Conférence Européenne des Directeurs des Routes

Conference of European Directors of Roads

Energy efficiency in road operations and management

October 2016

Authors

This report was compiled by **CEDR Task Group I3 (Energy Efficiency)**.
Task Group leader and main author: **Mr Stuart Beale, Highways England.**

With contributions from the following countries:

Denmark	Maja Rørbæk Nielsen Søren Vedel Hellgreen Laursen
Italy	Fabio Pasquali Sandro La Monica
Norway	Bob Hamel
Sweden	Åsa Lindgren
Switzerland	Christian Kellerhals
UK	Stuart Beale

With additional information provided by Slovenia and Austria.

Approved by the Governing Board of CEDR: October 2016
Edited and published by: CEDR's Secretariat General
Ref.: CEDR report 2016/03 Energy Efficiency in Road Operations and Management
ISBN: 979-10-93321-19-6

Executive summary

In setting its third Strategic Plan[1] (SP3), the Conference of European Directors of Roads (CEDR) recognised energy efficiency in road operations and management as one of their key challenges. The aim of Task Group I3 (Energy Efficiency) is to disseminate to CEDR members best practice on approaches to reducing energy use when operating and managing road networks.

Energy costs represent 10–20% of routine maintenance budgets. In general, those costs are rising while the budgets available to pay them are falling. Energy costs may only represent as little as 2% of the whole life costs of a length of road network. This can result in these costs not receiving as much attention as required and often being dismissed as 'an unavoidable cost'.

There is a general consensus among the public and politicians to migrate to a low-carbon economy. However, emissions associated with maintenance and operation only account for less than 1/50th (2%) of the emissions from vehicles using the network – less if a country produces a lot of energy using renewable sources. It is, nevertheless, incumbent upon road operators to reduce the net contribution of that 2% and to do so in a cost-efficient manner without affecting the operation of the network or the safety of those using and maintaining it.

There are numerous interventions available to road operators that can be used to reduce energy use. This situation is both positive (options are available) and negative (it is hard to select the best option). This document identifies most of the interventions currently implemented by at least one NRA together with an easily understood assessment of the economic return, environmental and safety impact, and political acceptability of these interventions. The list can be used by different NRAs in different ways: for some, it will be a list of new opportunities; for others, it will be a checklist that they can use to ensure they are doing everything that can be done.

However, implementing any new initiative, such as energy reduction, into a large, complex, and inter-connected business such as national roads operators has its challenges. It can be highly disruptive if approached incorrectly. This report provides a pathway to achieve and sustain a reduction in energy use. It is based on the approach used by many multinational businesses and has a successful track record. The first step is for directors to announce that they want to see a change and will support those undertaking change.

The blockers to any change are usually a lack of budget and a lack of appropriately skilled staff. However, it should not be forgotten that using energy – and thereby generating a carbon footprint – is an unpopular, expensive, and labour-intensive activity. Reducing energy use will always result in a reduced whole life cost. It may require greater upfront costs in some instances, but if that is unaffordable, other solutions exist. Staff are generally well skilled in reducing energy costs. Again, their household energy costs are only in the region of 2% of their income, but they understand the technologies and economic cases of technologies such as LED lights, solar panels, and reducing hours of operation. They do not view it as an unavoidable cost.
Identifying what to target is relatively easy, it is every asset that consumes energy. Priority should be given to the greatest consumers of energy because that is where the greatest savings can be achieved. The greatest consumer of energy is usually road lighting. Reducing energy use for road

[1] CEDR, 2013 http://www.cedr.eu/download/Publications/2013/Strategic_Plan_2013-2017.pdf

lighting provides economic benefits in terms of reduced energy bills, environmental benefits in terms of reduced CO_2 emissions and reduced light pollution, and societal benefits in terms of reduced road worker exposure to risk through a reduced maintenance burden.

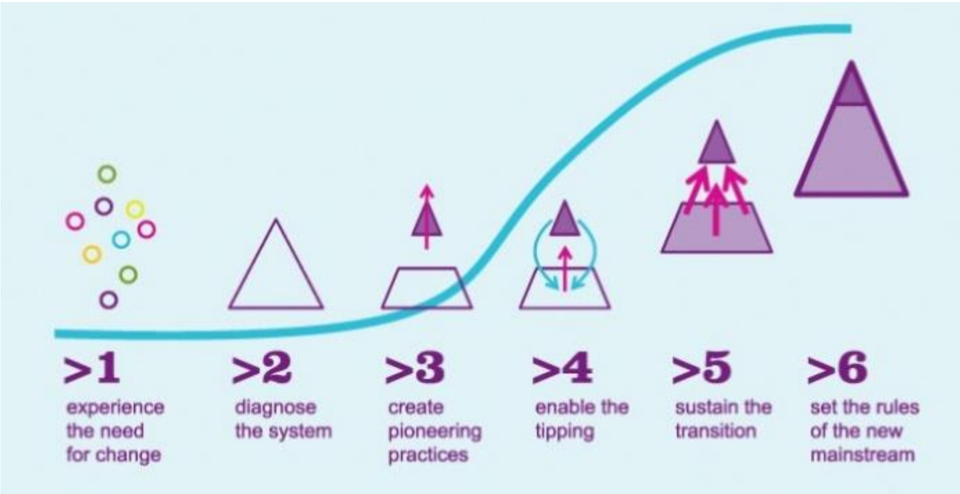
Table of Contents

1 Making it happen

'In politics, nothing happens by accident. If it happens, you can bet it was planned that way.'
Franklin D. Roosevelt

Energy reduction can be a highly disruptive process for NRAs and their suppliers, maintainers, and operators. Without a clear plan of action, it is likely that progress will be stalled or slow.

Forum for the Future, a charity based in the UK, advises large multi-national businesses on how to become more sustainable. This charity has a track record spanning nearly two decades. It has worked in partnership with pioneering companies such as Unilever, Pepsico, Telefonica O2, Skanska, and Akzo Nobel, and collaborated with businesses both large and small. Forum for the Future's process for change, which was adopted by the English Highways Agency, achieved a 22% reduction in energy use in five years. The diagram below sums up the process.



Briefly, the steps are as follows (a more detailed description is provided overleaf):

1) <u>Experience the need for change.</u> Nothing will change unless directors want it to. The staff need to know that this is something that the business wants to do…..and will continue to do for a long time.
2) <u>Diagnose the system.</u> The right things will not be changed unless directors have data that enables them to identify what should be changed.
3) <u>Create pioneering practices.</u> Not everything can be changed at once and not everyone can be convinced by conjecture. A few trials will demonstrate what can be done, for how little, and the wide-ranging benefits that energy reduction delivers.
4) <u>Enable the tipping.</u> What was done to the minority when creating pioneering practices also needs to happen to the majority.
5) <u>Sustain the transition.</u> A programme to make the relatively energy inefficient as efficient as the best in class needs to be implemented.
6) <u>Set the rules of the mainstream.</u> Change the rules by which the business operates so that only energy-efficient products are bought and they are operated in an energy-efficient way.

However, life is rarely that simple. It can be an iterative process. Sometimes it feels like a game of snakes and ladders.

Step 1: Experience the need for change

This is a relatively easy process. Setting out a strategy for or target of, for example, 'reducing energy use by X% over Y years'.

However, strategies often fail to be enacted or delivered because no-one develops a programme of activities needed to develop the outcomes. A programme of work needs to be put in place to analyse the 'system' and implement some pioneering practices.

Obtaining buy-in to that target may be challenging. Very rarely will a new target be welcomed, particularly if it is perceived as being counter to other targets such as reducing costs or improving safety for the road user. However, everyone is already exhibiting the desired behaviours in their home lives (e.g. buying cars with good km/litre ratings and A*-rated fridges), and it needs to be clear that there are enough opportunities to meet the target without compromising safety.

Step 2: Diagnose the system

It requires significant effort to collect data, a lot of which may not have been measured in the past, probably because it was difficult to measure. It is not just a matter of collecting data about which assets consume how much energy when and at what cost. Understanding the benefits that the service provided by the asset delivers is equally challenging. The assets and services that consume the most energy need to be identified because they will provide the greatest potential savings. The benefits each asset provides need to be understood as this will indicate the likely level of objections from road users that may be received should the hours of operation be reduced or the asset removed entirely. It is also important to understand the dis-benefits of operating the asset in terms of CO_2 emissions, light pollution, road worker costs, and road worker exposure to risk, as this will reinforce the argument for change.

Step 3: Create pioneering practices

This requires no effort on the part of directors. There is no problem concerning energy reduction that has not already been addressed by another NRA. While new technologies are coming on the market, the initial pioneering practices should be relatively low risk and proven, because part of this exercise is to instil confidence in the ability to deliver these new ways of working.

All the practices successfully implemented by other NRAs are given in Section 3.

Step 4: Enable the tipping

This can be challenging. The majority are happy to let the minority get on with what they perceive to be strange little pet projects, but will require some convincing to adopt such approaches themselves.

The best approach is to disaggregate the 'step 1 target' (reducing energy use by X% over Y years) among operating units and, of course, to provide some funding.

Unfortunately, the human is a highly creative creature, and the risk of implementing the wrong interventions is high and needs to be robustly managed and constrained by the data collected in step 2.

Step 5: Sustain the transition

Evaluation data from step-4 projects will demonstrate that not only do they reduce energy use, they are also good for a number of other business goals. These can be as diverse as reduced energy bills, reduced maintenance costs, reduced roadworks, reduced CO_2 emissions, reduced light pollution, and reduced road worker exposure to risk.

A continued programme of works is necessary to deliver the policy objective stated in step 1 (reducing energy use by X% over Y years).

Step 6: Set the rules of the mainstream

This is concerned not with changing what NRAs have on their networks, but making sure that what they add to the network meets their energy-reduction needs. It is about making low energy 'normal', not 'novel'.

This may require a re-drafting of requirement specifications, and perhaps a radically different approach to procurement values. But this does not need to be done all at once and instantly, a phased approach is often necessary to avoid too much disruption.

Directors will notice that not everyone is always willing to embrace change. One of the pushbacks directors will get is that an intervention is too expensive. A lot of the interventions listed later, if done at the wrong time, will be expensive. However, if done when replacing or upgrading the equipment as part of the normal maintenance or refurbishment activities, then the cost can be very low. Section 3 indicates the situations when it is most cost effective to implement a particular intervention. This provides NRAs with information to challenge designers to seek low-energy outcomes during design and during refurbishments.

2 Introduction

The following pages provide an overview of the energy-reduction interventions used by some CEDR members.

All interventions are split into one of four asset types: road lighting, tunnels, ITS, and 'good practice by the NRA' (which are things the NRA should do so that their suppliers do the right thing in terms of energy reduction). Each intervention is laid out in a near identical fashion and allows the reader to quickly assess the applicability of that intervention to their own network. Road lighting interventions can be implemented on any lighting for which the NRA is responsible, such as maintenance depot lighting or service area lighting.

Road lighting is very likely to be the biggest energy-consuming asset NRAs are responsible for, perhaps as much as three-quarters of an NRA's energy use. Consequently, NRAs that are looking for big reductions should start with their biggest energy user as this will have greatest potential for the greatest overall reduction. The report focuses on energy savings primarily as a cost to NRAs; the CO_2 savings realised by the energy savings will vary from country to country depending on the forms of electricity generation involved.

Tunnels are likely to be the most intensive energy users on a 'watts per km of network' basis simply because they use a lot of equipment around the clock. Again, where NRAs use most is where there is the greatest potential for savings.

ITS is an expanding asset and efforts to minimise energy use here will prevent a net increase in an NRA's energy use.

'Good Practice' covers approaches to procurement, sometimes seen as the problem in getting what directors want, but if driven the right way can deliver large energy reductions at almost no costs at all.

2.1 Key to a typical intervention

Part-night switch-off ← *Title*

Energy-saving potential = 40% ← *Possible energy savings*

What other benefits the NRA will derive

Other business benefits

Maintenance costs	*CO_2 footprint*	*Light pollution*	*Road worker risk*	*Less roadworks*
✓	✓	✓	✓	✓

How much and how quickly will the NRA get its money back

Affordability assessment

	Quick payback <five-years	Slower payback >5years
High cost (>€50k per scheme)		X
Low cost (<€50k per scheme)		

Description

Part-night switch-off is the switching off of lights when the predicted accident rate is very low, usually when flows are very low (<7% of capacity). However, there is likely to be only a limited number of locations where a fixed-time part-night switch-off can be implemented in an economical way. Highways England's five-year study showed that road user safety was not discernibly impacted, and the money saved was spent on far more cost-effective safety measures.

Data for a business case

Energy saving (%)	Up to 40%
Estimated implementation cost	€28,000 per km
Estimated annual electricity cost saving	€5,800 per km
Estimated annual energy saving	38,000 kWh per km
Payback time	five years
CO_2 savings	19 tonnes per km per year
Best time to do	During design

This section highlights possible resistance and mitigations

Pushback

There may be a perception that night-time accidents will dramatically increase, and the workforce may be concerned about a reduction in work. One possible response is to demonstrate that the lights are only switched off when the accident rate is far below the hourly average for the network. The workforce can be reassured by seeing their jobs up-skilled to work with the latest lighting technology.

The information is brief as the detail will often differ between different NRAs.

Obviously, a mix of interventions is possible (e.g. lighting equipment that includes both dimming and part-night switch-off), and this will increase the benefits for the same cost.

The implementation costs are purely indicative. Technology is evolving, so costs are coming down. However, a large proportion of the implementation costs is workforce costs and plant costs on site. Often this cost can be written off if the implementation is programmed to coincide with planned works such as lighting maintenance or tunnel refurbishment.

A 'quick-finder table' is provided below to allow NRAs to select those interventions that best meet their current business criteria.

Intervention	Energy saving	€/CO_2Tonne	Initial cost	Page
Road lighting				
Lighting removal	100%	30 t/km/year	€33,000 per km	13
Part-night switch-off	40%	12 t/km/year	€28,000 per km	14
Dimming	30%	9 t/km	€16,000 per km	15
Trimming	2%	0.6 t/km/year	€550 per km	16
Replacing lamps with energy-saving lamps	30%	9 t/km/year	€2,500 per km	17
Replacing lamps with less bright lamps	12%	4 t/km/year	€2,500 per km	18
Lighting design optimisation	10%	3 t/km/year	€2,500 per km	19
Lighting all-out optimisation	75%	22 t/km/year	€24,000 per km	20
Sign lighting	40%	0.06 t/sign/year	€300	21
Tunnels				
Switching off unnecessary lighting at the start of the threshold zone and exit zone	2%	8 t/tunnel/year	€100	23
Restricting the upper bound of access zone luminance	5%	21 t per 2 km of tunnel per year	€10,000 (includes control system)	24
Optimising tunnel interior lighting with a lighting control system	10%	42 t per 2 km of tunnel per year	€75,000	25
Replacing lamps with energy-saving lamps	15%	64 t/km/year	€20,000 per 2 km of tunnel	26
Lighting standards update	10%	42 t	€50,000	27
Adjusting jet fan thresholds	40%	8 t/tunnel/year	€2,000	28
Variable speed limits	5%	21 t/tunnel/year	€20,000 (assumes signals in place already)	29
Energy efficiency benchmarking	5%	21 t/tunnel/year	€15,000 (includes installing sub-meters)	30
Reducing the light level around the portal entrance	10%	42 t	€50,000	31
Optimising the tunnel power supply	8%	33 t/tunnel/year	€80,000	32
Tunnel lining panels	2.5%	9 t/tunnel/year	€200,000 (extra construction costs, else €20 M)	33
Electroluminescent light sources for illuminated signage	Minimal	Negligible	€280 per sign installed	34
Solar-powered tunnels	60%	256 t per 2 km of tunnel per year	€1,000,000	35
Intelligent road studs	1%	16 t per 2 km of tunnel per year	€50,000	36
ITS				
Adding whole life energy costs to suppliers' unit cost	Up to 80%		Initial equipment purchase price may be higher	38
Including renewable energy supply in tenders for ITS installations	50–100%		Will pay for itself within the lifetime of the equipment	39

3 Road lighting

Within the road lighting lifecycle, there are three key opportunities to reduce energy use:

- during design,
- at the mid-life refurbishment, when the luminaire is replaced, and
- during operation.

During design, the designer needs to be aware and incentivised to minimise energy use and strike a balance with all other priorities.

During refurbishment, the opportunity to 're-design' the scheme should not be neglected as the fitting of low-energy equipment is minimal compared with the overall expense of the refurbishment.

Operational changes are limited due to the inflexibility of equipment. It is, therefore, important that equipment that allows flexible operation is installed during the mid-life refurbishment.

3.1 Lighting removal

Energy-saving potential = 100%

Other business benefits

Maintenance costs	CO_2 footprint	Light pollution	Road worker risk	Less roadworks
✓	✓	✓	✓	✓

Affordability assessment

High cost	**€33k/km & ~4years**	
Low cost		
	Quick payback	Slower payback

Lighting removal is the removal of lighting and not replacing it. This is done where the accident risk is very low, typically more than 2 km away from junctions or where the night-time flow is low. Highways England's five-year study[2] showed that road user safety was not discernibly impacted at six of seven sites, and the money saved was spent on far more cost-effective safety measures. In all cases, road lighting is only removed when national guidelines allow.

Energy saving (%)	100%
Estimated cost	€33,000 per km (will have to be paid at some stage anyway)
Estimated annual electricity cost saving	€7,500 per km
Estimated annual energy saving	55,000 kWh per km
Payback time	4 years
CO_2 savings	30 tonnes per km per year
Best time to do	Near end of life (public tend to be more content)

Pushback

There may be a perception that night-time accidents will dramatically increase, and the workforce may be concerned about a reduction in work. One possible response is to demonstrate that the lights are only switched off where the accident rate is far below the hourly average for the network and that the money saved will be spent on more cost-effective measures. The workforce can be reassured by accepting that the removal of an unsustainable asset with a more sustainable accident-reduction asset provides greater job security.

[2] Road Lighting Strategy – Post-implementation Review: Report No.2 Strategy Performance Review. Available from RoadLightingEnquiries@highwaysengland.co.uk

3.2 Part-night switch-off

Energy-saving potential = 40%

Other business benefits

Maintenance costs	CO_2 footprint	Light pollution	Road worker risk	Less roadworks
✓	✓	✓	✓	✓

Affordability assessment

High cost		**€28k/km & <9 years**
Low cost		
	Quick payback	Slower payback

Part-night switch-off is the switching off of lights when the predicted accident rate is very low, usually when flows are very low (<7% of capacity). However, there is likely to be only a limited number of locations where a fixed-time part-night switch-off can be implemented in an economical way. Highways England's five-year study showed that road user safety was not discernibly impacted, and the money saved was spent on far more cost-effective safety measures.

Energy saving (%)	40%
Estimated cost	€28,000 per km (cheaper & simpler ways are possible)
Estimated annual electricity cost saving	€3,000 per km
Estimated annual energy saving	22,000 kWh per km
Payback time	Up to 9 years, but typically five years
CO_2 savings	12 tonnes per km per year
Best time to do	During design

Pushback

There may be a perception that night-time accidents will dramatically increase, and the workforce may be concerned about a reduction in work. One possible response is to demonstrate that the lights are only switched off when the accident rate is far below the hourly average for the network. The workforce can be reassured by seeing their jobs up-skilled to work with the latest lighting technology.

3.3 Dimming

Energy-saving potential = 30%

Other business benefits

Maintenance costs	CO_2 footprint	Light pollution	Road worker risk	Less roadworks
✓	✓	✓	✓	✓

Affordability assessment

High cost		**€16k/km & 7 years**
Low cost		
	Quick payback	Slower payback

Light levels are adjusted according to the measured or predicted traffic flow. European and national standards determine the acceptable level of dimming. These standards ensure there is no detrimental impact on road user safety. There are two types of dimming: dimming based on time and dimming based on real-time measured flows.

Energy saving (%)	30%
Estimated cost	€16,000 per km
Estimated annual electricity cost saving	€2,300 per km
Estimated annual energy saving	16,000 kWh per km
Payback time	7 years
Annual CO_2 savings	9 tonnes per km
Best time to do	During design

Pushback

Negligible, as very few motorists will identify that the lights have been dimmed.

3.4 Trimming

Energy-saving potential = 2%

Other business benefits

Maintenance costs	CO_2 footprint	Light pollution	Road worker risk	Less roadworks
	✓			

Affordability assessment

	Quick payback	Slower payback
High cost		
Low cost	**€0.5k/km & 3 years**	

Trimming is switching lights off and on at the optimum times so that the lights come on as late as possible at dusk and switch off as soon as possible at dawn. This optimum time is based on the lamp type and target light level and means replacing photocells, which are designed to cover a wide range of lamp types and target light levels.

Energy saving (%)	2%
Estimated cost	€550 per km
Estimated annual electricity cost saving	€150 per km
Estimated annual energy saving	1,100 kWh per km
Payback time	3 years
CO_2 savings	0.6 tonnes per km per year
Best time to do	During routine lamp-change maintenance

Pushback

Negligible, as very few motorists will identify that the switch on and off times of the lights have changed. However, care should be taken because contrast is very low at dusk and dawn, and road lighting can enhance contrast.

3.5 Replacing lamps with energy-saving lamps

Energy-saving potential = 30%

Other business benefits

Maintenance costs	CO_2 footprint	Light pollution	Road worker risk	Less roadworks
✓	✓		✓	✓

Affordability assessment

High cost		
Low cost	**€2k/km & 1 year**	
	Quick payback	Slower payback

Old lamps can be replaced with new energy-efficient lamps. For example, sodium gas discharge lamps can be converted to LED. There can be problems finding LED lights that are compatible with the existing column heights and spacings, but as LEDs become more powerful, the number of locations where this is a problem is dropping. Retrofitting LED into road lighting luminaires can be problematic if the protective glass has poor transmission and the optics are not adapted to the geometry. If the replacement occurs when the luminaire needs replacing (usually every 15 years), then additional costs are negligible.

Energy saving (%)	30%
Estimated cost	€2,500 per km (or €20,000 if not done as part of a planned refurbishment)
Estimated annual electricity cost saving	€2,300 per km
Estimated annual energy saving	16,000 kWh per km
Payback time	1 year
CO_2 savings	9 tonnes per km per year
Best time to do	During mid-life refurbishment (once every 15 years)

Pushback

It is possible that some motorists will find the glare of LED lights unacceptable. Careful selection of the lamps is necessary, look for a low 'I_{70}' lamp and a S/P ratio of less than ~2.2.

3.6 Replacing lamps with less bright lamps

Energy-saving potential = 12% (possibly up to 33%)

Other business benefits

Maintenance costs	CO_2 footprint	Light pollution	Road worker risk	Less roadworks
	✓	✓		

Affordability assessment

High cost		
Low cost	**€2k/km & 3 years**	
	Quick payback	Slower payback

Less bright lamps can often be used where road lighting was designed to an old standard that required a higher light level (up to 33% saving), or more likely, by using a lamp with a more blue/white spectrum (known as high S/P ratio lamps, up to 12% saving). Reference should be made to CIE Technical Report 191:2010 'Recommended System for Mesopic Photometry Based on Visual Performance.'

In many cases, existing electrical components will not permit another lamp to be simply inserted, as is the case in the home. It is therefore only feasible to undertake this when the luminaire needs replacing (usually every 15 years).

Energy saving (%)	12%
Estimated cost	€2,500 per km
Estimated annual electricity cost saving	€1,000 per km
Estimated annual energy saving	7,000 kWh per km
Payback time	3 years
CO_2 savings	4 tonnes per km per year
Best time to do	During mid-life refurbishment (once every 15 years)

Pushback

In terms of light level, negligible, as motorists are unlikely to perceive any drop in light level and will be used to driving in the new light level elsewhere on the network.

Provided that a reasonable S/P ratio (e.g. <2.2) is used, there should be no adverse comments from motorists. Higher S/P ratios can discernibly increase light pollution (sky glow) and the use of very high S/P ratios is counter-productive for older drivers as their eyes may only transmit a fraction of the blue-rich light compared with younger drivers.

3.7 Lighting design optimisation

Energy-saving potential = 10% (average)

Other business benefits

Maintenance costs	CO_2 footprint	Light pollution	Road worker risk	Less roadworks
✓	✓	✓	✓	✓

Affordability assessment

High cost		
Low cost	**€3k/km & 3years**	
	Quick payback	Slower payback

The aim of lighting design optimisation is to optimise lighting design in order to save energy. This is best implemented through a system where the energy consumption of the design is compared with existing lighting schemes (using metrics such as kW/m²) and by challenging the extent of the proposed lighting scheme. For example, why is there lighting all the way between junctions when 90% of accidents occur within 3 km of a junction (using a metric such as number of night-time accidents per km).

Energy saving (%)	10%
Estimated cost	€2,500 per km
Estimated annual electricity cost saving	€750 per km
Estimated annual energy saving	5,500 kWh
Payback time	3 years
CO_2 savings	3 tonnes per km per year
Best time to do	During design

Pushback

The likely pushback is from the workforce and the motorists. The workforce will be concerned about the reduction in work; motorists will be concerned that the road is no longer continuously lit. The approach to take is to indicate that the money that would have been spent on lighting a road that cost more than the benefits is now being spent on other road safety schemes that improve safety far more than lighting, for example, a greater length of roadside barriers along the route or better quality road markings.

3.8 Lighting all-out optimisation

Energy-saving potential = 75% (average)

Other business benefits

Maintenance costs	CO_2 footprint	Light pollution	Road worker risk	Less roadworks
✓	✓	✓	✓	✓

Affordability assessment

	Quick payback	Slower payback
High cost		
Low cost	**€3k/km & 3 years**	

This involves the use of LED lights that are dimmed and part night-operated according to traffic flow and proximity to a junction. The switching-on and -off times are controlled by systems that monitor the ambient light level and activate at pre-programmed thresholds. The spectrum of light chosen reduces the light level.

Energy saving (%)	75%
Estimated cost	€24,000 per km
Estimated annual electricity cost saving	€5,600 per km
Estimated annual energy saving	41,250 kWh
Payback time	4 years
CO_2 savings	22 tonnes per km per year
Best time to do	During design

Pushback

Provided the NRA has a clear policy of where and when it lights and to what level, and has communicated that internally and to the public, then there should be minimum number of objections. A fully controllable asset permits changes in operation in response to public or political priorities concerning costs, carbon, and safety.

3.9 Sign lighting

Energy-saving potential = 40% (average)

Other business benefits

Maintenance costs	CO_2 footprint	Light pollution	Road worker risk	Less roadworks
✓	✓		✓	✓

Affordability assessment

	Quick payback	Slower payback
High cost		
Low cost		**€300/sign & 3 years**

Small lighted signs can be replaced with retro-reflective signs or larger unlit signs. Where sign lighting is needed, there is obviously the potential to use LED lights and a photocell to ensure the lights only come on during the night.

NRAs could also consider whether the sign is needed at all. The bigger the sign, the bigger the potential saving and, therefore, the shorter the payback period.

Solar-powered sign lighting is available, but the economics currently dictate that it is only viable in remote areas where extending the electricity grid to the sign is expensive.

Energy saving (%)	40%
Estimated cost	€300
Estimated annual electricity cost saving	€12
Estimated annual energy saving	120 kWh
Payback time	25 years
CO_2 savings	0.06 tonnes per sign per year
Best time to do	During design

Pushback

Given the relatively small energy and carbon savings that can be achieved compared with road lighting, staff may see this as 'tokenism' and a bit of a distraction. The response should be that it cost just as much in time and money (measured over the whole life of the asset) to get it right as it does to get it wrong.

4 Tunnels

There are three key opportunities to reduce energy use over the tunnel lifecycle:

- during design,
- at the 20 year refurbishment stage, and
- during operation.

During design, the designer needs to be aware and incentivised to minimise energy use and strike a balance with all other priorities.

During refurbishment, the opportunity to 're-design' the scheme should not be neglected as the fitting of low-energy equipment is minimal compared with the overall expense of the refurbishment.

Operational changes are limited due to the inflexibility of equipment; therefore it is important that equipment that allows flexible operation is installed during refurbishment.

On the following pages, all figures relate to a 2-km tunnel.

There should be little public pushback as the changes will not be discernible. Staff, particularly those responsible for tunnel safety, will need to be convinced that the change does not impact safety.

4.1 Switching off unnecessary lighting at the start of the threshold zone and exit zone

Energy-saving potential = 2%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
✓	✓		✓	

Affordability assessment

High cost		
Low cost	**€100/sign & 1 year**	
	Quick payback	Slower payback

The threshold zone is the part of a tunnel entered by a motorist. Daylight penetrates into the tunnel to some extent. Usually the first and last 10 m of a tunnel do not need luminaires, so depending on the tunnel design, the lights in the first 10 m of the apex of a tunnel entrance portal can be permanently switched off.

It might be possible for the lights in a further 10 m or more to be switched off (this will vary depending on the tunnel bore dimensions, orientation, and to some extent, the time of day and year).

Energy saving (%)	2%
Estimated cost	€100 (simply don't replace the bulbs when they blow)
Estimated annual electricity cost saving	€2,400
Estimated annual energy saving	17,000 kWh per bore
Payback time	less than one year
CO_2 savings	8 tonnes per tunnel per year
Best time to do	During design

Pushback

Tunnel entrances can experience higher accident rates than the approach roads, which is why the removal of light can increase the trepidation with which motorists approach the tunnel.

4.2 Restricting the upper bound of access zone luminance

Energy-saving potential = 5%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
✓	✓			

Affordability assessment

High cost		
Low cost	**€10k & 2 years**	
	Quick payback	Slower payback

Tunnel lighting levels adjust automatically in accordance with daylight levels outside the tunnel. A photometer should be located at the start of the access zone to measure access zone luminance.

Energy saving (%)	5%
Estimated cost	€10,000 (includes control system)
Estimated annual electricity cost saving	€6,000
Estimated annual energy saving	42,000 kWh
Payback time	5 years
CO_2 savings	21 tonnes per 2 km of tunnel per year
Best time to do	During design

Pushback

Tunnel entrances can experience higher accident rates than the approach roads, which is why the removal of light can increase the trepidation with which motorists approach the tunnel.

4.3 Optimising tunnel interior lighting with a lighting control system

Energy-saving potential = 10%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
✓	✓		✓	✓

Affordability assessment

High cost		**€75k & 6 years**
Low cost		
	Quick payback	Slower payback

The optimisation of tunnel interior lighting in accordance with regulations costs approximately €75,000. This system dims the lighting throughout the tunnel when the ambient light outside the tunnel lowers. It also measures the actual light in the tunnel, thus providing feedback for the system and making it more efficient.

Energy saving (%)	10%
Estimated cost	€75,000
Estimated annual electricity cost saving	€12,000
Estimated annual energy saving	85,000 kWh
Payback time	6 years
CO_2 savings	42 tonnes per 2 km of tunnel per year
Best time to do	During design

Pushback

This additional technology can increase the fault rate and maintenance costs.

4.4 Replacing lamps with energy-saving lamps

Energy-saving potential = 15%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
✓	✓	✓	✓	✓

Affordability assessment

High cost		
Low cost	**€20k & 1 year**	
	Quick payback	Slower payback

Old lamps can be replaced with new energy-efficient lamps. For example, fluorescent lights can be converted to LED. If the replacement occurs when the luminaire needs replacing (usually every 15 years), then additional costs are negligible.

Energy saving (%)	15%
Estimated cost	€20,000 per 2 km of tunnel (or €200,000 if not done as part of a planned refurbishment)
Estimated annual electricity cost saving	€18,000
Estimated annual energy saving	130,000 kWh per 2 km of tunnel
Payback time	1 year
CO_2 savings	64 tonnes per km per year
Best time to do	During mid-life refurbishment (once every 10 years)

Pushback

There can be problems finding LED lights that are compatible with the existing spacings. However, as LEDs become more powerful, the number of locations where this is a problem is falling.

4.5 Lighting standards

Energy-saving potential = 10%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
✓	✓	✓	✓	✓

Affordability assessment

High cost	**€50k & 4 years**	
Low cost		
	Quick payback	Slower payback

Updating from the old (1992) to the new lighting standard (2003) would mean that less lighting is required and/or at a lower level. This is cheap to implement if all that is required is a re-programming of the lighting control system.

Energy saving (%)	10%
Estimated cost	€50,000
Estimated annual electricity cost saving	€12,000
Estimated annual energy saving	85,000 kWh
Payback time	4 years
CO_2 savings	42 tonnes
Best time to do	When lighting standards change

Pushback

As very few drivers will be able to discern a change in light levels, little pushback from the motorists is expected. However, tunnel managers may have a 'brightest is best' mindset and may require convincing that a reduction in light level is safe.

4.6 Adjusting jet fan thresholds

Energy-saving potential = 40%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
✓	✓		✓	✓

Affordability assessment

High cost		
Low cost	**€2k & 1 year**	
	Quick payback	Slower payback

Jet fans discharge high-velocity jets to induce longitudinal air flow in tunnels to prevent the build-up of pollutants. Energy consumed by tunnel jet fans may be significant in tunnels that are bi-directional or have frequent traffic congestion. Jet fans switch on at certain pollution levels. The jet fan threshold at which the fan switches on should be reviewed if fans run for over two hours a day. By lowering the jet fan threshold, jet fans are not switched on excessively and unnecessarily at lower pollution levels.

Energy saving (%)	2%
Estimated cost	€2,000
Estimated annual electricity cost saving	€2,000
Estimated annual energy saving	17,000 kWh
Payback time	1 year
CO_2 savings	8 tonnes per tunnel per year
Best time to do	whenever

Pushback

It is necessary to note that while there tend to be vehicle emission decreases each year, mandatory standards for air quality are generally becoming increasingly tightened.

4.7 Variable speed limits

Energy-saving potential = 5%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
✓	✓	✓	✓	✓

Affordability assessment

High cost		
Low cost	**€20k & 3 years**	
	Quick payback	Slower payback

Variable speed limits have the potential to reduce lighting usage at lower speeds. This is because the stopping distance is shorter. If speeds are reduced to 80 km/h, the throughput of traffic will be maximised. Moreover, the jet fans will be used less due to less congestion.

Energy saving (%)	5%
Estimated cost	€20,000 (assumes signals in place already)
Estimated annual electricity cost saving	€6,000
Estimated annual energy saving	42,000 kWh
Payback time	3 years
CO_2 savings	21 tonnes per tunnel per year
Best time to do	whenever

Pushback

Setting speed limits needs to take into account the speed limits on surrounding roads. To improve compliance with the posted limits, the reason for the setting should be apparent or explained using message signs.

4.8 Energy efficiency benchmarking

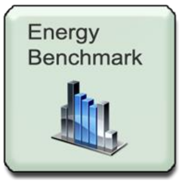
Energy-saving potential = 5%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
	✓			

Affordability assessment

High cost		
Low cost	**€15k & 3 years**	
	Quick payback	Slower payback



Energy efficiency benchmarking involves comparing energy use between different tunnels. While benchmarking the entire energy consumption of a tunnel with another, extra benefits can be achieved by comparing tunnel sub-systems (jet fans, water pumps, lighting, control building use, etc.). This level of detail may involve additional energy-use monitoring equipment.

Energy saving (%)	5%
Estimated cost	€15,000 (includes installing sub-metres)
Estimated annual electricity cost saving	€6,000
Estimated annual energy saving	42,000 kWh
Payback time	3 years
CO_2 savings	21 tonnes per tunnel per year
Best time to implement	During tunnel refurbishment

Pushback

Operators may feel that they are being spied on; full co-operation may require some collaborative working.

4.9 Reducing the light level around the portal entrance

Energy-saving potential = 10%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
	✓			

Affordability assessment

	Quick payback	Slower payback
High cost	**€50k & 4 years**	
Low cost		

Reducing the access zone luminance allows a lower light level to be used throughout the tunnel during daylight hours. This can be achieved by reducing the portion of the sky within the approaching motorist's 20 degree field of view.

This can be done in one of four ways: 1) placing a perforated structure on the approach, 2) planting trees on the approach, 3) painting the walls on the approach a dark colour, and/or 4) tensioned fabric structures. The lighting control system will then require re-programming.

Energy saving (%)	10%
Estimated cost	€50,000
Estimated annual electricity cost saving	€12,000
Estimated annual energy saving	85,000 kWh
Payback time	4 years
CO_2 savings	42 tonnes
Best time to implement	During design

Pushback

Such structures will incur additional maintenance costs and may cause issues in cold climates due to formation and falling ice.

4.10 Optimising the tunnel power supply

Energy-saving potential = 8%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
	✓			

Affordability assessment

High cost		**€50k & 4 years**
Low cost		
	Quick payback	Slower payback

Optimisation of tunnel power supply voltage allows devices to operate at their maximum energy efficiency. For example, most devices will work just as well at 210 volts as at 220 volts, but will use less power. While the cost of equipping an entire tunnel can be high, sub-systems can be individually equipped, for example, the water pumps and jet fans only.

Energy saving (%)	8%
Estimated cost	€80,000
Estimated annual electricity cost saving	€10,000
Estimated annual energy saving	67,000 kWh
Payback time	8 years
CO_2 savings	33 tonnes per tunnel per year
Best time to implement	During design

Pushback

Additional equipment placed in series on the power supply may compromise availability of that power supply.

4.11 Tunnel lining panels

Energy-saving potential = 2.5%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
✓	✓	✓	✓	

Affordability assessment

High cost		**€200k & 60 years**
Low cost		
	Quick payback	Slower payback

Self-cleaning tunnel lining panels maintain lighting performance. A better wall surface performance enhances the contrast of objects for drivers and improves safety by preventing drivers from being 'wall-shy' (that is the reluctance of road users to travel in the centre of a lane close to the tunnel wall) and helping them to use the full driving lane.

Energy saving (%)	2.5%
Estimated cost	€200,000 (extra construction costs, else €20M)
Estimated annual electricity cost saving	€3,000
Estimated annual energy saving	21,000 kWh
Payback time	60 years
CO_2 savings	9 tonnes per tunnel per year
Best time to implement	During design

Pushback

Very slow payback, so has to be installed during construction.

4.12 Electroluminescent light sources for illuminated signage

Energy-saving potential = minimal

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
✓	✓	✓		

Affordability assessment

High cost		
Low cost		**€280 per sign & 14years**
	Quick payback	Slower payback

The sign faces of internally lit signs (e.g. regulatory way-finding signs) can be replaced with electroluminescent sign face panels that generate the light instead. These signs are used widely on merchant vessels.

Energy saving (%)	minimal
Estimated cost	€280 per sign installed (cost of a lit sign installed €200)
Estimated annual electricity cost saving	€5
Estimated annual energy saving	35 kWh
Payback time	14 years
CO_2 savings	negligible
Best time to implement	During design

Pushback

This technology is relatively new, therefore its feasibility has not been proven. There is also a potential issue that electroluminescent signs may not be bright enough.

4.13 Solar-powered tunnels

Energy-saving potential = 60%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
	✓			

Affordability assessment

High cost		**€1,000k & 14 years**
Low cost		
	Quick payback	Slower payback

Photovoltaic systems of solar panels can be installed on tunnel roofs, in the cuttings on the approach to the tunnel, above the tunnel, or on any surplus land within the vicinity of the tunnel. Examples of where this has been implemented are Blackfriars Bridge in the UK, which had been equipped with 4,400 solar panels, and in Belgium where 16,000 solar panels were installed on the roof of 3 km of rail tunnel (producing an estimated 3.3 GWh of electricity per year).
Tunnels use more energy during the day than at night (more traffic and more light needed), so solar panels provide a good 'load match' in that they provide energy when the tunnel needs it most.

Energy saving (%)	60%
Estimated cost	€1,000,000
Estimated annual electricity cost saving	€72,000
Estimated annual energy saving	514,000 kWh
Payback time	14 years
CO_2 savings	256 tonnes per year per 2 km of tunnel
Best time to implement	During design

Pushback

Suitable land may not be available near the tunnel. Local residents may object to the pollution of their landscape by a solar farm.

4.14 Intelligent road studs

Energy-saving potential = 1%

Other business benefits

Maintenance costs	CO_2 footprint	Tunnel safety	Road worker risk	Less roadworks
	✓	✓		

Affordability assessment

High cost		**€50,000k & 10 years**
Low cost		
	Quick payback	Slower payback

Intelligent road studs provide guidance and warnings to drivers when there is a traffic event. They can be used for lane delineation in tunnels. There is the potential to reduce lighting levels provided there is a well performing incident detection system installed and traffic flows are low. Safety is improved due to lane delineation and dynamic lane markings, which makes the tunnel lanes more visible and self-explaining.

Energy saving (%)	4%
Estimated cost	€50,000
Estimated annual electricity cost saving	€5,000
Estimated annual energy saving	32,000 kWh
Payback time	10 years
CO_2 savings	16 tonnes per year per 2 km of tunnel
Best time to implement	During design

Pushback

Additional maintenance costs will be incurred where there is a lot of lane-changing within the tunnel, particularly by lorries.

5 ITS (Intelligent Transport Systems)

ITS is different to road lighting and tunnels in that the only time where there are opportunities to reduce energy use is at the design stage as there are often no scheduled refurbishments or upgrade opportunities.

The nature of the interventions is such that the public will not notice any difference. It might become necessary to publicise the changes so that the public have an appreciation of how energy use is being reduced by the NRA.

5.1 Adding whole-life energy costs to suppliers' unit cost

Energy-saving potential = 80%

Other business benefits

Maintenance costs	CO_2 footprint	Equipment reliability	Road worker risk	Less roadworks
✓	✓	✓	✓	✓

Affordability assessment

	Quick payback	Slower payback
High cost		
Low cost		**€0 & 6 years**

When tendering to buy equipment, whole-life energy costs could be added to the supplier's unit cost. This would be implemented when tendering to buy equipment, thus causing suppliers to innovate so that energy costs would be reduced. For example, if a variable message sign is offered by one manufacturer for €50,000 and is calculated to use €50,000 of energy over its 12-year life, and another offers a €70,000 which only uses €10,000, the €70,000 sign should be chosen.

Energy saving (%)	Up to 80%
Estimated cost	Initial equipment purchase price may be higher
Estimated annual electricity cost saving	Varies, but always justifies the cost, otherwise suppliers would not offer it because they know they would not win the contract.
Estimated annual energy saving	
Payback time	Within lifetime of equipment
CO_2 savings	yes
Best time to implement	During procurement

<u>Tips for implementing this option</u>

Provide a 'use scenario'. For a message sign, this could be 4 hours on, showing one message, and 20 hours off. Highways England found that the biggest energy savings were made when designers reduced the energy consumption when the sign was turned off. If it is something like a CCTV camera, then the 'use scenario' is on for 24 hours.

A 'mission scenario' describing typical outside temperatures and humidity is also needed. This drives designers to consider the size of heater they put in equipment and how it is controlled, the thermostat or humidistat, or whether a heater is needed at all.

Remember to allow for inflation in energy prices across the 12 years of the product. Highways England allows 3% per year.

Pushback

Suppliers do not like the disruption to their steady state of business and will initially be restrained.

5.2 Including renewable energy supply in tenders for ITS installations

Energy-saving potential = 50–100%

Other business benefits

Maintenance costs	CO_2 footprint	Equipment reliability	Road worker risk	Less roadworks
	✓			

Affordability assessment

	Quick payback	Slower payback
High cost		
Low cost		**€0 & 6 years**

Including renewable energy supply in tenders for ITS installations would reduce non-renewable energy use. Provide infrastructure designs that allow solar panels to be fitted, for example on the back of message signs and use the 'whole-life energy cost' approach described in the 'adding whole-life energy costs to suppliers' unit cost' to incentivise suppliers to use this space. Or, if the device is relatively small in terms of energy use, for example a traffic or weather detector, simply state that mains electricity will not be made available for the device and the device must be self-powered.

Energy saving (%)	50%
Estimated cost	Will usually pay for itself (more so, if cabling and trenching costs are taken into account.)
Estimated annual electricity cost saving	
Estimated annual energy saving	
Payback time	During the lifetime of the product.
CO_2 savings	
Best time to implement	During procurement

Pushback

Equipment suppliers may not be sufficiently skilled in terms of solar generation and may be reluctant to offer self-powered devices.

6 Good practices by the client

Once these practices are engrained in the business, they ensure that whatever the NRA is doing, it achieves a reduction in energy use. Contractors prefer consistent behaviour from a client as they can then have consistent processes that deliver a consistently high-quality product.

❶ Purchase equipment based on the whole-life cost of the equipment

Do not simply assess the product on the basis of the purchase price. This is not what people do at home, for example when buying a fridge. Instead, they asses the whole-life cost, which is the unit cost plus the cost of energy over the whole life of the product (see the first intervention for ITS).

❷ Conduct design reviews

Before purchase or after the design but before the start of construction, challenge the designer to determine whether the energy use has been minimised in the context of the target price and delivery timescale. Understand the energy use relative to previous similar products and what energy-saving measures have been implemented, and more importantly, which ones were not and why not.

❸ Do not pay someone to buy on your behalf and expect them to buy the best

NRAs often pay contractors to buy from suppliers on their behalf. Contractors (for example, a contractor has been paid to replace jet fans in a tunnel) will purchase quite low-cost equipment in order to get their overall tendered contract price low. A better approach would be to award the contract based on the design-and-build cost, and for the NRA to pay the cost of equipment selected by the contractor. However, the contractor must select equipment based upon the NRA's whole life cost model. (*A similar situation would be if a home-owner asked a builder to extend his/her kitchen and fit a new kitchen unit/equipment. Most people would pay the builder for the building work, buy the new kitchen themselves, and then get the builder to fit it, otherwise they run the risk of the builder installing the cheapest kitchen he/she could find)*.

❹ Monitor and manage

Keep data on how energy use is changing over time. The purpose is to identify which asset types are using more energy than in the past, whether manufacturers' claims about energy use are being realised at the roadside, and whether there are regional variations in energy use. This enables NRAs to identify emerging weak points in the system and to react.

CEDR report 2016/03 Energy Efficiency in Road Operations and Management

TD Innovation 2016

ISBN: 979-10-93321-19-6

Conference of European Directors of Roads
Avenue d'Auderghem 22-28
1040 Brussels, Belgium

e-mail : information@cedr.eu
Tel. : + 32 (0) 2 771 2478