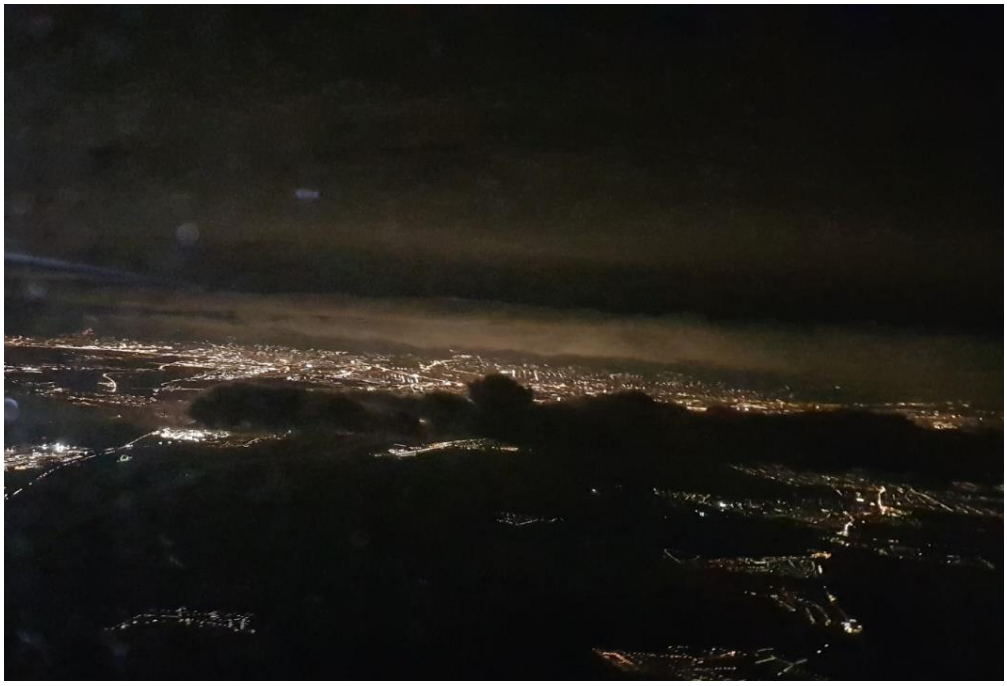

Literature study: The effects of reduced public lighting on crime, fear of crime, and road safety

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1. Introduction

1.1 Stating the problem: security versus climate and economic challenges

Public street lighting as a public service is often taken for granted. However, its impact on the nocturnal perception of public space should not be underestimated. It encourages people to get out, feel safe, and be safe. Indeed, Welsh and Farrington suggest that public lighting enhances social control, cohesion, and a feeling of community pride (Welsh & Farrington, 2008b). According to (Williams, 2008), this is due to the special meaning attached to the darkness of night in society. It is associated with changes in social norms and values, transgression, the release of social control, feasting, drinking, and pleasure. Meanwhile, the darkness of night generates unpredictability, uncertainty and, therefore, fear. Illuminating the night chases away these feelings; people feel reassured and safer (Schivelbusch, 1995).

Public lighting also has an effect on the way people experience their displacement. Elvik and colleagues state that road lighting probably makes it more pleasurable to drive and reduces feelings of insecurity in traffic (Elvik, Hoye, Vaa, & Sorensen, 2009, p. 279). Because the information needed for driving is mainly visual, enhancing visual conditions is important for safe travel: 'in the dark, the eye picks up contrast, detail and movement to a far lesser extent than in daylight…' (Elvik et al., 2009, p. 272). The huge amount of scientific literature on accidents of cars, bikes, and pedestrians points to certain situations where accidents are reduced due to good public lighting (Murray & Feng, 2016, p. 14). It has a clear effect on feelings of security while travelling.

For crime, fear of crime, and road safety, the demand for more lighting is constantly present in modern society. This is an awkward finding when confronted with the current debates on lighting interventions. The high prices and ecological effects of public lighting led recently[1] to questioning of the evidence of these systems and the criteria used. Cities and communities all over the globe have begun initiatives to switch off public lighting permanently or temporarily (certain hours at night), dimming (reducing the intensity) of light sources, or replacing them with more energy efficient LEDs in order to cut costs and the CO2 gas emissions associated with the production of electricity. In addition to these effects, specialists point out that these lighting interventions will contribute to lowering the disturbance of sleep rhythms of children and adults, and have effects on animal and plant life and lighting pollution (Haans & de Kort, 2012; Longcore & Rich, 2004; Murray & Feng, 2016, p. 14; Navara & Nelson, 2007; Peña-García, Hurtado, & Aguilar-Luzón, 2015, p. 142; Perkins et al., 2015).

While interventions in public lighting are often based on these findings, they are nonetheless confronted with strong, emotional reactions of citizens (Perkins et al., 2015, p. 7). Protest and action groups try to influence the decision makers to turn back the measures taken (Boomsma & Steg, 2014, p. 22) and can influence trust in local government (Perkins et al., 2015). People oppose to switching off public lighting fearing more crime in the dark. But research pointed out that there is nearly no relationship between the real crime situation (objective security) and the fear (subjective security) people are experiencing. The gap between objective and subjective security, called the

[1] Although it seems to be a 'new' discussion, historical research has revealed that in the period of the implementation of the first public street lighting (candles, oil lamps) in the 17th century, local authorities (for example, in Brussels) and also citizens resisted or reversed the implementation because of cost (Koslofsky, 2011, pp. 153–154).

reassurance gap, has widened since the 1990s. Crime rates are dropping since 2000 and, despite the efforts of governments to communicate this excellent news, people are hard to convince. This is arguably even more problematic in the context of projects to reduce public lighting, including turning obsolete lighting off (Blumstein & Wallman, 2000; Caneppele & Aebi, 2019; Dijk, 2013; Doran & Burgess, 2012; Eysink Smeets & Foekens, 2018; Fernández-Molina & Bartolomé Gutiérrez, 2018).

In the past, public lighting was seen as a merely technical problem to be resolved by engineers (Murray & Feng, 2016, p. 14). However, the arguments above highlight the political nature and emotional components of the discussion. These equally important but competing considerations demand a balanced approach. It is important to face the complexity of turning off or dimming public lighting because it affects different domains in society that have contradictory interests. In order to implement these interventions, an integrated approach is needed and should involve a multitude of disciplines such as economics, criminology, urban studies, engineering, and psychology.

The scheme developed by Perkins et al. (2015, p. 18) gives a good overview of the different interconnected domains when carrying out public lighting interventions that might influence health and well-being. As will be demonstrated in the presentation of the results of the impact of public lighting on crime, fear of crime, and road security, the current research most often lacks a complex approach to this question. This complex model can be used as a guideline to judge current research and has been used as inspiration for new research.

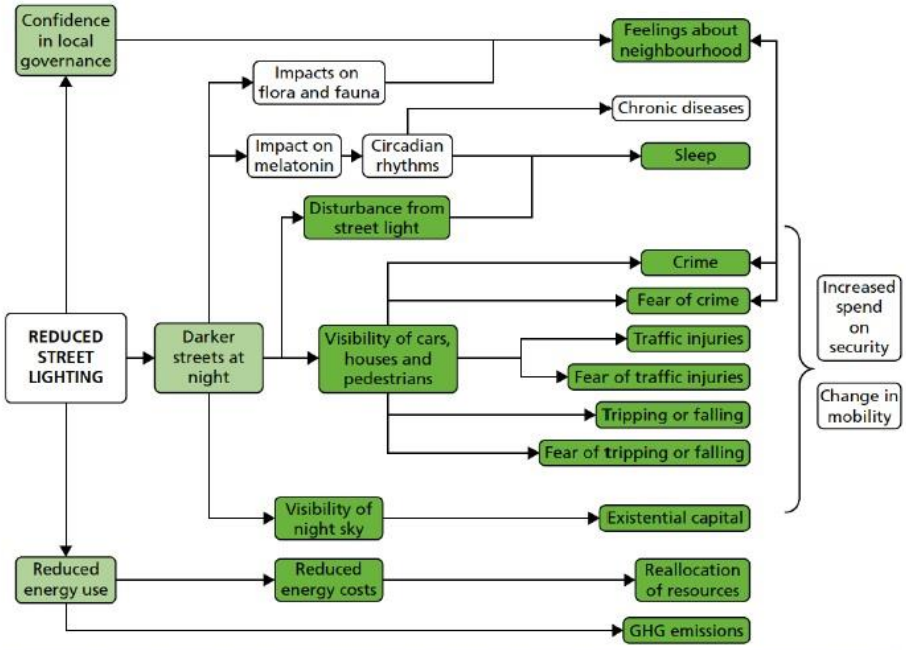

FIGURE 1 A model of potential pathways linking reductions in street lighting to health and well-being. Health outcomes are on the right, with those raised in the rapid appraisal in shaded boxes. GHG, greenhouse gases.

Figure 1: Perkins, C., Steinbach, R., Tompson, L., Green, J., Johnson, S., Grundy, C., Wilkinson, P. & Edwards, P. (2015). What is the effect of reduced street lighting on crime and road traffic injuries at night? A mixed-methods study. Public Health Research.

1.2 Purpose and outline of the study

Since the 1960s, a large volume of studies and reviews describing the impact of improved street lighting on crime, fear of crime, and road traffic accidents have been published. In the 1960s, improved street lighting had been introduced as a crime prevention strategy in light of increasing crime rates (Palmer, 2000; Wright, Heilweil, Pelletier, & Dickinson, 1974). More recently, the interest of policy makers has shifted to the reduction of street lighting and its effect on the economy and the environment. Interest in the impact of reduced street lighting on social aspects, such as crime, fear of crime, and road traffic accidents seems to have faded. This literature study intends to focus on the social effects of the current interventions by trying to find answers to its central question: what is the impact of reduced street lighting on crime, fear of crime, and road safety?

The objective of this paper is to present an overview of the most relevant literature available. Because specific research on the reduction of street lighting is scarce, we also discuss the impact of improved street lighting on these social aspects. It is important to point to the difference between the effects of lighting interventions on crime and traffic accidents, on the one hand, and on feelings of insecurity, on the other. This distinction between objective security versus subjective security is crucial. In the past, research focused mainly on crimes; the concept 'fear of crime' has only emerged since the 1960s (Cohen, 1980; Godfrey, 2018; Lee, 2013; Vanderveen, 2006). The boom of research after that contributed to a recent consensus in criminology that crime and fear of crime are nearly unrelated, both having their own dynamics and relationships. This has led to the current intense debates about the concept of 'fear of crime' itself (Farrall, Bannister, Ditton, & Gilchrist, 1997; Farrall, 2004; Farrall & Ditton, 1999; Lee, 2013) .

This literature study is structured in two parts: crime and road safety. In Part One, we first discuss the relationship between street lighting interventions and crime. We subsequently discuss the current knowledge about street lighting interventions and fear of crime. Part Two follows the same structure, but with a focus on road safety. We finish with conclusions for both parts.

2 Street lighting and crime

2.1 Evolution of the conceptions of night, public lighting, and crime

Historical research has revealed that already in early modern Europe, crime was often linked with the night and its darkness (Koslofsky, 2011; Palmer, 2000). Religion played an important role in the development of this association. On the basis of a huge variety of sources from the Christian tradition, a complex and sustained discussion of darkness and night can be found, where both serve as powerful metaphors. Darkness bears a strong, but not exclusively negative association with evil and separation from God. In the Middle Ages, users of the night were 'physically in their movements, and metaphorically […] being linked to the evil abroad in the darkness.' (Youngs & Harris, 2003). When demonologists tied witchcraft to crime in the 16th and 17th centuries, this process was further intensified (Koslofsky, 2011). Day and its light stood for God; evil and the devil were connected to darkness and the night. Evil was than associated with crimes like homicide, robberies, and fights, but also with activities such as rebellion, conspiracy, meetings of secret societies, making of poison by the use of plants etc. (Palmer, 2000). In his book on the history of the night from the 17th to the 18th century, Alain Cabantous tries to answer the question of whether the night is indeed more criminal than daytime. Although very hard to research because of a lack of accurate sources, he concludes that nighttime crime doesn't differ from daytime crime, but has

> specificities which manifest themselves as much in the criminal organization as in the acts pursued. Night gives another dimension to old crimes, because it encourages the originality of deviance because of the social and cultural context it helps to create. (own translation; Cabantous, 2009, p. 168)

In the second half of the 17th century, street lighting with candles or oil lanterns was implemented in big cities like Paris, Amsterdam, Berlin, and Copenhagen, to mention a few. They were not constantly burning; in most cities, local authorities and the public saw no need for lighting in summertime. By 1850, most of the major cities worldwide had public lighting powered by gas, which was later replaced by exterior electric lighting systems (Boyce, 2014). These developments led to an important change in perceptions of the night. As Koslofsky (2011, pp. 133–134) states:

> The new street lighting of the seventeenth century certainly was intended to promote law and order, but it also beautified a city and provided convenience and social amenity by encouraging respectable traffic on city streets after dark. Public street lighting reflected a new willingness to use the night and to reorder daily time by relaxing curfews. This lighting represents both an unprecedented concession to the growing use of city streets after dark, and a renewed attempt to regulate and secure this nocturnal sociability.

The lighting of the cities resulted in a colonizing by the elites of the courts and city of the night. The evening and night became a time for showing off, making pleasure, and consumption in the public sphere of respectable citizens. These 'illuminated' were the ones to use the night. The night workers, prostitutes, and low class people were associated with crime and were easier to detect and discipline after implementing public lighting. Providing public lighting had the specific aim of combating crime and maintaining public order, which gave rise to the 'good lamp is the best police' metaphor (Bouman, 1991; Brantingham & Brantingham, 1993).

Although the perceptions of the link between crime, the night, and darkness have evolved over time from a Christian dualistic view to a much richer and complex meaning system, the connection between public lighting and crime is still present in modern times. The role of public lighting has become a very prominent way to police the night. In the 1960s, several US local governments invested in the implementation and improvement of street lighting due to the increasing crime rates (Wright, Heilweil, Pelletier, & Dickinson, 1974). In this period, street lighting was approached as a crime prevention strategy that would deter potential offenders and encourage informal social control. Unlike the historical policy of using public lighting to police the city, which was based on the meanings given to the night, in modern times these policy measures were followed by evaluation studies because of the development of social sciences and research techniques. Initially, these research studies suffered from methodological weaknesses, but evolved to more sophisticated evaluations. The most important problems were (and still are) due to the problems of measuring crime, the lack of precise data on the exact period of crime, and a clear definition of the night. In the following section, we will give a short introduction to the problems encountered when researching the effect of public lighting on crime.

2.2 Researching the impact of public lighting on crime

2.2.1 Problem of measuring crime by means of police records

In nearly every country of the world, the source for crime numbers are formally recorded crime statistics (Carrabine, Cox, Lee, Plummer, & South, 2009). These statistics are created on the basis of the complaints and the declarations of citizens to the police, on the one hand, and the police force's own findings that are officially recorded. To enable enumeration, a standardized, legally defined category system of offences is used.

Since the establishment of these statistics, the reliability of these numbers has been largely taken for granted (Maguire & McVie, 2017, p. 165). However, research in the 1960s seriously challenged this source's acceptance as an instrument to measure trends and patterns in crime and its use to make policy. The role of the citizens and victims in the production of the numbers became clear because of growing conflictual relationships between the public and the police (Bottomley & Coleman, 1981, pp. 55–59). The resulting loss of legitimacy of the police influences the willingness to report to them and has a serious effect on crime numbers. Research on police and police culture shows the rather unimportant contribution of the police in the production of crime numbers. Police work is mainly influenced by the public; only 20% of the force's time budget is used to carry out criminal enquiries initiated by the police itself. Within this 20% of time, the police were found the be selective towards certain types of crime, persons, ethnicities, and gender (Bottomley & Coleman, 1981, pp. 53–54). Both influences of citizens and the police itself results in a 'dark figure': crime that has taken place, but is not recorded in the official statistics (Bottomley & Coleman, 1981). In a very influential article on the uses of official statistics, Kitsuse and Cirourel conclude that '…rates can be viewed as indices of organisational processes rather than as indices of the incidence of certain forms of behaviour' (Kitsuse & Cicourel, 1963, pp. 136–137).

2.2.2 Alternatives for measuring crime

Since the 1980s, these criticisms led to a search for an alternative way of measuring crime. The implementation of crime victim surveys in which respondents of a representative sample of the population were asked whether they had experienced victimization in the previous year, became a

valuable alternative source for measuring crime. Seen at the start as being complementary to the police records, this way of measuring has now become the most reliable method (Maguire & McVie, 2017, pp. 165–166). Crime victim surveys are implemented in nearly every Western country. However, in 2008, the Belgian government decided to stop this collection of data due to its high cost.

2.2.3 Measuring the effects of public lighting on crime

The evaluation studies on the effects of lighting on crime started in the 1980s when 'rising crime' (Maguire & McVie, 2017, p. 165) became a major political issue. As already mentioned, implementing public lighting in unlit situations or enhancing lighting was then seen as an important preventive policing strategy. Although aware of the criticisms of official crime statistics, these numbers were largely used in these evaluations because of a lack of alternative measurements; this is the major weakness of the older studies.

Crime is a very complex concept. Although everybody seems to know what kind of conduct should be called 'crime', research points to very little consensus when studied within a concrete social situation. It is impossible to define crime (Lanier, Henry, & Anastasia, 2014) and it has an enormous amount of possible causes (biological, psychological, rational choice, education, problematic social situations, neighbourhood, and discrimination are just some of the enormous range of theories which attempt to explain the phenomenon). Most of the studies limit the factors causing crime that should have been kept under control in order to be able to evaluate the pure effect of implementing public lighting interventions. The concept of crime includes a multitude of different types of crime which all have their own dynamics, perpetrators, victims, causes, and reactions, making comparison extremely difficult.

2.3 Results of the impact of public lighting on crime

Studies which examined the impact of improved street lighting on crime have come up with mixed results. Wright et al. (1974) evaluated a lighting project in Kansas City using crime reports and found that improved street lighting indeed led to a decrease in the prevalence of certain types of crime, particularly violent robbery and assault.

Tien, O'Donnell, Barnett, and Mirchandani (1977), in contrast, found no statistically significant effect of improved street lighting on crime after evaluating 15 street lighting projects in the USA. The authors selected street lighting projects based on five criteria: (1) the measured outcome had to be the prevalence of crime, (2) highway lighting projects were excluded because their focus is on vehicle safety instead of pedestrian safety, (3) the areas researched had to have a population of at least 25,000, (4) the projects must have been completed after 1970, (5) and the selected projects had to provide pertinent evaluation-related information. These 15 studies evaluated the implementation of public lighting in various neighbourhoods of different American cities. The authors criticized the fact that all studies involve using the uniform crime report (UCR) and call for crime incident measurements based on victim survey (Tien et al., 1977, pp. 42–43). Boyce (2014) pointed out, however, that the studies included in Tien and colleagues' review had several limitations, including inappropriate or inadequate measurements, and statistical analyses which call into question the reliability of the results.

Other studies conducted in the 1970s also draw inconclusive results and highlight some interesting limitations and points of attention. First, the crime reducing effect of improved street lighting on

property crimes could be seen as part of an overall reduction in property crimes (Krause, 1977; Lewis, 1979). When evaluating crime rates in areas where street lighting improvements were implemented, it is necessary to compare these results with crime rates of other (aggregated) areas, because crime could be decreasing on a wider scale. In that case, there is not necessarily a causal link to street lighting improvements. Second, the impact of other crime prevention strategies (e.g., CCTV, security surveys) should also be taken into account when evaluating the impact of street lighting on crime, because these can also have an impact on crime rates (Griswold, 1984). Third, it is unclear what the influence of crime displacement is on these results (Wright et al., 1974). Indeed, it is possible that by improving street lighting in certain areas offenses are relocated to other non-relit areas or to the daytime. We could not identify any study that has investigated this possible paradoxical effect of improved street lighting; thus, no conclusive statements can be made.

In the 1980s, several lighting projects were implemented by local governments. Atkins, Husain, and Storey (1991) conducted a research study on the impact of improved street lighting in London on the prevalence of crime. The authors analysed crime rates before and after improvements and compared these results with areas where no improvements had been carried out. The study concluded that:

> no evidence could be found to support the hypothesis that improved street lighting reduces reported crime. Although some areas and some crime types did show reductions in nighttime crime relative to the daytime control, the dominant overall pattern, from which the study draws its authority, was of no significant change. (p. viii)

These negative conclusions could be the result of increased reporting of crime to the police, instead of an actual increase in crime because offenses are more visible to citizens. According to Pease (1999) the study of Atkins et al. was of high academic quality, but he has one major comment nonetheless. The main assumption in the Atkins study is that improved street lighting will have an effect which is restricted to the nighttime. Pease notes that the overall crime rate in the targeted areas dropped by 15% after the reintroduction of lighting. The question remains if this drop could also be observed in the control areas. Because a retrospective analysis is not possible, this question remains unanswered. Based on a rough analysis of the data available, Pease concludes that this decrease in crime rates could not be found in the control areas; hence, the decrease in crime rates in the treated areas are significant and the result of relighting.

Painter (1996) and Painter & Farrington (1997, 1999) conducted substantial research on the impact of improved street lighting on crime, fear of crime, and use of the streets. Painter's major comment on the previously conducted studies is the limited reliability of the used police crime statistics due to the clustering of crime types and the low level of reported crimes (Boyce, 2014). Using on-street pedestrian surveys before and after relighting initiatives in the treatment areas, carried out after dark, Painter examined the impact of lighting on pedestrians' experience of particular crimes (i.e., violence against the person, vehicle crime, and harassment) in a limited area in London. She concludes that improved street lighting does have a significant preventive effect on crime. Further, she noticed a diffusion of benefits, implying that improvements in street lighting also have a positive effect on nearby non-relit streets (Painter & Farrington, 1999). For these areas, Painter found small decreases in crime. Yet, she notes that: 'most of the reductions reported relate more to threatening and disorderly incidents than to crime' (Painter, 1996, p. 197). However, the main weakness of this study is the selection of the control and treatment areas. The areas used in the Dudley Project

(Painter & Farrington, 1997) are not comparable in terms of demography (residents in the control area were on average older than in the treatment group).

In the Dudley Project, Painter & Farrington (1997) used two different data sources in order to examine the impact of improved street lighting on the level of crime in one treatment and one control area in Dudley (West Midlands, England) before and after street lighting improvements. On the one hand, Painter and Farrington conducted interviews with adult residents of the two investigated areas. These interviews showed that residents in the treatment area experienced less crime after improved street lighting compared with the control area. On the other hand, they carried out a self-reported delinquency survey among youngsters (i.e., aged 12 to 17) living in both areas, which showed a larger decrease in admitted offenses in the relit area compared with the non-relit area.

In 2002 and 2008, Farrington and Welsh conducted similar systematic reviews, including eight American and five British studies, all examining the impact of improved street lighting on crime (Farrington & Welsh, 2002; Welsh & Farrington, 2008b). Five criteria were taken into account when selecting the included studies: (1) the main intervention in the studies was improved street lighting, (2) the outcome measure was crime (mostly violent and property crimes), (3) the studies had to be of high methodological quality with measures before and after in treatment and control areas, (4) the studies involved at least one treatment and one comparable control area, and (5) the areas examined in the studies had to have at least 20 crimes in order to have sufficient statistical power to detect changes in crime. The results of the eight included American studies were mixed. Four studies reported results that confirm the impact of improved street lighting, whereas the other four found no evidence for this crime prevention effect. In fact, increases in some types of crime were observed. These conclusions could be the result of increased reporting of crime to the police instead of an increase of the actual crime, because offenses are more visible to citizens when street lighting is improved. Overall, the meta-analysis conducted by Farrington and Welsh suggested a near-significant 7% decrease in crime in the relit areas of the American studies. In contrast, the five included British studies reported more uniform conclusions. The meta-analysis showed an overall 20% significant decrease in crime in the treatment areas compared with the control areas.

Two years later, Marchant (2004, 2005) argued that the statistical claims and methods used by Farrington and Welsh were unfounded and that there is a conflict between the evidence of the different included studies and the interpretations of Farrington and Welsh. Two principal statistical errors were made in the review carried out by Welsh and Farrington. The first error observed by Marchant was the ‘unit of observation error’, by which he claims that related crimes (e.g., through repeat offending) were treated as statistically independent events, resulting in a large variability, making it uncertain what the true underlying level of crime is. The second error is the ‘regression towards the mean’ caused by comparing areas with different crime levels from the start. The treatment area had a higher crime rate than the control area, resulting in a greater increase of crime. Marchant states that, based on this review, it is not possible to conclude that improved street lighting reduces or increases the prevalence of crime. As a reaction, Farrington and Welsh (2006) stated that regression to the mean only causes a 4% decrease in crime, which is a much smaller number than the overall decrease in crime caused by improved street lighting.

To summarize, the international literature is not conclusive about the crime prevention effect of improved street lighting (Boyce, 2014; Pain, MacFarlane, Turner, & Gill, 2006; Steinbach et al., 2015).

Further, it is very difficult to compare the results of the different studies for three main reasons. First, the different studies discussed here use a different operationalization of 'crime' and a general accepted definition of the concept is lacking. Second, the studies examined different areas with different socioeconomic characteristics with different crime rates. Third, the different studies examined different crime types and used different clusters of crimes.

Ramsay and Newton (1991) stated:

> Better lighting by itself has very little effect on crime. There are some limited local 'blackspots' where improved street lighting may have a modest impact on crime and perhaps a larger one on incivilities. Also, in conjunction with other measures, better lighting may help to improve an area. Indirectly, this may conceivably assist in reducing crime – although such an outcome is not guaranteed. There is no scope for reducing crime on any broad basis simply by investing in better street lighting. (p. 24)

Whereas the results of research on the impact of improved street lighting is inconclusive, research on the reduction of street lighting is almost non-existent. In 2015, Perkins et al. investigated the impact of four street lighting adaptation strategies on crime by analysing geographically coded police data in England and Wales. The four reduction strategies studied were: permanent switch-off, part-night switch-off, dimming, and replacing traditional lamps with more energy efficient LEDs (Steinbach et al., 2015). The study suggests that reduced street lighting has no significant increasing effect on crime rates. According to their results, permanent and part-night switch-off initiatives were not associated with an increase in crime. Dimming the street lights and replacing the lamps with LEDs were even associated with a small reduction in crime, although estimates were imprecise. Although this study demonstrates that reductions in street lighting do not result in increased crime rates, it has certain limitations in terms of generalizability; thus, results must be interpreted with caution. First, the results are specific to the context of England and Wales and, therefore, cannot be generalized to other countries. Second, there are only a small number of areas that implemented a permanent switch-off; thus, results concerning this reduction strategy are imprecise. Third, the analysis is based on police data, which are affected by the willingness to report offenses by the public; hence, not all offenses are taken into account (Bottomley & Coleman, 1981; Skogan, 1975). Fourth, the confounding effect of other preventive measures (e.g., CCTV, improved road markings) in areas with improved street lighting remains unclear. It is important to consider the impact of improved public lighting together with the implementation of other crime prevention initiatives. Finally, it is not possible to draw any conclusions about the impact of street lighting reductions on crime based on only one study. Further research on this topic is therefore necessary. It is generally expected that reducing public lighting will result in increased crime rates, but we did not find any research to back this statement.

3 Street lighting and fear of crime

3.1 The definition of fear of crime

Fear of crime is a broad concept and a widely accepted definition of the concept is lacking due to the fact that it comprises a wide assortment of sub-constructs with a large variety in the sense of risk, concern, anxiety, worry, and fear. For that reason, measuring fear of crime is challenging. According to Ferraro and LaGrange (1987), fear of crime is a perception that is solely based on subjective interpretations of the objective risk and results in physical and psychological reactions, such as a high heart rate and isolation. Different factors have an influence on the occurrence of fear of crime, such as biological, psychological, and societal factors. In an era that is characterized by globalization and localization, citizens experience high levels of uncertainty and vulnerability, which could result in fear of the 'unknown'. Fear of crime, thus, has an uncomfortable effect on people and should not be overlooked.

The concept of fear of crime is associated with three types of paradoxes (Ceccato, 2012; Doran & Burgess, 2012; Innes, 2017). First, fear of crime is not linked to the objective prevalence of crime. Although we can observe a worldwide decrease in crime, the experienced level of fear of crime seems to remain relatively stable (Eysink Smeets & Foekens, 2018). Second, there is no causality between actual experienced victimization and fear of crime. Fear of crime is mostly created by stories from other people's experiences with and stories about crime and victimization, which could lead to an overestimation of the least frequent crimes and an underestimation of the most frequent crimes by citizens (Innes, 2017; Slovic, 2000). Third, the implementation of crime prevention measures can have the paradoxical effect of increasing feelings of unsafety and fear due to the increased awareness of risk (Innes, 2017).

3.2 Measuring fear of crime

Fear of crime is often measured by examining attitudinal and behavioural changes of citizens, which results in a very complex analysis and statistical interpretation (Atkins et al., 1991). Surveys are influenced by the type of questions asked and the phrasing of these questions. For example, hypothetical questions are generally used in surveys to examine behavioural and attitudinal changes and reactions, although these kinds of questions make it difficult to value the results because respondents were not actually in the described situation (Ditton, 2000; Ramsay & Newton, 1991). Therefore, it is important to keep possible bias in these responses in mind, such as interpretation bias.

When considering fear of crime, visibility (i.e., being able to see what is going on in the immediate surroundings) is one of the key aspects, together with 'eyes on the street' or natural surveillance. Different characteristics of the environment and public lighting have an impact on the feelings of safety in public places. For citizens, high levels of prospect (open view), low levels of concealment (few hiding opportunities for potential offenders), and low levels of entrapment (possibility of escape) are crucial elements in order to assess the situation and to feel safe in public places (Dastgheib, 2018; Fisher & Nasar, 1992). Other aspects, such as facial recognition, glare, and light source colour play an important role in the assessment of street lighting by citizens in relation to fear of crime (Boyce, 2014).

Two important variables which influence experiences of fear of crime are gender and age, with women and the elderly experiencing higher levels of fear of crime than men and young people, especially in the dark (Foster, Giles-Corti, & Knuiman, 2010; Koskela & Pain, 2000). Different studies report on the positive effect of improved street lighting on experienced fear of crime for these vulnerable groups (Atkins et al., 1991; Herbert & Davidson, 1994; Ramsay & Newton, 1991). There are several possible explanations for the difference between men and women. First, it is assumed that women are more subjected to stories told in the media and by others about their vulnerability and risk for (sexual) crimes (Koskela & Pain, 2000; Valentine, 1989). Second, some authors suggest that there is a tendency towards over-reporting by women and under-reporting by men about their feelings of unsafety and fear (Innes, 2017; Sutton & Farrall, 2005).

3.3 The effect of implementing public lighting on fear of crime

Whereas the results of research on the impact of improved street lighting on crime are inconclusive and those for fear of crime are more consensual, research on the consequences of the *reductions* in street lighting on crime and fear of crime is almost non-existent. There is evidence that improved street lighting does reduce fear of crime (Atkins et al., 1991; Kim & Park, 2017; Painter, 1996; Tien et al., 1977).

Fear as a result of reduced street lighting does not exclusively mean fear of crime. Citizens also fear tripping, physical injuries, and traffic accidents due to poor lighting (Pain, 2000). The study by Perkins et al. (2015) focused on road safety, fear of crime, mobility, and seeing the night sky. They found that citizens expressed very strong and polarized views on public fora which emphasized the potential negative effects of reduced street lighting on their health and wellbeing, with deep concerns for their personal safety when walking at night. However, during the group interviews conducted as part of their research, Perkins et al. noticed that the opinions were more moderate; the emphasis was more on the possible positive effects of street lighting reductions, such as reducing carbon emissions and being able to see the stars at night. What was interesting during the individual in-depth interviews conducted by Perkins et al. was the low degree of awareness among citizens of the reductions in street lighting in the local areas of the interviewees. Several interviewees mentioned that the changes in street lighting went unnoticed. Yet, in these interviews, respondents expressed their concerns about personal safety and mobility. According to several respondents, mostly women, fear of the dark affects their mobility, because they are less likely to go out in the dark by foot and are more tempted to use a car or take a taxi. This fear of the dark is also strongly linked to unfamiliarity with places and situations. Finally, the household surveys carried out in the Perkins et al. study did not report any significant association between levels of fear of crime and reduced street lighting, although it is possible that fear of the dark affects the wellbeing of citizens in other ways (Green, Perkins, Steinbach, & Edwards, 2015).

3.4 Potential impact of *reduced* street lighting on (fear of) crime

Because empirical research on the impact of reduced street lighting on crime and fear of crime is still scarce, this paper explores the potential and expected impact based on a critical examination of the international literature on improved street lighting. Reducing street lighting is treated in the literature and viewed by different actors as having the reverse effect of improving street lighting. This presupposition can be questioned. The social context is much more complex and different elements have an unexpected and confounding effect on both the prevalence of crime and fear of

crime, which makes it difficult to predict the impact of reduced street lighting on these social aspects.

Based on the above results, two hypotheses can be detected in the literature which explain the assumed crime prevention effect of improved street lighting. The first hypothesis assumes that improved street lighting results in increased visibility, which could deter potential offenders by increasing the possibility of detecting crimes and identifying offenders (Atkins et al., 1991; Tien et al., 1977; Welsh & Farrington, 2008a; Wright et al., 1974). According to the situational crime prevention theories and the first generation of Crime Prevention Through Environmental Design (CPTED), it is possible to prevent crime by manipulating the urban context and to influence the behaviour and decision-making processes of offenders by doing so. Based on this hypothesis on improved street lighting and its impact on crime, it can be assumed that reducing street lighting has the reverse effect, which is an increase in crime rates. However, this premise can be questioned. *Rational choice theories* have been largely criticized. First, as mentioned by Wortley (2010), situational crime prevention (as an example of the rational choice approach) focuses almost exclusively on target-hardening, which neglects the complexity of the social context. Too little attention is paid to interacting factors of crime, such as poverty, inequality, discrimination, poor parenting, and so on (Wortley, 2010). Second, attention must be paid to the possible crime displacement to nearby non-relit areas (Wright et al., 1974). This displacement of crime is a paradoxical effect of the improvement of street lighting and could result in increased crime rates in nearby areas. Further, increases in crime rates in a certain potentially unlit area, does not necessarily mean an overall increase in crime rates. Third, in-depth research is necessary into the decision-making processes of offenders, such as burglars (Ramsay & Newton, 1991). In the study of Bennett and Wright (1984), for example, no mention was made of the lighting conditions affecting the interviewed burglars when choosing their targets (Ramsay & Newton, 1991).

A second widespread hypothesis relates to the increased social cohesion caused by improved street lighting. This hypothesis assumes that improving street lighting will result in increased visibility, which leads to an increased use of public places by citizens during darkness. As a consequence, more people present at public places leads to more natural surveillance, which results in less crime and citizens feelings safer(Jacobs, 1961/1992, pp. 56–57). In addition, improved street lighting can be seen as a symbol of positive attention of local governments, promoting certain neighbourhoods and combating the degradation of these areas. Social cohesion leads to community pride and informal social control of one's own neighbourhood (Boyce, 2014; Farrington & Welsh, 2004). When considering a reduction of street lighting, it is generally assumed by citizens and other actors that citizens will experience a higher level of fear of crime in dark public places. In this respect, attention must be paid to confounding variables, such as the familiarity with the place and the reputation of a certain neighbourhood. Therefore, no conclusive prediction can be made, based on this hypothesis, about the impact of reduced street lighting on crime and fear of crime.

3.5 Discussion and conclusion

The results of this literature review suggest that there are mixed outcomes for the crime prevention effect of improved street lighting on crime and that there is no immediate link between reduced street lighting and an increase in the prevalence of crime. Conversely, in the literature, more consensus could be found with regard to the impact of street lighting on fear of crime, although no strong evidence could be found. According to the international literature, improving street lighting

does reduce fear of crime amongst citizens, especially among women and the elderly – two groups that experience the highest levels of fear of crime. The results of the study of Perkins et al. (2015) suggest that reduced street lighting does make citizens aware of possible risks and negative effects, but also recognize its positive consequences, such as the environmental benefits. Although citizens do recognize the possible benefits, they nevertheless report some degree of behavioural changes during nighttime, such as their mobility at night.

Although reducing street lighting may cause a reduction in carbon emissions and financial costs, the perception of unsafety by citizens cannot be overlooked. On the one hand, local, national and international authorities are taking action against the environmental changes that we face, and efforts are being made to decrease carbon emissions, light pollution, etc., by reducing street lighting as one example. On the other hand, authorities are investing in crime prevention initiatives in order to protect their citizens against different types of crimes, including property crimes and violent crimes. Crime prevention measures often have the paradoxical effect of reigniting fear of crime due to the increased awareness of risks. Reducing street lighting is seen as a measure that increases feelings of unsafety amongst citizens, and thus may not simply be overruled by the environmental and financial gains. Environmental consciousness and fearlessness of citizens might be not mutually exclusive, but authorities that decide to reduce street lighting must be aware of these conflicting values and must be scientifically informed during their decision-making process.

The findings of this paper are subject to at least three limitations. First, we conducted a literature review in order to offer a summary of the most relevant findings related to improvements of street lighting and crime and fear of crime. No systematic review or meta-analysis was carried out; thus, the conclusions made in this paper should be interpreted carefully. Second, only a limited series of street lighting adaptation regimes were reviewed, with restricted attention to other, ‘smart’ alternatives, such as street lighting which illuminates when a person passes by. Third, it remains unclear from the reviewed studies what the influence is of other crime prevention initiatives that exist alongside street lighting. It is a challenge to measure the impact of interventions that have the objective of preventing certain behaviours or emotions. For that reason, the impact of improved and reduced street lighting must be seen in its interaction with other crime prevention initiatives.

Based on the international literature, it is not possible to draw clear conclusions about or to make any predictions about the effect of improved or reduced street lighting on the prevalence of crime and fear of crime amongst citizens because crime and fear of crime are two concepts that are embedded in a complex reality that is difficult to measure and predict. More research on the topic is necessary, with special attention to the impact of reduced street lighting on fear of crime by comparing treatment and control areas that are similar in terms of socio-demographic characteristics and official crime rates because this would increase the reliability of the study. It is important that future studies are clear in their use of the concepts ‘crime’ and ‘fear of crime’ because both lack a widely accepted definition.

4 Street lighting and traffic

4.1 Methodological problems and choices for this research

4.1.1 Evolution of the complexity of the research

> During the 1950s and 1960s studies began to be conducted to assess the role that street lighting could play in improving the safety of the ever busier and more dangerous roads of motorised nations. The International Commission on Illumination (CIE) argued in 1960 that lighting reduced crashes on urban traffic routes (original report updated in 1992 (CIE 1992)), and work during the following decade suggested the magnitude of this reduction to be approximately 30%. Since then the provision of street lighting has generally been justified on the basis of cost savings expected from the increased service and safety levels (MacAuley 1989). (Beyer & Ker, 2010, p. 3)

Research on the effect street lighting on accidents started in the 1950s and 1960s because of the growing amount of car accidents due to the mass production of cars and their democratic prices. The questions asked concentrated on the cost of lighting installations versus the cost of accidents. Studies revealed that reducing road lighting standards would not save money. Early studies calculated the costs of nighttime accidents to be about three times the annual cost of the lighting. (MacAuley, 1989, cited in Beyer & Ker, 2010, p. 3). In later research, attempts to calculate the economic impact of traffic accidents taking into account all possible costs estimated a total economic loss of about 2% of GDP in EU countries (Plainis, 2006). A recent EU Transport White Paper recognizes that traffic will continue to increase in the future and social costs will rise to €60 billion higher by 2050. Recent estimates of the benefits to society, if no traffic accident had happened since 2010, are in the order of €105 billion (Jost, Allsop, Steriu, & Popolizio, 2011).

The research question of the first studies was fairly uncomplicated. Although factors such as road type were taken into account, the studies concentrated on the causal relationship of street lighting to (mainly car) accidents. This rather one-sided, linear approach was challenged by critiques (Assum, Bjørnskau, Fosser, & Sagberg, 1999; Theofilatos & Yannis, 2014). Scientists questioned the lack of a strong theoretical basis for road evaluation research (Elvik, 2004) and identified risk factors that would probably affect the relationship. Assum et al. (1999) found, for example, that older drivers avoid driving in darkness and will only engage in driving at night when lighting is installed. Old age, normally seen as a risk factor, influences the results of darkness in a positive way because of these drivers' absence on the road. However, when disaggregating the data in categories such as type of road user, location, and crash type, a problem of small numbers arises (Focant & Martensen, 2016, p. 4).

More complex research questions and analytic models were developed, driven by enhanced possibilities generated by computerization, the availability of a variety of datasets (Theofilatos & Yannis, 2014, p. 244), and innovations in statistical approaches. These involve a large amount of risk factors influencing the relationship between street lighting and traffic security. However, these methodologically very interesting developments were accompanied by significant problems in terms of comparing results of different studies. Not every research study implies the same risk factors in the models used and the involved factors can be operationalized differently. Elvik et al. state that 'It

must be therefore concluded that studies allowing well-controlled estimates of the contributions of various risk factors to injuries in road accidents do not exist.' (Elvik et al., 2009, p. 75).

4.1.2 Problems of measuring road safety

When wanting to study the effect of street lighting on road safety, the definition, operationalization, and measurement of 'road safety' become central. Studying the definitions used in a wide range of publications makes clear that a generally accepted definition is lacking. This concept embodies a multitude of different meanings. It is not surprising that, over the years and throughout different studies, discussions on the content of 'road safety' have led to different operationalizations. These choices in definition and operationalization made it very difficult to compare research results.

Hauer and Hakkert (1988) conducted a meta-study in 1988 of studies using 'reported motor vehicle accidents' as an indicator for 'road safety'. They concluded that 'reported motor vehicle accidents' as a proxy is unreliable due to large underreporting, diversity in methods of study, and genuine differences associated with time and place. They found that the severity of the accident largely influences its reporting. Fatal accidents are reported more often than serious injuries, which in turn are better reported than minor injuries (Hauer & Hakkert, 1988, pp. 2–3). This was confirmed by a meta-analysis more than 10 years later studying the reporting level for injury accidents in official road accident statistics for 13 countries by Elvik & Mysen (1999). They reported difficulties in comparing the level of accidents in different countries because of a lack of clear definition, variations in definition, and the use of varying data sources. A complex analysis of the provided data led to the findings that:

> the reporting level for these injuries ranged from 21 to 88 percent, with a weighted mean of 39 percent. The mean reporting level for the countries included in this study is 95 percent for fatal injuries according to the 30-day rule, 70 percent for serious injuries (admitted to hospital), 25 percent for slight injuries (treated as outpatient), and 10 percent for very slight injuries (treated outside hospitals). ...Reporting level tends to be highest for car occupants and lowest for cyclists. This pattern is consistent across countries. The reporting of single-vehicle bicycle accidents is particularly low—below 10 percent in all countries studied. (Elvik & Mysen, 1999, p. 139)

They conclude that working with recorded numbers of accidents is incomplete at all levels of injury severity.

Solutions for this problem are found by combining police numbers with those from hospitals, insurance records, other company records, and self-reported accidents. None of these sources are complete on their own. Combining them and determining their overlap would be the most appropriate way of collecting data. In 2009, Elvik et al. reported that up to then this had never been done. Virtually all studies they researched compared just two sources of data: police and hospital records (Elvik et al., 2009, pp. 50–54; Elvik & Mysen, 1999, p. 139) .

4.1.3 Measuring effects

In conclusion, when reporting the effect of lighting on traffic security, studies use comparisons. The way these comparisons are carried out has a large impact on the quality and validity of the studies and the possibility of generalization. We will not enter into the methodological problems of

regression to the mean, the use of the appropriate statistical methods, etc.; rather, we will give an overview of the used comparisons, their strengths, and weaknesses.

There are three commonly used methods: with/without comparisons using cross sectional or longitudinal statistical models or a with/without comparison, observational before–after studies, and case-control epidemiological studies (Sasidharan & Donnell, 2013).

A. Way of comparing

With/without comparison. Random sampling of the areas under study ensures that systematic bias is avoided. The areas involved should have exactly the same characteristics with the only difference being the lighting intervention. Possible characteristics for matching the areas could be: 'location of the roads (e.g. residential or rural), volume of traffic and speed' (Beyer & Ker, 2010, p. 4). Changes in the traffic security can then be ascribed to the lighting intervention under the condition of controlling changes in all other risk factors (Sasidharan & Donnell, 2013). It is clear that these methodological requirements might be possible in a laboratory situation. Because of the complexity of our society, these conditions are rarely met. Even if possible, the lack of a sample frame renders random sampling often problematic (Elvik et al., 2009, pp. 100–101). When no random sampling is used, the results of the study can, strictly speaking, not been generalized to other sites (Fiona R Beyer & Ker, 2009a; Elvik et al., 2009, p. 147).

Before–after studies. There are some studies available where the situation on a site before the intervention is compared with the situation after implementing or upgrading lighting (Fiona R Beyer & Ker, 2010, p. 4). These studies avoid bias better than the former because, in addition to the central variable, a range of other factors can be measured and controlled by using appropriate statistical techniques like regression models. A limitation of this method is that the comparison has to be done for several years to correct for regression to the mean (Sasidharan & Donnell, 2013).

Epidemiological case-control studies. An alternative way of comparing used in many studies is to take the daytime crash statistics for the intervention area as control data. This design is based on the presupposition that street lighting has no effect on traffic security in daytime. The numbers of crashes in daytime are then used as a perfectly matched control for those at nighttime with a lighting intervention (Beyer & Ker, 2010, p. 4).

B. Length of observations

Beyer & Ker (2009) point to the importance of the time period of the data collection:

> The longer the time period the more likely that short-term changes will be less significant. For an intervention like street lighting, it is better for data to have been collected over at least a year to account for seasonal adjustments in daylight at different latitudes. (p.10)

C. Sample size

In addition to the way results are compared, the size of the sample, determined by the size of the site and the accidents, has an effect on the results. Too small samples are problematic in many studies (Elvik et al., 2009, p. 147). Most studies on traffic safety do not simply evaluate the effects of one measure, such as the presence of lighting. As explained in the first section, it is important to be able to distinguish the net effect of each measure on safety, but also to understand the combined

effects of all the measures. As Elvik (2009, pp. 19–20) explains, it is not obvious that the effect of a lighting intervention will be the same when implemented together with all the others, compared with implementation on its own.

4.1.4 Methodological choices for the literature study

The previous section on methodology gave a short overview of the methodological issues when researching the effect of lighting on traffic security. To achieve a reliable evaluation, the methodology used is of utmost importance because such shortcomings can strongly affect the results of studies (Elvik et al., 2009, p. 100).

Next to individual studies on the relationship between lighting interventions on traffic security, a range of systematic reviews[2] and meta-analyses[3] have been conducted. A systematic review can contain a meta-analysis. It is a quantified synthesis of results by using the weighted mean estimate of effect (Elvik et al., 2009, p. 20). Working with these estimates is another solution for the poor quality of official accident records. Instead 'the expected number of accidents'[4] is used as a proxy for traffic security. This 'expected number of accidents' has to be estimated; these are based on data collected on a large number of units such as junctions, road types, types of vehicles, etc.

> that will vary with respect to the characteristics that are believed to influence the expected number of accidents. By means of statistical analysis, we then try to determine the amount of systematic variation in accident counts and identify factors that produce it. (Elvik et al., 2009, p. 83)

The estimates are expressed in odds ratios[5]. In 2009, Johansson et al. proposed a new method for assessing the risk of accidents associated with darkness. They used a more complex odds ratio[6] that tries to control for seasonal variation and involves the hour of the accident.

In this part of the literature study, we will rely on the existing systematic reviews and meta-analyses. They guarantee the quality of the research used and are, in addition, able to estimate within confidence intervals for each summary effect in the case of meta-analyses (Elvik et al., 2009, p. 21). These can include both older and newer studies, making it possible to confront conclusions; refine, confirm, and falsify results; and cumulate knowledge (Elvik et al., 2009, p. 16).

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[2] A systematic review 'attempts to collate all empirical evidence that fits pre-specified eligibility criteria in order to answer a specific research question. It uses explicit, systematic methods that are selected with a view to minimizing bias, thus providing more reliable findings from which conclusions can be drawn and decisions made' (Green et al., 2008) .

[3] 'Meta-analysis is the use of statistical methods to summarize the results of independent studies. By combining information from all relevant studies, meta-analyses can provide more precise estimates of the effect…. They also facilitate investigations of the consistency of evidence across studies, and the exploitation of differences across studies.' (Green et al., 2008)

[4] The expected number of accidents 'is the number of accidents (e.g. on a specific road or in a specific junction) that one can expect per time unit, based on known properties of the road or junction. It is the average number of accidents that will occur per unit of time in the long run, given that exposure and all risk factors remain constant' (Elvik et al., 2009, p. 81)

[5] 'A weighted mean estimate of effect is calculated on the basis of the estimates of effect found in the studies that have been retrieved. Combining logarithms of ORs yields an unbiased estimate of the weighted mean effect of a set of studies.' (Elvik et al., 2009, p. 21; Johansson, Wanvik, & Elvik, 2009, pp. 810–811; Sullivan & Flannagan, 2002, 2007)

[6] '…defined as follows: [(number of accidents in darkness in a given hour of the day)/(number of accidents in daylight in the same hour of the day)]/[(number of accidents in a given comparison hour when the case hour is dark)/(number of accidents in a given comparison hour when the case hour is in daylight)]' (Johansson et al., 2009, p. 809).

4.2 Effects of implementing, dimming, and cutting public lighting on traffic security

The huge amount of literature on the role of public lighting concentrates on lighting unlit roads. Even when, today, lots of initiatives exist to cut lighting or dim it, we only find a small proportion of research on the effects of these approaches. First, we will discuss lighting unlit roads. Cutting existing public lighting is treated in the literature as having the reverse effect of lighting unlit roads. This presupposition can, in our opinion, be questioned.

4.2.1 The effect of lighting unlit roads on traffic security: results

The question of whether lighting formerly unlit roads will affect traffic accidents has an long tradition; the first study found by Elvik (2009) was from 1948. At the start of this research tradition, the questions and methodology used were relatively simple. In a critical review of 29 publications, Vincent concluded in 1983 'that all of the studies claiming statistically significant accident reductions resulting from road lighting are deficient in any or all of: site selection, types of comparison, accident measures, measures of lighting and statistical evaluation techniques.' (cited in Elvik, 1995, p. 112).

Donnell, Porter, and Shankar (2010) detail a summary of results of 62 studies on the effects of lighting and accidents carried out by the International Commission on Illumination from 15 countries. The studies included only before–after analyses involving the installation or upgrading of lighting along roadways. Looking at the overall results, 58% of them showed an average reduction of nighttime accidents of at least 30% due to lighting interventions. At rural intersections a reduction of 26% to 44% in accidents was measured. On the bases of this study, the international commission expects a 38% reduction in fatalities and injury due to lighting interventions at intersections (Donnell et al., 2010, pp. 1436–1437).

A quantitative meta-analysis of 37 studies[7] in 11 different countries on the effect of public lighting on road safety from 1948 to 1989 by Elvik in 1995 recognizes the methodological problems. However, Elvik claims it is possible to use the selected studies to estimate the mean safety effects by selecting the most valid results and using a weighted mean. Restricted to the situation where formerly unlit roads were subsequently illuminated and the effects studied by means of before-and-after studies, comparative studies[8] (case-control studies), and simple case-control studies,[9] he concludes that 'Nighttime fatal accidents are reduced by about 65 percent, nighttime injury accidents are reduced by about 30 percent, and nighttime property-damage-only accidents are reduced by about 15 percent.' This effect remained constant over time and between the different countries studied. It was the same for urban, rural, and freeways, even when controlling for accident severity (Elvik, 1995, p. 119). From the studies that involved accidents with pedestrians, it can be concluded that road lighting has a greater effect on pedestrian accidents than on any other type of road users. Elvik found a greater effect at intersections than at other locations (Elvik, 1995, p. 120). This was confirmed by Bruneau and Morin who found that lighting intersections in rural areas reduces the accident rate in darkness between 29% and 39%, depending on the type of implemented lighting (Bruneau & Morin, 2005, p. 122). Donnell et al. found similar results, but with much smaller percentages; lighting would

[7] All these studies were included again in this 2009 meta-study.

[8] One or more lit locations constituted the cases, whereas one or more unlit locations constituted the controls.

[9] Cases and controls are compared directly with no control for confounding variables

lead to a reduction of 3%. According to them, high percentages in older studies were caused by a lack of controlling for other safety influence features (Donnell et al., 2010, p. 1443).

Elvik is aware of the methodological weaknesses of the used studies but evaluates his results as robust. Contradictory results were due to inappropriate statistical techniques and could be the result of biased sampling. Future research should, in his opinion, pay more attention to correct sampling and rely on more complex statistical techniques such as multivariate analyses (Elvik, 1995, p. 120).

Beyer and Ker (2009) conducted a meta-analysis on 17 controlled before–after studies[10] that covered a time period from 1948 to 2006. From the 17 studies involved, 15 were also included in the study of Elvik. However, their selection criteria were more severe than the ones used by Elvik. The overall conclusion is in line with the results of Elvik: 'This systematic review and meta-analysis of controlled before–after studies suggests that street lighting may prevent road traffic crashes, injuries and fatalities.' (Beyer & Ker, 2009, p. 9)

In 2009, Elvik et al. published an update of his former study of 1995 which examined more than 70 publications from 1948 to 2008. Overall, the authors concluded:

> …there is hardly any doubt that traffic volume is the single most important factor that influences the number of road accidents. This is likely to be the case all over the world, although of course the precise shape of the relationship between traffic volume and the number of accidents will vary from place to place. (Elvik 2009, 56–57)

On the basis of 47 publications[11] studying the lighting of formerly unlit roads, the authors found statistically significant changes in fatal accidents were reduced by 60%, and injury and property damage were reduced by 15% due to lighting. However, due to methodological weakness of the studies, it is possible that these effects were caused by other factors than lighting. The results point at a relationship between road lighting and the seriousness of accidents. The effect of lighting is very prominent for pedestrian accidents. It affects accidents at junctions and has more effect in urban areas. This was illustrated by the effect on mortal accidents which are higher in rural areas. They found no effects on motorways except at junctions (Elvik et al., 2009, p. 275).

The question was reversed by the study of Johansson, Wanvik, and Elvik (2009), based on three data sets of road accidents from Norway, the Netherlands, and Sweden. They studied the risk of accidents in darkness and used a new method. The results of Elvik et al. (2009) on the relationship of the

[10] Box 1972; Box 1989; Christie 1958; Cornwell 1972; Huber 1968; Isebrands 2006; Lamm 1985; Lipinski 1976; Pegrum 1972a; Pegrum 1972b; Richards 1981; Sabey 1973; Seburn 1948; Tamburri 1968; Tanner 1958; TVA 1969; Walker 1976.

[11] Seburn (1948) (USA); Tanner and Christie (1955) (Great Britain); Borel (1958) (Switzerland); Tanner (1958) (Great Britain); Taragin and Rudy (1960) (USA); Billion and Parsons (1962) (USA); Christie (1962) (Great Britain); Ives (1962) (USA); Transportforskningskommissionen (1965) (Sweden); Christie (1966) (Great Britain); Institute of Traffic Engineers (1966) (USA); Tamburri, Hammer, Glennon and Lew (1968) (USA); Cleveland (1969) (USA); Tennessee Valley Authority (1969) (USA); Walthert, Mäder and Hehlen (1970) (Switzerland); Fisher (1971) (Australia); Jørgensen and Rabani (1971) (Denmark); Box (1972) (USA); Cornwell and Mackay (1972) (Great Britain); Pegrum (1972) (Australia); Sabey and Johnson (1973) (Great Britain); Austin (1976) (Great Britain); Lipinski and Wortman (1976) (USA); Walker and Roberts (1976) (USA); Andersen (1977) (Denmark); Fisher (1977) (Australia); Ketvirtis (1977) (Japan, USA); National Board of Public Roads and Waterways (1978) (Finland); Polus and Katz (1978) (Israel); Jørgensen (1980) (Denmark); Brüde and Larsson (1981) (Sweden); Schwab, Walton, Mounce and Rosenbaum (1982) (several countries); Brüde and Larsson (1985) (Sweden); Lamm, Klöckner and Choueiri (1985) (Germany); Brüde and Larsson (1986) (Sweden); Cobb (1987) (Great Britain); Box (1989) (USA); Griffith (1994) (USA); Jacoby and Pollard (1995) (GBR); Hogema and Van der Horst (1998) (NL); Painter (1998) (Great Britain); Preston and Schoenecker (1999) (USA); Bauer and Harwood (2000) (USA); Isebrands et al. (2004) (USA); Mäkelä and Kärki (2004) (Finland); Wanvik (2007a) (Norway); Wanvik (2007b) (Netherlands); Wanvik (2007c) (Sweden); Helai, Chor and Haque (2008) (Singapore).

seriousness of the accident and lighting were confirmed. They concluded that the mean effect of road lighting on injury accidents during the hours of darkness is -50% and that the effect during hours of twilight is about two-thirds of the calculated effect during hours of darkness. The risks of fatal accidents increased from 1.1 to 5.9 and from 1.0 to 2.6 for injury accidents in darkness. The above-mentioned risks vary depending on the presence of other risk factors, such as winter versus summer, slippery versus non-slippery road, etc. (Johansson, Wanvik, & Elvik, 2009, p. 813). When differentiating between road users, the authors found that the risk of car accidents in urban areas showed no increase in risk. In rural areas, a modest increase in risk was noticed, but with high variations. When analysing car accidents in rural and urban areas together, the overall risk in darkness did not increase. The safety effects of road lighting on pedestrian, cyclist, and moped accidents are significantly larger than on automobiles and motorcycle accidents. Pedestrians' risks in darkness (relative risk from 1.2 to 7.4) increase more than other types of road users (relative risk range from 0.7 to 4.6). In urban areas, their risk is twice as high in darkness than in daytime. In rural areas, the estimations are highly variable. Johansson et al. (2009) state that this suggests a slightly increased risk in rural areas over urban areas. Cyclists have similar estimates to pedestrians. Their risk is higher in the darkness of urban areas. In rural areas, high variety is found. When both areas are combined, their risks in the darkness increase by 55%.

On average, they found a risk increase in darkness in urban areas of 30% and in rural areas of 50%. In conclusion, the authors state that darkness in urban and rural areas increase accident risks more for pedestrians, cyclists, and motorcyclists than for car occupants. The risks increased more in rural areas than in urban areas for all groups of road users. However, the variation is higher in rural than in urban areas (Johansson et al., 2009, pp. 813–814).

Focant & Martensen undertook a meta-study in 2016 of five research studies[12] focusing on unlit roads and the related consequences. They concluded that the effect of darkness is strongest for pedestrians (depending on the study, a risk of two to four times higher than in daytime) who have a higher risk than powered two-wheelers. The enhanced risk for this last group is only found in urban areas. For cars, they did not find significant differences in crash risk between daytime and in the darkness. Only two studies researched the severity of crashes. Both of them found more serious injuries in darkness than in daytime, but the opposite was found for minor injuries. They concluded that darkness increases crash severity (Focant & Martensen, 2016, p. 8).

4.2.2 The effect of improving existing lighting on traffic security: results

Elvik et al. (2009) studied 25 publications[13] evaluating the effect on accidents of improving existing lighting. Doubling the existing lighting has nearly no effect on traffic security. Increasing lighting between two to five times the original levels lowers accidents at darkness by 10%. Increasing the

[12] Gaca & Kiec, 2013; Gray, Quddus, & Evans, 2008; Johansson et al., 2009; Michalaki, Quddus, Pitfield, & Huetson, 2015; Olszewski, Szagała, Wolański, & Zielińska, 2015.

[13] Seburn (1948) (USA); Tanner and Christie (1955) (Great Britain); Wyatt and Lozano (1957) (USA); Tanner (1958) (Great Britain); Turner (1962) (Australia); Christie (1966) (Great Britain); Sielski (1967) (USA); Huber and Tracy (1968) (USA); Tamburri, Hammer, Glennon and Lew (1968) (USA) ; Box (1972a) (USA) ; Box (1972b) (USA) ; Box (1976) (USA); Friis, Jørgensen and Schiøtz (1976) (Denmark); Andersen (1977) (Denmark); Fisher (1977) (Australia); Richards (1981) (USA); Lamm, Klöckner and Choueiri (1985) (Germany); Ludvigsen and Sørensen (1985) (Denmark); Foyster and Thompson (1986) (Great Britain); Pfundt (1986) (Germany); Danielsson (1987) (Sweden); Janoff (1988) (USA); Schreuder (1989) (Netherlands); Schreuder (1993) (Netherlands); Uschkamp, Hecker, Thäsler and Breuer (1993) (Germany).

lighting more than five times the previous level has the same effect as lighting an unlit road and reduces accidents by around 30% (Elvik et al., 2009, p. 277).

4.2.3 The effect of cutting lighting on road security: results

Elvik et al. found 11 studies[14] on the reduction of lighting during certain periods in order to save energy. They stated that:

> The usual way of reducing lighting is to turn off every other lamp. The reports can therefore broadly represent the effects of halving the level of lighting. On the basis of these studies, the estimated effect on injury accidents in darkness is a significant increase by 17% (95% CI [+9; +25]), and the estimated effect on property-damage-only accidents in darkness is a significant increase by 27% (95% CI [+9; +50]). (Elvik et al., 2009, p. 278).

The researched situations in these 11 studies are not comparable with the current policy of cutting public lighting within a certain time period at night (part-night lighting).

Perkins et al. (2015) studied four lighting adaption strategies: switch-off, part-night lighting, dimming, and white light, and their effect on casualties. They concluded that switch-off (permanently turning street lights off) was not associated with an increase in nighttime traffic collisions, but warned that the results might be imprecise because of the small number of areas using this strategy in the study. Part-night lighting (e.g., street lights are switched off between 12 a.m. and 6 a.m.), using white light, or dimming didn't lead to an increase in night-time traffic collisions. The authors point to some limitations in their study. Without having information on exposure, they don't know whether the lighting interventions have affected the mobility at night of road users. It is possible that car users, cyclists, motorcyclists, and pedestrians avoid using these roads. A decrease in numbers of (certain types of) road users can explain why they didn't find an increase in accidents, particularly for pedestrians and cyclists, that other studies found (Perkins et al., 2015, p. 38).

A recent study of the Belgian Federal Police (2017) found no effect of part-night lighting on accidents but has mayor methodological limitations[15] and will not be discussed here (Dienst Strategische Analyse Federale Politie West-Vlaanderen, 2017).

4.2.4 Conclusions about the effect of lighting on road security

All the previously cited research gives us insight into the effects of lighting on road security. We can conclude that lighting does influence the amount and severity of accidents, but the risks are unevenly distributed. All the research, except the study of Perkins et al. (2015), point towards an increased risk for accidents in the dark for pedestrians. They are the most vulnerable group of road users, followed by cyclists and motorcyclists, who not only have a higher risk but also more severe injuries. This is not influenced by the area; in urban as well as in rural areas, these three groups of vulnerable road users have higher risk and more severe injuries. The studies show some variety in the estimates of risks for accidents and severity, but they are probably the result of local specificities. The study of Perkins et al., which found no influence of turning off light, part-time lighting, using

[14] Huber and Tracy (1968) (USA); Box (1976) (USA); Friis, Jørgensen and Schiøtz (1976) (Denmark); Richards (1981) (USA); Lamm, Klöckner and Choueiri (1985) (Germany); Ludvigsen and Sørensen (1985) (Denmark); Pfundt (1986) (Germany); Danielsson (1987) (Sweden); Yin (2005) (USA).

[15] Only based on accidents reported to the police involving personal injury, no matching of control areas with experimental areas, short time span, no control for regression to the mean, samples with too small numbers, no distinction between road type users, no control for exposure.

white light, and dimming, did not control for exposure[16]. It might be that certain types of road users avoid these roads, an effect found by Assum et al. (1999) for older road users. However, as suggested by Griswold and colleagues, it is also possible that no effect is measured because the lighting was only cut around midnight. His results, based on an exploratory visual analysis, show that the first hour of darkness typically has the greatest frequency of pedestrian fatal collisions. He suggests that the twilight hour and transition from light to dark has its own negative effect on fatal pedestrian crashes (Griswold, Fishbain, Washington, & Ragland, 2011, pp. 305–306).

Although in older studies a higher risk for accidents with car drivers was observed in the darkness, more recent and methodologically more accurate research shows no increase in risk. The location of the roads in either an urban or rural area does not influence the risk and severity of accidents. However, this conclusion is limited to richer countries with high investments in well-constructed roads and not in poor countries (European Commission – European Road Safety Observatory, 2017; Meesmann, Torfs, Nguyen, & Van den Beghes, 2018).

4.3 Explaining the relationship between lighting and traffic security

In addition to having data on the effect of lighting and traffic security, it is as important for policy making to understand the relationship between them. A few studies try to explain the higher risks of certain types of road users. This is influenced by the already mentioned problem of a lack of a serious theoretical framework in studies on traffic security (Elvik et al., 2009).

Explanations can be found by looking at (a) situational factors and (b) the behaviour and interactions of the different types of road users.

4.3.1 Situational factors

Elvik et al. (2009, pp. 57–58) explain the high risks of pedestrians, cyclists, and moped riders because they travel mainly in urban areas. These areas generally have a higher accident rate than rural areas. Moped riders are often young and inexperienced drivers. Motorcycle drivers are mostly more experienced but are capable of travelling at higher speeds. The difference in injury rate can be attributed to the differences in protection when they have an accident. Accident rates are not very different from the ones for more vulnerable road users, but have a higher proportion of property damage. It has been found that roads carrying mixed traffic are more prone to accidents than those with separate facilities for pedestrians and/or cyclists. Although this is no guarantee; at junctions, they mix with car traffic. When the number of pedestrians increases from 100 to 1000, the risk for each of them drops by about 50%; a further increase from 1000 to 2000 leads to a reduction of 17%. For pedestrians, more dense traffic is beneficial in two ways. When traffic is dense, drivers have to pay more attention and speed goes down, resulting in less severe accidents. Similar dynamics are observable for cyclist and motor accidents. There is a notable paradox:

> While each road user, in each of the groups that interact, is safer in heavy traffic than in light traffic, the total number of accidents involving the interacting categories of road users

[16] Exposure is defined by Elvik et al. (2009, p.35) in the following way: 'Exposure denotes the amount of activity in which accidents may occur. Any human activity is exposed to the risk of accident, but as far as road traffic is concerned, the amount of activity usually refers to the amount of travel, that is the number of person kilometers of travel performed.'

> increases more than in proportion to the total interacting volumes.' (Elvik et al., 2009, pp. 57–58).

The fact that pedestrians mainly travel in urban settings leads Retting, Ferguson, and McCartt (2003, pp. 1461–1462) to try to explain what causes their risks in cities. They point to the fact that their risks are strongly affected by the number of parked cars obscuring the vision of pedestrians and drivers. Parking restrictions such as the removal of on-street parking and implementation of diagonal parking into the direction of the traffic flow reduces the number of pedestrians entering the roads in front of a parked car. Bus users have a tendency to enter the roadway in front of a stopped bus at signal-controlled intersections. Reallocating the bus stop from the near side to the far side of intersections can increase the visibility and conspicuity of pedestrians because they are restrained from entering the roadway in front of a stopped bus. Crosswalk pavement markings are intended to reduce pedestrian accidents, but are known to be largely ineffective (see further European study - Meesmann et al., 2018,) and can be harmful in some settings (Retting et al., 2003, pp. 1461–1462).

4.3.2 Behaviour and interactions of different types of road users

Visual losses at night

A first encountered explanation relates to human vision at night. The high risk of pedestrians, cyclists, and motorcycles is explained by the visual losses experienced by the human vision system at night (Leibowitz & Owens, 1977). In the dark, motorists have difficulties in recognizing the presence of pedestrians (Griswold et al., 2011) and are not aware of their limitations resulting in too high speed (Leibowitz, Owens, & Tyrrell, 1998). According to Plainis et al. (2006) a plausible physiological explanation is that 'with low luminance, low contrast images are processed slowly to the visual apparatus, due mainly to the limited temporal characteristics of the rod photoreceptors' and this influences the estimates of stopping distances so that even an experienced driver reacts less adequately than in good lighting conditions (Plainis, 2006, p. 127).

Griswold et al. (2011) showed on the basis of an exploratory visual analysis that the twilight hour and transition from light to dark has its own negative effect on fatal pedestrian crashes, quite separate from pedestrian exposure effects. They state that the:

> most plausible explanations for this observed phenomenon are that: (1) dusk is a time when glare and associated reduced visibility occurs for both drivers and pedestrians westerly facing; (2) reduced visual contrast during the transition from daytime to darkness makes headlights less effective; (3) vision adapts more easily outside of a car, so that pedestrians are less aware of the reduced visibility of drivers; (4) pedestrians and/or drivers do not compensate appropriately for the reduced visibility and increased crash risk of pedestrians during these times.

Weekly patterns of pedestrian fatal collisions and seasonal changes for the month December demonstrate the concentration of collisions around twilight and the first hour of darkness during weekdays. In June, they are heavily concentrated around twilight and the first hours of darkness on Friday and Saturday. In summer, the risks for pedestrians are the highest at the weekend from sunset until the early morning. Grisword et al. suggest that alcohol impairment and teen driving are the main reasons for these higher risks (Griswold et al., 2011, pp. 305–306).

Poorly visible pedestrians and cyclists

A report of the EU Commission states that pedestrians and cyclists are poorly visible in the dark, resulting in difficulties for drivers noticing them in time to lower speed or to take other actions to avoid collisions (European Commission – European Road Safety Observatorium, 2018). They are smaller and less (well-) equipped with headlights (Focant & Martensen, 2016, p. 2). For car drivers, looking for vehicles as large as theirs, the limited physical visibility of cyclists causes serious problems for detection, particularly when they approach them alongside or from behind. This is reinforced, at least in countries where cycling is not very common, by their lack of 'social visibility': car drivers do not see cyclists because they do not expect to see any (European Commission – European Road Safety Observatorium, 2018).

Conduct of road users

A large-scale European research study in 38 countries[17] interviewed road users on their safety practices. Speeding is the main problem for car drivers; they drive over the speed limit on motorways (between 56% and 68%) and drive over the speed limit outside built-up areas (excluding motorways) (between 65% and 51%; Meesmann et al., 2018, p. 18). About 30% admit to driving after drinking alcohol[18], 25% drive while on medications that carry warnings against driving, and 13% drive after using illegal drugs (Meesmann et al., 2018, pp. 25–26). More than three-quarters of the car drivers secured themselves and children with safety devices such as seatbelts or car seats (Meesmann et al., 2018, pp. 26–27). About three-quarters of cyclists do not wear a helmet, half of them cycle while listening to headphones, and between 42% to 52% of cyclists cross the road when the light is red. Around 45% to 50% of moped or motorcycle users do not use a helmet (Meesmann et al., 2018, p. 28). An overall of 82% of pedestrians admit to walking across streets not at pedestrian crossings; between 64% and 68% of them admitted to walking across the street when the pedestrian light is red (Meesmann et al., 2018, pp. 28–29).

4.4 Subjective effects of dimming and cutting public lighting

The fear of road insecurity has been examined only in a very restricted number of studies. An older EU study on social attitudes to road traffic risks found that 45% of car users feel very concerned about road safety. However, only 20% are personally concerned with the risk of having a car accident and just 18% discuss this with families and friends. Most car drivers consider driving to be not at all or not dangerous (Barjonet, Benjamin, Huguenin, & Wittink, 1994, p. 9). Twenty-six percent of cyclists do not feel safe in traffic, especially when they are travelling in mixed traffic on roads with heavy car traffic. A larger proportion of motorcyclists feel unsafe (Elvik et al., 2009, p. 155). The study of Perkins et al. concluded that there is little impact on individual well-being from reducing street lighting; a minority reported negative effects on mobility. However, at the social level, reduced street lighting may have an effect because of the association residents make between well-lit streets and trustworthy and competent governance (Perkins et al., 2015).

The European Commission European Road Safety study from 2017 reported a moderately strong relationship between road security and the concern about risks of accidents among their users. The

[17] Thirty-eight countries across the world, 40,000 respondents

[18] 'In terms of DUI (alcohol), Western European countries – Belgium, France, Switzerland, Spain, and Portugal – have the highest reported percentages in "drive after drinking alcohol" with 43%, 41%, 38%, 35%, and 34%, respectively'(Meesmann et al., 2018, p. 30).

feared risk is in line with the objective numbers of road accidents in the different countries (Meesmann et al., 2018, p. 20).

5 Final conclusion: effect of street lighting on crime, fear of crime, and road security

The objective of this literature study was to determine the impact of reduced street lighting on crime, fear of crime, and traffic accidents.

In general, our consultation of the literature suggests that an immediate link between reduced street lighting and crime rates cannot be established, because no significant increase in crime rates could be noted in the revised literature. Even when assessing the impact of improved street lighting, mixed and undecided results were found. While there was more consensus in the literature about the impact of street lighting on fear of crime, the evidence is not strong. Improving public lighting does reduce fear of crime among citizens, especially among women and the elderly who generally experience the highest levels of fear of crime. Reduced street lighting seems to make citizens aware of possible risks and some of them report some degree of behavioural changes during nighttime; they also recognize the possible environmental benefits. In general, street lighting has no significant effect on the prevalence of crime or fear of crime, although no conclusions can be made about the impact of reduced street lighting on these social aspects. We conclude that improved or reduced street lighting does not directly have an impact on the prevalence of crime, but affects the behaviour and perceptions of citizens.

The literature study on the effect of lighting on traffic demonstrated the complexity of answering this question. A whole series of methodological challenges and problems were identified. Even though a lot of progress has been made in this type of research, the quality of many studies remains questionable. From a catalogue of systematic reviews and meta-analyses, the most reliable studies were detected and discussed.

Interventions in street lighting have an impact on road safety. Using roads in the dark significantly increases the risk of accidents for pedestrians, cyclists, mopeds, and motorcyclists. All studies, except one, found this effect. Although previous research found a higher risk when driving by car in the dark, more recent studies offer no evidence of an increased risk. However, this should be restricted to countries with well-equipped and well-maintained roads. This does not apply to poor countries with a completely different road infrastructure. In this context, the risk of nocturnal traffic accidents is much higher. Increasing the quality of lighting has little effect unless it is increased to five times more than the previous level (which is equivalent to illuminating an unlit road).

All studies that examined reduced street lighting, except for the study by Perkins et al., found an increased risk for pedestrians, cyclists, mopeds, and motorcyclists. However, the studies in question did not study the partial disconnection at night. This is the case for the study of Perkins et al. in which no increase in the risk of accidents was found. Although this is only one study, it is possible that these results do not contrast with an increased risk of accidents in the dark. Several studies pointed to the importance of twilight and the period just after, with a very strong increase in the number of accidents. This can be explained by the fact that the human eye has difficulties in adjusting to low contrast. It is also in these periods that traffic is dense, with all types of road users involved, because it coincides with the end of the working day. When the street lighting is switched off from, for example, twelve o'clock at night until six o'clock in the morning, this is not during the period of high risk. This hypothesis is only tested in one research study; it is clear that new detailed research on this matter is absolutely necessary.

We strongly agree with the conclusion of the Royal Society of Prevention of Accidents (UK; RoSPA) which states:

> There are economic and environmental reasons why some organizations may wish to reduce the amount of lighting. However, there are safety reasons why lighting needs to be available. In some locations, a reduction in lighting quality may not increase the risk of an accident. However, there is the danger that an unconsidered removal or reduction in quality could actually increase accidents and their severity. Therefore, when considering removal or dimming of lights, location-based traffic and accident evidence should be assessed. Accident rates should be monitored to ensure that sacrificing the quality of lighting does not unduly increase the risk. Increases in risk may ultimately lead to lives being lost. (RoSPA, 2018, p. 3)

It is not recommended to switch off all street lighting permanently. Instead, we suggest 'the right amount of light' by which we mean lighting adequate to the specific situation as a balance between energy saving and comfortable citizens. Street lighting regimes must be adapted to the specific situation and must be as efficient and effective as possible. For example, good illumination is necessary in parks in order to facilitate natural surveillance and increase feelings of safety among passers-by (Iqbal & Ceccato, 2016). In residential areas, on the other hand, street lighting can be switched off during certain hours of the night when citizens are not using the public space.

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