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Exposure to night-time light pollution and risk of prolonged duration of labor: A nationwide cohort study

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Abstract

Background: Light pollution (LP) is a ubiquitous environmental agent that affects more than 80% of the world's population. This large nationwide cohort study evaluates whether exposure to LP can influence obstetric outcomes.

Methods: We analyzed Austrian birth registry data on 717 113 cases between 2008 and 2016 and excluded cases involving day-time delivery, <23 + 0 gestational weeks, and/or birthweight <500 g, induction of labor, elective cesarean, or cases with missing data. The independent variable, that is, degree of night-time LP, was categorized as low (0.174 to <0.688 mcd/m^2), medium (0.688 to <3 mcd/m^2), or high (3 to <10 mcd/m^2). Duration of labor and adverse neonatal outcomes served as outcome measures.

Results: Cases in regions with high LP (odds ratio [OR], 1.43; 95% confidence interval [CI], 1.30-1.57) and medium LP (OR, 1.22; 95% CI, 1.14-1.31) showed increased odds of prolonged labor ($P < .0001$ each). Newborns born in regions with high LP (OR, 1.12; 95% CI, 1.07-1.16) and medium LP (OR, 1.07; 95% CI, 1.04-1.10) showed increased odds of experiencing adverse outcomes ($P < .0001$ each). Preterm delivery <28 + 0 weeks was also associated with the degree of LP ($P = .04$).

Conclusions: Night-time LP negatively interferes with obstetric outcomes. The perceived influence of LP as an environmental agent needs to be re-evaluated to minimize associated health risks.

KEYWORDS

environmental pollution, night-time lighting, obstetrics, pregnancy outcome

1 | INTRODUCTION

The present global environment is radically different from the environment of evolutionary adaptedness (EEA) that humans evolved in Ref.1,2 Ancient organisms, including hominins, lived in harmony with natural conditions over millions of years, especially in rhythm with light, which was solely created by the illumination of the sun, moon, and stars.[3] Different species adapted phenotypically and genetically to the regularity of these day/night rhythms according to Charles Darwin's theory of natural selection.[3,4] As a result, beneficial adaptations related to reproduction, nourishment, sleep, and protection from predators were selected for over time.[4,5] However, these evolved traits that were once advantageous are now mismatched with the living conditions found in contemporary human-altered environments. The discordance hypothesis describes the inability of slow biological adaptation to keep pace with the rapid cultural and technological changes of modernity.[6] As a core aspect of evolutionary medicine, the discordance hypothesis explains how evolutionary patterns can leave us susceptible to diseases and other poor health outcomes. Essentially, the mismatches or discordances between the conditions under which humans evolved (i.e., high physical activity, diets of lean meat and no processed foods) and the environments we live in today (i.e., sedentary lifestyles, high sugar foods and beverages) are pathogenic.[1] Examples of evolutionary mismatches are numerous since human culture and related environmental modifications have occurred relatively rapidly.[7]

One area that has been dramatically altered in industrialized societies is that of environmental light/dark cycle, which balance was disrupted by the most transformative human invention of the 19th century—the first commercially viable light bulb—which initiated the era of lighting technology. However, the positive effects of the subsequent global electrification are widely believed to have been overridden by the excessive and misdirected use of artificial light (AL) to illuminate urban areas around the clock.[3,4]The extent and intensity of AL currently affects more than 80% of the global population.[5,8] However, this anthropogenic environmental phenomenon, defined as ecological light pollution (LP), entails far-reaching consequences.[4]

The introduction of AL to night-time landscapes can disrupt animals' natural physiology and behavior, including reproductive fitness traits.[9] For example, some evidence shows that AL negatively affects mating and reproductive output.[4,5,9] However, animals may not be the only species susceptible to LP. In humans, LP mediates various adverse conditions, including sleeping disorders, metabolic disruptions, cancer, cardiovascular diseases, psychiatric disorders, and infertility.[5,10] These effects of AL are positively correlated with the exposure time, and their risk is elevated when light is present during night-time versus daytime.[11] The association between LP and related health problems has been linked to chronodisruption by most authors.[12,13] The suprachiasmatic nucleus (SCN) of the hypothalamus coordinates circadian rhythms throughout the body by regulating the light/dark-dependent secretions of the pineal hormone melatonin, which shows oncostatic, antioxidant, and anti-inflammatory properties, and optimizes mitochondrial function.[14]

The natural rhythm of melatonin involves peak concentrations at night and 10- to 15-fold lower levels during the day, as hormone production is acutely suppressed by light. In pregnant women, the night-time peak melatonin levels rise after 24 weeks and reach maximum values by the end of the third trimester.[15] Adequate melatonin levels and appropriate circadian rhythms are prerequisites for: (a) controlling the timing of labor; (b) maintaining maternal reproductive health and fetal development; and (c) avoiding prenatal modulation of offspring diseases.[14,15]

A thorough understanding of the risk factors that are likely to disturb the alignment of circadian environmental cues to physiological functions has practical implications for perinatal care. To date, the only available study on this topic showed that AL altered birthweight and gestational length.[10] Our study is the first to demonstrate how LP affects obstetric outcomes in terms of labor duration and neonatal short-term health. We aim to add data from the neglected field of obstetrics to the complex array of human health problems exacerbated by society's propensity for illuminating the night.

2 | METHODS

2.1 | Study design and participants

This retrospective analysis was based on the Austrian birth registry—a prospective, population-based, nationwide registry of all deliveries in Austria that includes comprehensive information about maternal characteristics and perinatal outcomes from all 82 obstetrics departments in the country. Data from this registry were collected quarterly to ensure adequate data control and quality. To analyze night-time LP, we identified cases between 2008 and 2016 that involved delivery during night-time (9:00 PM to 5:59 AM) at $\geq$23 + 0 gestational weeks and a birthweight of $\geq$500 g. For a more precise analysis, we matched night-time LP (in terms of acute short-term exposure) to night-time deliveries and the related acute short-term outcome variables. The definition of civil twilight, that is, the time when the geometric center of the sun's disk is at most 6 degrees below the horizon, was used to set the lower and upper limits for the night-time period. During this time, AL may already be needed, especially in unclear weather conditions. Because of the short time frame for the night-time period selected, twilight between 9:00 PM and 5:59 AM occurred independent of the four seasons.[17] Data on women who underwent elective cesarean or induction of labor, and cases with missing data were excluded from the analyses. For obstetric outcome analysis, duration of labor and adverse neonatal short-term health (ie, 5-min Apgar score <7 and/or an umbilical cord arterial blood pH <7.2) was chosen.

2.2 | Light pollution assessment

The evaluation of LP was based on calculation of the mean zenithal night sky brightness (NSB). Satellite imagery was used as raw input for the number and intensity of light sources, allowing precise measurement of the brightness of the sky through AL. This imagery was put into a physical model to compute the sky brightness in different regions.[18] Maps showing enhanced sky brightness are available for the entire world.[8] To obtain nationwide data, this map, based on Visible Infrared Imaging Radiometer Suite (VIIRS) calibrated data, was matched in the geographic information system QGIS with the Oak Ridge National Laboratory LandScan 2015 Dataset to eliminate uninhabited areas.[19,20] The resulting map was supplemented with a spatial layer for the Austrian municipalities and extended with ZIP codes from the Austrian Postal website.[21] Finally, the NSB for each ZIP code was assessed.

To investigate whether LP influenced duration of labor and/or neonatal short-term outcomes, we categorized LP into the following different degrees: low (0.174 to <0.688 mcd/m^2), medium (0.688 to <3 mcd/m^2), and high LP (3 to <10 mcd/m^2).[8] In relation to the natural sky brightness (0.174 mcd/m^2), low and medium LPs indicate sky brightness that is up to 3.9-fold and 17.2-fold higher, respectively, whereas high LP indicates a level of illumination at which night adaptation is no longer possible for human eyes.[8] Cases were assigned to LP categories according to the postal codes of the living areas. Austria has a total area of 83.882 km^2, and the areal sizes covered by postal codes range from 0.1 to 462.8 km^2 (mean, 39.4 km^2). Figure 1 shows the distribution of light polluted regions in Austria as they were stratified for this study.

2.3 | Outcome measures

Other studies have described associations between various environmental variables and obstetric outcomes, but exposure studies focusing on labor duration and neonatal short-term outcomes are missing.[10,22,23] In our study, we defined the onset of labor as the occurrence of regular, painful contractions at least once every 10 minutes.[24] Labor duration served as the primary outcome, with prolonged labor being defined as both first active (cervical dilatation ≥4 cm) and second stage of labor and birth extending more than 20 hours for nulliparous women, or more than 15 hours for multiparous women.[25-27] This literature-based definition includes the potential time delay because of epidural anesthesia use. The concept of prolonged labor has been controversially discussed since Friedman's pioneering work, but ongoing research is important to obtain consistent knowledge of accurate definitions and risk factors influencing birth duration.[28,29]

"Adverse neonatal short-term outcome"—a composite variable based on early neonatal data—served as the secondary outcome variable. This outcome was defined as either a 5-minutes Apgar score <7 and/or an umbilical cord arterial blood pH <7.2. We used the 5-min Apgar score, since it is an easy-to-use and well-known parameter for both obstetricians and neonatologists.[30] In addition, an umbilical cord arterial pH <7.2 constitutes a mild degree of cord acidemia and is associated with an increased risk of adverse neurological outcome in the newborn.[31] Both outcome measures were prespecified.

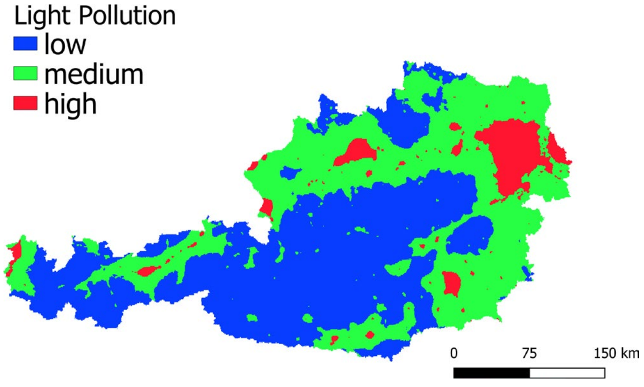

FIGURE 1 Austrian regional map stratified by the degrees of light pollution

2.4 | Statistical analyses

To determine whether LP was a potential risk factor contributing independently to prolonged labor and/or adverse neonatal outcomes, multivariate logistic regression models were applied. First, with a forward variable selection strategy, we used likelihood ratio to test whether a priori selected covariates yielded a statistically significant contribution to the model. For the second model, we used a backward strategy for variable selection. Based on the available literature, we included the following covariates in the model: maternal age, parity (nulliparous, multiparous), gestational age, birthweight, mode of delivery (spontaneous vaginal, instrumental-assisted, vaginal breech position, nonelective cesarean), the volume of the maternity unit (tertiary perinatal center, no tertiary perinatal center), and prolonged labor (only for the model predicting adverse neonatal outcome).[32-34] Univariate and multivariate adjusted odds ratios (ORs) with 95% confidence intervals (CIs) were calculated for each risk factor. Data were presented as frequencies (n) and proportions (%), as medians with 25th and 75th percentiles, or as mean values with standard deviation (SD). A two-sided *P* value of <.05 was considered to be statistically significant. For the statistical analyses, we used the Stata software version 13 (StataCorp LLC, College Station, TX, USA).

3 | RESULTS

3.1 | Study population

Among the 717 113 births recorded between January 1, 2008, and December 31, 2016, 716 614 (99.9%) fulfilled the inclusion criteria of gestational week ≥23 + 0 and birthweight ≥500 g. On the basis of the exclusion criteria, we omitted 225 531 births, and another 97 963 were omitted because of missing data. Of the 393 120 remaining births, 198 303 daytime births were excluded. Thus, 194 817 night-time births were eligible and included in the analyses (Figure 2). Of these, 132 289 (67.9%), 45 112 (23.2%), and 17 416 (8.9%) births occurred in regions with low, medium, and high LP, respectively. The baseline characteristics of the study participants in total and stratified by the degree of LP are shown in Table 1. Preterm delivery before <28 + 0 gestational weeks occurred in 173/132289 (0.1%), 86/45112 (0.2%), and 27/17416 (0.2%) births in the regions with low, medium, and high LP, respectively. These differences were statistically significant ($P = .04$).

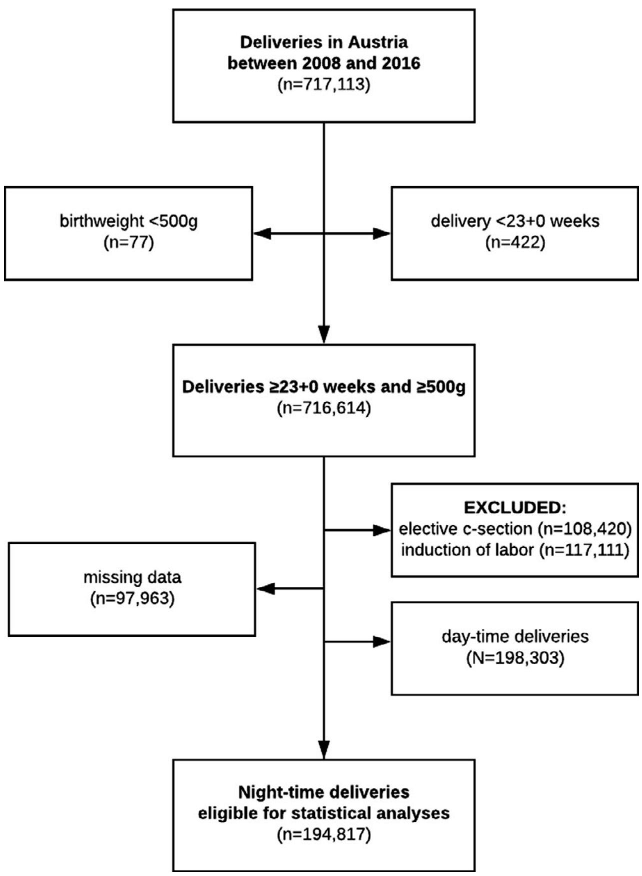

FIGURE 2 Eligibility of the 194 817 night-time cases during the study period

3.2 | Labor duration

The overall mean duration of labor was 6.30 (±4.74) hours, and the corresponding values for regions with low, medium, and high LP were 6.10 (±4.57), 6.62 (±4.95), and 6.98 (±5.27) hours, respectively ($P < .0001$). Figure 3 demonstrates the prolongation of labor duration in relation to the degree of LP, stratified by the women's parity ($P < .0001$). Moreover, 4592 (2.4%) births involved pathologically prolonged labor, including 2826/132289 (2.1%), 1197/45112 (2.7%), and 569/17416 (3.3%) births in regions with low, medium, and high LP, respectively ($P < .0001$).

Univariate analysis showed increased odds of prolonged labor duration in regions with high LP (OR, 1.55; 95% CI, 1.41-1.70; $P < .0001$) and medium LP (OR, 1.25; 95% CI, 1.17-1.34; $P < .0001$). A likelihood ratio test to determine the covariates that provide a relevant contribution to the model for prediction of prolonged labor showed significant effects of all selected parameters (maternal age, gestational age, birthweight, mode of delivery, parity, and volume of maternity unit). After adjustment for these confounders, we found that regions with high LP (OR, 1.43; 95% CI, 1.30-1.57; $P < .0001$), and medium LP (OR, 1.22; 95% CI, 1.14-1.31; $P < .0001$) still had increased odds of prolonged labor, as shown in Table 2 and Figure 3.

3.3 | Neonatal outcomes

In total, 37 091 (19.0%) births showed adverse neonatal short-term outcomes, of which 24 349/132 289 (18.4%), 9152/45 112 (20.3%), and 3590/17 416 (20.6%) occurred in regions with low, medium, and high LP, respectively. The separate distributions of newborns with a 5-minutes Apgar score <7 and/or an umbilical cord pH <7.2, in total and stratified by the degree of LP, are shown in Table 3.

Univariate analysis revealed that newborns born in regions with high LP (OR, 1.15; 95% CI, 1.11-1.20; $P < .0001$), and medium LP (OR, 1.13; 95% CI, 1.10-1.16; $P < .0001$) had increased odds of experiencing adverse neonatal short-term outcomes. After adjustment for potential confounders, newborns born in regions with high and medium LP still showed increased odds of experiencing adverse neonatal outcomes (high LP: OR, 1.12; 95% CI, 1.07-1.16; $P < .0001$; medium LP: OR, 1.07; 95% CI, 1.04-1.10; $P < .0001$), as shown in Table 4.

4 | DISCUSSION

4.1 | Main findings

The present study sought to identify how exposure to night-time LP affects obstetric outcomes, namely, prolonged duration of labor and neonatal short-term health. In regions with

TABLE 1 Baseline characteristics, as total and stratified by the degree of light pollution, among 194 817 night-time deliveries in Austria from 2008 to 2016

Variable	Frequency (N) (proportion, %)			
	Light pollution			
	Low 0.174 to <0.688 mcd/m^2	Medium 0.688 to <3 mcd/m^2	High 3 to <10 mcd/m^2	Total
Maternal age (y)				
<18	548 (0.4%)	292 (0.6%)	117 (0.7%)	957 (0.5%)
18-29	61 129 (46.2%)	20 997 (46.6%)	7591 (43.6%)	89 717 (46.0%)
30-34	44 927 (34.0%)	14 076 (31.2%)	5449 (31.3%)	64 452 (33.1%)
35-40	21 082 (15.9%)	7821 (17.3%)	3421 (19.6%)	32 324 (16.6%)
≥41	4603 (3.5%)	1926 (4.3%)	838 (4.8%)	7367 (3.8%)
Total	132 289 (100.0%)	45 112 (100.0%)	17 416 (100.0%)	194 817 (100.0%)
Singleton/multiple gestation				
Singleton	130 832 (98.9%)	44 513 (98.7%)	17 225 (98.9%)	192 570 (98.8%)
Multiple	1457 (1.1%)	599 (1.3%)	191 (1.1%)	2247 (1.2%)
Total	132 289 (100.0%)	45 112 (100.0%)	17 416 (100.0%)	194 817 (100.0%)
Mode of delivery				
Spontaneous vaginal	112 776 (85.2%)	37 308 (82.7%)	14 383 (82.6%)	164 467 (84.4%)
Instrumental-assisted	9483 (7.2%)	3567 (7.9%)	1353 (7.7%)	14 403 (7.4%)
Vaginal breech position	269 (0.2%)	134 (0.3%)	48 (0.3%)	451 (0.2%)
Nonelective cesarean	9761 (7.4%)	4103 (9.1%)	1632 (9.4%)	15 496 (8.0%)
Total	132 289 (100%)	45 112 (100%)	17 416 (100%)	194 817 (100%)
Gestational age at birth (wk)				
≥37 + 0	125 256 (94.7%)	42 734 (94.7%)	16 534 (94.9%)	184 524 (94.7%)
32 + 0-36 + 6	6411 (4.9%)	2128 (4.7%)	806 (4.6%)	9345 (4.8%)
28 + 0-31 + 6	449 (0.3%)	164 (0.4%)	49 (0.3%)	662 (0.3%)
23 + 0-27 + 6	173 (0.1%)	86 (0.2%)	27 (0.2%)	286 (0.2%)
Total	132 289 (100%)	45 112 (100%)	17 416 (100%)	194 817 (100%)
Birthweight (g)				
<1000 g	131 (0.1%)	70 (0.2%)	22 (0.1%)	223 (0.1%)
1000-1499 g	278 (0.2%)	113 (0.2%)	30 (0.2%)	421 (0.2%)
1500-2499 g	4462 (3.4%)	1534 (3.4%)	532 (3.1%)	6528 (3.4%)
2500-3999 g	117 458 (88.8%)	39 418 (87.4%)	15 258 (87.6%)	172 134 (88.3%)
≥4000 g	9960 (7.5%)	3977 (8.8%)	1574 (9.0%)	15 511 (8.0%)
Total	132 289 (100%)	45 112 (100%)	17 416 (100%)	194 817 (100%)

high or medium LP, labor duration was significantly longer than in regions with low LP; rates of prolonged labor were also higher in regions with high and medium LP. With regard to neonatal outcomes, the risks for a 5-minutes Apgar score <7 and/or an umbilical cord pH <7.2 were significantly higher in regions with high or medium LP.

4.2 | Interpretation

In addition to the study's findings, there is a substantial body of comparative literature from nonhuman mammalian studies that are relevant to our interpretation of the influence of LP on obstetric outcomes as these effects have been already clearly documented in animals.[35,36] For example, night-time LP has been linked to delayed onset of parturition and/or prolonged labor in house-dwelling bats and in tammar wallabies.[35,36] However, only one previous study assessed the influence of LP on obstetric outcomes in humans.[10] Consistent with our data, the authors identified AL as a pollutant that negatively affects birthweight and gestational length. More specifically, increased LP was linked with an increased likelihood of preterm birth and underweight newborns.[10] In contrast, our data showed the first of these relationships only for preterm birth

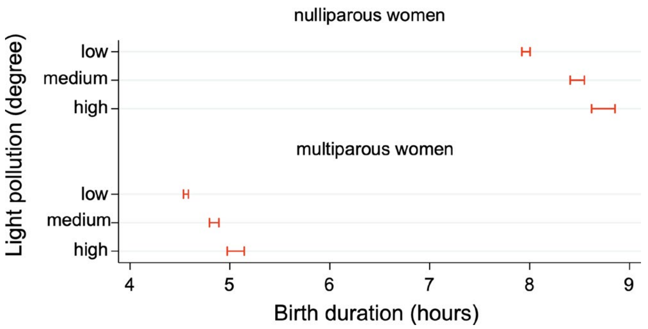

FIGURE 3 Mean value (± standard deviation) of labor duration, stratified by the degree of light pollution and parity, among 194 817 night-time deliveries in Austria from 2008 to 2016

TABLE 2 Multivariate logistic regression of variables predicting prolonged labor among 194 817 night-time deliveries in Austria from 2008 to 2016

	OR	95% CI	*P*-value
Light pollution			
Low	Reference		
Medium	1.22	1.14-1.31	<.0001
High	1.43	1.30-1.57	<.0001
Maternal age (y)			
0-17	0.90	0.60-1.35	.61
18-29	Reference		
30-34	0.88	0.82-0.94	<.0001
35-40	0.87	0.80-0.95	<.05
≥41	0.93	0.79-1.09	.36
Mode of delivery			
Spontaneous vaginal	Reference		
Instrumental-assisted	2.40	2.19-2.62	<.0001
Vaginal breech position	0.27	0.07-1.07	.07
Nonelective cesarean	3.32	3.07-3.59	<.0001
Gestational age at birth (wk)			
≥37 + 0	Reference		
32 + 0-36 + 6	0.62	0.51-0.75	<.0001
28 + 0-31 + 6	1.21	0.62-2.37	.58
23 + 0-27 + 6	0.86	0.15-4.96	.87
Birthweight (g)			
≥2500 g	Reference		
<1000 g	0.84	0.15-4.79	.85
1000-1499 g	0.36	0.13-1.02	.06
1500-2499 g	0.70	0.56-0.87	<.05
>4000 g	1.34	0.22-1.48	<.0001
Parity			
Nulliparous	Reference		
Multiparous	0.72	0.67-0.77	<.0001
Volume of maternity unit			
Tertiary perinatal center	Reference		
No tertiary perinatal center	1.32	1.24-1.42	<.0001

Abbreviations: CI, confidence interval; OR, odds ratio.

<28 + 0 gestational weeks, which can be explained by the incorporation of more detailed categories in our analyses. Thus, both covariates, gestational length and birthweight, were included in our regression model for a more valid analysis.

In contrast to the limited information regarding LP in the field of obstetrics, its role in other health risks, such as cancer, metabolic dysfunction, cardiovascular diseases, and in sleep and mood disorders is already well-known.[5,37] For example, satellite-based studies have shown that exposure to AL increases the risk of breast, prostate, and colorectal cancers, but it has not been shown to increase the risk of malignant tumors of the lung.[5,38] The positive association between LP and the incidence of breast cancer is well described among white, premenopausal women, for past and current smokers, for the invasive cancer type, and for short-wavelength (blue) light.[39-41] Kloog et al reported a 30%-73% increased risk of breast cancer in communities exposed to the highest LP, in comparison with countries exposed to the lowest LP worldwide.[38,42] Some authors have even identified AL as the potential link between shift work and cancer.[5,13] However, the available literature suggests that the full impact of LP on human health is not yet known, and many studies are still to be conducted. Importantly, future research should assess the complex mixture of environmental pollutants (eg, air/noise/water pollution, urban heat islands) in relation to adverse health outcomes, since some authors suggest that simultaneous exposure effects may not always be additive, but interactive.[43] In this context, studies have focused on fetal growth, birthweight, and prematurity; analyses of other outcomes are missing to date.[44] Addressing multipollutant frameworks would help to assess the risk of individual pollutants and their interactions more clearly, and to identify proxies for human development on local level. Unfortunately, all environmental stressors are regarded as a negative externality of the modern society. Only a transition toward a more sustainable society can avoid an otherwise exploding environmental crisis.[16]

Attempts to explain the pathogenic effects of LP on human health have focused on both disruption of circadian rhythms and/or on decreased levels of melatonin—a multifaceted hormone secreted by the pineal gland at night and, in a nonlight/dark-dependent circadian manner, by peripheral organs (eg, the placenta).[5,14] Since both mechanisms are under the control of the suprachiasmatic nucleus, it is often challenging to separate the sequelae of general circadian disruption from those associated with alterations in the circadian melatonin

TABLE 3 Neonatal outcomes, as total and stratified by the degree of light pollution, among 194 817 night-time deliveries in Austria from 2008 to 2016

	Frequency (N) (proportion, %)			
	Light pollution			
Variable	Low 0.174 to <0.688 mcd/m^2	Medium 0.688 to <3 mcd/m^2	High 3 to <10 mcd/m^2	Total
Umbilical cord arterial blood pH				
<7.1	2733 (2.1%)	1074 (2.4%)	429 (2.5%)	4236 (2.2%)
7.1 to <7.19	19 778 (14.9%)	7456 (16.5%)	2926 (16.8%)	30 160 (15.5%)
≥7.2	109 778 (83.0%)	36 582 (81.1%)	14 061 (80.7%)	160 421 (82.3%)
Total	132 289 (100%)	45 112 (100%)	17 416 (100%)	194 817 (100%)
5-min Apgar score				
0-6	679 (0.5%)	247 (0.5%)	77 (0.4%)	1003 (0.5%)
7-10	131 610 (99.5%)	44 865 (99.5%)	17 339 (99.6%)	193 814 (99.5%)
Total	132 289 (100%)	45 112 (100%)	17 416 (100%)	194 817 (100%)

cycle.[14] At a molecular level, the circadian clock is regulated by a group of core clock genes (eg, *CLOCK*, *BMAL1*, *PER1-3*) that work together in a transcriptional/translational feedback loop and eventually orchestrate physiological processes in humans, including hormone production, cell regulation, reproductive physiology, and other biological activities.[15,45] In obstetrics, the nocturnal phasing of parturition seems to be related to a nocturnal increase in maternal circadian melatonin. Studies have shown that spontaneous birth preferentially occurs between 2:00 and 5:00 AM, and that the likelihood of labor is higher during nighttime versus daytime.[46,47] In addition, melatonin strengthens, in synergy with other hormones such as oxytocin, the force of uterine contractions during the night.[14,15] More specifically, Kanwar et al have documented higher rates of vaginal delivery, and fewer cesareans, need for labor augmentation, artificial rupture of membrane, and shorter first-stage duration in a night-labor, compared to a day-labor group.[48] From an evolutionary perspective, the nocturnal phasing of human parturition has been suggested to be a residual of human evolutionary heritage. For primates, night-time onset of labor evolved via natural selection to insure some protection from predators.

In addition to helping to regulate parturition, melatonin is highly effective in reducing mitochondrial oxidative damage (eg, during preeclampsia) throughout the body.[15] Furthermore, by passing unaltered through the placenta, the hormone entrains the regulation of fetal circadian rhythms and helps initiate programming for extrauterine life.[14] Studies have repeatedly confirmed that melatonin levels in fetal circulation mirror the maternal circadian cycle.[15] Torres-Farfan et al proved that suppression of maternal circadian melatonin by exposure to AL alters the expression of clock genes in the fetal suprachiasmatic nucleus.[49] Intriguingly, circadian disturbances are linked to long-term effects in the offspring, including an increased likelihood of childhood obesity and related comorbidities (eg, hypertension).[14,15,50] Thus, gestational circadian rhythms are a powerful regulator of the mother-placenta-fetus interface.[14,15]

Based on studies proving that nocturnal melatonin concentrations drop precipitously in the presence of AL, the effects of LP on human health and obstetric outcomes via disturbed melatonin cycles seem likely.[3,45] Although melatonin is likely not the only factor involved in pathogenesis of LP, but also others such as oxytocin and cortisol, it should be definitively considered as a factor in a presumably multifactorial event.[5]

4.3 | Implications for policy makers

LP is part of a long list of environmental pollutants, but it is one of the most pervasive forms, and its scope has dramatically increased throughout the last centuries. LP is reported to be three times worse in the United States (except in Hawaii and Alaska) than in Europe, although strong regional differences exist. LP is emitted by residential areas and nonstop economic activities, and is thus, most severe in the highly-industrialized, densely populated regions of North America, Europe, and Japan. In less industrialized regions of the world, densely populated cities do not show severe LP because of the high cost of energy relative to income.[8] Thus, a comparison

TABLE 4 Multivariate logistic regression of variables predicting adverse neonatal outcomes among 194 817 night-time deliveries in Austria from 2008 to 2016

	OR	95% CI	*P*-value
Light pollution			
Low	Reference		
Medium	1.07	1.04-1.10	<.0001
High	1.12	1.07-1.16	<.0001
Maternal age (y)			
0-17	1.04	0.89-1.21	.62
18-29	Reference		
30-34	1.00	0.98-1.03	.72
35-40	1.02	0.99-1.06	.17
≥41	1.03	0.97-1.10	.32
Mode of delivery			
Spontaneous vaginal	Reference		
Instrumental-assisted	2.11	2.03-2.19	<.0001
Vaginal breech position	3.38	2.80-4.08	<.0001
Nonelective cesarean	0.64	0.61-0.67	<.0001
Gestational age at birth (wk)			
≥37 + 0	Reference		
32 + 0-36 + 6	0.93	0.88-0.99	.03
28 + 0-31 + 6	2.09	1.66-2.63	<.0001
23 + 0-27 + 6	5.40	3.27-8.90	<.0001
Birthweight (g)			
≥2500 g	Reference		
<1000 g	1.76	1.02-3.04	.04
1000-1499 g	1.41	1.04-1.91	.03
1500-2499 g	0.94	0.87-1.02	.13
>4000 g	1.52	1.46-1.58	<.0001
Parity			
Nulliparous	Reference		
Multiparous	0.57	0.55-0.58	<.0001
Volume of maternity unit			
Tertiary perinatal center	Reference		
No tertiary perinatal center	0.79	0.78-0.81	<.0001
Prolonged labor			
No	Reference		
Yes	1.04	0.97-1.12	.29

Abbreviations: CI, confidence interval; OR, odds ratio.

of urbanicity versus rurality cannot fully predict the degree of LP. In our study, we incorporated the covariate "volume of maternity unit" into the analyses to mirror potential differences in medical care systems because of geographical region and population density. Despite the regional differences, LP definitively represents an environmental risk factor that is global in nature and of international concern.[16]

To increase awareness around the health impacts of LP, research must be prioritized, and data should be obtained to facilitate the development of smart illumination policies and strategic planning. Meanwhile, individuals should be urged to curb LP by recommendations from the International Dark-Sky Association and other experts.[5]

4.4 | Strengths and limitations

The greatest strength of this study is its novelty; this is the first study to demonstrate that obstetric outcomes may be adversely affected by LP. This study distinguishes itself from the existing literature by analyzing LP through the use of NSB data, which actually includes both artificial skyglow (the light from different sources reflected back from the sky) and natural components.[8] Furthermore, original features of our study include the separate analyses of varied degrees of LP, as well as the precise matching of night-time LP to night-time cases.

The main limitation of this study is its retrospective nature. Although the nationwide setting enabled the availability of an enormously large data set, we were unable to incorporate maternal outcome measures and epidural anesthesia use into our analyses. Since these data were of heterogeneous quality, their inclusion might have produced misleading findings. Furthermore, bias may have been introduced by Modifiable Areal Unit Problem (MAUP) and the ecological fallacy.[51] These related concepts represent the potential disconnect between scales of processes (eg, observations of different categories of LP) and the scales of spatial data used to represent them. Recommendations for approaching and minimizing these issues have focused on finding the best possible scales at which the processes being studied operate.[52] To this end, we decided to assign cases to the categories of LP according to the postal codes of the living areas, as attempted by previous environmental exposure studies.[11,23] Finally, future studies should integrate a detailed temporal resolution analysis to take the per year increase of LP into account.

4.5 | Conclusions

In conclusion, our findings emphasize the importance of achieving the same global awareness and priorities for the mitigation of LP in relation to maternity care outcomes as for other health concerns.[16] Our study is the first to describe an increased risk of prolonged labor duration and adverse neonatal outcomes in regions that are exposed to LP. Awareness of this environmental issue must be strengthened by initiating a rethinking process. Since LP is a modifiable risk factor, it is an attainable target to minimize adverse effects and health risks in the global ecosystem, including adverse outcomes in obstetrics.

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ETHICS STATEMENT

The study was conducted in accordance with the Declaration of Helsinki and the Good Clinical Practice guidelines. Approval was received by the Ethics Committee of the Medical University of Vienna (reference number 2074/17). Because of the study's retrospective character, the ethics committee waived the need for informed consent of the study subjects. All patient data were de-identified before analyses.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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