TELECOM INFRA PROJECT

Leveraging Streetlights for the Digital Future

Exploring the drivers, barriers, and opportunities
based on interviews with experts, conducted
in the German streetlighting ecosystem

mmWave Networks Project Group

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Table of Contents

1. Introduction

Enabling comprehensive broadband coverage and developing smart cities are core tasks in this digital age. They converge in their need for fast and flexible deployment. And they're interdependent, in that providing broadband access—especially in public—is a basic requirement for enabling smart cities. In turn this will drive demand for more bandwidth and better access through the promises of greater efficiency and better living they carry.

Demonstrably, optical fiber deployment isn't the only way to provide broadband access. Wireless networks having great speed and efficiency can be established, and can be created for substantially less cost and with minimal (if any) construction. Such wireless technologies can extend the same sort of reach as fiber deeper into neighborhoods. As laid out in *TIP Playbook for Smart Cities*, this means communities no longer have to wait years to finally get affordable, high-speed broadband access—in addition to other smart city services.

Deploying such networks requires assets in public space. The nature of new, fairly small radios used to build wireless networks no longer requires dedicated cell towers. This lets us consider other assets, such as residential or commercial rooftops, light standards, water tanks, street fixtures (e.g., light posts, traffic signals), and other vertically-oriented structures that provide line of sight to targeted facilities and residential areas.
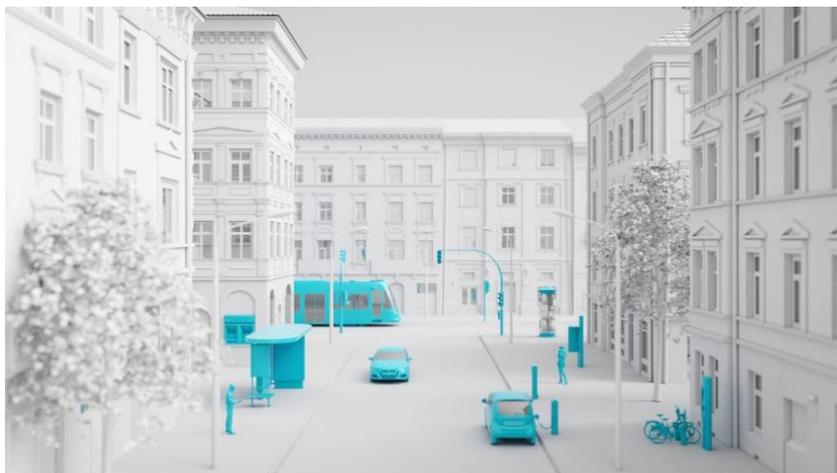
Figure 1

Given dense development in many European cities and the smart-city-driven need for a network presence public space, it would be beneficial to take a closer look at one such vertically oriented asset that is almost ubiquitous—streetlights.

In a Digital Networks Working Group handbook by the Federal Ministry of Transport and Digital Infrastructure (Germany), streetlighting infrastructure has been identified as being very suitable in comparison to other street fixtures.

		Extension of macro locations	Development of new macro locations	Development of new Small Cell locations	Remarks
Antenna masts		Very suitable	Very suitable	Not very suitable	Expansion for macro cells is necessary anyway.
Catenary masts			Not very suitable	Suitable	Country-wide availability. High voltage problematic.
Lighting poles			Not very suitable	Very suitable	Available everywhere and already completely expanded. Many regionally uniform VP.
Traffic lights			Not very suitable	Not very suitable	Above all, road safety aspects prevent its use.
Traffic information signs			Not very suitable	Suitable	Above all, road safety aspects prevent its use.
Passenger information boards			Not very suitable	Very suitable	Not available everywhere. From static perspective difficult.
Building roofs. Roof edges		Very suitable	Very suitable	Suitable	Mostly unsuitable for small cells. High number of contractors.
Building facades			Suitable	Very suitable	Extremely high number of contractors (VP).

Source: Cf.: **Potential for shared use of municipal carrier infrastructures for the expansion of the next 5G mobile phone generation**; A handbook of the Digital Networks Working Group of the Federal Ministry of Transport and Digital Infrastructure; Editor: Federal Ministry of Transport and Digital Infrastructure; Published September 2019; 38 pages

Deutsche Telekom initiated a study to explore such fixtures and possible pathways to accessing them. Before tackling any challenges, we wanted to understand what the "landscape of the players' ecosystem" looks like, what drives it, what slows it down or stops it from moving, how it works today, and what may need to change.

We did this specifically for our German home market, but feel confident that the study results can serve as pointers for the challenges and opportunities this asset poses for many other markets. We also believe the political and legal challenges will be very similar for similar assets apart from streetlights.

The study set out to describe the rules and regulations of public administration, public economy, and public law to which this infrastructure is subject, as well as to identify challenges, opportunities, and potential for its future design.

We chose a design thinking approach because we need to understand the players and stakeholders who control this infrastructure. And we wanted to undertake this before assessing what can and should be done with these potential assets to enable comprehensive broadband coverage and smart city development.

2. Objective, Method

Our goal was to analyze the ecosystem and gain a better understanding of its landscape. We sought to identify the pains and gains of respective players in the sense of their interests, drivers, barriers, and changes. We sought to flesh out starting point opportunities for successful, expanded use of streetlights for digital services.

This was part of a wider exploration of the subject that went under the working title of TelePoles. We'll be using this name as shorthand for the notion of having public utility poles (such as streetlights) serve as infrastructure in support of broadband access and smart city applications.

We specifically wanted to look into a possible installation platform for ICT equipment (transmission technology and smart city sensors/equipment) and shape the market for this. The challenge would be to imagine a fast, cost-efficient, and modular ecosystem having a high degree of standardization that enables use of streetlight masts for digital services in public space.

The study was conducted by [Q] Research Agency along with Katja Henke and her Deutsche Telekom team, using desk research and interviews with experts within the entire ecosystem. We explored the current use, management, modernization, new use possibilities, and subsequent challenges.

Initial desk research was able to clarify some of the open questions. In a second step, we interviewed 17 streetlighting experts from disparate functions of the broader ecosystem between May and August 2019. Interview topics included:

- the current use and management of urban lighting and its modernization
- potential new uses of streetlighting along with its implications and challenges
- the views and interests of municipalities and other key stakeholders about the expanded use of streetlighting to help in providing broadband and smart city applications

Participants included officials from municipalities, operators, pole manufacturers, and service providers. Interviews lasted between 60 and 150 minutes and were conducted by way of personal conversation (7) or telephone (10). Each was based on a set of guidelines coordinated with the Telekom team and developed over the course of the project.

Through our exploration we have gained a good understanding of both what drives and hinders the respective players. Through uncovering comprehensive and valuable insights,

we've laid the foundation to address the challenges and even make initial recommendations.

As a result, we share our assessment that streetlighting can serve as a location for ICT technology. This is a technical upgrade accelerator for broadband supply and smart city.

Being streetlighting owners and responsible for their functionality and maintenance, municipalities are of central importance to this success factor. However, local authorities still lack prerequisites; exchange among experts remains at an early stage. Along the way, manufacturers and those responsible for lighting provided valuable insights regarding communities and the challenges they face.

A few municipal interviewees had long been thinking about possible streetlight use for purposes other than lighting. All had a good overview of municipalities and projects. Being well connected, their network would meet at seminars and congresses, as well as on a personal level. Yet others had little or no interest in this topic—they provided important insights regarding those who are at the beginning of such consideration.

In addition, there are streetlight manufacturers, planners, and operators who are directly or indirectly linked to municipalities as clients; they want and need to work closely with the latter. Given their external view of municipalities, and with respect to the future of streetlights as TelePoles, this group provided deep insights into challenges they face due to their own economic interests.

3. Inventory: Street Lighting Infrastructure Today

City lighting serves public safety and is therefore essential for all citizens. However, the state of such technology is very heterogeneous within and between municipalities. There is no federal cadastral registry.

Operation is often outsourced on long-term contracts to public utilities or private energy supply companies. Economically, they're considered a cost factor requiring long-term management to minimize costs. Networking and digitalization are discussed, but their potential is considered unspecific, risky, and currently not plannable. Thus, municipalities lack the vision regarding how to use and exploit streetlights, in addition to lacking the means and personnel to further the issue.

Opportunities can be seen in the ongoing conversion to LED and the trend toward "intelligent" lighting control for TelePole modernization. This ongoing development could be used to create synergies and expand subsidy programs for the modernization purpose. After existing contract expiration, a bidding requirement for entry with lighting partners can be used to further this. Offering monetizable benefits could open up possible economic benefits to municipalities.

3.1. Meaning and purpose of streetlighting

The future use of streetlighting to provide new digital services at street level is highlighted by their current global use and importance in municipal infrastructure.

Respondents unanimously described essential points. These reveal the great potential of this infrastructure—which covers almost the entire settled area—as a carrier for digital networking of the public space:

- Streetlighting is a municipal duty and an important concern for citizens. It contributes significantly to their subjective sense of security. Municipalities and their citizens are accordingly anxious for it to function well and without failure, to fit into the cityscape and meet aesthetic requirements.

- Interviewees reported "there is no other infrastructure in cities that is as continuous and as well developed as streetlighting." It's estimated there are about 9–9.5 million light points in 14,000 German municipalities. On average there is a mast every 50–60 meters, and in rural areas every 90–100 meters. Yet there is no

nationwide or locally differentiated cadastral register regarding the streetlight condition and composition.

- The function and infrastructure of urban lighting changes only slowly. Streetlight masts remain standing for 35–50 years or more. Lamps last about 25–30 years. Such longevity is an important aspect of municipal cost accounting, especially since streetlighting accounts for around 10% of electricity consumption in Germany (12.4% worldwide) according to studies by Naturschutzbund Deutschland e.V., a nature conservancy organization.

- Inventory is characterized by a great variety of conditions. Mast age ranges from new units with LED lights to post-war masts over 60 years of age. Usually the lights are electrically operated; rarely do some still use gas. Some are suspended from ropes across roads or attached to house walls.

  Light sources, mast heights, mast materials, foundations, static qualities, weak points, manufacturers, series, light sources, power consumption, control units, and contextual conditions (e.g., number of cables and cable cross sections) vary widely within and between municipalities.

- The economic analysis of streetlighting investment is a long-term affair. Renewal is planned over the long term; this is to avoid situations requiring quick replacement at great scale (i.e., the investment requirement). To relieve the burden on public coffers, each system is updated or replaced only if absolutely required.

3.2. Streetlight operation

City lighting operation varies. Some municipalities run systems themselves; others outsource it to external parties (e.g., municipal utilities, electricity supply companies). Contracts often run for decades. The link between a municipality and companies that operate streetlights is correspondingly close. But for some years these contracts have had to be bid upon when they expire. This offers opportunities for new players armed with good concepts for the expanded use of streetlighting.

3.3. Infrastructure value from local authority point of view

It was unanimously pointed out that municipalities see streetlighting as a cost factor representing a compulsory task. Fulfilling it is seen as valuable, but costly with no income generation. Increasingly yet still tentatively, municipalities are becoming aware of the importance and possibilities of network digitalization in the public sphere. The German government's Smart City Agenda—coupled with the public debate and the occasional

interested party having ideas for streetlight use—are increasing this awareness. The ground for positive perception is being prepared.

Expanded streetlight use not an issue to date

Because this perspective has been lacking so far, our discussion partners hardly had any plans to make more of existing streetlights. Yet individual inner city Wi-Fi projects and intelligent lighting control pilot projects do suggest basic interest and a related user perspective.

However, commercial implementation on a larger scale is not yet tangible. Practically everything is missing for new usage concepts:

- well-defined applications
- predictable use prospects
- resilient solutions for operation
- organization
- business models
- definition of responsibilities

Above all, municipalities lack the financial resources and personnel to take on the task., They're also dependent on local supervision and local politics. In addition, many clearly defined tasks demand their focus. Therefore, the room for "experiments" with new digital networking possibilities is often limited.

Some non-municipal conversational partners also complained about this. The expanded use of streetlighting is not progressing due to 1) the local authorities' fixation on cost, and 2) their lack of imagination regarding potential use cases and monetization strategies. Since municipalities don't recognize the opportunities, they only invest in what is absolutely necessary.

> *"Municipalities just don't think like entrepreneurs. They're risk averse. They can't and won't afford experiments. And that's why they don't undertake anything."* (lighting systems manufacturer)

So much is still in its infancy. But this also means there are currently great opportunities for players who can present suitable technological solutions and interesting business models to municipalities—demonstrating how the expanded use of streetlights can reduce costs, generate revenue, and facilitate necessary investments.

The opportunity presented by the LED modernization wave is currently being used only hesitantly. Promoting the integration of technical prerequisites for the expanded use of streetlighting in this process could mobilize many synergies. Since this isn't happening at present, opportunities and commercial potentials remain untapped. There are several reasons for this:

- LED conversion takes place within the framework of existing resources and strict economic viability audits. Financing, economic efficiency, and technology must be planned. An administration and city council must examine and approve them. This also applies to investments, future operating costs, and incidental costs for new applications. However, these are not currently known to TelePoles and therefore cannot be defined and scheduled. Existing funding programs that play an important role must also be expanded in this direction.

- Decisions pertaining to technical modernization and the awarding of contracts are based on approved standards and technologies. Any technology that has not been tested, checked, and approved cannot be taken into account.

- Planning made in this way cannot simply be overturned. Every major change requires renewed coordination and approval processes.

4. Interests, Barriers, and Framework Conditions to Street Lighting Use for Future Digital Services

The lighting network today is at its limit in many places. The power supply is limited, and continuous current is often not applied; all the while specifics of the power supply and safety requirements must be observed. Masts often have narrow static limits. Upgrades are only partly possible. Business models don't yet exist, and their development is still in its infancy. Legal and political challenges require solutions.

Opportunities present themselves in the LED retrofitting, as that will partially free up power capacity. Defined minimum requirements for masts and related power supply make upgrades and renewals more predictable. Financing of upgrades—or new masts—could be attractive for municipalities. Anyone who now offers viable and acceptable business models and legal solutions while adapting to the political environment will gain great advantages.

To enact expanded use of streetlighting, some challenges have to be addressed with old inventory as well as with that which is already modernized.

4.1. Technical aspects

Power supply challenge – In many cases, there is currently a lack of sufficient power supply for an expanded use of streetlighting.

What to keep in mind:

- In many municipalities, streetlighting only has electricity during hours of darkness. A constant power supply is a prerequisite for TelePoles.

- In many places, the lighting grid and power supply for the masts are at their load limit. Additional consumption scenarios are therefore difficult or impossible because the energy supply is insufficient. LED conversion and the resulting reduction in power consumption can make capacities available. Currently a mast consumes between 60–120W. However, safety requirements have to be observed.

  o Approaching the load limit range slows down the release speed of fuses. Full exhaustion of the technical load limit would be tantamount to a breach of safety. The prescribed switch-off safety would be endangered.

- o Special safety requirements exist at hazardous points, such as traffic lights or pedestrian crossings. These require a particularly high level of reliability. The use of this infrastructure as TelePoles is considered problematic by the involved parties.

- The most common case is a three-phase 32A supply. Only every third mast is connected to the same phase to distribute the load.

- Cable length is important in determining total resistance. The longer the cable, the lower the load capacity.

Conclusion – Power supply is a core critical issue. This is why many of the interviewees observed that streetlighting would not be the right infrastructure for supplying future e-mobility with charging capacity.

> *"For me, it's quite clear that the entire issue of energy supply for e-mobility will have nothing to do with the lights. That's not possible. We will prevent this from happening at the outset. We've made it clear that it must be connected to such a point where the energy supply is stable and sufficient for this purpose. City lighting isn't one of them."*
>
> (energy supplier)

Possible power supply solution

- LED conversion makes it interesting for some municipalities to switch to permanent voltage to better control their lights. However, for streetlight operation this technology change means a paradigm shift that requires investments to design cables, control systems, and fuse systems accordingly.

- o A lighting operator reported they wanted to use the former control line as a continuous current line in their network. Two connections can thus be realized in the cable junction box—one with continuous load and one with day/night switching.

- o However, reference was made to the consequences of continuous voltage—it must be possible to operate switching for each lamp individually, so it doesn't light up permanently. This implies a new control technology and therefore costs. As a rule, maintenance and repair work may only be carried out without voltage. To do this, electricity would have to be switched off for entire streets, which would leave other consumers without power.

- The use of rechargeable batteries to bridge the daytime switch-off was also discussed. It wasn't considered to be very viable, as they had to be serviced and replaced at regular intervals. In addition, there are hardly any pole solutions that really enable battery operation (e.g., lack of space, inappropriate use conditions).

Mast challenge – Many masts are not prepared for further applications.

What has to be considered – Mast statics play an essential role for what can still be attached to them. The scope is frequently narrow. Due to strict regulations, a new stability test must be carried out by specialized companies when mast modifications are made.

- Some lamp masts are built without foundations, which leads to lower load capacity.

- Mast free load capacity is reduced because special precautions have to be taken into account, such as wind pressure and ancillary uses (including temporary uses, such as traffic signs and election or advertising posters).

- Some municipalities have installed masts with a higher load-bearing capacity; they're able to act more flexibly in the future when requirements change, e.g., retrofitting or upgrading to traffic light masts. This is a positive development.

- In some cases, there are no masts alongside the street. Streetlighting is suspended from wires stretched across streets, because onsite circumstances require this (e.g., narrow sidewalks, no space for erecting masts).

Some masts are not suitable for upgrading due to their height.

- The so-called "vandalism height" of at least 4.5m for equipment attached to masts cannot always be guaranteed.

- Mast height varies, so line of sight (for example) cannot always be guaranteed. This sets limits on transmission technologies that require line of sight, such as 60 GHz.

- In some new development areas, lower lighting poles are often used for aesthetic reasons.

- Trees can interfere with wireless transmissions. In some cities there are also programs to increase tree-planting.

Mast solutions

The range of possibilities for upgrading old masts is unclear, as respective technical conditions vary. The question will be, 'What costs are acceptable?' Here a catalog of minimum requirements for existing masts would be helpful to obtain clarity. If upgrading isn't an option, new masts would be a solution.

In this context, streetlighting operator interviewees specified requirements for a standardized ecosystem:

- DIN standards should be observed. These aren't always prescribed, but network operators usually follow them.

- To be compatible with other smart city systems already in use, TelePoles should have open interfaces (i.e., IEEE certified).

- TelePoles require an open and modular system architecture to be connectable, upgradeable, and retrofittable (and thus future proof). A further goal is to make service, maintenance, and repairs easier, faster, and more standardized. As of now far too little attention has been paid to this because lighting function dominates the planning.

- Connectivity is also needed for the lamps—the ability to dock to an IoT platform/APE interfaces, compatibility with CISCO, Microsoft, et al.

> *"Open systems are the key, even before we start talking about any product solution."* (city administration, city of 250-500k inhabitants.)
>
> *"If we want to talk about IoT—and smart city means IoT—then I need open systems."* (manufacturer of lighting and smart city products)

4.2. Business models

The challenge – There are hardly any ideas as to what business models could look like for an expanded use of streetlights. This is not an issue yet and hasn't been thought through by municipality respondents at this juncture. However, they were aware of the issue's importance, which will inevitably arise through the integration of other players.

What to keep in mind: The focus is on financial and long-term economic viability.

- Risks and costs must be limited or eliminated; they're currently unknown over the long service life of a streetlighting unit and cannot be quantified. Opportunities and potentials are not specified either. Nobody knows, for example, which applications—such as those pertaining to smart city—really make sense and how they can be used.

- Local municipal conditions play a major role—in particular the financial strength of municipalities and operators and the willingness to invest. It will develop along the same lines as fiber optic rollout. Some municipalities look to private sector providers; others are in favor of networks operated by municipal utilities to make sure they can keep shares in the future.

- Predictability: The resulting distribution of burdens, returns, opportunities, and risks are essential and must be predictable. Currently they're not.

- Responsibilities and competencies: Business models must reflect the competencies and responsibilities of everyone involved. They must also reflect incurred costs (e.g., malfunctions, repair needs). This needs to be done with a view to resulting damages, coping measures, and claims for compensation, communication, and settlement with injured parties. During discussions it became clear that these questions had not been clarified in any way up to that point.

Solutions for business models

Respondents were unable to propose solutions, but were open to discuss aspects and some initial ideas. It became clear that it's imperative to lay the foundations—you can't develop business models without them. You need clear statements about applications, investments, costs, benefits, and revenues. The more clarity is created, the more interesting it becomes—and the more important business model design is likely to become. It's also important that the models make clear how municipalities will remain involved in this digital future.

"For us, modernization is also a burden, a disadvantage. If we modernize or rebuild for the benefit of new uses, this increases the expenditure in acquisition and operation for us in every respect and brings both advantages and disadvantages. We see this as one of the disadvantages that should be compensated."
(public utility company of a municipality with 250–500k inhabitants)

"Will investments pay for themselves at all?
Do they make economic sense?"
(Municipality, 100–250k inhabitants)

Individual ideas and elements for business models were addressed against
this background:

- Incidental costs: Users must bear the costs they incur with operators and municipalities (e.g., electricity, service costs, participation in other costs incurred). However, methods and systems must first be developed that can record such costs and attribute them to users. They could then be settled in regular intervals that need to be determined.

- Flat-rate: Amounts that users (such as telecommunications providers or others) pay to lamppost owners or operators are contractually fixed. But it's unthinkable that non-municipal operators would use their position and do new business without consent of the municipality. Contractual relationships between local authorities and operators would have to be taken into account and newly regulated.

- Third-party investments and term financing have an interesting effect if third parties carry out nationwide mast upgrades or replacements on their own. Here they would bear the initial financing, freeing operators or municipalities having little budgetary leeway from high initial investments. The modernization could then be paid off over a fixed period.

- Ecosystem suppliers (e.g., energy suppliers) could enrich their actual business (e.g., network operation) with additional modules for which they assume responsibility (e.g., TelePole maintenance). Larger partners, such as Deutsche Telekom, could bundle such services as main contractors and be fully accountable to the streetlighting operator. In this model, the latter would become purchasers of a standardized TelePole ecosystem with only one partner in charge.

- Important: Responsibilities have to be defined, in addition to development of procedures and cooperative partner processes to serve as a business model reference point.

4.3. Political and legal aspects

The political challenge

Larger investments have to be approved by the city council and find majorities. This applies to LED retrofitting projects as well as the retrofitting or expanded use of lamps. To accomplish this, city administration and the operator must come well prepared.

What to keep in mind

- Majorities only occur with arguments that city councils want to see and that are indisputable. Councils and the public ask questions about opportunities, risks, participants, and conditions. Without sufficient answers, such projects are political risks that tie up time and energy without promising a return.

- Expanded streetlight use would move the issue closer to citizens and attract attention. Our respondents expect it to generate fears and reservations. Resistance and polarization in the urban society should be avoided or absorbed through communication.

- In addition, this constitutes a strategic decision regarding future orientation and is not a one-off investment. It raises a question about the future viability of technologies and partners. (No one wants to be criticized for having placed their bet on the wrong horse.)

"This has to work properly, or it's my head on the block."
(Municipality, city of up to 100k inhabitants)

"If Telekom later fails or causes problems, I and everyone else in the decision-making process will be held responsible. That's when you think about what you're getting yourself into. Especially the mayor. In the past, we have had some pretty bad experiences with Telekom. That doesn't exactly stimulate an appetite for risk in those making political decisions."
(Municipality, city of 100–250k inhabitants)

Solutions for political aspects

Expanded streetlight use needs predictability and a clear, convincing, and verifiable benefit profile for municipalities and its citizens. For every municipality, it should be considered as a political project of fundamental and strategic importance, undertaken together with municipal partners. Such projects require communicative and acceptance-creating support. This means seeking early stage dialogue with key stakeholders in politics and

society—listening to them, taking them seriously, and responding to them. In addition to solutions to already-mentioned technical and economic challenges, approaches aimed at building acceptance, trust, and credibility must also be developed early on. Best practice experiences as well as a public dialogue platform can help in this respect.

The challenge of legal aspects

The aforementioned aspects and risks cannot be assumed without legal protection; the legal and business framework must be designed in accordance with the new conditions.

What to keep in mind

- The structure is changing from a bilateral "municipality <> operator" system to a multilateral one. New partners are added who change the established structure. This requires expertise and legal assistance, plus time and effort to assess legal risks and develop solutions.

- Details also count—for example, often masts are not available for modification (or only in very specific ways) without losing the manufacturer's warranty. Responsibilities and liability issues must be regulated when several mast participants come together. Claims for damages must be examined and safety regulations observed.

"No one must be allowed to shirk responsibility."
(Municipality, up to 100k inhabitants)

Solutions for legal aspects

For municipalities it could be very helpful if external players would create a legal framework together with other relevant players (e.g., from municipalities and their associations) to serve as a blueprint. Municipalities could then adapt such a guideline to their local needs without having to develop them from the ground up.

5. The Player and Stakeholder Landscape in the Current and Future Road Lighting Ecosystem
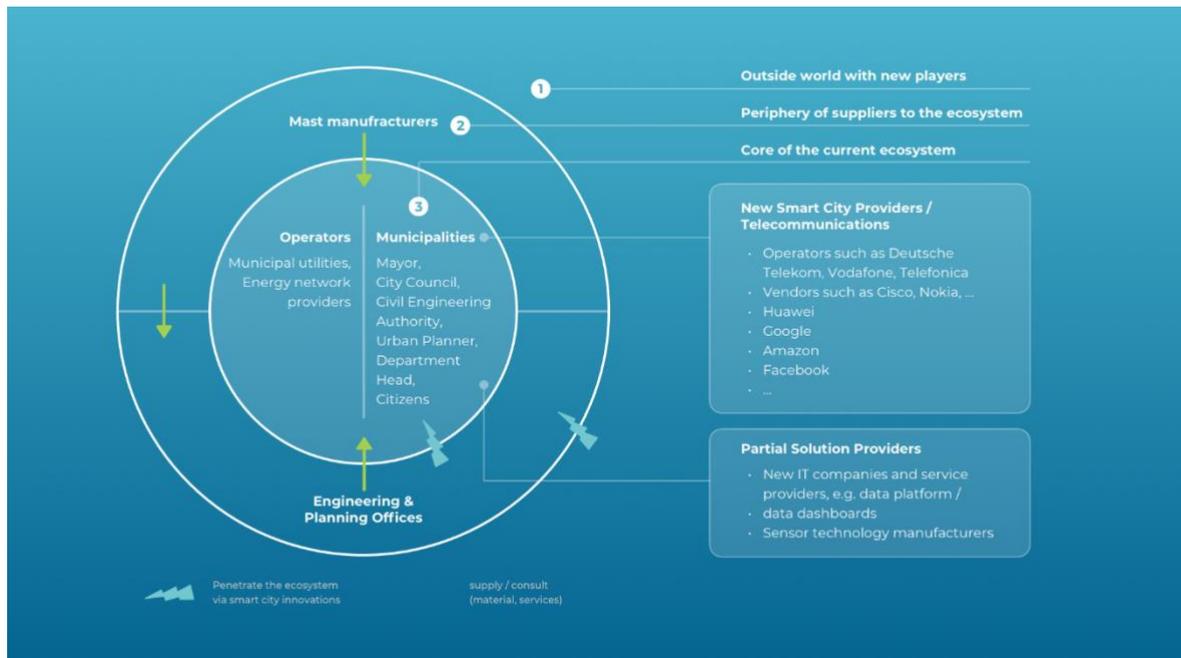
Figure 2 High-level view of the ecosystem players

Municipalities tend to be essential, risk-averse players in a well-established ecosystem. Within them, many players and their interests need to be balanced out. They lack the initiative, know-how and resources to develop digital urbanity. After municipalities, operators are the most important players, but depend on the mandate of municipalities. Next in line are various suppliers and service providers—some being of great importance, such as mast manufacturers.

Opportunities for the TelePoles project – All key players believe the prerequisite to future digital urbanity points to expanded use of streetlighting, as it holds great potential. But not one is willing or strong enough to take the lead. This offers outsiders having some weight and know-how the chance to enter and fill this ecosystem gap.

The determining factor to using streetlights as TelePoles lies primarily with municipalities —the owners. They hold the purse strings, deciding whether—and under what conditions—to invest, as well as which new applications will be given a chance.

Another important group are those who seek the contracts to help municipalities fulfil their lighting mandate. Here the most important players are the operators.

Our discussions highlighted the importance of all relevant players functioning and cooperating smoothly. Municipalities and their operators—the primary ecosystem relationship—succeed in doing this thanks to tried and tested contractual relationships. Rights and duties have been clear for decades. Innovations are limited and can be integrated into a familiar service portfolio with comparatively little effort.

The secondary ecosystem relationship requires coordination within the municipalities themselves. Here there are well established and commonly accepted principles and routines.

The third relationship level that of external players, such as manufacturers of masts and lights, construction companies, and planning offices. The same scenario applies here, in that everyone knows well what one can and must expect from others.
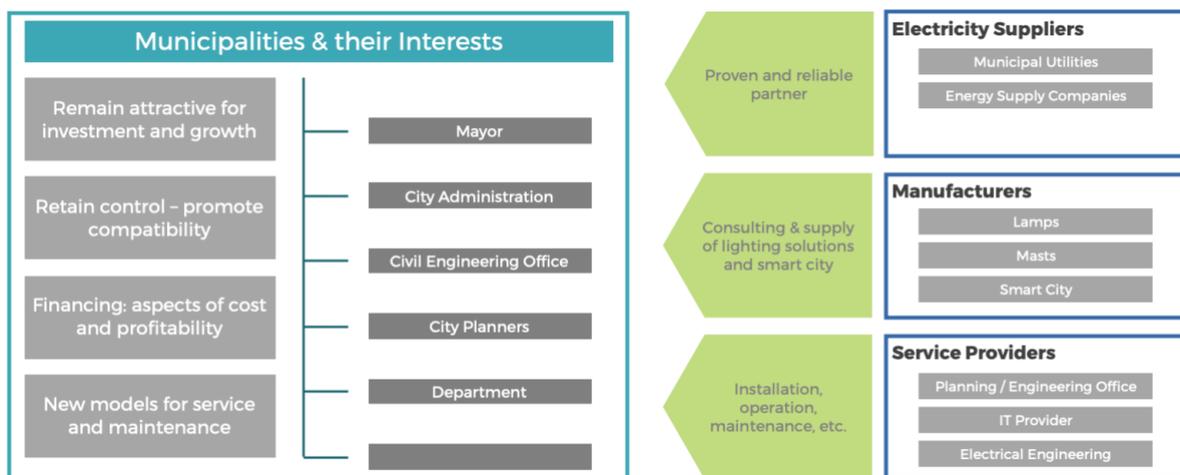
To better assess the streetlighting ecosystem players, we provide an overview of the stakeholders and their interests in reference to our research discussions.

5.1. Municipalities

Situation of municipalities today

Municipalities have little room to maneuver due to local supervision, lack of resources, and dependence on urban policy, local public, and existing legal framework. The following are at the center of their streetlighting considerations :

- Safeguarding and precautionary measures for the supply mandate of functional city lighting. The security of citizens and their sense thereof is essential.

- Future-proof financing and avoidance of additional costs without secure amortization.

- Avoiding great public outrage when integrating new uses (e.g., smart city).

Interest in expanded use of streetlighting – There is an interest in smart city and urban digitalization, as well as in understanding and (co)shaping this challenge better—rather than face the danger of passively suffering the consequences. Some recognize that this could help fulfill municipal tasks better and more efficiently - e.g. lighting, municipal public works, road maintenance, public safety, public transport and much more. The attractiveness of these new solutions is increased based on location and desire for more digital services from demanding residents and businesses. Some have also recognized that streetlighting can play a role in this, but don't know how this could be achieved.

Starting points

But skepticism exists based on practicality. Addressing concerns whether this new way, that breaks up existing methods and partnerships, could work at all. Financial viability is essential to eliminate doubts and create openness. This results in the following starting points:

- A direct advantage (and important argument) is the recognizable contribution to more efficient management of municipal tasks. Examples of such tasks include improving safety through lighting at cost, and through new methods of light management by motion sensors. This benefit to municipalities must be concisely shown and communicated accordingly.

- The business community and municipal citizens want a good supply of broadband connectivity. The recognition to be expected from business and citizens is an important incentive and benefit for mayors, city administrators, and local politicians.

- A good digital infrastructure is also an advantage in the competition between municipalities. Functioning traffic control and parking space management, as well as Wi-Fi networks in the city center make municipalities more attractive for citizens, as well as visitors. Municipal efficiency, digital potential, and quality of life are therefore important aspects of economic development—especially for those municipalities that are not in the center of metropolitan regions and don't want to be left out.

- Because municipalities aren't currently in a position to quickly master the challenges of smart city, interesting financing concepts and technical support

acumen are of importance. Offering this may provide opportunities to build interest and trust.

What to consider

Municipalities are not homogeneous; each must be considered independently. Streetlighting, context, and financial/human resources all vary, as do political orientations. Nevertheless, a number of similarities exist.

- Municipalities need clarity. If you want to expand the digital infrastructure, you have to explain exactly what and how you want to achieve it. Whatever is planned must stand up to a performance audit.

- Local authorities expect sustainable technical concepts that meet the requirements of streetlighting. Therefore, all potential applications and the technology and infrastructure need to:
  - function smoothly within the framework of streetlighting.
  - be tested, approved, and proven in practice.
  - be secure in every respect (e.g., secure in operation, financially secure, assure data security).
  - have no effect on the primary function of the lighting networks.

- Municipalities are often risk averse. Suggestions and plans concerning TelePoles have to prove to them that they're betting on the right horse (e.g., because demand exists, the technology is future-proof, future costs can be calculated). Legal questions with regard to existing assets, contracts, responsibilities, competencies, or foreseeable problems (e.g., failures, cooperation processes, responsibilities) must be clarified.

- Many stakeholders within municipalities are involved and—because of their individual roles—have specific interests.
  - Business development is often particularly close to the hearts of mayors. They can develop long-term urban visions and projects, take appropriate initiatives and ensure their continuity, propose and support priorities for the few free resources, and encourage committed employees. On the other hand, they can also be obstructionist or wholly indifferent.
  - Municipal department heads manage disparate business areas, e.g., central services, finance, social affairs, or construction. Carrying a lot of weight, they are important links between politics and the relevant departments/committees.

Some have immediate significance with respect to expanded use of streetlighting:

- Civil engineering offices are often responsible for lighting and are therefore direct points of contact.

- Urban planning must be included; networking and digitalization in public spaces can have considerable structural effects on the city and affect the urban appearance for which it is often responsible.

- Departments responsible for green areas have a say, if such areas (e.g., trees) play a role. Tree preservation has a high priority everywhere.

o City councils (parliaments as well as individuals) are important because municipal budgets and many projects need their approval. They also form important interfaces with civil society, represent political currents, and react to unrest among citizens accordingly. Regarding the expanded use of streetlighting, the experts asserted that they must also be involved at an early stage and that their acceptance must be sought.

"I have pursued this consistently from the beginning. Every other month I got a speaker to talk about smart city topics in the city council. I have made sure that the city councils have a better understanding of the issues involved and what it can do for us. That was really important."

(Mayor of a small town)

In some cases, the interests of these players are defined by law or regulations and aren't negotiable (e.g., safety regulations, principles of cost effectiveness, service law, municipal statutes). Others are weighed against different interests in conflicts and can be shaped politically. In any case, internal municipal stakeholders and their interests usually require a process of coordination and discussion (and therefore time).

- Finally, citizens are very important for municipalities. They are their customers, voters, and fellow citizens, and must not be alienated. However, issues such as mobile telephony (5G) or smart city are potential points of conflict. Lighting is of particular importance to them and is under their close observation.

"We don't need a digital damage reporting system. We are notified by citizens as soon as something's broken. You wouldn't believe how important streetlighting is to them."

(Public utility, municipality 100-250k inhabitants)

"Acceptance is an increasingly difficult issue today. We are observing that citizens have become increasingly sensitive in recent years. This also applies to streetlighting. No matter whether it's a conversion plan, the relocation of a mast, or a change of light color, or even for models that look different from the old ones." (Municipality, city of 100–250k inhabitants)

"People are afraid of radiation. That resurfaces with 5G."
(Municipality, city over 500k inhabitants)

5.2. Operators – Energy supply environment

The relationship between municipalities and streetlighting operators (usually public utilities or energy supply companies) is special. Those involved have often been working together for decades. For many municipalities, operators are also consultants and streetlighting innovation initiators.

However, the difference that utility companies are independent, and the majority of physical utilities are owned by municipalities is important. Streetlighting projects are likely to be rewarded to an energy supply company if they can offer a lower price. But if streets are to become part of a municipalities' digital infrastructure, then the option of municipal-owned utilities offers considerable advantages.

In addition, municipal-owned utilities can serve as the entrepreneurial arm of municipalities. They operate with less restrictions and more resources than traditional services, and are critical for transformation.

"Sometimes I'm jealous of my colleagues at the municipal utilities. They can just take 50,000 € and give something a try. I can't do that. If we wanted something like that, we'd definitely give it to the public utilities." (Municipality, city of 250–500k inhabitants)

However, operators also think and act like entrepreneurs. They're bound by contracts. Their tasks are fixed; their pay is limited. They must operate the network economically within this framework.

Some larger municipal utilities and energy supply companies are already working in relevant fields linked to digitalization and networking. In our opinion, the energy supply companies are ahead of many municipal utilities. Having an eye on further urban lighting

development, for example the new Philips Lighting brand Signify or EnBW's smart city solution startup Smight[1] have been working on such applications for some time now.

Some municipal utility respondents' understanding and natural affinity toward expanded streetlight use is substantially greater than with most. And yet their competence remains limited. Many are on the vanguard, being in the process of planning or undertaking their first experience. Their intention is to expand their competence and open up the field for themselves.

Interest in expanded use of streetlighting

Operator respondents were consistently more interested in urban digitalization than their municipal counterparts. They're more willing to try new possibilities, where expanded use of streetlighting is an option. There are many connections to other projects before them, so their interest definitely exists.

Starting points

We see common interests between municipal utilities and power supply companies. The latter often serve smaller municipalities that don't own their own utilities. They could be interesting partners to reach smaller communities without having to individually negotiate with each one. Municipal utilities are interesting partners because of their proximity to the municipality; as smaller companies they find it more difficult to acquire the specific know-how and technical capabilities that partners such as Deutsche Telekom can offer. We therefore see interest in cooperating with competent third parties.

But in some cases, public utilities (and local authorities) have reservations about Deutsche Telekom because of prior negative experiences or because they see it as a competitor. This is especially true where municipal utilities have their own interests in mind, e.g., where they drive broadband expansion themselves.

There are some starting points:

- **Entrepreneurial interest** – All network operators are looking for new business opportunities and options. Networking and smart city offer a lot of potential, so it's obvious to consider this, too.

- **USPs for future tenders** – Streetlighting operation will be put out to bid after the existing contract expiration. If the interest of local authorities in smart city grows,

[1] https://smight.com/en/about-us

competence and opportunities in this area could become decisive for future bidding.

- **Expansion of know-how through cooperation** – Municipal utilities could be prepared to work with third parties on pilot projects or concept development as long as these are designed as win-win projects. Our impression is there is more need for development here than with power supply companies (for example).

- **Partnerships for larger projects** – Projects can become too large for municipal utilities (in particular) to sensibly manage and execute them on their own. Here, too, cooperation with third parties could be created for mutual benefit.

What to consider

As interesting as expanded use of streetlighting may be, we were faced with similar skepticism about TelePoles from municipal utilities as from local authorities.

- Definitive concepts are needed that function technologically within the streetlighting framework, along with operational clarity, partner integration, good business models, and cooperation.

- For municipal utilities, it often wasn't clear which technologies were sufficiently future-proof and which applications were both interesting and created added value.

- Such project planning is considered quite a challenge. Where one used to have two years to affect planning and then could count on technical continuity, now one has to plan more flexibly and openly to take advantage of new technological possibilities. As a consequence, challenges cannot yet be comprehensively assessed.

- Close cooperation also turns municipalities into a partner for network operators, the latter having to be considered in such projects from the outset. This also means that the dominant task of city lighting must always be kept in mind. TelePoles must be able to integrate seamlessly and easily into the streetlighting requirements set.

5.3. External suppliers and service providers

The third group of actors are external suppliers and service providers.

5.3.1. Masts and lamps manufacturers

The situation

Masts and lamp manufacturers are indispensable. Masts are the basis that provide access to the supplying infrastructure and carriers of future solutions. However, only a few masts offer that which is necessary for expanded use of streetlighting and that are accepted by municipalities. This includes free space and interfaces for expansion modules, an independent power supply, and hidden places for applications—in addition to organic and natural TelePole designs rather than installations that provoke unwanted resistance.

But so far there have been few incentives to develop something new. Lighting dominates the behavior and bids of local authorities and operators. Manufacturers complained they lack clear specifications as to which requirements they should focus on.

According to some respondents, manufacturers are also under much pressure. Their products will become more interchangeable and margins will fall; business concentration and consolidation is apparent. Some companies are trying to evolve toward intelligent lighting control systems and offer masts that include options for additional functions. But respondents didn't trust them to take the lead in the expanded use of streetlighting. They are considered to lack competence and the required expertise.

Yet there are providers who have been active in this area for years and have taken a few steps. Among them are AEC Illuminazione in Italy, which has taken a proactive approach to the relationship between streetlighting and smart city.[2] Signify[3] and Schréder also offer solutions for intelligent streetlighting and IoT platforms.

Interest in expanded use of lamps

The expanded use of streetlights fits very well into the strategic image of the more active and forward-thinking manufacturers. Others seem ill-prepared; TelePoles could be more of a threat than a blessing for them.

Starting points

The difficult situation of some mast manufacturers could justify a willingness to cooperate so as to open up new opportunities and compensate for their own lack of competence. For those who are more advanced, their already strong interest and experience may be a starting point for cooperation.

What to keep in mind

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[2] http://www.aecilluminazione.com/aec-smart-system-outdoor-smart-street-lighting
[3] formerly Philips Lighting – www.signify.com

Cooperation must be worth a manufacturers' time and resources. With respect to those who jumped on the innovation bandwagon too late, we also suspect advanced manufacturers have strategic interests and more extensive requirements for their own role in the ecosystem.

5.3.2. Other suppliers

There are other players in addition to the aforementioned, external service providers and suppliers (who remain particularly influential). Some have already approached municipalities to discuss expanded use of streetlights. However, these talks failed very early on due to technical challenges.

The situation

- Manufacturers of devices and systems with smart city potential have been working on using sensors of all kinds (e.g., traffic censuses, environmental measurements, intelligent waste bins, cameras, data transmission) for some time to serve special municipal needs. Among them are such companies as Smight, Philips, and Urban Institute, as well as sensor manufacturers and a few streetlighting manufacturers (e.g. AEC Illuminazione, Schredér). They have expanded their business models and offer systems that extend far beyond lighting.

- Engineering/planning offices support municipalities and operators with project planning. Regarding technical questions, they check the quality of other service providers and prepare expert opinions (e.g., lighting product quality, mast statics). They know a lot about municipal streetlighting because their work brings them in close contact with local conditions. Being service providers, they follow requirements but do not shape the market themselves. And yet as advisors they hold influence on certain issues.

- With the increasing use of digital solutions, intelligent lighting control and networking, IT service providers and system integrators are becoming increasingly important for municipalities and public utilities. The latter usually lack the know-how, personnel, and infrastructure to cope with challenges that arise in setting up and operating such systems. Municipalities and public utilities (but not so much power supply companies) need advice and service providers who can help. But at the same time this also adds costs, dependencies, monitoring, and integration requirements into the streetlighting ecosystem. This presents a problem for many municipalities; solving it offers great opportunities to become partners of interest.

Interest in expanded use of streetlights

Interest can be expected from all those who feel up to the challenges associated with expanded use of streetlighting.

Starting points

Additional business opportunities and the fear of losing touch are the starting point for all. None of these players are strong enough to set the pace nor shape the market in the forthcoming infrastructure development. For them, it's of great strategic importance to find strong partners with whom they can survive in the changing market.

What to keep in mind

In addition to those who are looking to the future, there are probably also some suppliers who would like to stop this development because they are averse to change and do not feel prepared for it. Moreover, not all suppliers will probably be able to adapt to the new conditions.

5.3.3. Telecommunications providers

It goes without stating, but telecommunications providers are regarded as important players in fiber optic construction and as being technologically competent. In the streetlighting ecosystem, they have so far been foreign players with whom one has no previous experience. As such, they compete with long-established relationships between municipalities and operators. In addition, their image among municipal respondents was ambivalent.

Interest in the context of the expanded use of streetlights

Telecommunications providers are conceivable as possible players. However, our discussion partners had not yet noticed any definitive interest.

Starting points

Telecommunications providers are regarded as competent and financially strong. In theory, they could help close many gaps that exist among local authorities, municipal utilities, and mast/lighting manufacturers. This applies both to technical topics and tasks, as well as to development of business models, billing systems or—as with mast manufacturers—system management (which manufacturers are happy to join due to a lack of strength and competence on their part).

What to keep in mind

Our impression is that local authorities and operators don't wait for telecommunications providers and don't see them as natural partners. A difference in business cultures may

also play a role. For example, different ideas regarding flexibility, necessary regulations, responsibilities, due dates, and partnership exist. Local authorities and operators of urban lighting consider the task to be very long-term and are interested in stable and robust systems. Telecommunications providers are assumed to be much more fast-moving and superficial with regard to consequences.

6. The Road Ahead – Shining a Light into the Future

This document and the work behind it is only the beginning. Based on our hypothesis that streetlighting and similar assets may become vital components for building up comprehensive broadband coverage and developing smart cities, we looked at the stakeholder landscape to determine why its players act as they do—or sometimes appear to not act at all.

In this we could show that today's ecosystem is well-established, of limited complexity, and functions well. The expanded use of streetlighting requires considerable changes of a technological, legal, and organizational nature. It takes into account new players and responsibilities in addition to operating and business models. Driving these changes could well have disruptive consequences for the entire ecosystem. Each new application and player changes the balance of relevance and power. New competencies, contracts, and processes become necessary.

Many players will have to rethink their position and reassess risks and opportunities. Depending on incentives, benefits, and dependencies, they'll respond by either becoming drivers, remain indecisive/hesitant, or turn into determined footdraggers/obstructionists.

However, urban digital infrastructures have much public attention; they spark visions, expectations, and interests. While it's currently unclear exactly how they can be realized profitably, these are what drives development. To the experts we interviewed, smart city is still a distant mirage due to the burden of organizing strategies, standards, and processes. That, plus cooperation is too great for individual players.

Having identified these issues opens the way to solutions. We have identified specific points required to make headway toward using such street assets for comprehensive broadband coverage and smart cities.

6.1. Focus on common economic interest for partnership

In this current player landscape, it's necessary to find the intersection of a network operator's need (coverage, capacity) with a city's need (monitoring). Based on this, one could start building coalitions with infrastructure providers, by creating obvious and easy-to-understand, win-win situations. A *business solution design* approach—one that uses design methods to create solutions that work for everyone involved—would offer opportunities for creating such concepts. It's important to understand that expanding this

business of streetlighting with digital services isn't one of individual interests, but rather of finding a common goal and benefits, then working toward those.

This is also a matter that will have to be initially solved on the ground through loose alliances working together. It's certainly a matter of cooperation rather than a single player—however big—leading the way. One can imagine a loose coalition of players starting the conversation by creating a roadshow to communicate their topics to municipalities. Ultimately strategic alliances or consortia will be needed. Although this is probably outside the scope of TIP, our community could well be a place to further the conversation. So please share your experiences in this matter as well.

6.2. Make streetlights as digital assets more acceptable

Changing or upgrading such a commonplace asset as a streetlight requires wide involvement and participation. It's central to have at least the acceptance (preferably the support) of all involved. This specifically includes the citizenry, as streetlights are an essential asset—part of a municipality's universal service. Streetlights are needed and are a very visible part of a city's appearance. Any solution must guarantee the basic use case of providing lighting, as well as be aesthetically acceptable or even pleasing.

Beyond technology and business, therefore, a design approach should be chosen that includes aesthetics as well. Design research should include feedback of all affected. This relates to both designing lighting systems that already incorporate the new features in a satisfying way as well as design solutions for retrofits, for only 5–10% are replaced in any given year.

For the smart city approach, it would equally be necessary to:

- assess future impacts

- prepare urban discourse and policy making

- identify how smart city is changing the urban realm

- assess what positive and critical impacts this could have and how municipalities can deal with them

Architecture and guidance must therefore be neutral, realistic, useful, and applicable to local communities. In our opinion, this requires joint development with municipal representatives and other relevant players representing the existing and future ecosystem. This ensures that all relevant aspects are taken into account. In addition, these players can then act as ambassadors.

6.3. Reduce equipment cost by avoiding custom integrations

A design-driven approach would also help in creating solutions that are more manageable and implementable, avoiding custom-made solutions and integrations. This would create a large, horizontal market for communications equipment, and drive standardization and modularization. For this it is fundamental to research and define use cases and clear them with all involved, getting requirements from both the user and business perspective. And it should include the technical view, i.e., working out what features and use cases are actually feasible in relation to existing equipment.

In essence, it would be desirable to have:

- an inventory of existing technology available for retrofit solutions

- a definition for new installations, such that retrofits can be minimized

This should enable the design and creation of standardized, modular equipment that could be an important driver—not least because so much existing streetlighting is comprised of legacy technology.

The business model side of things would also benefit from developing standards such as uniform requirements as well as technical industry standards. Many questions have yet to be clarified, such as ownership of the disparate components. Having standardized legal contracts based on answers to these questions would be of benefit in the process toward project realization.

6.4. Develop blueprints to make deployment on streetlights more straightforward

All parties would greatly benefit if we were to collect best practices and share these and other findings in a blueprint detailing how to best realize these projects.

The present situation we observed during our field research and interview process showed that players wanting to make progress encounter local authorities and operators who are unable to make decisions or take action that goes beyond fiber optic expansion and individual trials. They don't just lack strategies—often they can't even name their goals, interests, and terms. And they have no plan how to get there. In turn this means providers lack orientation and their acting becomes a risk.

Having guidelines, a clear vision of shared benefits, and even a blueprint for realization would be of great help in overcoming this systematic inertia. A great opportunity could lie

in filling this gap, taking the lead in infrastructure development for the expanded use of streetlighting.

The requisite first step is to develop a strategy and architecture to help guide local authorities as to how to accomplish this task. These must provide answers to the aforementioned key questions/concerns:

- What is the benefit for those involved?
- What is the technological framework and how can the new technology be integrated into it?
- What are possible business models?
- What is the legal and regulatory basis for the models?
- What could be a prototypical roadmap or work plan toward realization?
- How does project management for such projects function?
- Who could offer advice and help during project realization?

In this context, conversion to LED is progressing without realizing potential synergies between it and expanded use of streetlighting. Our interviewees estimated that about 20–25% of the streetlighting has been converted so far. Already these are no longer available for another round of upgrading—at least not with municipalities participating in the costs. Further retrofitting reduces the potential for exploitable synergies. We therefore believe there is an urgent need to get involved in modernization as early as possible.

But for this an entity is needed that would enable exchange between all involved.

The same is true for field research that should be conducted outside of TIP to unearth more best practices, as well as to learn of interesting failures that might teach us how to succeed and which pitfalls to avoid. Based on work completed by [Q Research Agency], this white paper is an example of the more detailed field research needed in this realm.

7. Addendum: Research Sample

Detailed sample composition of the 17 experts was as follows:

- Seven participants came from municipalities with:
  - 5,000 inhabitants in the vicinity of a large city (mayor)
  - 50–100,000 inhabitants (head of city lighting)
  - 100–250,000 inhabitants (head of city lighting)
  - 100–250,000 inhabitants (head of civil engineering office responsible for city lighting and appearance)
  - (2) 250,000–500,000 inhabitants (head of city lighting)
  - more than 500,000 inhabitants (head of civil engineering office responsible for city lighting)
- Four city streetlighting operators of municipal utilities (management of city lighting operation):
  - A municipality with 50–100,000 inhabitants
  - A municipality with 100–250,000 inhabitants
  - Two municipalities with 250–500,000 inhabitants
- One energy supplier participant who also operates streetlighting networks on behalf of municipalities (responsible for doing business with municipalities)
- One owner of an independent office for planning and advice on city lighting
- Four participants from masts and streetlighting manufacturers
  - Manufacturer of masts, lamps, and digital solutions in the context of city lighting (head of municipal accounts and sales)
  - Manufacturer of masts and lamps (head of municipal accounts and sales)
  - Manufacturer of LED lighting technology and intelligent lighting control (municipal accounts management)
  - Manufacturer of masts and electrical components for urban lighting (sales and technical management)