However, it can be noted that within such cost reduction strategies, there is a gradual move towards a more sustainable approach. A certain number of innovative actions have been conducted with a clear step towards sustainable development, encompassing all three pillars. It has been observed that many countries have strategies and targets for energy savings. However, there are legal requirements that need to be met.

The following two sections summarize the current situation, with:

- Section 4.3 focusing on the reduction of operating costs;
- Section 4.4 presenting actions that reflect a more sustainable approach.

4.3. ACTIONS TO REDUCE TUNNEL OPERATING COSTS

As we saw earlier, the optimization of initial investments is a major concern for road tunnel designers, owners and operators. In addition to investments, it is necessary to take into account operating costs within a sustainable development approach. This section examines this subject in more detail. First, the various components of the operating cost of a road tunnel are identified. Then, the relative influence of each component is evaluated. Finally, cost reduction paths are presented.

Information on identifying the operating costs of a tunnel, as well as the appreciation of their respective weight is, in some cases, taken from previous PIARC reports [2], [3] and [4].

4.3.1 Identifying a tunnel's operating costs

Tunnel costs include energy and power supply, tunnel washing and cleaning, staff (control, maintenance and emergency crews), maintenance (preventive and corrective) and reinvestment (needed for refurbishment).

Some costs vary widely from country to country, partly because the regulatory requirements are different. It is for this reason that operating costs don't include the cost for periodic exercises and inspections, public information campaigns, training of personnel, and the cost of remaining informed on the latest innovations and improvements,

The present guide does not take into account reinvestment costs and we can therefore divide operating costs as follows:

- Energy;
- Maintenance;
- Staff.

Energy

Almost all of the equipment installed in a tunnel requires electrical energy which is usually bought from a supplier. Depending on the power required to guarantee the smooth running of equipment, power supply may be high-voltage or low-voltage. Generally, it is high-voltage if the tunnel is equipped with a ventilation system.

For a tunnel operator, energy expenses are directly related to two parameters: the power required for each family of equipment and the duration of functioning of each family of equipment.

Maintenance
The aim of tunnel maintenance is to ensure safe driving conditions for users by keeping the tunnel at the designed technical standard.

All maintenance tasks should be performed as preventive and/or corrective maintenance. As mentioned in a previous PIARC Report [2], these are defined as:

- Preventive maintenance, which keeps the systems in a good and safe condition. Preventive maintenance is justified on the grounds that without it, the systems could become unsafe and/or could only be brought back to a safe condition at high cost. This maintenance has the advantages of ensuring safe and optimum performance of the facility, limiting surprise failures and can be easily planned. The disadvantage is that parts of the facility will be prone to premature replacement.
- Corrective maintenance and/or replacement carried out after systems have become critical or failed. This has the advantage of achieving a maximum lifespan for components of the facility. The disadvantages are that planning is difficult, unsafe situations can arise due to failure and extra costs can be incurred in the event of damage resulting from the failure.

To both types of maintenance defined above, it is now very frequent to associate two other domains:

- The recycling of the various devices used in a tunnel when these devices reach the end of their life cycle;
- The treatment of effluents before their disposal outside the tunnel.

Staff
In broad terms, the operating staff can be classified into three categories:

- Operating personnel (control staff and maintenance staff), dealing with traffic management and technical management;
- Administrative and logistical support personnel (administration, finance, staff, management, etc.);
- Incident first response staff. There may be external emergency rescue teams. If the tunnel organization has enough resources they may have their own first response staff.

4.3.2 Respective impact of operating costs

The main energy-consuming devices in a tunnel during normal operation are:

- Lighting;
- Sanitary ventilation;
- Safety devices (signalling, closed circuit television CCTV, etc.);
- Pumping (in subsea tunnels or when there is water seepage.

The respective share of each of these energy-consuming systems varies greatly, depending on the specific characteristics of the tunnel: length, gradient, water ingress, etc. Let us consider, for example, the case of a short tunnel: it will not be ventilated (therefore the ventilation element is removed), but it will be lit with entrance zones covering almost its entire length and, due to its shortness; lighting will be a major energy-consumption factor. In contrast, for very long tunnels, the energy-consumption of lighting will be low compared with the energy-consumption of the ventilation system.

In terms of optimization, ventilation and lighting systems are very attractive because the potential gains can be high.

The table below summarizes the impact of broad families of equipment (with the exception of smoke extraction in case of fire) in terms of electrical consumption, according to the length and type of structure (unidirectional or bidirectional). The information provided should be considered as a general trend as the specific characteristics of a particular structure may lead to different findings.

TABLE 6. POSSIBLE INITIATIVES FOR A TUNNEL MANAGER OR TUNNEL OPERATOR

	L ≤ 500 M	**500 M < L ≤ 3 000 M**		**L > 3000 M**	
	uni and bidirectional	uni	bidirectional	uni	bidirectional
Lighting	Very major	Major	Average	Average	Minor
Ventilation*	No impact	Very minor	Average	Minor	Major
Safety equipment	Very minor	Minor	Minor	Average	Average
Auxiliaries and miscellaneous losses	Very minor	Minor	Minor	Average	Average
Pumping	Minor	Minor	Minor	Minor	Minor

Note: The information above only has comparative value within the same column (for instance, electrical energy consumed by lighting is greater when the length of the tunnel increases, but its relative share within the total consumption decreases).

* This includes the continuous ventilation of escape facilities and shelters. However, environmental ventilation (air exhaust to avoid portal pollution) is not considered in this table..

Finally, it must be noted that optimization for energy consumption has to be done not only during design and building phases but during all the tunnel life.

Maintenance

The maintenance share is difficult to assess as it is largely dependent on the maintenance policy in place.

If maintenance is mainly carried out by the operator's staff then the cost is relatively low, but as the number of personnel increases, staffing costs are greater. In contrast, if maintenance is completely outsourced, associated costs will be greater but the share for staffing costs will be less.

Generally, the operator has internal teams to carry out a significant amount of the maintenance work and will outsource the rest to subcontractors.

Staff

Regarding control staff, a legal framework exists in many countries. Some requirements are

compulsory, while others are only recommendations. For example, if regulations demand the presence of a supervisor at the control centre 24 hours a day, then this requirement must be met. Similarly, if regulations require patrols (at given intervals) or the presence of first response teams, it would be difficult to reduce the number of personnel on site.

According to the proportion of subcontracted maintenance, the size of the maintenance staff will vary. The use of subcontractors is strongly linked to the maintenance staff (number and competence) which the tunnel operating body can practically and economically fully employ. It also depends on the complexity and the nature of the installed equipment and the specialist skills required.

4.3.3 How to reduce tunnel operating costs

It is recommended to use a kind of benchmarking to evaluate the difference between different tunnels, regions, countries (e.g. energy consumption, staff hours…). Some practices are defined in a previous PIARC reports [1] and [2], (for example: optimization of resources and implementation of an operating strategy in compliance with approved safety concept).

Energy
In relation to energy expenditure, the first thing that an operator can do, for any given energy requirement is to play competitors off against each other by consulting several suppliers that provide the kind of electricity to be used (renewable energy). This approach assumes that the installation is optimized in terms of the power installed and the operating times of the various pieces of equipment.
In effect, we have seen that energy expenditure is closely linked to two factors: the power installed per family of equipment and each family of equipment's operating time.

For each family of equipment, the installed power is assessed during the study phase and is fixed during the implementation phase. Once the structure is operational, the power can mainly be changed during renovation. At this time, it may be decreased if the regulations haven't changed and if the energy performance of the replacement equipment has improved. It may be increased if regulations have become stricter (for example: greater smoke extraction capacities).

Basically, outside of renovations, if an operator wants to reduce its expenditure on electricity, it can only do so by optimizing the operating times of the installed equipment and by monitoring peak hours.

Maintenance
The nature and number of maintenance tasks to be carried out of course depend on the number and characteristics of the installed equipment, but also depend on the level of traffic and the working conditions on the road and in the technical facilities. That said, for any given structure, the operator may optimise its maintenance by focusing primarily on the planning of the tasks to be carried out.

It is important to consider not only maintenance costs but also the social impact of the closure of the tunnel (availability of the tunnel).

To do this the operator may:

- Develop its maintenance plan based on feedback;
- Use a computer-assisted maintenance management system;
- As far as possible, group tasks to reduce road marking costs;
- Establish internal monitoring indicators.

Staff

As we have already said, potential gains in terms of workforce optimization often depend on according regulatory requirements.

A greater degree of optimization is possible in relation to monitoring and maintenance methods. For monitoring, it is advisable to group the operation of several tunnels together.
For maintenance, it is preferable to call upon external companies for highly technical tasks if there are not a lot of equipment units.

4.4. ACTIONS THAT REFLECT A MORE SUSTAINABLE APPROACH

This section presents a few innovative ideas or studies that have been conducted or are currently being conducted in different fields and in various countries, and which reflect a more sustainable approach (non-exhaustive list):

- Escape gallery for users;
- Lighting;
- Ventilation;
- Air filtering;
- Treatment of effluents;
- Recycling;
- Maintenance;
- Staff and partnerships.

Some of the above-mentioned initiatives have actually been implemented (creation of an escape gallery in an urban context, remotely controlled lighting, more efficient jet fans and filtering of exhaust air).

These initiatives have been assessed (advantages and drawbacks) with regard to their possible economic, social and environmental impacts.

More detailed descriptions of the different actions recorded are provided in *appendix E* (Implementation of an escape gallery in an urban context, light transition arch, remotely controlled light sources, new jet fans, air filtering, optimization of transformers, solar energy).

4.4.1. Escape gallery for users

Depending on the regulations of each country and tunnel characteristics, certain road tunnels must be equipped in such a way that they enable users to reach a place of safety (emergency exits, cross-passages between tubes, escape gallery, shelters…). These safety facilities are quite costly to implement, but fortunately seldom need to be used.