning Act (German: Raumplanungsgesetz, RPG) serves the purpose of identifying parties responsible for carrying out the tasks of spatial planning, which is sustainable and economical handling of the land resources. Article 1 RPG deals with the aims, as well as the scope

of numerous planning challenges in Switzerland, which spatial planning should support. Further, it is specified that spatial planning has a task to support, protect, and maintain natural elements like soil, air, and water, as well as forest and landscape (Article 1(2a) RPG). This formulation gives a legislative basis for the implementation of mitigation measures against LP at the level of spatial planning, and to incorporate those into the spatial planning instruments.
A further host to such measures could be Article 3 RPG, which identifies the basic principles of spatial planning. Section 2 of this article refers to landscape protection with special emphasis on maintaining the unobstructed lake and river shorelines (Article 3(2c) RPG), maintaining the landscapes and recreational spaces in harmony with nature (Article 3(2d) RPG), and on maintaining the forests' natural functions (Article 3(2e) RPG). In the third section, a principle of keeping the residential area free of impact such as air pollution, noise, and vibrations is mentioned, although again, LE is not listed.
All that said, the language and scope of Article 3 RPGclearly creates an opportunity to introduce LE as a subject of regulation in the Act on the same basis as other emissions of other recognized pollutants.

Federal recommendations and guideline documents

Although recommendations and guideline documents are non-binding, they belong to the range of instruments that are often used to enforce mitigation measures, without the need for hard regulation. Over the past two decades, several documents referring to LP were published on behalf of the Federal Department of the Environment, Transport, Energy, and Communications (German: Departement für Umwelt, Verkehr, Energie und Kommunikation, UVEK).
The first step to address the unnecessary LE in Switzerland was Recommendations for Avoidance of Light Emissions published in 2005, and it was the first document entirely devoted to the LE topic. The document focuses on general recommendations and advisable technical solutions to avoid unnecessary lighting at night, without introducing guide values for emissions (KLAUS ET AL. 2005: 4).

In 2016 an extensive report on updating the guidance for avoidance of unnecessary light emissions offering a comprehensive evaluation of the LP issue was published. The report was dealing with several aspects that were not addressed previously, such as guide values, light planning, safety in public space, and in transportation. In this document, the existing international and foreign LE guide values, as well as zoning practices based on LE sensitivity of a given site were discussed (DEUBLEIN ET AL. 2016:1-5).
A new version of the guidance document is now in preparation. The Federal Office for the Environment issued a draft version of the document in 2017. The document is even more detailed than its predecessor and is designed to aid not only cantons and communes in the enforcement of the measures against unnecessary LE, but also to aid architects, planners, light-designers, constructors, etc. The report's authors mention also owners and managers of properties contributing to LP (BAFU 2017: 9) as recipients and set the purpose of the document to be used during the planning, construction, and renovation of light infrastructure, and during complaint procedures (BAFU 2017: 10).

Among documents of recommendations, there are a few, that deal with the LP issue only partially. One of them is the environmental checklist for national street projects which do not require an environmental impact assessment procedure. The document, published in 2017, has a section devoted to unnecessary LE, where it refers to the measures mentioned in the first version of the Recommendations for Avoidance of Light Emissions, norm SN EN 12464-2 (outdoor working spaces), and the recommendations prepared by the Swiss Ornithological Institute Vogelwarte Sempach (BAFU and ASTRA 2017: 20). It gives general recommendations, however, it lacks specific

recommendations for example on the type of color temperature of the light source (BAFU and ASTRA 2017: 20).

BAFU and ASTRA published in 2017 a baseline report focused on bat conservation ("Bat conservation for planning, construction, and renovation of transport infrastructure). Bats being night active animals are especially affected by LP, therefore the issue of LP is discussed in the document. BAFU and ASTRA as a measure against LP recommend optimizing the lighting and following the guidelines of Recommendations for Avoidance of Light Emissions, and norms VSS 640 246a, 640 247a (crossings for the pedestrian and bicycle traffic) and SIA norm 491 (avoiding unnecessary outdoor light emissions).

Norms

Although a norm is only a binding force when specifically referred to in the law, certain norms are used as a point of reference for measures against LP. The Swiss Engineer and Architect Organization (SIA) published norm SN 586 491: Avoidance of unnecessary outdoor light emissions in 2013. It follows the precautionary principle, deliberately does not set guide values, emphasizing the need of reducing the LE at the source without "repressive regulations" (KOBLER 2013: 33; SIA 2013: 5). Measure-wise, it is focused on technical solutions for illumination infrastructure and sets guidelines for implementation in spatial planning instruments (structure plans and land use plans) (SIA 2013: 16).

3.3 Legislation at the cantonal level

At the cantonal level, the subject of light is usually dealt with by the Environment Protection Office and the Engineering Office (German: Tiefbauamt) (when light means road lighting and safety on the roads). However, light considered as a harmful emission is rarely addressed at the cantonal legislation level, and acting against LP is normally understood to be a responsibility of municipalities (ETTWEIN ET AL. 2013; KANTONSRAT SCHWYZ 2019, CANTON THURGAU, USGV, ART. 33). There are traceable discrepancies in the approach and understanding of the problem, and depending on the canton, different policies are in force, but the common aspect of the available cantonal documents is that the competences in the subject belong to municipalities. In terms of LP at a cantonal level, the federal Environment Protection Act (Aargau, Schaffhausen, Sankt Gallen, Thurgau) or the Energy Act (Fribourg, Neuchâtel) are complemented by means of the corresponding introductory laws (German: Einführungsgesetze) and additional ordinances or decrees. Given their more technical nature in particular the emission values are normally set out in the latter. The Cantonal Council of Geneva issued a motion to the Council of State (French: Conseil d'État) in order to establish a binding cantonal strategy against LP (and additionally, to report and analyze LP situation in the canton, to carry out a test of dimming and switching off the public lights, and establishing dark corridors for wildlife) (De et al. 2018). The motion was answered a year later with an explanation, that LP measures are to be addressed in the cantonal biodiversity strategy issued in April 2020 (SECRÉTARIAT DU GRAND CONSEIL 2019). Indeed, actions 1.4 and 1.5 of the strategy refer to preserving the darkness of the night by analyzing the LE situation, mapping areas for preserved darkness and implementing the "dark grid plan" (French: Plan d'action «trame noire») at the cantonal level (CANTON GENEVA 2020: 68-69). In Schaffhausen the Green Party put in motion a cantonal initiative "More Space for the Night" (German: "Mehr Raum für die Nacht"), in order to change the Introductory Environment Protection Act by adding new regulations concerning e.g. threshold values for permitted light temperature and light intensity of outdoor light infrastructure, setting the

night curfew (EHRAT 2019; GRÜNE SCHAFFHAUSEN 2019). In case the initiative is accepted (voting date is not known yet), Schaffhausen will be the first canton with binding regulations covering a broad spectrum of LP issues.

Nonetheless, the majority of cantons issue non-binding guideline documents for municipalities, whether in the form of a leaflet or checklist (Basel Landschaft, Bern, Glarus, Jura, Luzern, Nidwalden, Obwalden, Schaffhausen, Schwyz, Solothurn, Tessin, Uri, Wallis, Zug, Zurich). Some cantons in order to support the municipalities issue additional documents, such as LE regulation templates (Canton Sankt Gallen: template for light immission regulation on the municipal level). Additionally to recommendations, the Canton Jura published a cantonal policy against Light Pollution in 2018. Although it speaks of binding mechanisms (in case the canton authorizes or subsidize a project) it remains a guideline document setting the framework for a cantonal strategy against LP (Canton Jura 2018), informing about the impacts of LP, possible measures to reduce LE. Other actions undertaken by cantons are LE monitoring (Zürich and Uri) or organizing meetings and open conferences for education and awareness (Thurgau, Jura). Even though the following overview does not claim completeness, the list of legislative actions and measures taken at the level of cantons as a result of the conducted research is presented in Table 3.1.

Table 3.1. Legislation and mitigation measures at the cantonal level in alphabetical order.

Canton	Type of focument	Document name (in German or French)
Aargau	Introductory law to the Federal Envrionment Protection Act	Einführungsgesetz zur Bundesgesetzgebung über den Schutz von Umwelt und Gewässern, § 27 Lichtemissionen, 2016.
	Additional regulations to the introductory law	Verordnung zum Einführungsgesetz zur Bundesgesetzgebung über den Schutz von Umwelt und Gewässern (V EG UWR), § 56 Lichtemissionen, 2008.
Appenzell Ausserrhoden	Not found	
Appenzelll Innerrhoden	Not found	
Basel Stadt	Not found	
Basel-Landschaft	Guidelines for outdoor work and public spaces	Richtlinie Beleuchtung, Bau- und Umweltschutzdirektion Kanton Basel-Landschaft, Hochbauamt.
Bern	Guidelines for open public spaces	Richtlinie Beleuchtung öffentliche Aussenräume.
	Guidelines	Lichtemissionen Vermeiden der Lichtverschmutzung und deren Auswirkungen auf Mensch, Flora und Fauna.
Fribourg	Cantonal Energy Act	Energiegesetz (EnGe), Art. 15a, 2,4.
Geneva	Motion	Proposition de motion (2422-A) pour un éclairage nocturne économe.
	Intercommunal project	La nuit est belle, 2019
	Cantonal Biodiversity Strategy	Plan Biodiversité 2020-2023 De La Stratégie Biodiversité Genève 2030
Glarus	Leaflet	Lichtverschmutzung vermeiden: Ein Merkblatt für Gemeinden.

Canton	Type of focument	Document name (in German or French)
Graubünden	Postulate (declined)	Postulattext Kt. Graubünden: Eindämmung der Lichtimmissionen, 2002.
Jura	Policy	Réduction des émissions lumineuses Politique poursuivie par les autorités cantonales, 2018.
	Leaflet	Merkblatt Lichtverschmutzung.
	Conference	Jura Environment Forum "Light Emissions", September 19, 2018.
Luzern	Leaflet	Merkblatt Lichtverschmutzung. http://www.umwelt-zentralschweiz.ch/
Neuchâtel	Amendment to Cantonal Energy Act	Amendement au projet de loi cantonale sur l'énergie (LCEn) Art. 61.
Nidwalden	Leaflet	Merkblatt Lichtverschmutzung http://www.umwelt-zentralschweiz.ch/
Obwalden	Leaflet	Merkblatt Lichtverschmutzung http://www.umwelt-zentralschweiz.ch/
Sankt Gallen	Introductory law to the federal Envrionment Protection Act	Einführungsgesetz zur eidgenössischen Umweltschutzgesetzgebung (EG-USG), Art.. 35
Sankt Gallen	Immission control regulations and a template for municipalities.	Immisionsschutzreglement, Art. 20. Bemerkungen zum Muster Immsionschutzreglement.(a leaflet)
Schaffhausen	Initiative	Initiative mehr Raum für die Nacht
	Introductory law to the federal Envrionment Protection Act	Einführungsgesetz zum USG, Art. 21
	Guidelines	Licht und Transparenz Optimaler Einsatz von Aussenbeleuchtung und Glas
Schwyz	Leaflet	Merkblatt Weihnachtsbeleuchtung
	Leaflet	Merkblatt Lichtverschmutzung http://www.umwelt-zentralschweiz.ch/
Solothurn	Guidelines	Umweltschutz beim Bauen Empfehlungen. Amt für Umwelt.
	Guidelines	Leitfaden Vermeidung von unnötigen Lichtemissionen
	Cantonal Construction Regulations	Kantonale Bauverordnung, KBV, Art. 61, 64
	Guidelines	Vermeidung von unnötigen Lichtemissionen – visualisierte Zusammenfassung, Amt für Umwelt.
	Guidelines	Vermeidung von unnötigen Lichtemissionen im Baubewilligungsverfahren. Checkliste zur Beurteilung von Baugesuchen, Amt für Umwelt.

Canton	Type of focument	Document name (in German or French)
Tessin	Guidelines	Richtlinien für die Vermeidung von Lichtverschmutzung.
	Guidelines Report	Ergänzungsbericht zur den Richtlinien für die Vermeidung von Lichtverschmutzung.
Thurgau	Ordinance	Verordnung des Regierungsrates zur Umweltschutzgesetzgebung, USGV, Art. 33.
	Workshop	Vollzugstagung über Lichtimmissionen, 2016.
Uri	Leaflet	Merkblatt Lichtverschmutzung http://www.umwelt-zentralschweiz.ch/
	Monitoring	Lichtmonitoring Andermatt
Vaud	Leaflet	Eclairage public et pollution lumineuse
Wallis	Guidelines	Hell Leuchtet Die Nacht! Wie Lichtverschmutzung Die Natur Belastet. 2019.
Zug	Mititgation measure	Streetlighting (Schochenmühlestrasse, Baar).
	Leaflet	Merkblatt Lichtverschmutzung http://www.umwelt-zentralschweiz.ch/
Zurich	Leaflet	Lichtverschmutzung vermeiden. Ein Merkblatt für Gemeinden. Baudirektion Amt für Abfall, Wasser, Energie und Luft Amt für Landschaft und Natur.
	Guidelines	Strahlungsrisiken im Kanton Zürich Auslegeordnung, Handlungsbedarf und Empfehlungen. Baudirektion Amt für Abfall, Wasser, Energie und Luft Amt für Landschaft und Natur
	Checklist	5-Punkte – Checkliste zur Beurteilung einer Beleuchtungseinrichtung. Baudirektion Amt für Abfall, Wasser, Energie und Luft Amt für Landschaft und Natur
	Monitoring	Sky Quality Meter: Resultate 2016. Baudirektion Amt für Abfall, Wasser, Energie und Luft Amt für Landschaft und Natur.

3.4 Legislation and measures against light pollution at the municipal level

In the process of online research and validation of obtained information on regulations, policies, as well as on mitigation measures, 143 municipalities were recognized as actively acting against LP. Although there are many more municipalities that adapt LED technology, it does not automatically mean, that the new lighting infrastructure reduces LE. Usually the reason behind the change is energy saving, and a lighting concept is not designed to avoid unnecessary LE, or to use environment-friendly warm light emitting LEDs. In case when a municipality introduced LED technology, but there is no information on measures designed to reduce LE, the case was not regarded as a measure against LP.

Among the cantons, the highest number of municipalities involved in acting against LP was found in Aargau (23 municipalities). Other cantons with a high number of municipalities with measures against LP were: Bern (16), Fribourg (14), Zurich (13), Baselland (10), and Vaud (10). No measures actively applied by municipalities were found for cantons Apenzell Innerrhoden, Nidwalden, Obwalden, and Zug. For Basel City there are measures planned to be implemented first in 2020 (SCHWALD 2018), however no specific information regarding implementation processes of those were found at the time of preparing this paper. When it comes to binding regulations, nine municipalities implemented a police decree regulating the lighting of buildings in the night hours (all in Baselland). Beside the police decree there is no other binding regulation on the municipal level, however Glarus Nord (Canton Glarus) has published a draft version of a Regulation for Outdoor Lighting (GEMEINDERAT GLARUS NORD 2020). This document is an updated version of the same draft from 2017 but is still not put into force.

There are 18 municipalities that own a Lighting Plan (most often referred to as a "Plan Lumière"). In these documents the municipalities describe their goals in the subject of outdoor lighting, what can be summarized as achieving sustainable, energy saving, environment friendly and high quality and esthetic lighting. The plans differ in details, some of the municipalities put more emphasis on reducing the negative impacts on the environment, while others focus mainly on energy saving issue.

Technical measures can be divided into three categories:

1) Night curfew (lights off at night, usually between 1 and 5 am);
2) Intelligent (dynamic) control system (motion sensors, dimming, special control software);
3) Mechanical adjustments of the infrastructure (shielding, adjusting light orientation).

It is important to highlight, that although in this chapter I refer to municipalities, measures were usually implemented only in selected parts of the municipalities, e.g. the main square, old town or residential area.

The most common measure is the implementation of an intelligent (also called "dynamic") control system, that allows adjusting the light intensity to actual needs (60 municipalities). The systems can be equipped in motion sensors that increase the brightness of specific light points in case a person or a vehicle approaches, or, in case of a more simple system, it dims the lighting in given areas to a given percent of the maximum brightness (can be as low as 10% of the maximum brightness (TOPSTREETLIGHT.CH 2018: 3). The second most popular measure is a night curfew (46 mu-

nicipalities). This measure is applied only in areas, where switching off lights is a reasonable solution and does not interfere with the safety of inhabitants. There are several municipalities, where a night curfew is in a test phase (evaluating the level of acceptance for the solution). There are also municipalities, that did not decide to implement this measure (such as Fislisbach, Aargau, (GEMEINDE FISLISBACH 2016)). All the municipalities considered to be acting against LP are listed in Table 3.2.

Table 3.2. Mitigation measures and regulations against LP at the municipal level in Switzerland

Lp	Canton	Municipality	Category
1	Aargau	Baden	Night curfew
2	Aargau	Bözen	Intelligent (dynamic) control system
3	Aargau	Brugg	Intelligent (dynamic) control system
4	Aargau	Ehrendingen	Night curfew
5	Aargau	Ennetbaden	Night curfew
6	Aargau	Kölliken	LED
7	Aargau	Langenthal	Intelligent (dynamic) control system
8	Aargau	Lenzburg	Intelligent (dynamic) control system
9	Aargau	Lupfig	Intelligent (dynamic) control system
10	Aargau	Merenschwad	Night curfew
11	Aargau	Neuenhof	Intelligent (dynamic) control system
12	Aargau	Obersiggenthal	Night curfew
13	Aargau	Rheinfelden	Lighting Concept
14	Aargau	Schöftland	Intelligent (dynamic) control system
15	Aargau	Suhr	LED
16	Aargau	Untersiggenthal	Night curfew
17	Aargau	Villnachern	Night curfew
18	Aargau	Wettingen	Night curfew
19	Aargau	Windisch	Night curfew
20	Aargau	Wohlen	LED
21	Aargau	Würenlinger	Night curfew
22	Aargau	Würenlos	Night curfew
23	Aargau	Zetzwil/Gontenschwil	Intelligent (dynamic) control system
24	Apenzell	Teufen	Night curfew
25	Baselland	Aesch	Police regulation
26	Baselland	Allschwil	Police regulation

Lp	Canton	Municipality	Category
27	Baselland	Binningen	Police regulation
28	Baselland	Gelterkinden	Police regulation
29	Baselland	Laufen	Police regulation
30	Baselland	Lausen	Police regulation
31	Baselland	Münchenstein	Police regulation
32	Baselland	Muttenz	Police regulation
33	Baselland	Oberwil	Night curfew
34	Baselland	Pratteln	Police regulation
35	Bern	Plateau de Diesse	Night curfew
36	Bern	Bern	Intelligent (dynamic) control system
			Lighting Concept
37	Bern	Corgémont	Night curfew
38	Bern	Cormoret	Night curfew
39	Bern	Cortébert	Night curfew
40	Bern	Courtelary	Night curfew
41	Bern	Interlaken	Night curfew
42	Bern	Le Plateau de Diesse	Night curfew
43	Bern	Münchenbuchsee	Intelligent (dynamic) control system
44	Bern	Muri	Night curfew
45	Bern	Ostermundigen	Intelligent (dynamic) control system
46	Bern	Sonvilier	Night curfew
47	Bern	St-Imier	Night curfew
48	Bern	Trubschachen	Intelligent (dynamic) control system
49	Bern	Wynau	Intelligent (dynamic) control system
50	Bern	Zollikofen	Lighting Concept
51	Fribourg	Belmont-Broye	Intelligent (dynamic) control system
52	Fribourg	Châtel-St-Denis	Intelligent (dynamic) control system
53	Fribourg	Courtepin	Intelligent (dynamic) control system
54	Fribourg	Freibourg	Intelligent (dynamic) control system
55	Fribourg	Granges-Paccot	LED
56	Fribourg	Le Mouret	Night curfew
57	Fribourg	Murten	Night curfew

Lp	Canton	Municipality	Category
58	Fribourg	Plaffeien	Night curfew
59	Fribourg	Remaufens	LED
60	Fribourg	Romont	LED
61	Fribourg	Siviriez	Night curfew
62	Fribourg	St. Antoni	Night curfew
63	Fribourg	Tentlingen	Night curfew
64	Fribourg	Wünnewil-Flamatt	Night curfew
65	Geneva	Meyrin	Lighting Concept
66	Geneva	Carouge	Lighting Concept
67	Geneva	Geneva	Lighting Concept
68	Glarus	Glarus Nord	Regulation
69	Glarus	Glarus Süd	Intelligent (dynamic) control system
70	Graubünden	Fläsch	Lighting Concept
71	Graubünden	Chur	Night curfew
			Lighting Concept
72	Graubünden	Felsberg	Intelligent (dynamic) control system
73	Graubünden	Fläsch	Intelligent (dynamic) control system
74	Graubünden	Landquart	LED
75	Jura	Bourrignon	Intelligent (dynamic) control system
76	Jura	Courrendlin	Intelligent (dynamic) control system
77	Jura	Delémont	Lighting Concept
			Intelligent (dynamic) control system
78	Jura	Develier	Intelligent (dynamic) control system
79	Jura	Haute-Sorne	Intelligent (dynamic) control system
80	Jura	Moutier	Intelligent (dynamic) control system
81	Jura	Porrentruy	Intelligent (dynamic) control system
82	Jura	Sonceboz-Sombeval	Intelligent (dynamic) control system
83	Jura	Val Terbi	Night curfew
84	Luzern	Flühli	Intelligent (dynamic) control system
85	Luzern	Luzern	Intelligent (dynamic) control system
			Lighting Concept

Lp	Canton	Municipality	Category
86	Luzern	Meggen	Intelligent (dynamic) control system
87	Luzern	Stäfa	Intelligent (dynamic) control system
88	Neuchâtel	La Chaux-de-Fonds	Night curfew
89	Neuchâtel	Le Cerneux-Péquignot	Night curfew
90	Neuchâtel	Le Locle	Night curfew
91	Neuchâtel	Le Pâquier	Mechanical Adjustment
92	Neuchâtel	Neuchâtel	Lighting Concept
93	Neuchâtel	Valangin	Night curfew
94	Neuchâtel	Val-de-Ruz	Night curfew
95	Schaffhausen	Andelfingen	Night curfew
96	Schaffhausen	Neuhausen	Mechanical Adjustment
97	Schaffhausen	Schaffhausen	Mechanical Adjustment
98	Schwyz	Freienbach	Intelligent (dynamic) control system
99	Schwyz	Schwyz	Lighting Concept
100	Solothurn	Laupersdorf	LED
101	Solothurn	Oberdorf	Night curfew
102	St. Gallen	Buchs	Night curfew
103	St. Gallen	St.Gallen	Intelligent (dynamic) control system
104	St. Gallen	Wittenbach	Night curfew
105	Thurgau	Amriswil	Intelligent (dynamic) control system
106	Thurgau	Frauenfeld	Intelligent (dynamic) control system
107	Thurgau	Hauptwil-Gottshaus	Intelligent (dynamic) control system
108	Thurgau	Kreuzlingen	Mechanical Adjustment
109	Thurgau	Steckborn	Night curfew
110	Thurgau	Wängi	Intelligent (dynamic) control system
111	Thurgau	Weinfelden	Intelligent (dynamic) control system
112	Ticino	Bellinzona	Intelligent (dynamic) control system
113	Ticino	Cadenazzo	Intelligent (dynamic) control system
114	Ticino	Lumino	Intelligent (dynamic) control system
115	Ticino	Mendrisio	Night curfew
116	Uri	Erstfeld	Intelligent (dynamic) control system
117	Valais	Monthey	Intelligent (dynamic) control system

Lp	Canton	Municipality	Category
118	Valais	Saviese	Intelligent (dynamic) control system
119	Vaud	Aigle	Intelligent (dynamic) control system
120	Vaud	Blonay	Intelligent (dynamic) control system
121	Vaud	Bougy-villars	Intelligent (dynamic) control system
122	Vaud	Crissier	Intelligent (dynamic) control system
123	Vaud	Lausanne	Lighting Concept
124	Vaud	Montreux	Lighting Concept
125	Vaud	Nyon	Lighting Concept
126	Vaud	Saint Barthélemy	Lighting Concept
127	Vaud	Vevey	Lighting Concept
128	Vaud	Yverdon-les-Bains	Intelligent (dynamic) control system
129	Wallis	Martigny	Mechanical Adjustment
130	Wallis	Sion	Night curfew
131	Zürich	Dietikon	Lighting Concept
132	Zürich	Steinmaur	Night curfew
133	Zürich	Winterthur	Intelligent (dynamic) control system
134	Zürich	Zürich	Lighting Concept
135	Zürich	Herrliberg	Intelligent (dynamic) control system
136	Zürich	Illnau-Effretikon	Intelligent (dynamic) control system
137	Zürich	Langnau am Albis	Intelligent (dynamic) control system
138	Zürich	Regensdorf	Intelligent (dynamic) control system
139	Zürich	Schlieren	Intelligent (dynamic) control system
140	Zürich	Urdorf	Intelligent (dynamic) control system
141	Zürich	Uster	Intelligent (dynamic) control system
142	Zürich	Wädenswil	Intelligent (dynamic) control system
143	Zürich	Zumikon	Intelligent (dynamic) control system

3.5 Legislation at the EU and national level in Europe

In this section, an overview of the legislative situation in Europe will be presented with a special emphasis on the differences in approach to LP issue between Switzerland and the neighboring countries. In this chapter, the role of the European Commission in policy making and legislation concerning measures against LP will be also characterized.

Austria

Up to this date, the concept of LP does not exist in either the Austrian constitution or laws, and is rather a subject of separate non-binding documents and norms, however similarly to Switzerland, addressing LP at the level of different competences of the government is possible. Possible frameworks where measures against LP could be embedded are e.g. protection of the environment, human health, construction law, and industry regulations (ARONOVITZ ET AL. 2015: 61; KONTROLLAMT DER STADT WIEN 2012: 13).

In 2018 Guidelines for Outdoor Lighting were published in a collaboration with most of the Austrian states. The document is non-binding but recommends technical limits for the light temperature (however with exceptions, like outdoor sport facilities or television broadcasting), time limits (night hours with no illumination), the direction of the light source (never above the horizon). When it comes to intensity limits the authors refrained from setting the maximal values, claiming, that the light intensity perception is very much an individual business and therefore it is impossible to set hard limits, but it is recommended to follow the principle of ALARA (As Low As Reasonably Achievable) (LANDESUMWELTREFERENTEN ALLER BUNDESLÄNDER 2018: 52).

Although the Guidelines avoid recommending limit values, the document often refers to norm ÖNORM O 1052:2016 06 0 (Light Emissions – Measurement and Assessment), and quotes the light intensity limits from this document. Norm O 1052:2016 06 0 deals with the impacts of LE on people and environment and sets light intensity limits in order to avoid immisions, hence negative consequences for human health and environment (AUSTRIA STANDARDS 2016). It also distinguishes safety-related necessary lighting (German: Sicherheitstechnisch begründete Beleuchtung, SB) and unnecessary light serving no safety purpose (German: nicht notwendige Beleuchtung, NNB), which as a criterium helps in decision making, whether given lighting is necessary or not (LANDESUMWELTREFERENTEN ALLER BUNDESLÄNDER 2018: 66).

France

The example of France provides one of the most progressive national policies acting on LP in the world. The Decree of 27 December 2018 on the prevention, reduction, and limitation of light pollution (French: Arrêté du 27 décembre 2018 relatif à la prévention, à la réduction et à la limitation des nuisances lumineuses) sets very high standards in the area of LP binding regulations (CHRISTOPHE 2019; LA RÉPUBLIQUE FRANÇAISE 2018). The provisions of the decree include:

- Lighting schedule (curfew)
- Upward light ratio
- Light temperature
- Density of luminous flux (lm/m^2)
- Light flux emitted downward (glare and intrusive light)

The decree's scope covers:

- Public and private roads
- Heritage lighting (churches, monuments)
- Parks and other free public spaces

- Outdoor sport facilities
- Industry indoor lighting
- Parking lots
- Temporary lighting of special events and construction works

Special requirements are also outlined for national and regional parks, nature reserves, and astronomical observatories. Compliance with all the provisions is mandatory by the start of 2025, however, phasing in started on 1 January 2019.

Germany

In Germany there is no specific law devoted to LE or LP, however the Act on Emissions refers to light as a source of emissions (or immissions), therefore it creates an opportunity for implementation of measures against LP (BUNDESAMTS FÜR JUSTIZ 2019). One specific document that deals with light emissions are Guidelines for Measurements, Assessment and Reduction of Light Immisions published in 2012 by the State Working Group for Pollution Control (German: Bund/Länder-Arbeitsgemeinschaft für Immissionsschutz, LAI). The document recognizes as areas worth of protection from LE only settlement areas. It provides maximum permitted values for light intensity immissions, namely light trespassing (in lx) in distinguished types of settlement zone (e.g. city centers, and industrial areas have higher threshold values than hospitals and residential areas) (LAI 2012: 5).

Italy

In Italy, similarly to other countries in Europe with exception of France, there is no specific law at the national level devoted to LP, however, it is considered to have the oldest regional laws protecting dark skies. The first such law: no. 1260 came into force in 1942 to protect a dark sky zone around the astronomical observatory of Tuscolo (municipality of Monte Porzio Catone, Latium) (ARONOVITZ ET AL. 2015: 41; COMITATO DI TUTELA E SALVAGUARDIA 2015). Almost all regions in Italy adopted laws on LP with the exception of Sardegna, Sicily, Calabria, Trentino-Alto Adige, and Molise, with the first being Veneto in 1997 (Cinzano 2006). The regional regulations differ in the extent of measures against LP, however, there are few main measures that appear most often (ARONOVITZ ET AL. 2015: 47-48):

- Zoning
- Public lighting technical requirements
- Reducing the intensity of lighting (however without setting the maximum levels of illumination)
- Exceptional shutdowns (for astronomical research purposes)
- Education and public awareness

Lichtenstein

There are no specific legislative instruments devoted to LP in Liechtenstein. In the Environment Protection Act (German: Umweltschutzgesetz, USG) of Liechtenstein light is considered as potentially harmful radiation, and as such is supposed to be reduced as much as possible with regards to safety and economical needs (Article 14(2) USG). According to the act, emission maximum values would be tightened only then, when the impacts are proved to be harmful and/or burdensome (Article 14(3) USG). The same applies to immissions (Articles 16-18 USG).

In relation to the USG update in 2008 the Environment Protection Office issued a report "Light Emissions in Liechtenstein". The report summarizes the LE situation in Liechtenstein and proposes at what level certain procedural steps should be implemented, as well as specifies responsible actors that should be included in the action processes. Specifically, the document refers to field of action, such as (RENAT AG 2008: 27-28):

- Public relations (education and awareness)

- Planning (reducing LP by collaboration with construction directors, architects, planners, academic experts)
- Municipality concepts for public lighting
- Regulation of advertising (e.g. large-format, billboards)
- Regulation of building and open areas lighting
- Regulation of special and extreme cases (e.g. skybeamers, outdoor sport facilities).

Legislation at EU level

At the level of the EU there are several instruments of different power. EU directive requirements are mandatory within the EU, and there are two directives aimed specifically at lighting:

- 2000/55/EC On Energy Efficiency Requirements For Ballasts For Fluorescent Lighting
- 2005/32/EC Establishing A Framework For The Setting Of Ecodesign Requirements For Energy-Using Products.

Both are focused on energy saving issues and greenhouse gas emissions related to the energy consumption of light, however, they do not address any LP issues (EUROPEAN COUNCIL 2000, 2005). Also, directives dealing with emissions such as Directive 2010/75/EU on industrial emissions (integrated pollution prevention and control), or dealing with pollution (Directive 2002/49/EC relating to the assessment and management of environmental noise, Directive 2008/50/EC on Ambient Air Quality And Cleaner Air For Europe), do not address LP (EUROPEAN COUNCIL 2002B, 2008, 2010).

Non-binding EU measures

The EU has recently published an update on Green Public Procurement Criteria for Street Lighting and Traffic Signals (GPP), which is a voluntary instrument with guidelines and technical criteria for lighting equipment. The target actors are decision-makers and professionals taking part in procurement and commissioning new or renovated street lighting. As the key environmental impacts energy consumption and greenhouse emission are mentioned, giving light pollution a secondary priority (together with mercury pollution) (EUROPEAN COMMISSION 2018: 7). GPP emphasizes the general rule for determining the levels of illumination: As Low As Reasonably Achievable (ALARA). Although ALARA is a recommended principle, GPP is drafted in line with standard EN 13201-1, (European Norm for road lighting standards), which sets only the minimal light intensity values (with the overriding principle of providing safety in the street traffic). Having said that, GPP is not providing an opportunity to reduce LP by reducing the intensity (setting the maximum permitted value) of installed light infrastructure (DARK SKY 2019).

Important criteria for reducing LP recommended in GPP are:

- TS2 (dimming control compatibility),
- TS3 (minimum dimming performance),
- TS7 (ratio of upward light output (RULO) and obtrusive light,
- TS8 (annoyance),
- TS9 (ecological light pollution and star visibility).

The document introduces also a new index for precise calculations of the blue light content in LED, which can help achieving the aim of GPP's of installing only illuminations of light temperature not exceeding 3000 Kelvin (EUROPEAN COMMISSION 2018: 26; JUNTA DE ANDALUCIA 2019).

Since 2017 Project Night Light Interreg Europe funded by the EU is taking place with participatory countries being: the Netherlands, Hungary, Spain, Luxemburg, Denmark, Slovenia, and Italy. The goal of the project is to improve regional policies in order to reduce LP, and the designation of dark night sky protection areas. A big portion of the project resources is used on educational activity and spreading public awareness. The project addresses policy instruments such as regional spatial plans, territorial and settlement development plans and Natura 2000 management programs (INTERREG EUROPE 2017).

3.6 Light pollution in Switzerland - Localizing the problem

According to the data from 2010-2012, no artificial radiance at night was observed only in some uninhabited alpine regions with total area of 8,150 km^2 what corresponded to 19% of Switzerland's territory. The highest values of LE were observed in the region of Jura, Central Plateau, and Southern Alps with the highest values emitted from the main cities in those regions (Figure 3.12).

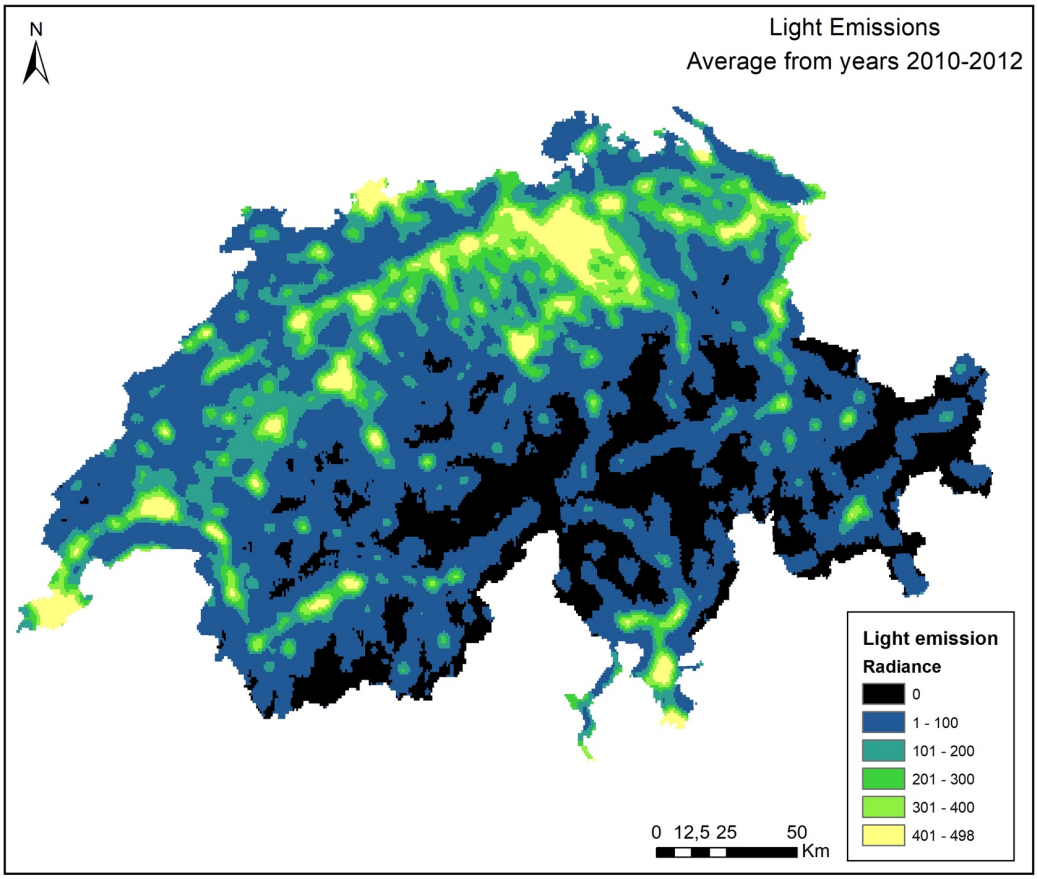

Figure 3.1. Average values of light emissions at night in Switzerland for time period 2010-2012.

Light emission image and data processing by NOAA's National Geophysical Data Center
Map data processing: Liliana Schönberger

The analysis of the recent changes in LE presented on Figure 3.12 revealed that there were some areas, where LE dropped (between 2014 and 2018). This contributed to 2% of Switzerland's area, and was mostly to be found in cantons Aargau, Fribourg and Bern. In most of Switzerland LE increased (66%), and this included also almost all the alpine regions, that were still considered LP free in the survey 2010-2012.

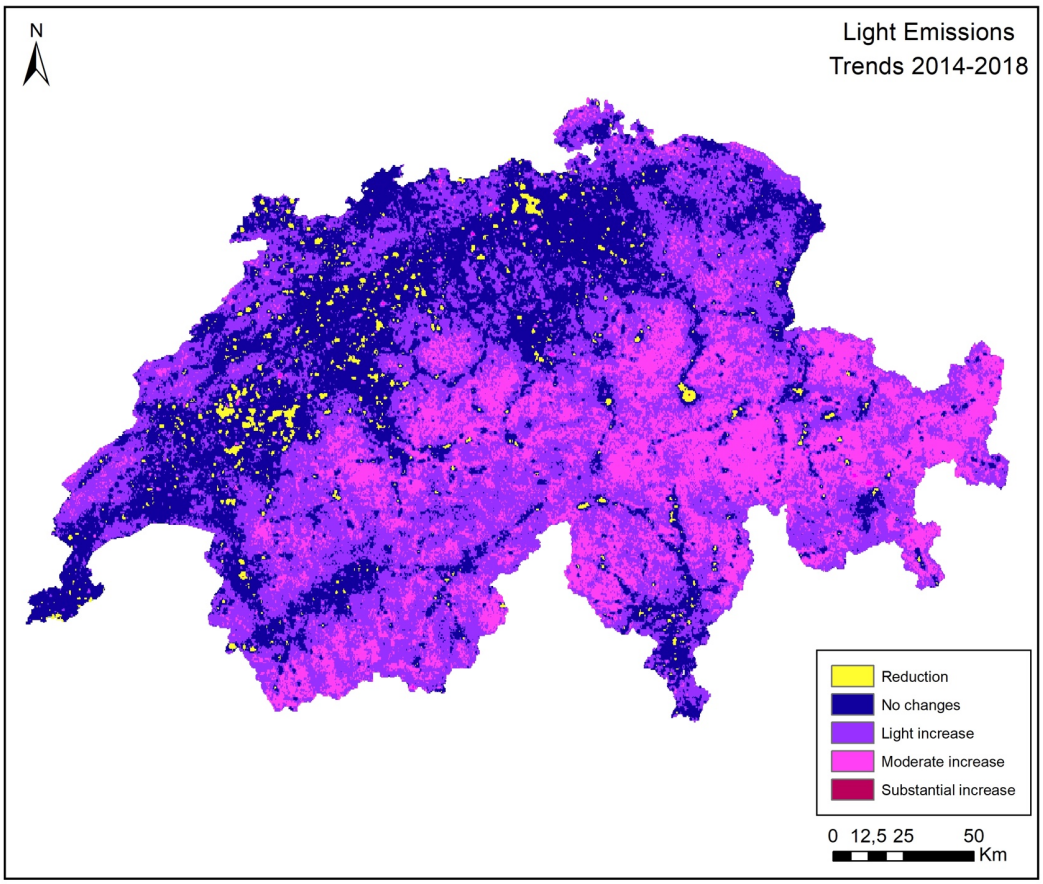

Figure 3.2. Changes in the light emissions at night in Switzerland between 2014 and 2018.

Map of the trends: Lukas D. Schuler for Dark-Sky Switzerland
Map data processing and map design: Liliana Schönberger

Nature and light pollution

The map presenting placement of different categories of natural areas (moorlands, BLNs, National Parks), shows, that in most cases nature is under LP pressure (Figure 3.3). This is the case especially in the Central Plateau, where mostly BLN areas and moorlands are affected.

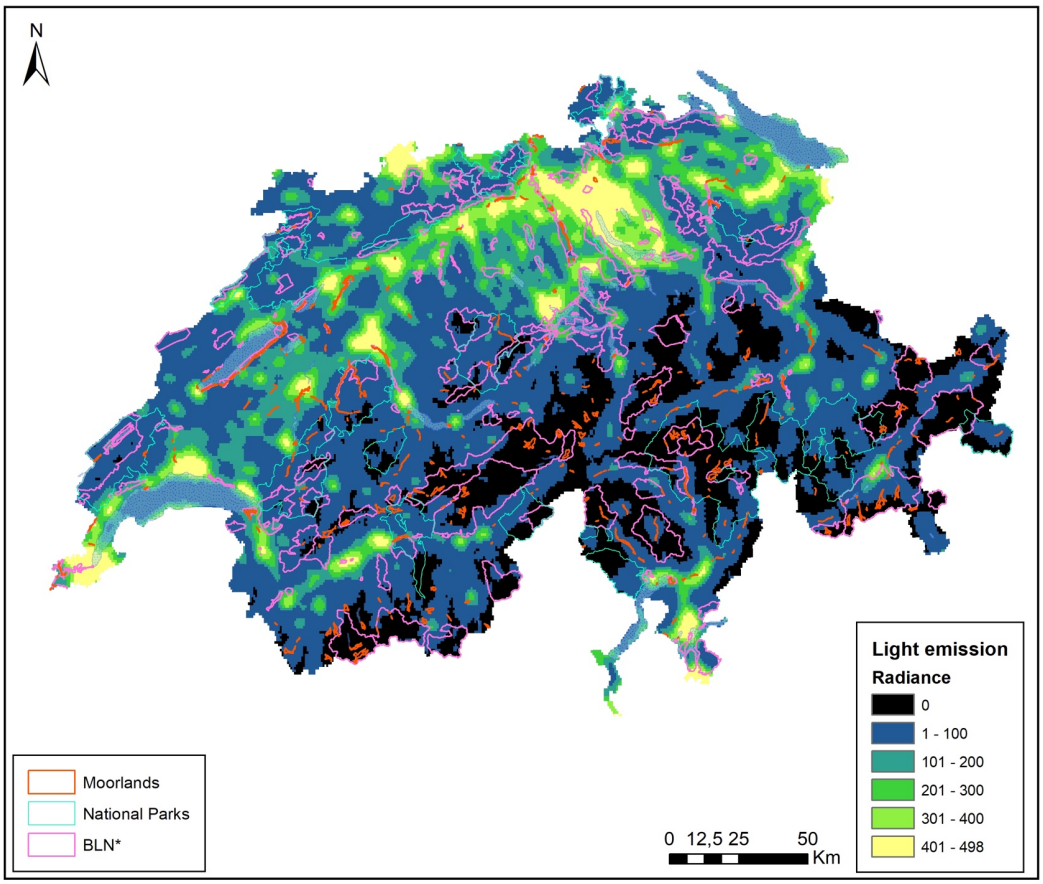

Figure 3.3. Moorlands, National Parks and areas belonging to Federal Inventory of Landscapes and Natural Monuments of National Importance and the LE values.

*Federal Inventory of Landscapes and Natural Monuments of National Importance (German: Bundesinventar der Landschaften und Naturdenkmäler von nationaler Bedeutung, BLN)
Light emission image and data processing by NOAA's National Geophysical Data Center
Moorlands, National Parks and BLN datasets: FOEN
Map data processing and design: Liliana Schönberger

The southern belt of the broad migration front and areas important for migratory birds, stretch over the heavily polluted Central Plateau and Jura (Figure 3.4), while the migration corridors following the alpine ridges and valleys were rather unaffected, with exception of the eastern part of the migration route between Rhine river and Alps (canton Sankt Gallen and Apenzell Innerrhoden) and Rhone Valley (canton Wallis) in the South.

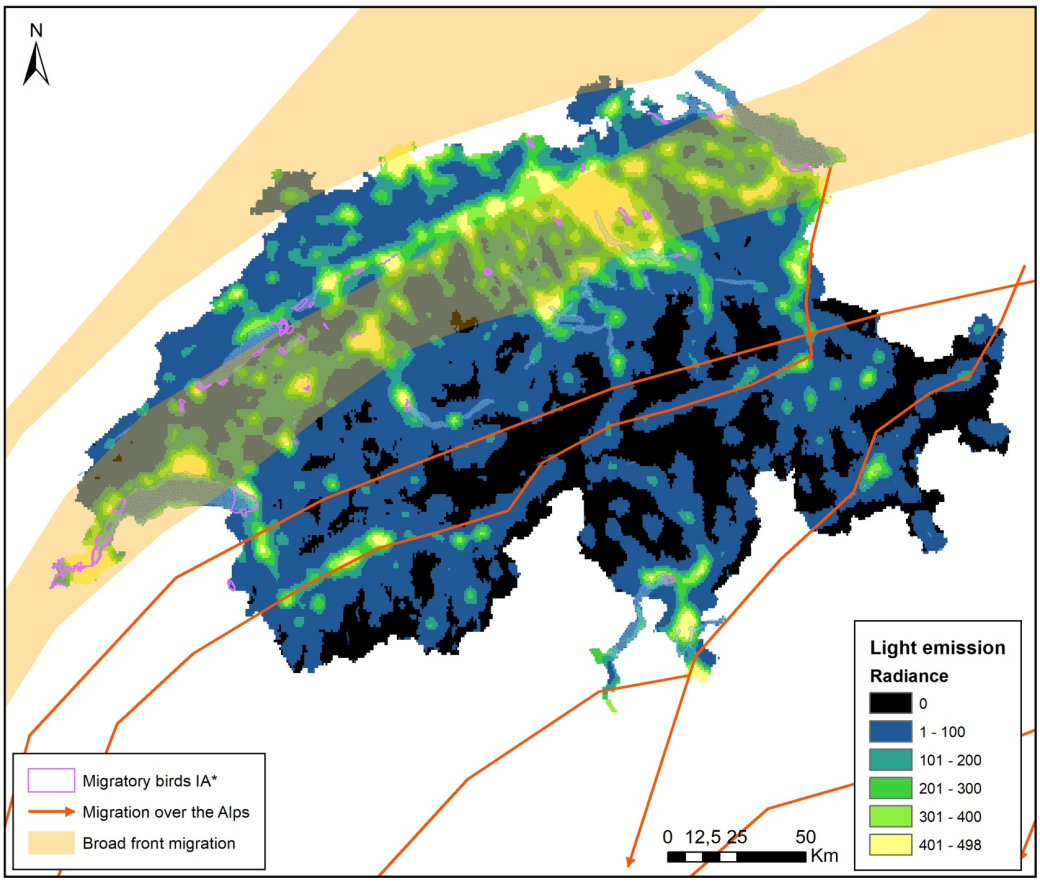

Figure 3.4. Migration Corridors and migratory birds important areas in Switzerland in reference to LE.

* Migratory birds Important Areas
Light emission image and data processing by NOAA's National Geophysical Data Center
Migratory Birds Important Areas datasets: FOEN
Migration corridors after (Bruderer 2017)
Map data processing and design: Liliana Schönberger

The statistics presented in Figure 3.5 show that among all the natural areas chosen for analysis, migratory bird important areas were the most affected by LE. All those areas were artificially illuminated at night, with the mean radiance 223,6. LE in National Parks was the lowest among all the categories with mean radiance 35,6. Among all BLN areas and Moorlands there are single places, where LE was not experienced, or was at levels equal to the natural night illumination, however, the maximal values were as high as 400 and 353 respectively.

Figure 3.5. Light emission in important natural areas in Switzerland. Whiskers: min and max value, box: 75% quartiles, line inside the box: mean value.

* Migratory birds Important Areas
** Federal Inventory of Landscapes and Natural Monuments of National Importance (German: Bundesinventar der Landschaften und Naturdenkmäler von nationaler Bedeutung)
Data processing and chart design: Liliana Schönberger

In order to distinguish natural areas impacted by elevated LE, only those areas were chosen, for which the mean radiance was higher than 100 (this level of radiance was set as a threshold for this study, as a maximal tolerable radiance). Municipalities, which territories overlap with selected areas, as well as municipalities having mean radiance higher than 100 and overlap with migration corridors are listed in the Annex 2, together with the type of area, that is affected. In total 603 municipalities are sharing their territories with impacted important natural areas. Most of the impacted areas belong to the Federal Inventory of Landscapes and Natural Monuments of National Importance (113), Migratory Waterbird Important Areas (78) and Moorlands (60). Among the National Parks, the mean radiance exceeds 100 only in two parks (Wildnispark Zürich Sihlwald, Zürich, Regionaler Naturpark Jurapark, Aargau) (Figure 3.6).

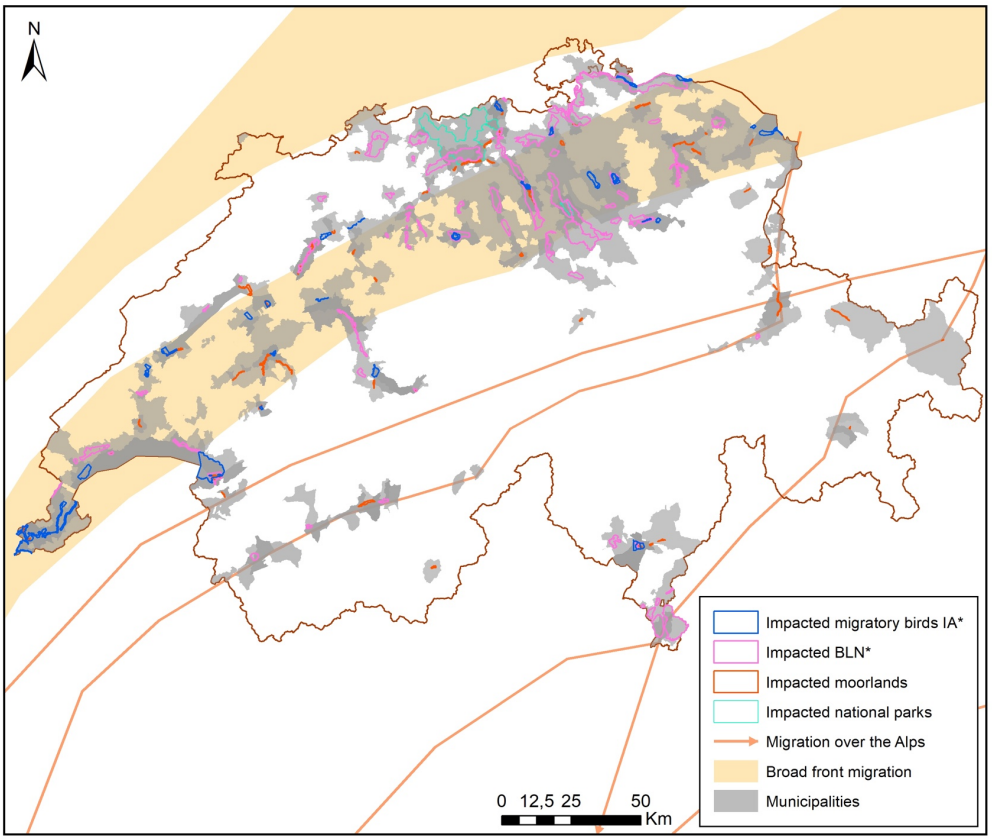

Figure 3.6. Municipalities (grey polygons) that overlap with important natural areas impacted by LE.

* Migratory birds Important Areas

** Federal Inventory of Landscapes and Natural Monuments of National Importance (German: Bundesinventar der Landschaften und Naturdenkmäler von nationaler Bedeutung)

Swiss grid and boundary: Federal Office of Topography swisstopo

Migration corridors after (Bruderer 2017)

Data processing and chart design: Liliana Schönberger

Light pollution and urbanization

The Geographically Weighed Regression results revealed that 69% of the variation in LE values were statistically explained by the population density (Adjusted R^2=0,69, AICc: 26406,13). The details of the analysis are presented in Annex 1. As an additional measure of relationship between urbanization and LP, a light emission index was calculated. The highest obtained values represent high population density and high LE values (mostly in the biggest Swiss cities), whilst 0 value corresponds to populated areas that are not affected by artificial light at night. However, in such areas only live 0,05% of the Swiss population (less than 3,800 people).

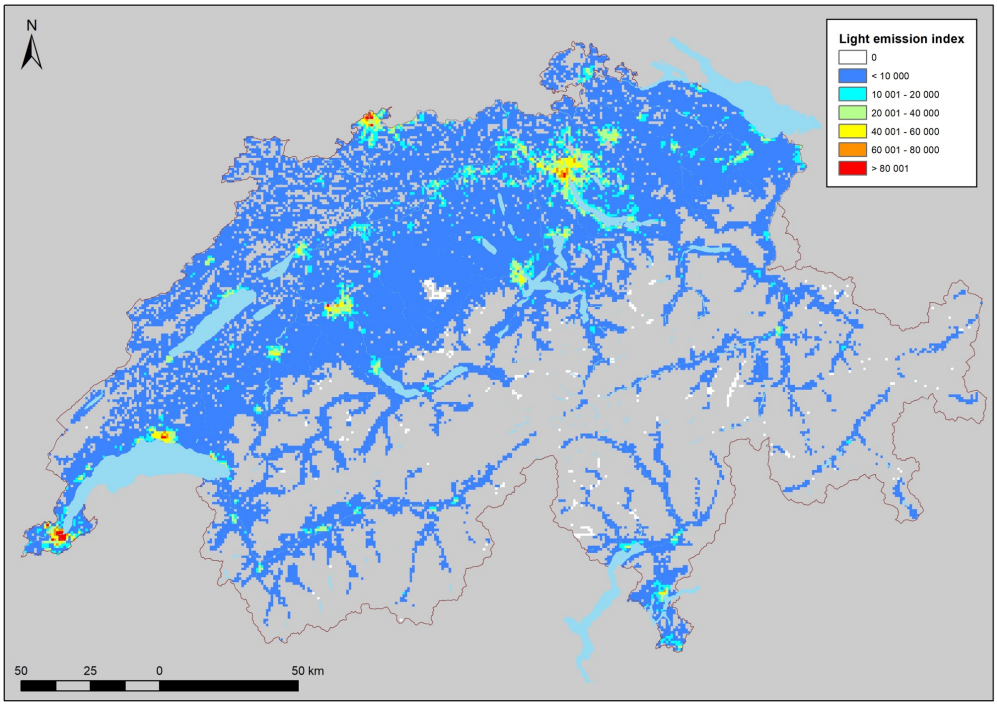

Figure 3.7. Light emission index map. The higher the values, the higher the population density and/or LE. Null values (grey) represent area with no data on population density.

Swiss grid, boundary, and lakes: Federal Office of Topography swisstopo
Map data processing: Liliana Schönberger

Light pollution at the level of municipalities

A comparison between two groups of municipalities (acting against LP and all swiss municipalities together) shows, that LE levels were higher in the first group (Figure 3.8).

Figure 3.8. Comparison between light emission levels (average from 2010-2012) in municipalities acting against LP and all swiss municipalities. Whiskers: min and max value, box: 75% quartiles, line inside the box: mean value.

Data processing and chart design: Liliana Schönberger

The spatial distribution of the municipalities, for which information on mitigation measures against LP were found, is presented in Figure 3.9.

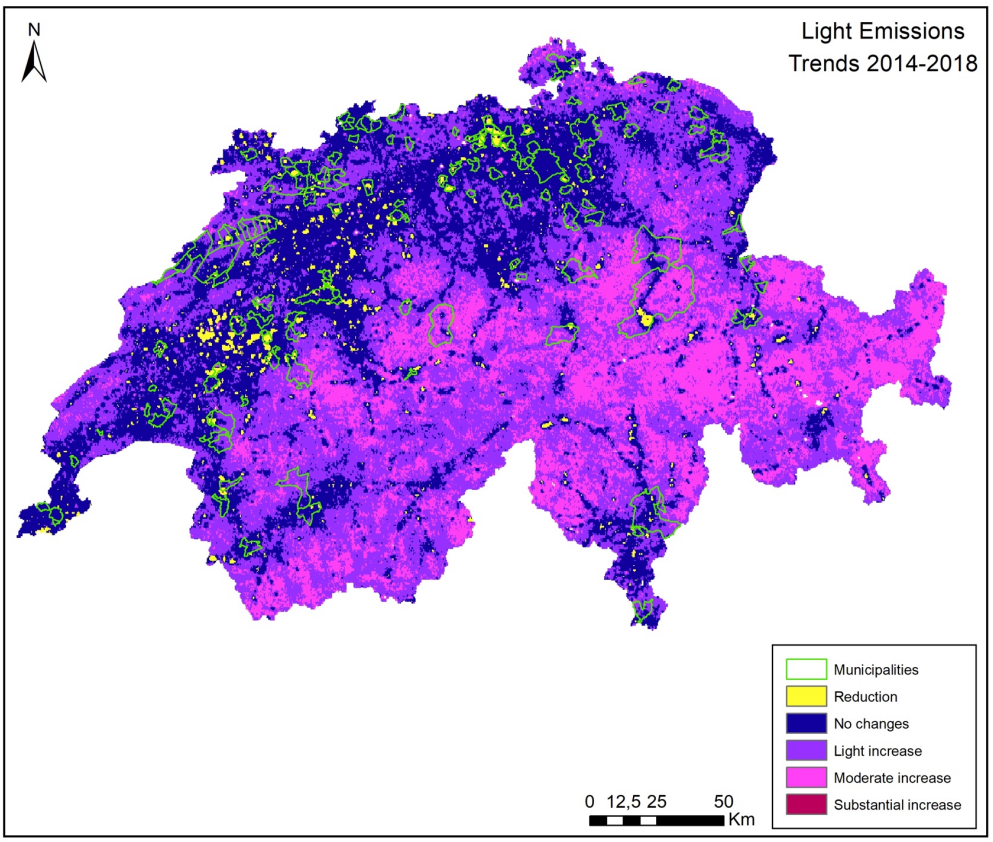

Figure 3.9. Light emissions trends 2014-2018 in Switzerland. The municipalities, that introduced mitigation measures against light pollution are outlined in green.

Map of the LE trends: Lukas D. Schuler for Dark-Sky Switzerland
Swiss grid and boundary: Federal Office of Topography swisstopo
Map data processing: Liliana Schönberger

In most cases the municipalities that engaged in acting against light pollution experienced a drop of LE (92 municipalities), or there was no change of LE (50) at least in some parts of their territories, however, in the same time, there were places where LE increased, (usually between light (46) and moderate increase (19)), what is presented on Figure 3.10. The most extreme discrepancy in the LE trends was observed in Glarus Süd, that experienced at the same time reduction of LE and substantial increase of LE, depending on the location (Figure 3.11).

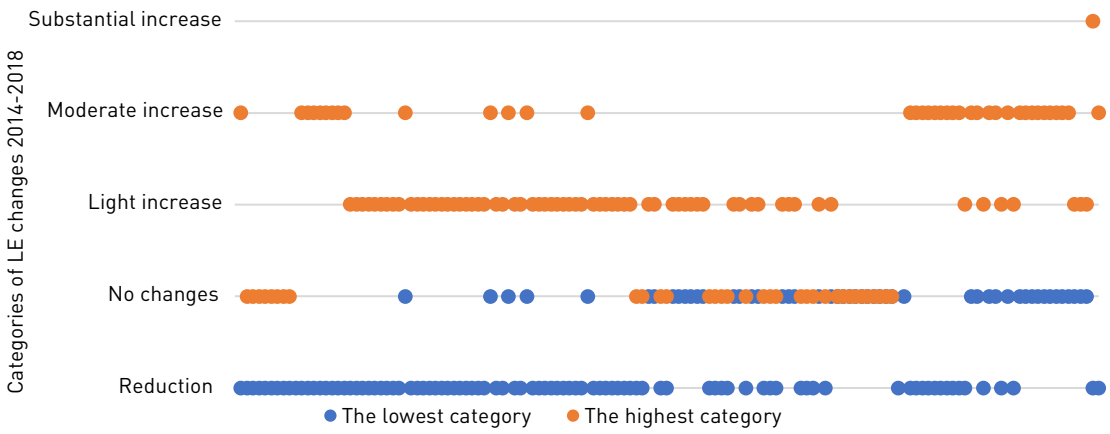

Figure 3.10. The lowest and highest category of LE changes between 2014 and 2018 experienced by 142 municipalities acting against LP in Switzerland.

The municipalities, which experienced LE reduction in the majority (more than 51%) of their territory were: Baden, Obersiggenthal, Romont, Schöftland, Neuenhof, Fribourg, Zumikon, Windisch, and Ennetbaden. In 99 municipalities a dominating trend category was "no changes" (Figure 3.12), whereas in 32 it was "light increase", and in two "moderate increase".

Table 3.3. Different categories of mitigation measures and regulations against LE among 142 investigated municipalities in relation to the most dominant LE trend category in a given municipality. Categories of LE change based on the Map of the LE trends: Lukas D. Schuler for Dark-Sky Switzerland.

Categories of mitigation measures and regulations	Light increase	Moderate increase	No changes	Reduction	Total
Intelligent (dynamic) control system	12	2	40	4	58
Night curfew	15		27	4	46
Lighting Concept	2		13		15
Police regulation	1		8		9
LED	1		6	1	8
Mechanical Adjustment			5		5
Regulation	1				1
Total	**32**	**2**	**99**	**9**	**142**

When it comes to implemented mitigation measures and regulations, the best results (LE reduction in the majority of the municipality) were obtained with intelligent lighting control and night curfew, and, in one case with LED technology applied in the whole municipality (Romont, Fribourg). Those measures were also dominating in municipalities, that experienced no changes in LE levels, as well as light increase of LE levels (Table 3.3).

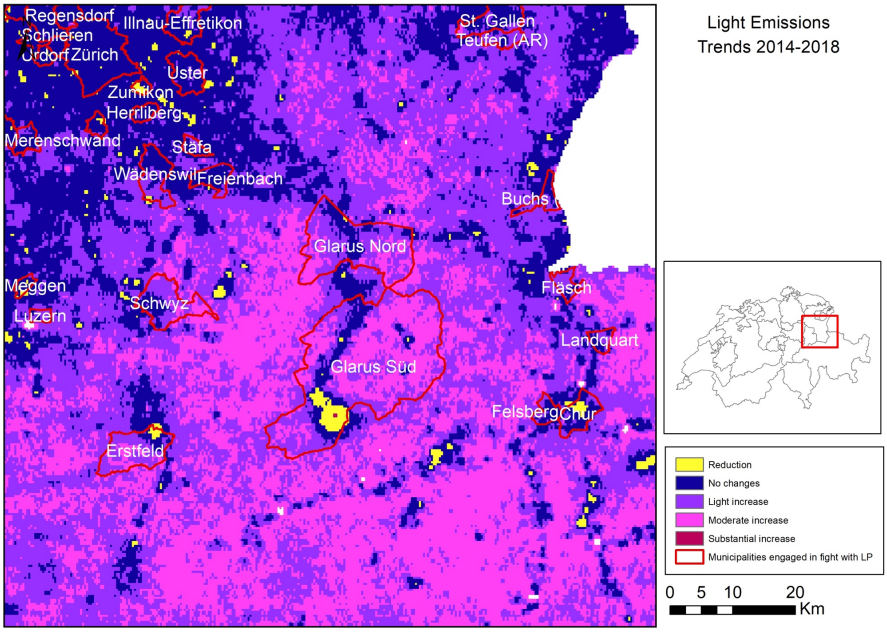

Figure 3.11. Light emissions trends 2014-2018 in Switzerland. The municipalities, that introduced mitigation measures against light pollution are outlined in red. An example of heterogenic trends within one municipality are visible for Erstfeld, Chur, and Glarus Süd.

Map of the LE trends: Lukas D. Schuler for Dark-Sky Switzerland
Swiss grid and boundary: Federal Office of Topography swisstopo
Map data processing: Liliana Schönberger

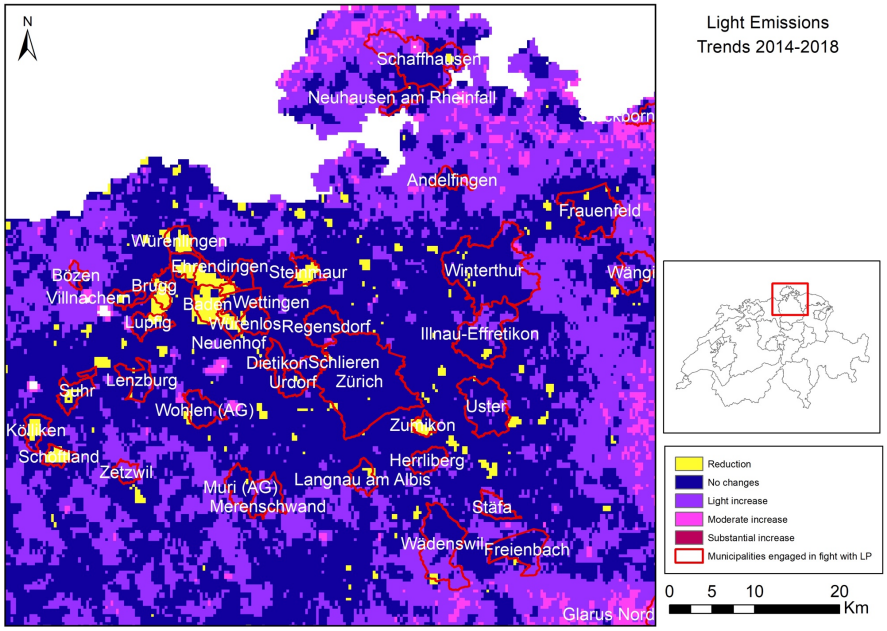

Figure 3.12. Changes in LE in NE Switzerland in years 2014-2018. The municipalities, that introduced mitigation measures against light pollution are outlined in red. Examples of municipalities, which majority of territory experienced no changes in LE levels (Zürich, Winterthur, Regensdorf, Lenzburg) and municipalities, which experienced mostly reduction of LE levels (Baden, Schöftland).

Swiss grid and boundary: Federal Office of Topography Swisstopo
Dataset Light Emission Trends: Lukas D. Schuler for Dark-Sky Switzerland
Map data processing and map design: Liliana Schönberger

4 Discussion

4.1 Legislation and mitigation of light pollution in Switzerland compared to neighboring countries

Binding regulation very often has a negative connotation being considered as a "ban" or "prohibition" limiting one's personal freedom. There is a common reluctance towards hard regulations (an expression "repressive regulations": Swiss Association of Architects and Engineers (KOBLER 2013)). This, together with citizen's right to feel secure and safe, makes it difficult for policymakers to implement hard laws in order to reduce LP (MORGAN-TAYLOR 2014).

In Switzerland and many other countries, there are no specific LP regulation instruments. Instead, the governments offer documents of recommendations and guidelines based on reports prepared by experts. However, as already mentioned, in recent years, only in Switzerland LE increased by more than 66%, therefore, the soft regulation approach should be discussed and evaluated as being inadequate. The main issues with tackling the problem and creating an effective policy against LP are a lack of unified definition of LP and a standardized method of measuring LE, misconception of the LP problem and not treating it seriously both by policymakers and end-users. Therefore, the process of setting threshold values, and other quantitative regulations is difficult and slow (MORGAN-TAYLOR 2014; MORGAN-TAYLOR 2014; ZIELINSKA-DABKOWSKA AND XAVIA 2019: 33). However, hard regulation can be implemented despite the lack of exact normative values, whether at the national level (France) or regional level (Italy), and it does not necessarily impede personal freedom or the freedom to conduct a business, security, and safety. In France the regulations avoid quantifying light, instead, curfew is enforced. In Italy, the regulations describe a percentage of the maximum illumination and regulate the angle of the lighting. Nonetheless, a striking similarity shared by different approaches to LP regulation is the importance of spreading awareness and education, seemingly being a key factor for efficient LP legislation, since it builds understanding for the purposes of the regulation (L. D. SCHULER, SCHATZ, AND BERWEGER 2018: 151). In Switzerland, the actual mitigation measures are mostly implemented on the municipal level in a non-regulatory way. This results in "patchiness" of the actions against LP taken. The involvement of municipalities is rather low, and the measures usually are not covering the whole municipality, and also, the results (efficiency in LP reduction) are not uniform. Regulation on national and regional level could contribute to a more robust and homogenous approach to the reduction of LP. Such regulatory measures would mean to abandon the ineffective case by case approach as currently practiced based on Articles 11(2) and 12(2) USG (see BGE 140 II 33 and BGE 140 II 214) and introduce maximum emission levels. A more radical policy option would be the legislation of a new self-standing law on LP addressing exclusively the challenges of LP as described above.

Although there is no ideal and universal solution to LP regulation, creating a robust policy, that is efficient and effective requires a holistic approach, where the fundamental part is understanding the problem, and where the spectrum of the problem is regarded as broadly as the current knowledge allows it.

4.2 Places in Switzerland where implementing mitigation measures is advisable

In Switzerland, less than one percent of the population lives under naturally dark skies. The problem is strongly connected to the level of urbanization expressed by population density. Although there are still areas with rather low LE values and very low population density, the analysis of the recent developments leaves no doubt, that more and more areas are affected by increasing LE also in uninhabited or scarcely inhabited areas. This might be connected to the rebound effect of LED technology (BAFU 2017 103; HESSISCHES MINISTERIUM FÜR UMWELT, KLIMASCHUTZ 2017: 10). Since LED technology became affordable and broadly available, it replaces more expensive, less energy-efficient, and less durable solutions like mercury or sodium-vapor lamps. Because of the fact, that LED helps saving as much as 48% of energy costs even when the lamps work all night (compared with quick-silver lamps main road infrastructure, (TOPSTREETLIGHT.CH 2013: 3), the lighting is often used without consideration of the impacts artificial light has on the environment, human health and perception of the landscape, resulting in LE increase, instead of its reduction.

Across the country actions against LP are taken in the first place by municipalities that are already heavily affected by LP, however the mitigation measures are very often limited to main settlement areas or selected neighborhoods. There, a reduction of LE is achieved, however, in other parts of municipalities LE increases, which very likely is due to the road lighting, proved to be a substantial contributor to LP (HISCOCKS AND GUÖMUNDSSON 2010: 5). This might be connected to the fact, that municipalities are not responsible for maintaining cantonal main roads, therefore, efficient mitigation measures such as intelligent lighting control system or night curfew are not applied outside of the settlements to the road lighting infrastructure.

Among implemented measures, especially night curfew and intelligent light control systems are efficiently helping reduce LE, although there is an ongoing debate, whether it is safe to turn off the outdoor lights at night and whether municipalities have a right to decide about it. There are concerns about the responsibility in case of an accident that happened on a dark road or a street crossing (ELEKTRON AG 2018). The owner (municipality or canton) of the road and the light infrastructure would be called upon responsibility, therefore, there is still a lot of hesitance when it comes to implementing those methods and even if they are implemented, it is limited to certain districts with lower night activity of the inhabitants. Nonetheless, the problem needs to be solved and multiple examples from Switzerland and from abroad show, that night curfew does not affect safety and is well received by the inhabitants (SRF 2015; STEINBACH ET AL. 2015: 1122, SCHULER, SCHATZ, AND BERWEGER 2018: 150). The optimal solution would be an intelligent control system of LED lighting combined with motion sensors. A good solution also would be dimming the light to 10% of their power instead of switching them off completely, to facilitate the security feeling of the inhabitants.

Although the LP is the biggest in highly urbanized areas of big cities agglomeration, LE increase also in remote, poor inhabited areas. An analysis of LP in the natural areas leaves no doubt, that many of the places are impacted by the elevated emission, even when, as in the case of my approach, the threshold value for radiance was set rather high (higher than 100). The main conflict area, between excessive outdoor lighting at night and nature takes place in the Central Plateau and Jura, where not only National Parks, Moorlands, BLN areas and Migratory Waterbird Important Areas are affected, but also from a global perspective a very important migration pathway between northern Europe and Africa. This broad front migration corridor is used by nocturnal migratory

birds, flying at heights between 1,000 and 4,000 meters, being especially affected by LP during their exhaustive migration through the continents. Using stars and Moon as a clue, the birds get disoriented by the artificial lights and lose energy reserves, needed to complete their migration (BRUDERER 2017: 209). Beside the broad front migration corridors, there are several other pathways along the valleys and ridges of the Alps, which are also affected in few places (municipalities in cantons Wallis, Ticino, Sankt Gallen, Graubünden). The selected municipalities presented in Annex 2 are those, that should act on LP in the first place.

4.3 Possible spatial planning measures to mitigate light pollution in Switzerland

Light pollution propagation depends on many factors, for example topography or scattering properties of atmosphere (particles and gases) (KOCIFAJ, SOLANO-LAMPHAR, AND VIDEEN 2019: 7712). These properties make light pollution a transboundary issue, which means, that light emitted in one municipality (canton) can affect neighboring and more distant municipalities (cantons) and natural protected areas. Possible solutions in order to spread awareness but also to create an incentive for cantons and municipalities to act would be including LP in the map service of the Federal Office for the Environment, in the similar way as other pollution sources are (BAFU n.d.). This would definitely help in recognizing light as a pollution, and help considering it a serious threat to the environment and human health. An additional ordinance (German: Verordnung) could be introduced to the Spatial Planning Act (RPG) and/or Environment Protection Act (USG) obliging the municipalities to follow SIA norm 491 (avoiding unnecessary outdoor light emissions), or a similar document outlying the ground rules for avoiding unnecessary LE.
The other possible solution at the federal level could be creating a new category of areas to include in the Federal Inventory: Areas of Protected Dark Skies. This way, according to Article 6(4) RPG, Article 5 NHG, and by the decision of the Swiss Federal Supreme Court BGE 135 II 209, those areas should be taken into consideration in the cantonal and municipal structure plans (BUNDESGERICHT 2009). However, designing criteria to distinguish which place should become an Area of Protected Dark Skies would be complicated, especially, because many of nature areas impacted by LP are placed in a close proximity to settlement areas, or even, within a settlement.

At the cantonal level, a structure plan (German: Richtplan) should be an instrument involved in addressing LP. Similarly, to noise thresholds, a LE zoning seems a good measure to implement. Zoning would enable planning and analyzing the necessity of lighting infrastructure before installment, saving the costs of post-fitting and adjustments. The approach to the zoning can be twofold. Zones could be understood as areas of different maximal allowed LE values, what makes sense for inhabited areas, or zones could determine where a use of artificial light at night should be restricted or prohibited, what would make more sense to the natural areas. Similarly, at the communal level, mitigation measures can be incorporated in zone plans (German: Zonenplan), construction – and usage regulation (German: Bau- und Nutzungsordnung, BNO), and construction and zone regulation (German: Bau- und Zonenordnung, BZO), giving municipalities a broad spectrum of instruments for implementation mitigation measures against LP.

A non-binding, however quite popular coordination instrument is a light concept, (or light strategy). Such concepts have many objectives, such as high quality and healthy lighting of important monuments, safety on the roads, feeling of security of the inhabitants and therefore, reducing emissions is not always the priority of this instrument, what is supported by the results of

this paper (see Table 3.3). However, a lighting concept is an outstanding platform to bring all stakeholders together and creates opportunities for knowledge and experience exchange and therefore, is a recommendable instrument.

4.4 Critical review of the methods

Although a thorough research was done in order to find the most comprehensive collection of implemented mitigation measures in Switzerland, the list is not definite. Not much of information was found for municipalities in the western part of the country (Fribourg, Vaud, Geneva), and according to the map of LE trends in this region there are many municipalities that experienced LE reduction in recent years, hence, mitigation measures must have been applied. The difficulty in finding all the information lays primarily in the fact, that the information about the undertaken measures is not officially released or published on the municipal websites, and there is no official (national, cantonal) register for LP oriented actions.
A lack of a standardized method for LE measurements limits the possibilities of evaluating the LP situation in Switzerland and compare the results with findings for other countries, as well as to compare the efficiency of applied mitigation measures.

Mapping of the broad migration fronts presented in the article is rather basic, and does not address nuances such as seasonal, or even day-to-day variation in the temporal-spatial dynamic of the phenomenon (TSCHANZ et al. 2019: 199) . It is known, that topography and weather conditions heavily influence the migration's timing and migration route and hence, it is impossible to determine a fixed migration corridors that would be true over multiyear terms.

Beneficial for further studies would be an official database where the actions applied by the municipalities would be listed, giving a possibility to study further the problem in order to find sustainable and suitable solutions. In order to evaluate efficiency of the mitigation measures in more detailed way, it would be of a great benefit to have an access to information not only about what technology was applied, but also in what dimensions was it implemented (curfew time, dimming percentage, how many light points, etc.).

5 Conclusion and Outlook

This paper was the first attempt to summarize the efforts of Switzerland at the federal, cantonal and municipal level to tackle LP problems, and to evaluate the actions against LP undertaken by municipalities. I presented the LP situation in Switzerland and distinguished the areas, where actions to reduce LP should be implemented. The evaluation of the implemented measures allowed to formulate recommendations for the best practices. An analysis of practices from neighboring countries created an opportunity for discussion on the optimal approach to LP regulation.

The government of Switzerland makes efforts to spread LP awareness and offers help in form of recommendations and technical reports to aid cantons and municipalities in implementing measures against LP. One of the suggested solutions is to create a new category of areas included in the Federal Inventory, to protect dark skies and with this, create an incentive for the cantons and municipalities to adjust their structure and zone plans. Another advisable approach would involve LE zoning that is possible to implement in two ways: by quantifying light and setting threshold values (maximal values) or by designating zones where lighting is restricted or prohibited. One of the

possible next steps in research of this subject could be preparing and evaluating criteria for a purpose of LE zoning that could be implemented in a cantonal structure plan.

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7 Annex 1

Geographically Weight Regression

Dependent variable: LE emissions
Explanatory variable: Average population density (N/ha per municipality)
R^2= 0,70
Adjusted R^2=0,69
AICc: 26406,13
Sigma: 70,68
Residual Squares: 11151806,26

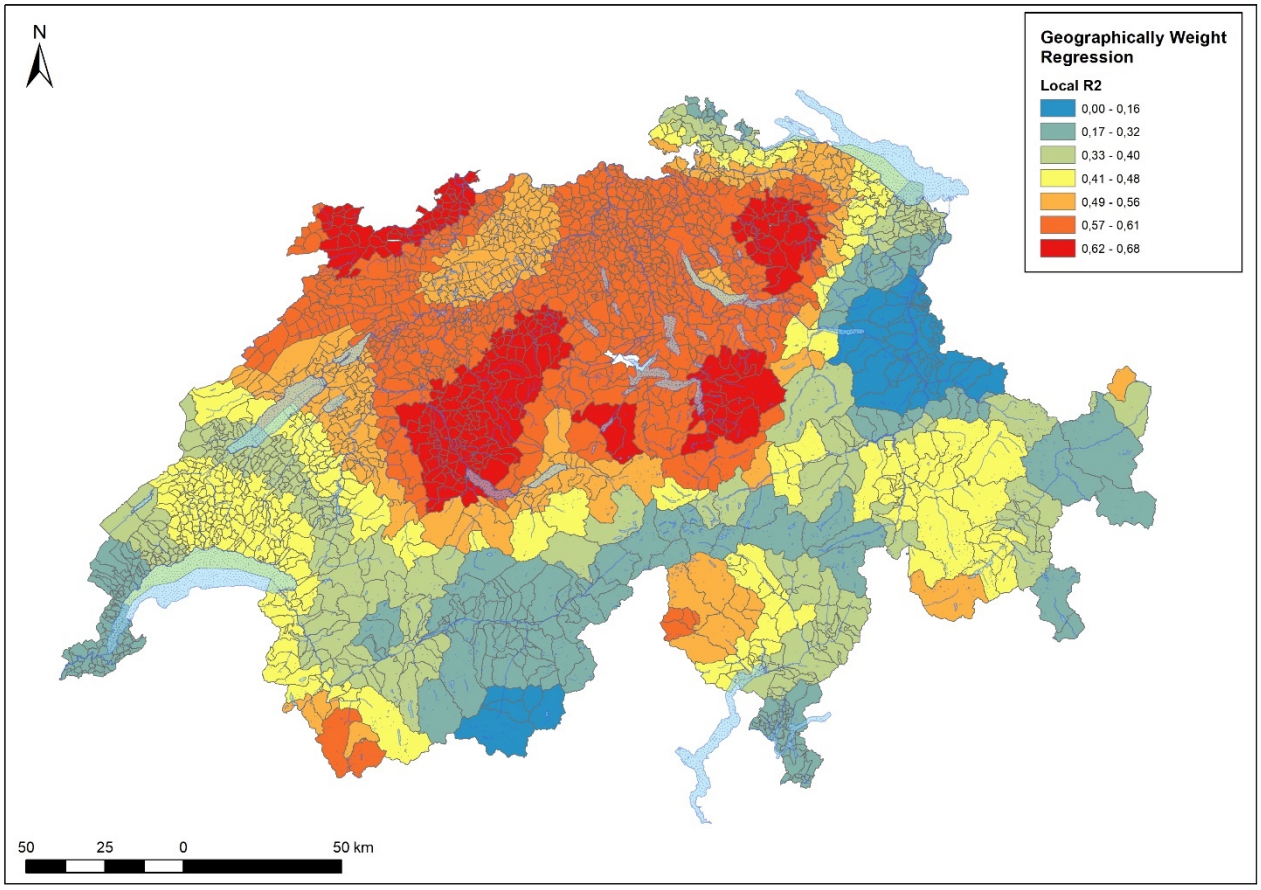

Fig. 1. Local R^2 values. Red color represents the highest portion of the variation in light emission values explained by population density factor, blue, the lowest.

Swiss grid and boundary: Federal Office of Topography swisstopo
Map data processing: Liliana Schönberger

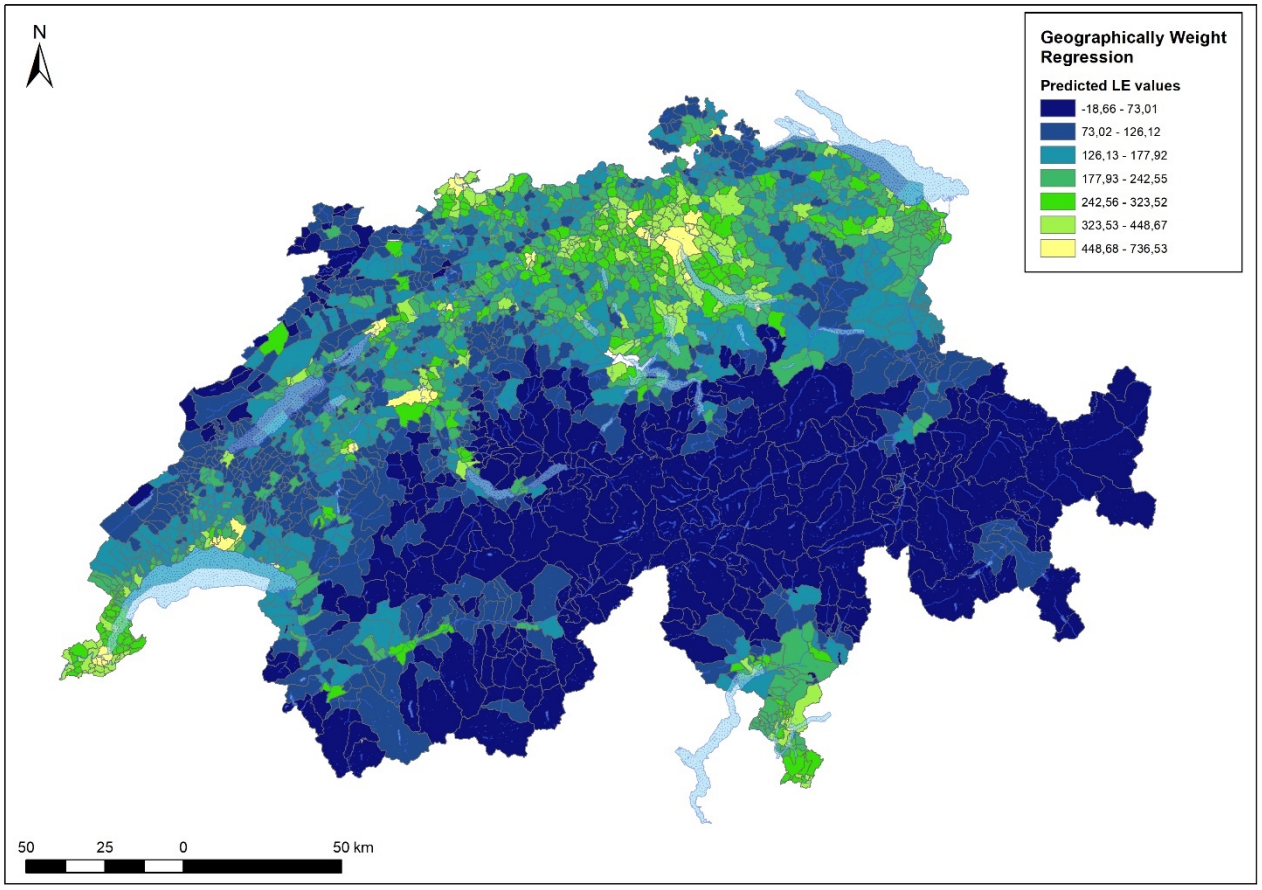

Fig. 2. Predicted light emission values based on the regression model.

Swiss grid and boundary: Federal Office of Topography swisstopo
Map data processing: Liliana Schönberger

8 Annex 2

Table 8.1. Municipalities that have important nature areas affected by LE (mean radiance higher than 100) falling within their territories. The numbers in brackets refer to the total number of areas impacted by LE in a given category. Migration corridors being not legally protected do not have an assigned number of impacted areas.

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
1	Aadorf	x						
2	Acquarossa	x		x	x		x	
3	Adelboden	x		x	x		x	
4	Aeschi bei Spiez	x			x			
5	Aigle	x						x
6	Airolo	x		x	x		x	
7	Albula/Alvra	x		x	x		x	
8	Alpnach	x		x	x			
9	Alpthal	x			x			
10	Altendorf	x			x			
11	Alterswil	x						
12	AltoMalcantone	x						
13	Altstätten	x			x			
14	Amden	x			x			
15	Amriswil	x						x
16	Andeer	x			x			
17	Andermatt	x		x	x		x	
18	Anniviers	x	x	x	x	x	x	
19	Appenzell	x						
20	Arbaz	x						
21	Arbedo-Castione	x						
22	Ardon	x						
23	Arosa	x	x	x	x	x	x	

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
24	Arth	x		x	x			
25	Arzier-Le Muids	x		x	x			
26	Attinghausen	x			x			
27	Avegno Gordevio	x			x			
28	Avenches	x						
29	Avers	x		x	x		x	
30	Ayent	x		x	x			
31	Baar	x			x			
32	Bad Ragaz	x			x			
33	Bagnes	x	x	x	x	x	x	
34	Balsthal	x						
35	Baltschieder	x			x			
36	Bäretswil	x						
37	Basel	x			x			
38	Bas-Intyamon	x			x			
39	Basse-Allaine	x			x			
40	Bassins	x						
41	Baulmes	x						
42	Bauma	x			x			
43	Beatenberg	x			x			
44	Beckenried	x			x			
45	Bedretto	x		x	x		x	
46	Beinwil (SO)	x			x			
47	Bellinzona	x	x	x	x	x	x	x
48	Belmont-Broye	x			x			x
49	Belp	x			x			
50	Benken (SG)	x						
51	Bergün Filisur	x	x	x	x	x	x	
52	Beringen	x						
53	Bern	x		x	x			x
54	Beromünster	x			x			

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
55	Bettmeralp	x			x			
56	Bever	x			x			
57	Bex	x		x	x		x	
58	Biasca	x		x	x		x	
59	Biel/Bienne	x						
60	Bielersee (BE)	x			x			
61	Bière	x			x			
62	Binn	x		x	x		x	
63	Blatten	x		x	x		x	
64	Blenio	x	x	x	x	x	x	
65	Blonay	x						x
66	Bodensee (SG)	x			x			
67	Bodensee (TG)	x	x	x	x	x	x	
68	Bolligen	x						
69	Boltigen	x		x	x		x	
70	Bosco/Gurin	x						
71	Boudry	x						
72	Bourg-Saint-Pierre	x		x	x		x	
73	Bregaglia	x	x	x	x	x	x	
74	Breggia	x			x			
75	Breil/Brigels	x		x	x		x	
76	Brienz (BE)	x			x			
77	Brienzersee	x			x			
78	Brig-Glis	x			x			
79	Brione (Verzasca)	x		x	x			
80	Brissago	x			x			
81	Brot-Plamboz	x						
82	Brusio	x			x			
83	Buchegg	x						
84	Buchs (SG)	x						
85	Bülach	x						

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
86	Bulle	x			x			
87	Bullet	x						
88	Bürglen (UR)	x		x	x			
89	Bussnang	x						
90	Bütschwil-Ganterschwil	x						
91	Buttisholz	x						
92	Calanca	x			x			
93	Campo (Vallemaggia)	x			x			
94	Capriasca	x			x			
95	Casti-Wergenstein	x			x			
96	Cazis	x			x			
97	Celerina/Schlarigna	x			x			
98	Centovalli	x		x	x			
99	Cerentino	x						
100	Cevio	x	x	x	x	x	x	
101	Chalais	x			x			
102	Cham	x						
103	Chamoson	x			x			
104	Champéry	x			x			
105	Château-d'Oex	x	x	x	x	x	x	
106	Châtel-Saint-Denis	x			x			
107	Chavornay	x						
108	Cheyres-Châbles	x						
109	Chur	x			x			x
110	Churwalden	x		x	x			
111	Clos du Doubs	x		x	x		x	
112	Collombey-Muraz	x			x			
113	Conters im Prättigau	x						

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
114	Conthey	x		x	x		x	
115	Corbeyrier	x						
116	Corgémont	x						x
117	Courgenay	x						
118	Courrendlin	x						x
119	Courroux	x						
120	Court	x			x			
121	Courtelary	x						x
122	Courtepin	x						x
123	Crans-Montana	x		x	x		x	
124	Cugnasco-Gerra	x						
125	Dagmersellen	x			x			
126	Därstetten	x			x			
127	Davos	x	x	x	x	x	x	
128	Delémont	x						x
129	Delley-Portalban	x						
130	Diemtigen	x	x	x	x	x	x	
131	Disentis/Mustér	x		x	x		x	
132	Domat/Ems	x			x			
133	Domleschg	x			x			
134	Düdingen	x			x			
135	Ebnat-Kappel	x			x			
136	Eggiwil	x		x	x		x	
137	Egnach	x						
138	Einsiedeln	x		x	x	x	x	
139	Eisten	x			x			
140	Elgg	x			x			
141	Emmen	x						
142	Emmetten	x			x			
143	Engelberg	x		x	x		x	
144	Ennetbürgen	x						

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
145	Entlebuch	x		x	x			
146	Ergisch	x			x			
147	Eriz	x						
148	Erlenbach im Simmental	x			x			
149	Ernen	x			x			
150	Erstfeld	x		x	x		x	x
151	Eschenbach (SG)	x		x	x			
152	Escholzmatt-Marbach	x		x	x	x	x	
153	Estavayer	x		x	x			
154	Evionnaz	x			x			
155	Evolène	x	x	x	x	x	x	
156	Faido	x	x	x	x	x	x	
157	Falera	x						
158	Ferden	x			x			
159	Ferrera	x		x	x		x	
160	Feusisberg	x						
161	Fideris	x			x			
162	Fieschertal	x	x	x	x	x	x	
163	Finhaut	x			x			
164	Fischenthal	x			x			
165	Fischingen	x			x			
166	Flims	x		x	x			
167	Flüelen	x						
168	Flühli	x		x	x	x	x	x
169	Flums	x		x	x		x	
170	Fontenais	x						
171	Forel (Lavaux)	x						
172	Frasco	x			x			
173	Fraubrunnen	x			x			

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
174	Frauenfeld	x			x			x
175	Freienbach	x						x
176	Frutigen	x		x	x		x	
177	Fully	x			x			
178	Furna	x			x			
179	Gais	x						
180	Gambarogno	x		x	x		x	
181	Gampel-Bratsch	x			x			
182	Gams	x						
183	Genève	x						
184	Gersau	x			x			
185	Gibloux	x			x			
186	Gimel	x						
187	Giornico	x						
188	Giswil	x		x	x		x	
189	Glarus	x		x	x	x	x	
190	Glarus Nord	x	x	x	x	x	x	x
191	Glarus Süd	x	x	x	x	x	x	x
192	Gommiswald	x			x			
193	Goms	x	x	x	x	x	x	
194	Gonten	x			x			
195	Göschenen	x		x	x	x	x	
196	Gossau (SG)	x			x			
197	Gossau (ZH)	x						
198	Grabs	x		x	x			
199	Grandvillard	x			x			
200	Grâne	x						
201	Gränichen	x						
202	Grenchen	x			x			
203	Grengiols	x		x	x		x	
204	Grindelwald	x	x	x	x	x	x	

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
205	Grono	x			x			
206	Grosswangen	x						
207	Grüsch	x			x			
208	Gruyères	x			x			
209	Gsteig	x		x	x		x	
210	Guggisberg	x		x	x			
211	Gündlischwand	x						
212	Gurmels	x						
213	Gurtnellen	x		x	x		x	
214	Guttannen	x	x	x	x	x	x	
215	Habkern	x		x	x			
216	Haldenstein	x						
217	Hasle (LU)	x			x			
218	Hasle bei Burgdorf	x						
219	Hasliberg	x			x			
220	Haute-Ajoie	x			x			
221	Haute-Sorne	x		x	x		x	x
222	Haut-Intyamon	x		x	x		x	
223	Heimiswil	x						
224	Hemberg	x						
225	Herbetswil	x						
226	Hérémence	x		x	x	x	x	
227	Hergiswil (NW)	x						
228	Hergiswil bei Willisau	x			x			
229	Herisau	x			x			
230	Hinwil	x						
231	Hitzkirch	x			x			
232	Hohenrain	x			x			
233	Homburg	x			x			
234	Horgen	x			x			

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
235	Horrenbach-Buchen	x						
236	Horw	x						
237	Hospental	x			x			
238	Hundwil	x			x			
239	Hünenberg	x						
240	Huttwil	x						
241	Hüttwilen	x						
242	Icogne	x			x			
243	Ilanz/Glion	x	x	x	x	x	x	
244	Illnau-Effretikon	x			x			x
245	Ingenbohl	x						
246	Innerthal	x		x	x		x	
247	Innertkirchen	x	x	x	x	x		
248	Ins	x			x			
249	Iseltwald	x						
250	Isenthal	x		x	x		x	
251	Jaun	x		x	x			
252	Jenaz	x			x			
253	Jorat-Menthue	x						
254	Kaisten	x						
255	Kallnach	x						
256	Kaltbrunn	x						
257	Kandergrund	x			x			
258	Kandersteg	x	x	x	x	x	x	
259	Kemmental	x			x			
260	Kerns	x		x	x		x	
261	Kirchberg (SG)	x			x			
262	Kleinlützel	x						
263	Klosters-Serneus	x	x	x	x	x	x	
264	Kloten	x						

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
265	Köniz	x		x	x			
266	Krauchthal	x						
267	Kriens	x			x			
268	Küssnacht (SZ)	x			x			
269	La Baroche	x			x			
270	La Brévine	x			x			
271	La Chaux-de-Fonds	x		x	x			x
272	La Chaux-du-Milieu	x						
273	La Grande-Béroche	x			x			
274	La Punt-Chamuesch	x		x	x		x	
275	La Rippe	x						
276	La Roche	x			x			
277	La Sagne	x			x			
278	Laax	x			x			
279	L'Abbaye	x			x			
280	Lac de Neuchâtel (NE)	x		x	x		x	
281	Lac de Neuchâtel (VD)	x			x			
282	Lac Léman (VD)	x	x	x	x	x	x	
283	Langenthal	x						x
284	Langnau im Emmental	x			x			
285	Lantsch/Lenz	x						
286	Lauenen	x		x	x		x	
287	Lauperswil	x						
288	Lausanne	x			x			x
289	Lauterbrunnen	x	x	x	x	x	x	
290	Lavertezzo	x		x	x		x	

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
291	Lavizzara	x	x	x	x	x	x	
292	Le Chenit	x		x	x		x	
293	Le Lieu	x			x			
294	Le Locle	x			x			x
295	Le Mouret	x						x
296	Le Noirmont	x						
297	Lenk	x	x	x	x	x	x	
298	Les Bois	x			x			
299	Les Ponts-de-Martel	x						
300	Les Verrières	x			x			
301	Leuk	x		x	x			
302	Leukerbad	x		x	x		x	
303	Leysin	x						
304	Leytron	x			x			
305	Liddes	x		x	x		x	
306	Liestal	x						
307	L'Isle	x						
308	Lostallo	x		x	x			
309	Lugano	x		x	x		x	
310	Lumnezia	x	x	x	x	x	x	
311	Lungern	x			x			
312	Luthern	x			x			
313	Lützelflüh	x						
314	Luzein	x		x	x		x	
315	Luzern	x			x			x
316	Madiswil	x			x			
317	Maggia	x	x	x	x	x	x	
318	Maienfeld	x			x			
319	Malters	x			x			
320	Martigny	x			x			x

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
321	Martigny-Combe	x			x			
322	Medel (Lucmagn)	x	x	x	x	x	x	
323	Meiringen	x			x			
324	Mels	x	x	x	x	x	x	
325	Mendrisio	x			x			x
326	Menzingen	x			x			
327	Menznau	x			x			
328	Merishausen	x						
329	Mesocco	x	x	x	x	x	x	
330	Mettauertal	x						
331	Möhlin	x						
332	Montagny (FR)	x						
333	Montanaire	x			x			
334	Monteceneri	x			x			
335	Montfaucon	x						
336	Monthey	x						x
337	Mont-la-Ville	x						
338	Mont-Noble	x			x			
339	Montreux	x			x			x
340	Montricher	x			x			
341	Mont-Vully	x			x			
342	Morschach	x			x			
343	Mosnang	x		x	x			
344	Moutier	x						x
345	Mühleberg	x			x			
346	Mümliswil-Ramiswil	x			x			
347	Münsingen	x						
348	Muotathal	x	x	x	x	x	x	
349	Murgenthal	x						
350	Murten	x						x

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
351	Muttenz	x						x
352	Naters	x	x	x	x	x	x	
353	Neckertal	x		x	x			
354	Nendaz	x		x	x		x	
355	Nesslau	x		x	x		x	
356	Neuchâtel	x						x
357	Neuenegg	x						
358	Neuenkirch	x			x			
359	Neunkirch	x						
360	Niederbipp	x						
361	Niederbüren	x						
362	Niedergesteln	x						
363	Niederhelfenschwil	x						
364	Nods	x			x			
365	Oberägeri	x			x			
366	Oberbüren	x						
367	Oberdiessbach	x						
368	Oberdorf (NW)	x						
369	Oberems	x		x	x			
370	Obergoms	x	x	x	x	x	x	
371	Oberiberg	x			x			
372	Oberried am Brienzersee	x						
373	Oberriet (SG)	x			x			
374	Obersaxen Mundaun	x		x	x		x	
375	Oberwil im Simmental	x			x			
376	Ollon	x		x	x		x	
377	Onsernone	x		x	x	x	x	
378	Ormont-Dessous	x		x	x		x	
379	Ormont-Dessus	x		x	x		x	

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
380	Oron	x			x			
381	Orsières	x	x	x	x	x	x	
382	Orvin	x						
383	Payerne	x			x			
384	Personico	x			x			
385	Péry-La Heutte	x			x			
386	Petit-Val	x			x			
387	Pfäfers	x	x	x	x	x	x	
388	Pfäffikon	x						
389	Pfaffnau	x						
390	Plaffeien	x		x	x		x	x
391	Plasselb	x						
392	Plateau de Diesse	x			x			
393	Pleigne	x						
394	Pontresina	x	x	x	x	x	x	
395	Poschiavo	x	x	x	x	x	x	
396	Prato (Leventina)	x						
397	Provence	x			x			
398	Puidoux	x			x			
399	Quarten	x		x	x		x	
400	Quinto	x		x	x		x	
401	Randa	x		x	x			
402	Rapperswil (BE)	x						
403	Rapperswil-Jona	x			x			
404	Raron	x			x			
405	Realp	x		x	x		x	
406	Reichenbach im Kandertal	x	x	x	x	x	x	
407	Reiden	x			x			
408	Rheinfelden	x						x
409	Rheinwald	x	x	x	x	x	x	

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
410	Riddes	x			x			
411	Ried-Brig	x			x			
412	Riederalp	x						
413	Riggisberg	x			x			
414	Risch	x			x			
415	Riviera	x		x	x		x	
416	Rochefort	x			x			
417	Römerswil	x						
418	Romoos	x			x			
419	Rossa	x		x	x		x	
420	Rossinière	x			x			
421	Röthenbach im Emmental	x			x			
422	Rothenthurm	x			x			
423	Rougemont	x		x	x			
424	Roveredo (GR)	x			x			
425	Rüderswil	x						
426	Rüeggisberg	x			x			
427	Rüschegg	x		x	x		x	
428	Ruswil	x			x			
429	Rüte	x			x			
430	Saanen	x	x	x	x	x	x	
431	Saas-Almagell	x	x	x	x	x	x	
432	Saas-Balen	x			x			
433	Saas-Fee	x			x			
434	Saas-Grund	x			x			
435	Sachseln	x		x	x		x	
436	Safiental	x	x	x	x	x	x	
437	Saignelégier	x			x			
438	Saint-Cergue	x			x			
439	Sainte-Croix	x			x			

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
440	Saint-Gingolph	x			x			
441	Saint-Imier	x						
442	Saint-Martin (VS)	x			x			
443	Sâles	x						
444	Salvan	x		x	x			
445	Samedan	x		x	x		x	
446	Samnaun	x		x	x			
447	San Vittore	x						
448	Sarnen	x		x	x		x	
449	Satigny	x						
450	Sattel	x						
451	Savièse	x		x	x		x	
452	Savigny	x						
453	Saxeten	x						
454	Saxon	x			x			
455	Schaan	x						
456	Schaffhausen	x			x			x
457	S-chanf	x	x	x	x	x	x	
458	Schangnau	x			x			
459	Schänis	x			x			
460	Schattdorf	x						
461	Schattenhalb	x			x			
462	Schiers	x		x	x		x	
463	Schlatt-Haslen	x						
464	Schleitheim	x						
465	Schübelbach	x			x			
466	Schüpfen	x						
467	Schüpfheim	x			x			
468	Schwarzenberg	x			x			
469	Schwarzenburg	x			x			
470	Schwellbrunn	x						

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
471	Schwende	x		x	x		x	
472	Schwyz	x		x	x			x
473	Scuol	x	x	x	x	x	x	
474	Seeberg	x						
475	Seedorf (BE)	x						
476	Seedorf (UR)	x						
477	Seelisberg	x						
478	Seewen	x						
479	Seewis im Prättigau	x		x	x			
480	Selzach	x						
481	Sembrancher	x						
482	Semsales	x			x			
483	Sennwald	x			x			
484	Serravalle	x		x	x		x	
485	Sevelen	x			x			
486	Sierre	x						
487	Signau	x						
488	Sigriswil	x		x	x			
489	Silenen	x	x	x	x	x	x	
490	Sils im Engadin/Segl	x		x	x		x	
491	Silvaplana	x			x			
492	Simplon	x		x	x		x	
493	Sins	x						
494	Sion	x			x			x
495	Sisikon	x						
496	Siviriez	x						x
497	Soazza	x			x			
498	Sonogno	x			x			
499	Sonvilier	x			x			x

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
500	Spiez	x						
501	Spiringen	x			x			
502	St. Antoni	x						x
503	St. Gallen	x			x			
504	St. Moritz	x			x			
505	St. Niklaus	x		x	x		x	
506	St. Stephan	x		x	x		x	
507	St. Ursen	x						
508	Stammheim	x			x			
509	Stansstad	x						
510	Sufers	x			x			
511	Sumiswald	x		x	x		x	
512	Sumvitg	x		x	x		x	
513	Surses	x	x	x	x	x	x	
514	Tamins	x			x			
515	Täsch	x		x	x		x	
516	Termen	x						
517	Thayngen	x						
518	Thun	x						
519	Thunersee	x			x			
520	Törbel	x						
521	Trachselwald	x						
522	Tramelan	x			x			
523	Triengen	x						
524	Trient	x			x			
525	Triesen	x			x			
526	Triesenberg	x			x			
527	Trimmis	x			x			
528	Trin	x			x			
529	Troistorrents	x			x			
530	Trub	x		x	x		x	

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
531	Trun	x		x	x			
532	Tschappina	x			x			
533	Tschiertschen-Praden	x			x			
534	Tujetsch	x	x	x	x	x	x	
535	Turbenthal	x			x			
536	Turtmann-Unterems	x			x			
537	Ueberstorf	x						
538	Unterägeri	x			x			
539	Unterbäch	x						
540	Unteriberg	x			x			
541	Unterschächen	x		x	x		x	
542	Untervaz	x			x			
543	Urnäsch	x			x			
544	Uster	x			x			x
545	Utzenstorf	x						
546	Val Müstair	x	x	x	x	x	x	
547	Val Terbi	x			x			x
548	Valbirse	x						
549	Valbroye	x			x			
550	Val-de-Charmey	x	x	x	x	x	x	
551	Val-de-Ruz	x	x	x	x	x	x	x
552	Val-de-Travers	x	x	x	x	x	x	
553	Val-d'Illiez	x			x			
554	Vallorbe	x			x			
555	Vals	x	x	x	x	x	x	
556	Valsot	x	x	x	x	x	x	
557	Vaz/Obervaz	x			x			
558	Vechigen	x			x			
559	Villeneuve (VD)	x			x			

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
560	Villeret	x						
561	Vilters-Wangs	x			x			
562	Vionnaz	x						
563	Visperterminen	x		x	x			
564	Vogorno	x			x			
565	Vollèges	x						
566	Vorderthal	x			x			
567	Vouvry	x			x			
568	Vuisternens-devant-Romont	x			x			
569	Vully-les-Lacs	x						
570	Wädenswil	x			x			x
571	Walchwil	x						
572	Wald (ZH)	x			x			
573	Waldkirch	x			x			
574	Walenstadt	x		x	x			
575	Walkringen	x						
576	Wängi	x						x
577	Wartau	x			x			
578	Wassen	x		x	x		x	
579	Wattwil	x		x	x			
580	Weggis	x			x			
581	Werthenstein	x						
582	Wetzikon (ZH)	x						
583	Wiesendangen	x						
584	Wigoltingen	x						
585	Wil (SG)	x						
586	Wilchingen	x						
587	Wildhaus-Alt St. Johann	x		x	x		x	
588	Willisau	x			x			

		Impacted natural area						
	Municipality	Broad front migration corridor	Alpine migration corridors	Moorlands (60)	BLN (113)	National Parks (2)	Waterbird IA (78)	Measures already applied
589	Wimmis	x						
590	Winterthur	x		x	x		x	x
591	Wohlen bei Bern	x			x			
592	Wolfenschiessen	x		x	x		x	
593	Worb	x						
594	Wynigen	x			x			
595	Zermatt	x	x	x	x	x	x	
596	Zernez	x	x	x	x	x	x	
597	Zillis-Reischen	x			x			
598	Zug	x			x			
599	Zuoz	x		x	x			
600	Zürich	x		x	x		x	x
601	Zürichsee (ZH)	x		x	x			
602	Zweisimmen	x		x	x		x	
603	Zwischbergen	x		x	x		x	
	Total	603	58	181	417	65	143	49

9 Abbreviations

LP	Light Pollution
LE	Light Emission
Lx	Lux
Cd	Candela
BLN	Federal Inventory of Landscapes and Natural Monuments of National Importance (German: Bundesinventar der Landschaften und Naturdenkmäler von nationaler Bedeutung)
BAFU	Federal Office for the Environment FOEN (German: Bundesamt für Umwelt)
GSchG	The Water Protection Act (German: Gewässerschutzgesetz)
NHG	The Federal Act on the Protection of Nature and Cultural Heritage (German: Natur- und Heimatschutzgesetz)
USG	Environmental Protection Act German: Umweltschutzgesetz)
BV	Federal Constitution (German: Bundesverfassung)
RPG	The Spatial Planning Act (German: Raumplanungsgesetz)