REPORT

THE ROAD TO SUSTAINABILITY:

TRANSITION TO RENEWABLE ENERGY IN PUBLIC TRANSPORT

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INTRODUCTION

For many years, a significant proportion of public transport operations have relied on polluting fossil fuels. However, public transport is an energy-efficient mode of travel and is already partially powered by electricity, positioning the sector as a leading provider of sustainable transport. In order to maintain this leadership role and take its share of the burden of reducing emissions, the sector is currently decarbonising its activities by transitioning to renewable energy sources. This includes the electrification of vehicle fleets (including buses, boats, shared cars and trains) and investing in fleets powered by other alternative energy sources, such as hydrogen or biofuels. For the sector to achieve this transformation and meet its decarbonisation objectives, it must invest both in new green fleets to ensure that they have access to green and renewable sources of energy; the energy supply for existing fleets and other public transport assets must not be ignored in striving for CO_2 benefits throughout an organisation.

This report provides guidance on how public transport undertakings can achieve a successful energy transition to their decarbonisation goals, including examples of best practices from around the world.

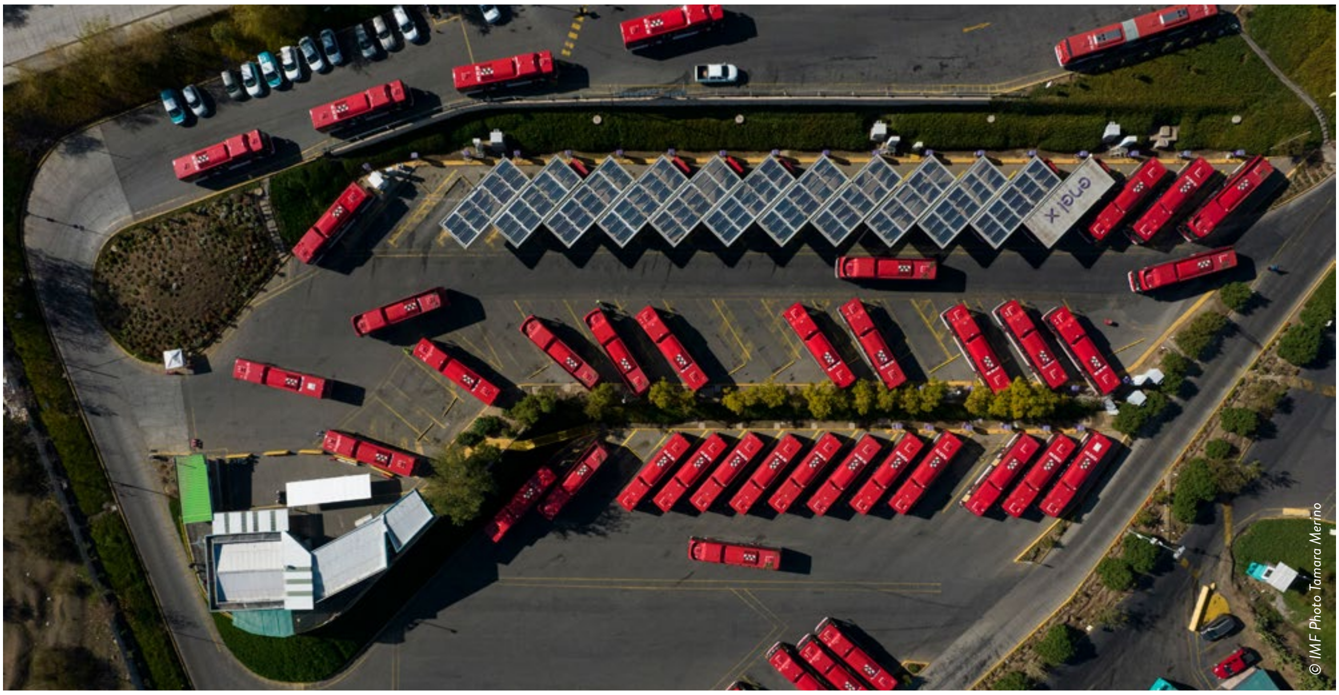
PUBLIC TRANSPORT AND ENERGY CONSUMPTION

ENERGY USE IN PUBLIC TRANSPORT

Energy is one of the key inputs for public transport operations, both in terms of costs and carbon emissions. While the sector is more energy efficient than car traffic (less energy consumed per passenger transported), it nevertheless remains an important energy consumer. For example, it is estimated that the Dutch train operator NS (Nederlandse Spoorwegen, operator of both mainline services and public transport) accounts for approximately 1% of the total electricity consumed in the Netherlands. As such, reducing energy consumption and moving to greener supplies offers considerable potential for emissions reduction impact.

This reports takes a holistic view of energy consumption, from the different transport modes managed by operators to the consumption of other assets owned by public transport undertakings.

Rolling stock in a public transport context - including intercity and regional trains, heavy and light metros as well as trams - is most frequently electrically powered, although some remain reliant on diesel. In general, rolling stock consumes significant amounts of electricity, despite substantial improvements to the energy efficiency of trains in recent years.



Aerial view of the charging terminal "Electroterminal Los Espinos" in Chile, the largest e-bus fleet outside China.

The energy consumed in the traction of vehicles can be split between different sources and different modes. For many decades, road transportation - mainly buses in the public transport context - was heavily dominated by internal combustion engines (ICEs) relying on fossil fuels. Now, in light of climate objectives, the decarbonisation of vehicles fleets is underway in many cities around the world. New propulsion technologies are allowing the carbon emissions of vehicles to be significantly reduced and is also bringing other benefits, such as reducing environmental pollution.

Many public transport undertakings have started to increase the number of clean vehicles in their road transportation fleets, be it by investing in new vehicles or by updating the fuel supply for existing vehicles.

Similarly to road transportation, waterborne public transport applications still rely on fossil fuels. This sector is also following the path of energy transition – albeit to a lesser extent - by introducing electric-powered boats or other fuel technologies for operations.

In this report, and according to the EU's Clean Vehicles Directive (EU Directive 2019/1160), clean vehicles are considered to be those fuelled by:

- Electricity
- Hydrogen
- Natural gas (CNG, LNG)
- (Most) biofuels not blended with conventional fossil fuels
- Liquefied petroleum gas (LPG).

It is important to differentiate between 'clean' vehicles and energy provision. The way an energy source is produced impacts the carbon emissions in operating the solution. For example, the energy supplied for a CNG vehicle has strong implications on the overall carbon intensity of operation, depending on whether it is from natural gas (non-renewable) or biomethane (produced from agriculture or residential waste, considered renewable). A vehicle identified as 'clean' from a regulatory perspective can be powered with non-renewable energy.

In the EU, the EU taxonomy provides a reference on what activities should be considered sustainable. In terms of urban road passenger transport (activity 6.3), from 2026 the taxonomy will only recognise sustainable transport activities where direct (tailpipe) CO_2 emissions are zero. In this respect, it should be noted that the EU taxonomy does not consider vehicles powered by biogas and biofuels as being sustainable[1]. However the section 4.13 of the taxonomy referring to Manufacture of biogas and biofuels for use in transport and of bioliquids considers it can be sustainable under certain technical criteria which should be taken as reference by public transport operators (PTOs) willing to consider biogas as a way to transition to renewable energy.

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In addition to power for traction energy, it is also important to consider the energy consumption of other assets managed by public transport undertakings. As significant real estate owners, relatively large quantities of electricity and gas are required to power, cool and heat office buildings, depots, stations and other assets needed for operations.

Therefore, energy consumption for public transport is:

- **Spread between a variety of assets, which may cover multiple transport modes**
- **Shared between different energy sources.**

Managing energy consumption and supply needs to be considered in a holistic way in order to capture the full benefits of the energy transition and deliver meaningful CO_2 benefits.

Energy transition is associated with a variety of upfront costs, from the purchase or retrofit of vehicles, the construction of supporting infrastructures and purchase of renewable energy. However, in light of the ongoing energy crisis that many countries are facing, energy transition measures hold the potential to have a more-controlled and sustainable energy ecosystem.

DECARBONISATION OF MOBILITY AND THE ROLE OF PUBLIC TRANSPORT

Decarbonisation of the transportation sector

The International Energy Agency (IEA) estimates that **energy consumption by the transport sector accounts for 24% of global emissions**[2]. With these emissions showing persistent strong and steady growth, rapid decarbonisation of the transport sector will be crucial to achieving the aims of the Paris Agreement.

Decarbonisation of transportation must also be achieved as part of the UN Agenda 2030 and the Sustainable Development Goals (SDGs). This work must take into account, in an cohesive manner, multiple objectives such as security and accessibility of transport, reducing local pollutant emissions, reducing traffic congestion, improving energy security, connectivity, industrial development, economic growth, equity and employment.

As part of the European Green Deal, the EU has set a binding target of achieving climate neutrality by 2050. Realising this objective will require significantly cutting greenhouse gas emissions levels in the coming decades. As an intermediate step towards this goal, the EU has raised its 2030 climate ambition, committing to cutting emissions by at least 55% by this date. The EU is currently revising its climate, energy and transport-related legislation as part of the 'Fit for 55' legislative package, aimed at aligning current laws with the 2030 goal.

On human health, the transportation sector is recognised as producing a consistent quota of emissions of smaller particles and nitrous oxides arising from the combustion of both biomass and fossil fuels. These emissions have significant impacts on health of city inhabitants. Globally, it is estimated that more than four million premature deaths are due to ambient air pollution, half of which are occurring in China and India.[3]

Public transport: A leading role in the decarbonisation of mobility

Avoiding car use can already deliver significant decarbonisation benefits. The shared nature of public transport offers an inherent advantage in terms of energy efficiency - and therefore emissions intensity - over alternative-powered modes within a local transport context. Furthermore, **the public transport sector is fully committed to decarbonisation, something reflected in the results of the UITP Sustainable Development Survey (shown below and throughout the report).** Energy transition offers a unique opportunity for the public transport sector to lead the move towards NetZero mobility.

Undertaking a full lifecycle assessment on carbon, public transport has to work on a variety of levels to fully decarbonise its activities, ranging from vehicle manufacturing and construction of infrastructure to operations. The operation of public transport vehicles comprises an significant proportion of emissions and is the reason why operators need to prioritise reductions in this area. This entails not simply the phasing out fossil fuels use in public transport, but also securing energy supplies from renewable sources and reducing overall energy consumption (of all public transport assets). Emissions associated with vehicle manufacturing also represent an important share in the lifecycle of public transport; these are starting to be accounted for increasingly often when reporting emissions (see text box below).

Lifecycle assessment of public transport

To deliver its service, an organisation normally has a carbon footprint along a wide value chain, including upstream (purchase of goods and services from suppliers), direct operations and downstream (from customers). For public transport, this includes the following:

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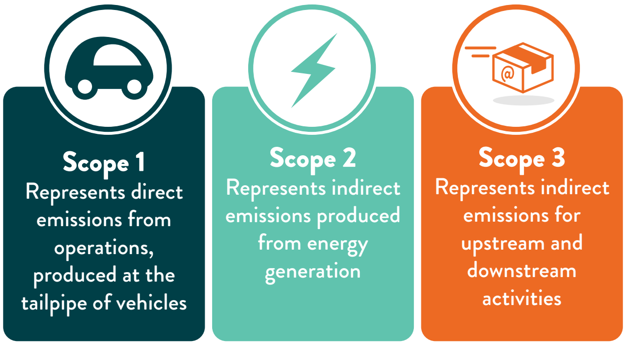
Lifecycle assessment of the entire value chain has only recently started to be considered, and is still rarely accounted for entirely by any economic sector. This can be explained by the lack of consistent standards and processes for accounting for emissions along the value chain and the complexity of involving all stakeholders to obtain a complete overview of whole life cycle carbon emissions.

Emissions are categorised into different scopes:



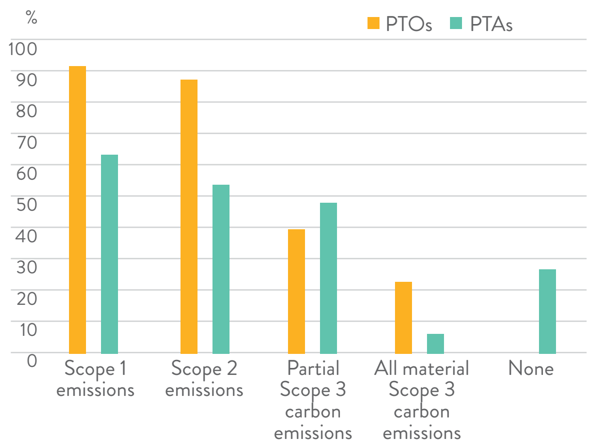
UITP Sustainable Development Survey

In March 2022, UITP conducted a survey to collect information on where its members stand on specific aspects of sustainable development. Some 58 PTOs and public transport authorities (PTAs) along with 12 industry and service providers from around the world responded to the questionnaire. Results relating to energy transition and renewable energy are presented throughout the document. More information on the data collected can be found on the UITP Website.

Carbon neutrality targets by public transport undertakings

Some **73% of PTOs and PTAs have a carbon neutrality target**. Those targets mainly focus on Scope 1 and 2 at this stage, rather than on the full value chain. Therefore, those targets can be achieved by the reduction of operational emissions and energy supply. Other emissions, such as vehicle manufacturing or embodied carbon emissions are less-often included in carbon emissions target.

Figure 1: Emissions reported by PTOs and PTAs with a decarbonisation target



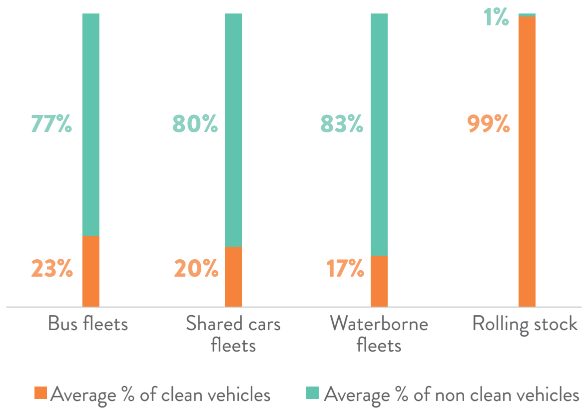
The GHG Protocol Guidance on Scope 2 states that "to reduce these emissions, companies typically turn to energy conservation, efficiency upgrades and low-carbon electricity supply". For some public transport vehicle types, achieving complete decarbonisation in the operations phase can be relatively straightforward. Electric vehicles (EVs) such as light rail, metro and rail require only the sourcing of renewable electricity to reduce operating emissions to close to zero. For ICE vehicles, such as diesel or gas-fuelled buses, partial decarbonisation can be achieved by substituting fossil fuels for biofuels. This offers the advantage of immediate emission reduction without the need for substantial investment in fleet replacement; however, depending on the source of supply, there may be issues around the sustainability of some biofuels. More complete decarbonisation for buses and other road vehicles can be achieved through implementing new technologies such as electric or hydrogen vehicles, depending on the appropriate usage context.

Clean public transport vehicles fleets

The majority of bus, waterborne and shared car fleets are composed of vehicles not classified as clean. However, among buses for example, the share of clean vehicles has increased by 88% in the past five years. More information can be found in the Clean Bus Report (EU data).

Rolling stock has a higher percentage of clean vehicles in operations than other modes. It is, however, important to point out that the results below are mostly based on large operators and authorities in urban areas, mainly in Europe. Diesel rolling stock is still in operations in many settings (some regional trains, in some regions...).

Figure 2: Share of clean vehicles in public transport fleets



Framework on renewable and non-renewable energies

Switching to renewable energy supplies for public transport fleets has the greatest potential in helping operators reach climate objectives and reduce their impact on the environment. The framework below shows what is considered as a renewable energy and will serve as a basis for the rest of the document:

Table 1: Framework on renewable energy and non-renewable energy

	Renewable energy	Non-renewable energy
Electricity generated from	Solar, wind, hydro, geothermal and tidal	Fossil fuels and nuclear
Hydrogen synthetised with	Renewable electricity (Green hydrogen) according to the EU's RED II Directive	Non-renewable electricity and gas
Biofuels	Converted from agricultural waste, residential waste and low-risk Indirect Land Use Change (ILUC) biofuels	High ILUC biofuels and blended biofuels, natural gas

Financing the energy transition of public transport

Enabling the energy transition also requires unlocking the financial means to cover the investments required. The current backdrop of crisis - where access to funding is shrinking at the public end - means that the channelling of subsidies, green bonds, financial guarantees, performance contracts, State Aid, equity funds or private investments will become pivotal in implementing the energy transition in public transport. In the EU, the new Smart and Sustainable Mobility Strategy has proposed a standard for how companies and public authorities can use green bonds to raise funds on capital markets. They can then use these to finance ambitious large-scale investments while meeting demanding sustainability requirements and protected investors. As a fundamentally low-carbon and sustainable transport mode, encouraging private sector investments should ensure a swifter modal shift in cities.[4]

PROVIDING DECARBONISED ENERGY TO POWER PUBLIC TRANSPORT ASSETS

Public transport undertakings, as is the case for all energy consumers, are reliant on the provision and supply within their energy markets. However, some instruments - such as attribution certificates - are available to public transport to enable the provision of decarbonised and renewable energy to operate their services.

In this section, we will explore the general implications of each energy source on public transport. In particular, we will look at the challenges and future perspectives of differing energy market segments (on both production and supply sides) to the various schemes available to the sectors using a series of case studies.

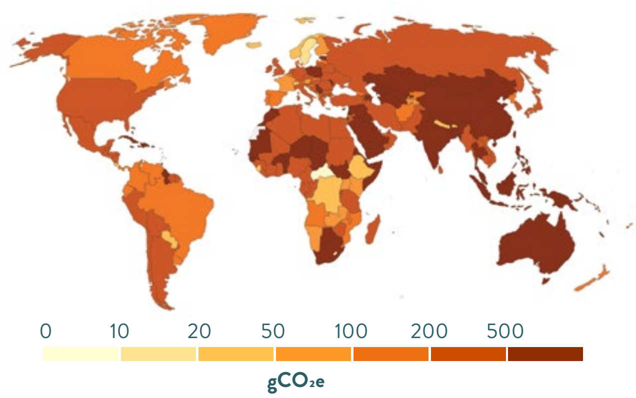
ELECTRICITY

General context: energy

Production of renewable electricity has been increasing steadily over the past 10 years, with the large-scale deployment of solar panels and wind turbines. Despite droughts affecting hydropower generation in 2021, renewable electricity generation grew by 7% over the year.

Figure 3: Carbon intensity of electricity, 2021[5]

Carbon intensity is measured in grams of carbon dioxide-equivalents emitted per kilowatt-hour of electricity.



Source: Ember Climate

This growth in renewables is, however, inconsistent between countries. The average carbon intensity of global electricity production is estimated at 442g of CO_2 per kilowatt-hour, but with wide variation between countries, depending on the dominant methods of electricity generation (see figure 3). In 2021, for example, electricity produced in Norway comes almost entirely from hydropower, with an average emissions intensity of 26g of CO_2 per kilowatt-hour. By way of comparison, India's electricity is produced mainly from coal and has an average emissions intensity of 633g of CO_2 per kilowatt-hour.

Consequently, cost premiums for renewable electricity vary widely depending on the context. In some countries, access to the reliable provision of electricity may even be an issue, as a consequence of an unstable electricity grid and generation.[6]

A continuing rapid growth in renewable generation capacity around the world will be essential for decarbonising our electricity mix. Achieving the energy transition will require overcoming a series of challenges.

- Matching the production curve of renewable sources with the consumption curve of electricity of consumers.
- Land-use issues to construct further assets.
- The reliability of the electricity grid in some countries.
- Future grid capacity.
- Fluctuation in electricity pricing due to crises and disturbances in global energy supply chains.
- Administrative and legislative difficulties to obtain building permits for new energy generation plants in some countries.
- Raw materials availability and energy storage.

If public transport operators are to accelerate the energy transition, they cannot rely on national ambitions and energy sector alone. They must proactively **look for solutions for decarbonising their electricity supply while also working with their electricity suppliers to either purchase low-carbon electricity or to sign an agreement.**

According to the legislation in place - and to the choice from the organisation – the methods used for accounting for emissions from electricity consumption (Scope 2 emissions[7]) differ. In order to account for carbon efforts in their emissions inventory, operators should use a market-based methodology.

In this section, we will focus on market-based schemes, Energy Attribute Certificates (EAC) and Power Purchase Agreements (PPAs). Those schemes allow the tracing and certification of the origin of the electricity produced. However, it is important to note that **certain legislation does not allow market-based (only location-based) reporting or requires expensive remedies to account for reduced emissions.**[8]

Power Purchase Agreements

A Power Purchase Agreement (PPA) is a long-term contract to purchase clean energy from a specific asset at a predetermined price or formula. The agreement is struck between a renewable developer and a consumer (generally an organisation with a large electricity demand) or between a developer and a supplier who then resells the energy. Signing a PPA can be understood as the sale of the environmental attributes (see 'Guarantees of Origin' in the following section) of a given project to another contractor. It is a commitment that allows a renewable developer to make an investment decision using the criteria of profitability versus risk and/or achieve the funding necessary to execute the project. PPAs are becoming increasingly common with companies around the world.[9]

There are several types of PPA available, **depending on where the energy is generated.**

- **On-site PPA:** Contract for the supply of electricity from an ad-hoc renewable plant located on the customer's property and connected to its internal network behind the meter. The renewable plant developer usually makes the investment and designs, installs, operates and maintains the plant. The energy generated is that the customer no longer needs to purchase from the grid, and where the customer doesn't have to pay a system access fee and/or other taxes or charges related with this energy.
- **Off-site PPA:** Contract associated with a utility-scale wind farm or photovoltaic plant connected to the transmission or distribution network of the country's electricity system, to take energy from its point of origin to the consumption point.

Off-site PPAs on the point of delivery of the energy

- **Physical PPA:** The developer sells the renewable energy to an end customer through an energy retailer, which in turn supplies the energy from the renewable asset. Any shortfall is supplied from the retailer's generation portfolio. At the end of the month, the customer receives a single bill for all its consumption, be it from the renewable installation under the PPA or at the spot price.
- **Virtual PPA:** The customer deals directly with a renewable developer to agree the price of the energy (PPA price). In addition, it buys electricity from its preferred energy retailer. At the end of the month, the retailer sends the customer the bill for its physical consumption of energy. It also receives a bill/payment from the developer showing the outcome of the adjustment for the difference between the spot price and the agreed PPA price. In addition, the developer will transfer the guarantees of origin generated by the installation to the end customer. The virtual PPA allows covering the needs from different countries, provided grids are connected.
- **Sleeved PPA:** In markets where the renewable developer does not have a retailing licence and the customer wants a physical PPA, an agreement with a local retailer can be reached. This will allow the conditions

of the PPA between the client and the renewable developer to be transferred to the customer.

Renewable sources (particularly wind and solar) do not producing electricity continuously. Such sources have their own production shape. According to their production availability.

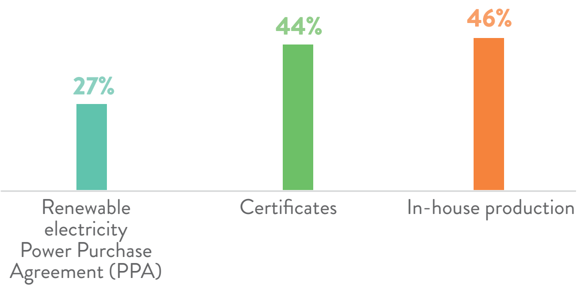
- **Solar assets:** work only at daylight, with a peak at noon and no production at night.
- **Wind assets:** work only when the wind is blowing. Not a consistent production on a daily basis but can produce electricity during more hours in a year than solar plants.
- **Hydro assets**: may be constant production and are adaptable to electricity needs.

Different models of PPAs are available to match patterns of generation of electricity and consumption, as generated, baseload or 'as consumed'[10]. The selection of an appropriate model should be made using on consumption profiles and taking into account the economic balance.

There are some customers who want to cover all their consumption with renewable energy. In this event, at any given time, energy will be provided by the appropriate renewable asset. A combination of solar and wind generation alongside some form of energy storage would be needed, which is still under development (see case study of NS).

Schemes for green electricity supply in public transport

Figure 4: Share of PTOs and PTAs using schemes for renewable electricity supply



Around half of the respondents indicated that they have some type of on-site electricity production (such as solar panels). Certificates are also relatively well-used by public transport undertakings to track the production origin of the renewable electricity.

In addition, a mix of EACs and PPA can allow 100% of coverage of needs to be secured.

In the context of the ongoing energy crisis, PPAs can deliver major financial advantages for organisations, both to lock prices and to provide greater cost visibility. This was also recognised by the European Commission, whose crisis response package REPowerEU (May 2022) included recommendations for speeding up permit-granting procedures for renewable energy projects and facilitating PPAs.

Recommendations for the public transport sector in implementing a PPA

When signing a PPA with an energy provider, a public transport undertaking should make sure it recruits expertise on how to build the contract either internally or externally. The process should involve multiple departments, from different assets managed to the legal or finance departments.

The final selection of the model depends on what objective the organisation is seeking to achieve; for example, greater stability but with higher prices, or lower prices at a greater risk.

Energy Attribute Certificates (EAC)

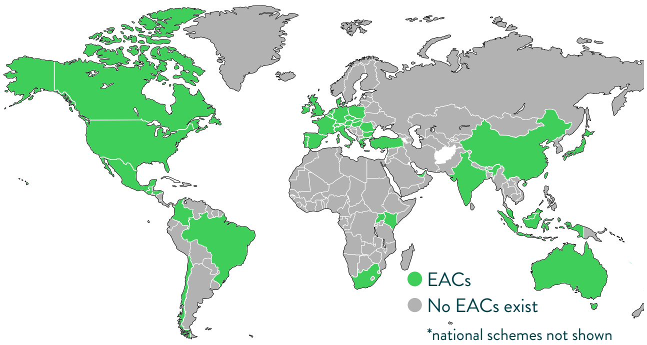
An EAC is a market instrument that verifies that one megawatt-hour of renewable electricity was generated and added to the grid from a green power source. The main purpose of these certificates is to enable buyers to report their sustainability efforts transparently.

These certificates are used to prove that the electricity being consumed comes from a specific renewable energy asset, one that can be precisely identified through each certificates.

The EACs do not represent the electricity itself (they are usually unbundled from the production); rather, they are contractual instruments that can be acquired on secondary markets to convey information about the produced electricity such as the:

- specific location of the renewable energy assets
- particular renewable technology used (for example solar or wind)
- total volume of green electricity consumed, represented by the sum of the received EACs
- particular date/period of consuming green electricity from this particular site.

EACs exist in global markets. They are known as Renewable Energy Certificates (RECs) in North America, Guarantees of Origin (GOs) in the EU and I-RECs or Tradeable Instruments for Global Renewables (TIGRs) in certain developing international markets.



In addition to the above EAC systems, other national approaches also exist:

- Australia (Renewable Energy Target Certificate)
- Brazil (RECS Brasil (usage of I-RECS))
- Hungary (MEHK)
- Japan (Green Power Certification System)
- South Africa (zaRECS).

EACs are valuable instruments in a number of situations; they can support decarbonisation of organisations when volumes are limited or uncertain; optimise costs and aid easy or quick implementation. However, it should be noted that EACs do not participate in developing new renewable energy facilities in the same way as other initiatives, such as PPAs.

Additionality principle

To help the decarbonisation of the economy, more renewable energy must be produced and consumed. **Additionality refers to organisations directly adding new renewable capacity to the grid that otherwise would not have occurred.** For these organisations to be able to invest in this new capacity, they must be certain that the energy produced by these new assets is sold to consumers.

The market actors (sellers and buyers) can use different contracts to bring additionality.

Doing nothing: With this approach the energy mix will change, depending on environmental commitments, and the final consumers will have access to renewable energy depending on the country's environmental commitments.

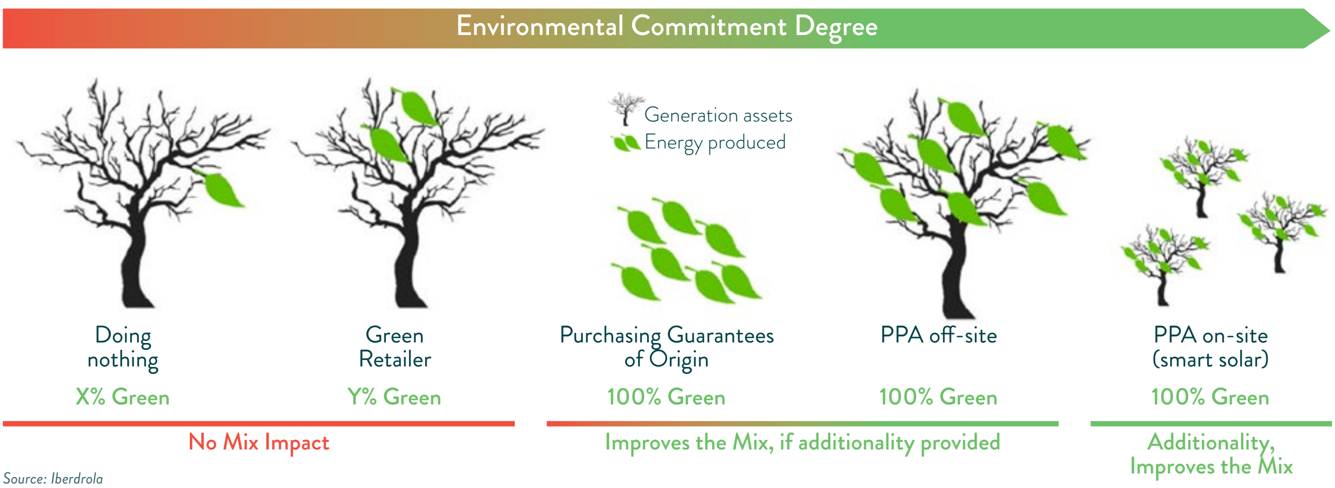
Purchasing EACs: If the consumer buys EACs in an amount equal to the energy consumed, the client is helping to provide value to the renewable energy generation. However, this is not guaranteeing additionality, for example if the energy is provided from assets already constructed.

PPA off-site: In this case, there is a direct supply from a renewable asset, specifically built within the framework of the PPA. In this case, the client can reach its sustainability goals while the mix is improved by bringing additionality

PPA-on site: In this case, the electricity is generated in the client's assets, as in the case of the PPA-off site, meaning clients are able to reach their sustainability goals while guaranteeing additionality. Moreover, this type of PPA uses built-up areas and production is local.

It is important to note that **additionality is above 'Business-As-Usual' (BAU) emissions. These are emissions that would occur without any efforts to reduce them.** For example, some standards treat EACs as BAU emissions, as they would have been avoided by the market anyway. Some other standards consider that purchasing EACs affects the demand for renewable electricity on the market and encourages the development of further production capacity among energy providers.

The additionality principle is over and above BAU emissions, as it actively brings new assets on the market and emissions reduction that would not have happened if not introduced. A PPA is a contracting instrument that follows this additionality principle, allowing the consumer of electricity to bring new assets on the market. Benefits are more concrete with such schemes.



Source: Iberdrola

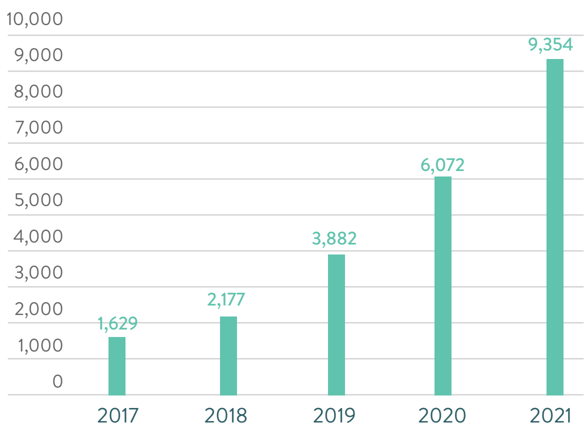
It is also important to notice that in some jurisdictions, there is a risk of the double counting of emissions with location-based accounting and energy certificates. If emissions from electricity are calculated by an organisation according to the grid average, and are not corrected by the associated tracking instruments, emissions from a renewable asset can be accounted twice via the purchase of a EAC and in the grid average accounting of another organisation.[11]

Electricity for public transport

As an energy source, electricity plays a pivotal role in the decarbonisation and energy transition of public transport. It is used by a **variety of assets** owned by public transport undertakings and is set to play an increasing role for operations. While electricity has always been mainly used to power offices, depots, stations and rail operations, the ongoing electrification of road transportation fleets around the world means it is increasingly the primary energy source for many public transport undertakings.

Electric bus sales increased by 40% globally in 2021[12], representing 4% of the global bus fleet. China has the largest electric bus fleet in the world, with 54% of battery vehicles in the national urban bus fleet. In Europe, the amount of battery stock has increased over for the past few years; in 2021, new registrations of battery electric buses were 22% higher than in 2017 (22% of new registrations in 2021were for battery buses).[13] According to ongoing strategies and decarbonisation targets globally, the expansion of electric EVs in public transport fleets is expected to increase dramatically to achieve the decarbonisation objectives of the sector.

Figure 5: Battery vehicle stock in Europe



Source: ASSURED project, 2021

Electric bus mobility is now a relatively well-established technology, with large scale deployments in many fleets worldwide. It has proved to be an efficient way to reduce local carbon emissions and improve air quality in the operational area. Direct operation is therefore zero emission, **however other sources of emissions should not be ignored and should be accounted for** if covered by your boundary of control:

- Energy supply, where carbon emissions can vary significantly according to how the electricity is generated.
- Vehicle manufacturing, which can be more intensive than with other vehicles due to the production of the batteries.

As the demand for electricity from public transport grows, the decarbonisation of electricity grids leads to reduced emissions, even where renewable energy is not specifically purchased. The entire sector should therefore consider sourcing energy supplies from renewable sources as an integral part of their decarbonisation targets and strategies. This will go beyond the decarbonisation of the grid alone and accelerate the transition.

To ensure the provision of this renewable energy, public transport undertakings can cooperate with energy providers. As previously seen, a variety of contracts and options are available to energy consumers for supplying renewable energy.

On-site production of electricity, with solar panels installed on the roofs of stations, depots and office buildings, represent an attractive opportunity for public transport undertakings to generate a significant proportion of the energy consumed by the organisation for themselves. Different operators have started to deploy different assets on their network. In Delhi, for example, the local Metro Rail Corporation LTD (see case study) has done so. Meanwhile in Vienna, there is a solar panels pilot project in place on the roof of the Wiener Linien metro stations.[14]

Another option is the leasing of assets to companies interested in generating renewable power for the sector. This can create new revenue streams for the sector, but implementing such schemes requires the coordination of different sectors and actors as well as new sources of finance. National coordination bodies should therefore be established to make this possible.[15]

The on-site installation of solar panels can also be technically complex, depending on roof structures, space available. It may require capital investment that is not available, or there may be insufficient area available to meet the total energy consumed by the organisation.

For such reasons, undertakings may choose to source energy from **off-site renewable electricity assets, which offer the potential to cover a more significant share of electricity consumed by operations.** Experiments are also ongoing to combine renewables in order to cover actual energy consumption, such as seen with NS in the Netherlands (see case study). Power utilities could offer lower rates to charge electric bus fleets during daytime, when renewable energy is abundant, as well as overnight when power demand is lower.[16] Both of those approaches should ensure more stable electricity costs, as they are most often fixed price, long-term contracts.

Manufacturers of vehicles and rolling stock, such as Alstom, are also engaged in the energy transition. It is developing its renewable electricity production through a combination of off-site and on-site production (see case study).

On the vehicle side, the transition towards electromobility is a process that presents some challenges. The shift from ICEs to new technologies requires adaptation within the organisation in order to support:

- New maintenance processes
- New operational requirements to recharge vehicles
- Changed safety procedures.

Investments to implement the transition towards electromobility are also required in order to roll out supporting infrastructure, purchase new vehicles and adapt the organisation as mentioned above. Those investments are usually at least partially compensated for in the longer term through the lower maintenance costs required by EVs compared to their ICE counterparts.

Compared to diesel, EVs are more energy efficient. Compared to other alternative fuels technologies, further analyses are required for buses, as the weight of batteries should also be factored in when assessing the results of clean technologies.

Air quality in the operational area, alongside a reduction of car traffic, is also greatly improved by the introduction of EVs. Recent studies shows that considering the operational life of Battery Electric Vehicles (BEVs) - compared to that of ICE vehicles the amount of H+, CO_2, O_3 and particulate matter produced is zero. This is not the sole justification for the production of the vehicles and of the energy needed to propel them, but **at the end of the whole life cycle analysis, the environmental impact of BEVs is 36% lower than ICE vehicles (in low-carbon electricity countries, the environmental impact is around 80%)17**. In Shenzhen, China, the introduction of electric buses allows to save around 194,000 tons of CO_2 per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year.[18] As highlighted by European Environmental Agency in 2020 the introduction of EVs has contributed to the decrease of 12% in CO_2 emissions in EU.[19]

Direct electrification is, however, less flexible than other technologies, as charging times are longer in comparison to the refuelling of vehicles using other technologies. This should be a consideration in operational processes and when building new infrastructures to support deployment of the technology.

Electromobility has the potential to contribute to modernising the public transport service offer and to improve customer satisfaction and the liveability of cities. A recent study by the University of Gothenburg showed that the health of residents living alongside a bus route in the city was significantly improved by the introduction of electric buses, as they are significantly quieter than the hybrid and diesel buses they replaced.[20] Noise reduction also brings benefits to users and drivers of public transport.

However, it should be noted that in some situations, such as where the electricity grid is not reliable or electricity supply is not consistent, introducing EVs could pose operational risks. **The electricity supply needs to be strong and steady to ensure that there is no negative impact on public transport operations.** The assessment of available fuelling options is essential in making sure that the solution introduced is also sustainable in terms of the security of supply.

OFF-SITE AND ON-SITE ELECTRICTY PRODUCTION USING SOLAR PANELS TO POWER THE METRO STATION: DELHI METRO RAILWAYS CORPORATION, INDIA

In New Delhi, DMRC is implementing one of the most ambitious plans for on-site renewable energy production on stations, car sheds (train depots) and other assets owned by the metro operator. Rooftop solar panels currently meet 3% of the total energy consumption of the organisation.

Solar plants are developed, installed, financed, operated and owned by the service company providing the solution. The power generated by the panels is then provided to the consumer – in this case DMRC - or redirected to the grid when production is higher than consumption. This model allows DMRC to avoid any capital expenditure and to save on energy costs, reduce CO_2 emissions and realise benefits from carbon credits earned.

This scheme is also complemented with an off-site solar plant, which supplies approximately 31% of the energy consumed by the organisation. The construction of an off-site production outside Delhi allows for a greater capacity than would be possible inside the city, given the high value of real estate.

Through this combination of on- and off-site solar plants, DMRC is fulfilling 65% of its daytime energy requirement from solar, which represents nearly 35% of their total energy consumption.

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ON-SITE SOLAR PANELS, CERTIFICATES AND VIRTUAL PPAS SCHEMES FOR 100% GREEN ELECTRICITY: ALSTOM, PUBLIC TRANSPORT INDUSTRY

Alstom has committed to achieving Net Zero in its value chain by 2050 and has established ambitious 2030 carbon reduction targets in line with the aims of the Paris Agreement. As part of its decarbonisation strategy, Alstom has set a goal of sourcing 100% of the electricity for its factories and facilities from renewable sources by the end of 2025. It is securing this through a number of methods. This includes direct generation at its sites, predominantly through the installation of rooftop solar panels. Solar panels have been installed at 11 sites to date, including Charleroi in Belgium, Nola in Italy, Sri City in India and Villeneuve in Switzerland, with feasibility studies for multiple further installations underway. Ultimately, Alstom plans meet 10% of electricity demand through self-generation.

A large part of Alstom's electricity requirements is within Europe, and the company is preparing a virtual PPA that will underwrite the construction of a new, large-scale renewable energy project in the region. This will provide renewable electricity attribution for around 40% of the company's total demand. For the remainder, Alstom will secure Energy Attribute Certificates. During 2021-22, Alstom already achieved a 42% share of renewable electricity.

TRAINS AND STATIONS POWERED WITH A COMBINATION OF WIND TURBINES AND SOLAR PANELS: NEDERLANDSE SPOORWEGEN, NETHERLANDS

Since 2017, trains in the Netherlands have been 100% run using energy from wind power. Energy consumed by the operator is equivalent to the total electricity consumption of all households of Amsterdam (1% of the electricity consumed in the country). Even for the Dutch renewable energy market, NS' electricity consumption represents 85% of the entire renewable energy market of the country. Half the electricity consumed originates from wind farms in the Netherlands, while the remained originates from wind farms located in Sweden, Finland and Belgium.

This 100% wind energy provision does not, however, cover the entire actual energy consumption of the organisation, as it is currently still technically and meteorologically impossible. Nederlandse Spoorwegen (NS) is currently working to improve the situation, to match the production of renewable electricity to its consumption. Together with knowledge institutes and energy providers, the organisation has the ambition to make sure that the energy NS uses each hour (opposed to the total energy consumption) is actually delivered from a renewable asset. One promising approach is to work on more-efficient energy storage for wind and solar energies. Another potential improvement being studied is to develop ways to combine different renewable energy production methods (solar, wind and hydro power), find ways to spread the generation of renewable energy over time and reduce energy consumption at peak hours (particularly in winter).

Renewable energies in the EU

The ongoing revision of the Renewable Energy Directive (RED II) is pushing for the deployment of renewable electricity in the EU. In 2021, the European Commission proposed a target of 40% for the share of renewable energy in the EU's energy mix by 2030. In addition, the transport sector's greenhouse gas intensity is to be reduced by 13% by 2030. Given the energy crisis and the REPowerEU plan, these targets were increased to 45% and 16%, respectively.

HYDROGEN

General context on the production of hydrogen

The use of hydrogen as a fuel offers great potential for decarbonising public transport operations and tackling various critical energy challenges in transportation. Pilot projects and the deployment of fuel cell vehicles are ongoing worldwide, and use cases for the technology are being developed.

Hydrogen can be produced using a variety of energy sources, including renewable electricity, nuclear, natural gas, coal and oil. When produced from renewable sources, it is known as 'green' hydrogen, while production from fossil fuels with associated carbon emissions is known as 'grey'. Once produced, the hydrogen can then be used to power fuel cell vehicles. If produced from electricity through electrolysis, this transformation process is often referred to as 'indirect electrification'. Hydrogen can be transported either as a gas by pipeline or as a liquid by ship; it can or even produced on-site.Today, hydrogen is mainly used on an industrial scale in processes for the chemical and refining industries, supplied using grey hydrogen or from industrial by-product hydrogen.

For example, some regions already have a reliable supply and value chain such as the circumstances for industrial by-product hydrogen in the State of North Rhine-Westphalia in Germany. Other regions are making concrete plans to invest in green hydrogen production, as currently being studied in the Netherlands.[21]

The use of hydrogen within the transport sector is still developing and to date has mainly been seen in pilot operations. The larger scale deployment of the technology is conditioned by a number of significant challenges:

- High production cost and lack of demand
- High upfront investment required to kick-start production
- Slow deployment of hydrogen infrastructures (transportation and distribution)
- Production more commonly available from non-renewable sources
- Risk of competition between electricity used for the grid and for hydrogen production.

With most hydrogen still produced from fossil fuels, this process is responsible for 830 million tonnes of CO_2 emissions each year, equivalent to the emissions of the UK and Indonesia combined[22]. Reducing emissions from production will be one of the main challenges in ensuring that hydrogen can make a meaningful contribution to reaching carbon neutrality targets. For transportation, the upstream emissions of hydrogen production should be taken into account when shifting towards this type of energy, particularly as the supply of green hydrogen is still limited. Purchases of new hydrogen-powered public transport fleets should be used wherever possible to spur local investment in green hydrogen supply.

Green Hydrogen production and purchase

The carbon intensity of hydrogen varies according to the energy used to produce it. To be considered renewable, a power plant can work via different models.

- **Full on-site production:** a renewable energy asset is dedicated solely to one electrolysis facility.
- **Electricity from the power grid:** the electrolyser is connected to the grid and consumes renewable electricity as with any other consumer.
- **Hybrid solution:** the electrolyser is connected to one or more renewable energy power plants and to the grid.

Following a long debate on the Renewable Energy Directive (RED II), in September 2022 the European Parliament agreed on the framing for renewable hydrogen production. The Parliament has committed to an overall renewable energy contribution of 45% of the total energy mix by 2030.

Furthermore, as affirmed with the REPowerEU communication, the EU will strive to achieve a supply 20 million tonnes of green hydrogen by 2030 – 10 million produced within the EU and 10 million imported – tied to new, binding targets for different sectors. Specific plans and budgets from governments around the world to promote and develop hydrogen are also being implemented.

The situation for hydrogen as a by-product - meaning hydrogen produced in large quantities as by-product of an industrial process - however is still under debate. Although it locks in more carbon emissions than the above models, in some contexts it can be considered as a transition hydrogen to develop the local demand, as is the case in China.[23]

General context for public transport

In public transport, the adoption of Fuel Cell Electric Vehicles (FCEVs) technology is more recent than that of BEVs, and deployment has yet to reach the same level of maturity. There are currently a few projects in the EU piloting the deployment of fuel cell buses (FCBs), such as JIVE/JIVE2, 3Emotion or H2BUS. The JIVE/JIVE 2 projects is aiming to deploy almost 300 FCBs in 16 European cities, the largest deployment attempted to date in Europe. Similar efforts are taking place in other regions of the world. In rail, the first fleet of hydrogen fuel cell regional trains commenced operations in western Germany in August 2022, and a number of other small fleets have been ordered, including in Italy and France.

Manufacturing of FCEVs is still limited in comparison with BEVs and remains more costly than other technologies. However, additional FC players are gradually entering the market.

The ongoing pilots are important to gather more information on the technology and better understand both its potential and its potential application in a public transport context.

In comparison to direct electrification, fuel cell technology provides an operational flexibility that is closer to that offered by traditional ICEs. The autonomous range is greater than BEVs and refuelling is easier and faster than recharging. This makes FCEVs potentially more relevant for long distance lines.

Similarly to BEVs, FCEVs do not emit any air pollutants during operation and, in comparison to ICEs, help reduce noise both within and outside the vehicle.

Carbon emission reduction potential is also important. If a green hydrogen supply is ensured, FCEVs can be zero

emission. However the main challenge remains in the energy efficiency of FCEVs compared to BEVs. With hydrogen production and usage, there is consequent energy loss in both the process of fuel production ('Well-to-tank') and in operations (Tank-to-wheel). It is estimated that three times more renewable energy is needed to power a fuel cell vehicle than with a direct charging technology (see graph below).

In addition to the lower energy efficiency, the lack of understanding and visibility over the sustainability of hydrogen production makes it difficult to assess the scale of likely sustainability benefits of the fuel. The recent changes to EU regulations and investment could have a strong impact on the upscaling of hydrogen production and the definition of sustainability criteria beyond the borders of the continent.

With deployment of FCEVs at an early stage of understanding, the technology still needs to mature. More data needs to be collected from local operational conditions in order to improve estimates of likely energy consumption and to develop the business case for the technology. The involvement of academia can provide an opportunity for supporting data collection and improving

Figure 6: Efficiency of electricity and hydrogen for road transport. Source: Transport and Environment

		Direct charging	Hydrogen
		100% renewable energy	100% renewable energy
Well to tank	Electrolysis		22% energy loss
	CO_2 air capture or FT synthetesis		
	Transport storage and distribution	5% energy loss	22% energy loss
	FUEL PRODUCTION EFFICIENCY	95%	61%
Tank to wheel	Charging equipment	5% energy loss	
	Battery charge efficiency	5% energy loss	
	H2 to electricity conversion		46% energy loss
	Inversion DC/AC	5% energy loss	5% energy loss
	Engine efficiency	5% energy loss	5% energy loss
	OVERALL EFFICIENCY	77%	30%

the understanding of the technology. Data collection will also be essential to perform the LCA of the FCEVs. A true comparison between the full carbon emission of FCEVs and other technologies cannot be undertaken until this happens. The need for further collection of data and results also relate to HRS (Hydrogen Refuelling Stations) as essential elements of supporting infrastructure.

Prices of Fuel Cell Buses (FCBs) have significantly decreased since the first FCB projects funded. However, the Total Cost of Ownership (TCO) of the vehicles remains high, from the purchase of the vehicle to the operation with the purchase of the fuel. For the vehicles, the price varies depending on specifications, but it was observed through the JIVE project that for orders of more than 10 buses, lower prices are available.

Procurement needs to factor in both the vehicles and energy supply, unlike with direct electrification technologies. This makes the process of procurement of vehicles more complex, as it relies on the availability of the fuel and the deployment of new refuelling infrastructures. With demand for hydrogen currently still limited, the availability of the fuel for a larger energy system remains a challenge and the development of more wide-ranging hydrogen economy will also be required to reduce fuel prices. Delivery and HRS are essential to the deployment of fuel cell technology. Developing both is complicated for an operator to implement alone (in terms of costs and justification for a small-scale project). Seeking synergies with other stakeholders could be key in the justifying deployment, but of course depends on local willingness and potential to roll out to the technology. To ensure a smooth start-up of operations the HRS and hydrogen supply should be procured in parallel to the vehicles.

Governments and authorities need to work on clarity and certainty for operators by providing the right regulatory framework.

Future perspectives for hydrogen

It remains difficult to forecast the future uptake of hydrogen in public transport at this stage of deployment. As detailed, there remain significant uncertainties over both hydrogen production and the fuel cell technology. This creates a polarised debate on the potential success of the technology but there are some clear understandings.

A higher demand for hydrogen

To implement the technology, scaling and developing the following are pivotal:

- Production
- Transportation
- Distribution infrastructures

Alongside those required developments, the availability and affordability of renewable electricity production for green hydrogen from electrolysis will be essential for establishing a broader green hydrogen economy.

The scaling-up of hydrogen production is being supported by number of countries and by the EU's REPowerEU plan (see textbox above). This has the potential to reduce production costs, improve supply infrastructure and dramatically increase the size of the market.

Hydrogen and indirect electrification may also hold the potential to store surplus of renewable electricity production and deliver it to areas where renewable electricity production is insufficient to cover the needs. This, of course, depending on a significant reduction in the price of electrolysers and continuing strong growth in renewable electricity production.

On transportation and distribution of hydrogen fuel

The infrastructure to transport hydrogen currently already exists in part. The pipelines and other infrastructure used to transport and distribute natural gas can be retrofitted for use for hydrogen delivery. The European Hydrogen Backbone (EHB) initiative[24], developed by the gas transport system operators in Europe, is a good example of this. It provides a vision for the conversion of 60% of the European gas transport network to hydrogen by 2040. A similar transformation is also possible at the distribution level.[25]

Technological maturity

Compared to BEVs or biofuel-powered vehicles, FCEVs remain a less mature technology. We can expect further insights to become available in the coming years to better understand the operational and carbon potential of the technology in public transport settings.

Use case of the technology

Looking at the current performances of the fuel cell vehicles, FCEVs could have a role to play either in complementing other solutions or under specific contexts and conditions.

- Long distance lines, where greater autonomy is required.
- Importing green hydrogen in locations where renewable energy production is not easily and widely available and/or where electric charging infrastructures would be difficult to roll out. However, it is important to point out that this is still an expensive process and that it is more carbon intensive than local production.
- FCEVs may have role in PTO/PTAs strategy for zero emission fleets, depending on the resources/capabilities and regional energy context. This will influence their strategic visions and the related energy matrix that can be applied to zero emission fleets.

Case studies

HYDROGEN STRATEGY AND HYDROGEN TRAINS TRIAL: JR EAST, JAPAN

JR East is committed to the Zero Carbon Challenge 2050, with a long-term, group-wide goal of net-zero CO_2 emissions by fiscal year 2051. The aim is to improve its environmental competitiveness and continue to be a corporate group that creates new value for society in the future. As a part of this effort, JR East is working to achieve a hydrogen society by studying the use of hydrogen at its own thermal power station, and has started test runs of the hydrogen-hybrid train 'HYBARI' since March 2022.

'HYBARI' is a system that is composed of hydrogen fuel cells and storage batteries as its power sources. It is the first heavy rail train to use high-pressure hydrogen up to 70MPa, which is expected to increase travelled distances compared to the 35MPa-hydrogen-powered trains. JR East group has also introduced fuel cell buses, fuel cell vehicles and hydrogen supply stations near its train stations. It has also installed a hydrogen-based off-grid energy supply system to one of its train stations.

These efforts to promote hydrogen-based mobility are in cooperation with various partners, including Toyota, Hitachi and ENEOS, one of the major energy suppliers in Japan

FUEL CELL BUSES: TMB, BARCELONA, SPAIN

For TMB, moving to a fleet of sustainable vehicles is an important step in the fight against climate change. This objective is set out in TMB's 2025 Strategic Plan, which calls for the incorporation of 410 clean-energy buses, of which 46 will be hydrogen. The projected investment in hydrogen vehicles to 2025 will be €36 million. The company is thus seeking to diversify its renewable energy sources.

TMB has already integrated the first eight hydrogen buses in its fleet. The model chosen is the H2 City Gold LHD from Caetano Bus, 12 metres long. The technology core of the buses is a 60-kilowatt fuel cell, manufactured by the Japanese company Toyota. The manufacturer estimates a daily consumption of 20kg of hydrogen and a range of 300km.

TMB promoted the creation of the infrastructure needed to power the hydrogen buses through a public tender. It was ultimately awarded to Iberdrola, thus creating the first public plant in Spain to supply green hydrogen, as It will also serve other companies in the area.

This is the first time that this type of renewable energy source has been generated in Spain for commercial use and with fleet capacity, making TMB and Iberdrola pioneers in decarbonising heavy urban mobility.

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HYDROGEN IN LOCAL PUBLIC TRANSPORT: FNM GROUP, ITALY

'H2iseO Hydrogen Valley' is an Italian hydrogen-based industrial value chain for a sustainable mobility system in Valcamonica, a UNESCO World Heritage Site. It runs along the unelectrified Brescia-Iseo-Edolo railway line, gateway to the Milan-Cortina 2026 Winter Olympic Games.

The H2iseO project, implemented by FNM Group in collaboration with Trenord, aims to develop a 'Hydrogen Valley' in Valcamonica, starting with the use of hydrogen in local public transport. It will reduce greenhouse gas emissions for FNM Group's local public transport offer.

The project involves the purchase of 14 fuel cell hydrogen trains for the Brescia-Iseo-Edolo railway line, with commercial service starting in 2024. These would replace the current diesel-powered trains and see the construction of hydrogen production plants, initially intended for the new trains. The project also foresees extending the hydrogen solution to road transport by 2025, starting with the approximately 40 vehicles operated in Valcamonica by FNM Autoservizi.

In December 2020, FNM entered into a Framework Agreement with Alstom for 30 bidirectional hydrogen-powered trains, and signed the first Executive Contract for the supply of six trains, with delivery of the first by December 2023.

FNM has also signed Memoranda of Understanding with some of the main players in the energy and hydrogen sector, including A2A, Enel Green Power, ENI, Sapio and SNAM.

BIOFUELS

General context

In certain specific contexts, biofuels can play a role in decarbonising public transport and energy consumption.

The findings of a scenario analysis of the transport sector for 2030 in Europe, undertaken by the Stockholm Environment Institute, have underlined the importance of reducing emissions from existing fleets. Even in a rapid electrification scenario, a substantial portion of the fleets already deployed in Europe would still be running by 2030. **In the most positive scenario, 50-75% of new sales of trucks and buses will be EVs by 2030, while 90% of road vehicles will still be powered by ICEs.**[26] Replacing fossil fuels in these with biofuels could further support the decarbonisation of transportation. When the blend of biofuels used is pure, emissions of CO_2 at the tailpipe are reduced.

However, from a life cycle perspective, it is important to consider how biofuels are produced. As a result, different concerns and perspectives arise.

- **Feedstock-based biofuels** create concerns over sustainability, as they are produced using crops and land that may be diverted from food production. In addition, the production of biofuels, if not framed properly, can contribute to deforestation – also known as Indirect Land Use Change (ILUC) risk.
- **Waste-based biofuels** can contribute to the local circular economy and allow the recovery of energy from wastes. There are, however, carbon emissions associated with the transportation and transformation process.

Type of biofuels:

- **Ethanol** is made from various sugar and starch-rich plants. It is an alcohol, often used as a blending agent with gasoline/petrol. The most-common blend is E10: 10% ethanol, 90% gasoline. There is also an ethanol fuel for heavy duty diesel engines: ED95, with 95% ethanol. Brazil and the USA produce large amounts of ethanol, from sugar cane and corn/maize, respectively.
- **Biodiesel** is a liquid fuel produced from renewable sources, new and used vegetable oils, organic waste and animal fats. It can be blended with diesel in any percentage or even used pure in engines. The most common blend is B20, sometimes referred to as RME/FAME. It is most-commonly produced from rapeseed in Europe.
- **HVO – Hydrogenated Vegetable Oil** is a type of biodiesel made from the same sources as biodiesel, but is more similar to standard diesel. It can replace diesel in most existing engines and is most often blended with traditional diesel. It is important to note that HVO and biodiesel have different fuel standards, HVO is EN15940, while Biodiesel is EN14214. The processing technologies and chemical makeup of the two fuels differs.
- **Biogas** is a gas - normally with a methane content of 50-60% - derived from the natural decomposition of organic waste such as crop residues, animal manure, municipal waste and wastewater sludge.[27] Vehicles need to be retrofitted to accept biogas.
- **Biomethane** is produced by upgrading biogas to remove CO_2 and impurities; it is fully interchangeable with natural gas, CNG. The two can be blended in any proportions.

In the US and Europe, HVO production is expected to triple in the coming years [28], as both policy environments value the GHG reductions this fuel can bring when substituted for crude oil-based diesel. Ethanol and biodiesel use is increasing in Latin America and Asia, arising from a combination of growing demand and increases in ethanol-blending mandates in countries such as India, Indonesia and - to a certain extent - Brazil.

Biofuels for public transport

History

Public transport has often been a pioneer in developing decarbonisation solutions for transport, and biofuels have historically been one of the most cost-effective and GHG-efficient tools for this purpose (although today, direct electrification is more cost-effective than biofuels in most cases). In Sweden, for example, biofuels such as ethanol, biomethane and biodiesel have been used during the journey from a 100% fossil-fuel-dependent public transport system in the early 2000's to today's 94% fossil-free public transport sector.[29] The region of Stockholm has achieved a 100% renewable fuels public transport system in 2018 (but not yet fossil free from a lifecycle perspective). EMT Madrid, the bus operator in Madrid, also has a diesel-free fleet since 2022, with approximately 88% of its fleet running on biogas.

Sustainability and GHG reductions

In the early 2000s, the strong EU enthusiasm for biofuels led to the supply of fuels with poor, or even negative, lifecycle emissions such as palm oil from deforested areas. This caused understandable concern among NGOs and PTAs alike. Following the introduction, in 2008, of the EU RED Directive [30], sustainability criteria were applied to biofuels that provide information on reduction of 'Well-to-wheel' GHG reduction and include land-use factors. In India, the National Policy on Biofuels also includes requirements to source biofuels from sustainable feedstocks that do not threaten food security. Low-carbon fuel standards are also available in Canada, in the US in the states of California and Oregon, as well as in Brazil.[31 32 33 34]

Biofuels also add further additional benefits.

- Replacing costly fossil fuels imports and contributing to local energy security.
- Removing landfills, turning waste into sustainable fuels.
- Creating local jobs in the energy and waste sectors.
- Making it possible for those developing countries that lack access to both sufficient electric infrastructure and clean diesel qualities to leap-frog to Euro VI emission levels and improve air quality (with particulate matter).

However, certain limits remain with biofuels:

- The energy efficiency of biofuels powered vehicles is lower than EVs.
- There is still a certain degree of carbon emissions locally (tailpipe).
- There is a lack of transparency on the origin of the biofuel in certain contexts.
- For crop-based fuels: emissions associated to crop transportation and use of fertilizers.
- Upscaling production is limited in line with the low ILUC principle or due to waste material available.

Following Russia's invasion of Ukraine, questions have arisen over whether biofuels can support reducing fuel prices, ensuring energy and food security and reducing GHG emissions. Some governments are using biofuels as a way of reducing fuel costs (in the US or Argentina, for example); others are limiting crop-based biofuel use (in Belgium or Germany).[35]

Future outlook

Biofuels will - as electrification rapidly becomes more economically viable and sustainable - play a role in supporting electrification and for specific applications. In public transport, this could be for regional and long-distance buses and - in some specific cases - for ferries and diesel trains.

However, biofuels have a role to play during the next decade in speeding up the decarbonisation of public transport in existing fleets, since many buses, trains and ferries have a long-life span, where biodiesel and biomethane swiftly can replace diesel and fossil CNG. Biofuels will also be vital for initiating decarbonisation and delivering energy security and local jobs, particularly in developing areas of the world, where electrification could still be hard to achieve over the next decade due to infrastructure restrictions.

It is important to point out, however, that the decarbonisation potential of the technology is lower than that with the electrification of fleets. Some public transport undertakings with fleets running on biofuels are also rolling out EVs to further decarbonise their operations. Furthermore, the main application of biofuels should increasingly be reserved for difficult-to-abate sectors, such as shipping or aviation.

Case studies

BUS FLEETS RUNNING ON 100% CERTIFIED BIOMETHANE: STADTWERKE, GERMANY

Since 2011, Stadtwerke Augsburg has been operating one of the most environmentally friendly bus fleets in Germany, with 100% biomethane.

The biomethane is produced from residual and waste materials, in particular liquid manure and dung. The operator ensures from their suppliers that crop-based biofuels are not powering their vehicles. This is documented by sustainability certificates from the Federal Agency for Agriculture and Food. These also indicate that GHGs are reduced by 95% compared to fossil-gas-powered vehicles. This means that the operator is able to save 7000 tonnes of CO_2e annually.

Stadtwerke Augsburg is also currently working on improving bus efficiency. A tender will soon be launched for more energy-efficient buses, which would use 20% less fuel during operations.

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A TRANSITION FROM POLLUTING CNG TO BIOGAS: EMT MADRID, SPAIN

Since the 2000s, EMT Madrid has introduced CNG buses in operations and is now 100% fossil-fuel free in operations, relying on various biofuels sources.

A public-private agreement for the production and use of landfill biomethane was signed between different partners in the Madrid region. The Municipality of Madrid, through the Valdemingómez Technology Park, is in charge of the collection, transportation and treatment of organic waste collected from households in the area. The operator has an agreement to consume 6GWh of biomethane per year, representing 1% of their overall fleet. The amount of biomethane provided could be extended in the future. For the operator, using such an alternative was a solution that did not require any investments in buses nor in the infrastructure, but allows for CO_2 emission reductions from ongoing operations.

INTEGRATING BIOFUEL PRODUCTION AND USE: SCANIA, COTE D'IVOIRE

Abidjan is one of West Africa's fastest-growing urban centres. To ensure the city is prepared for the future with an attractive and efficient public transport solution, the bus manufacturer, Scania, is working on a major BRT project in partnership with the Ministry of Transport, the transport company SOTRA, and others. The project covers 450 buses (400 compatible with biodiesel and 50 with biogas), a complete intelligent transport system, the construction of a new bus depot and the establishment of an 'excellence centre' for drivers and technicians. The aim is to have all buses running on biodiesel and biogas produced from local waste.

This is being done in partnership with the national rural agency ANADER and local start-up LONO. A feasibility study has been completed and a pilot phase has started. The first biodiesel production will come from waste rubber plantations, while the first biogas production will rely on sources such as food waste and chicken and pork manure. This will reduce CO_2 emissions by over 80%, whilst also helping solve local waste problems and creating local jobs. In addition, the sustainable by-products of the biofuel production – such as fertilizer, animal feed and energy briquettes - will help increase incomes for local farmers.

The decarbonisation and energy transition of informal transport

Informal transport systems or paratransit systems provide shared transport services for the majority of population in the developing world that do not have access to formal bus- or rail-based public transport systems. Therefore, transitioning paratransit services around the world from ICEs to electric power train technologies will deliver the maximum 'clean passenger-km' among all modes. While the upfront cost of EVs remains higher than ICE vehicles, the high daily mileage of commercial paratransit vehicles will allow them to maximise the energy efficiency and lower operating cost benefits that arise from EVs.

Despite the benefits on offer, paratransit systems have seen limited uptake of EVs, due to a combination of technological and financial challenges that require government intervention. Technological challenges such as inadequate charging infrastructure and the lack of a supply chain for spare parts need to be addressed through mapping paratransit's operational needs, investing in the charging infrastructure at the most appropriate locations and formulating industrial policies to harness local supply chains. Financial challenges for paratransit electrification include a lack of access to finance to allow paratransit operators to invest in the higher upfront costs of EVs due to their limited creditworthiness. Countries such as India are developing innovative financial risk-sharing instruments including interest subvention on loans, supporting 'first loss facility', which takes care of defaulted loans up to a certain threshold, thereby encouraging financing institutions to lend to the sector.

Implementing these measures will, in turn, deliver a lower TCO and thereby increase the net incomes for millions of paratransit operators and their families who are dependent on these services for their livelihood.

SETTING UP THE ENERGY TRANSITION

To capture the full potential of the energy transition, public transport undertakings should set strategic objectives and pathways for achieving the desired outcomes. As previously demonstrated, this is not only a question of switching to clean vehicles, but also requires considering the energy supply used for those vehicles.

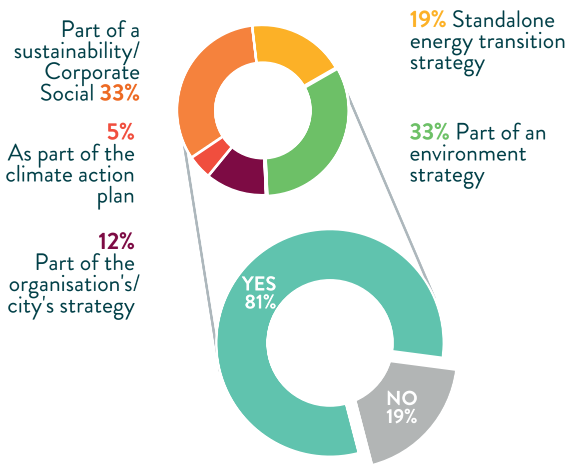
Public transport undertakings should take a holistic approach to assets, local conditions, stakeholders and financial means, among other considerations. Strategies should provide guidance and support in reaching pre-defined objectives in terms of decarbonisation, socioeconomic aspects, financial sustainability and stability of the public transport system. It should also incorporate other local benefits brought by the transition.

ENERGY TRANSITION STRATEGIES

An energy transition strategy provides an organisation with a roadmap for the phasing out of fossil fuels and for navigating the uncertainty within the energy landscape. It does this by outlining the required strategic choices on the demand side, supply side and in the value chain.[36] A well-designed and implemented strategy can bring to life the organisation's vision and ensure both energy security and reductions in carbon emissions while also creating opportunities for the organisation and other stakeholders.

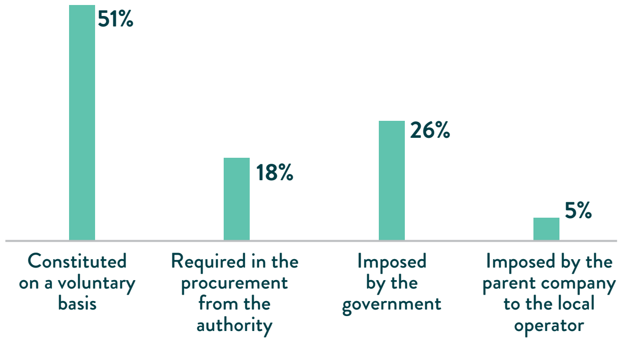
Strategies and commitments of PTOs and PTAs on energy transition

Figure 7: Share of PTOs and PTAs that cover energy transition in their strategy



Based on the results of the UITP Sustainable Development Survey, most respondents include energy transition as part of their strategies, most frequently within another strategy of the organisation (see figure 7). For a majority of the respondents, the strategy was included on a voluntary basis, as opposed to being imposed by governments (see figure 8).

Figure 8: Reasons for PTAs and PTOs to build an energy transition strategy



While more than 60% of respondents have a commitment to only procuring clean vehicles in future, less than half have a commitment to a provision of 100% renewable energy (see figures 9 and 10).

Figure 9: Commitment to procure/tender clean vehicles from PTAs and PTOs

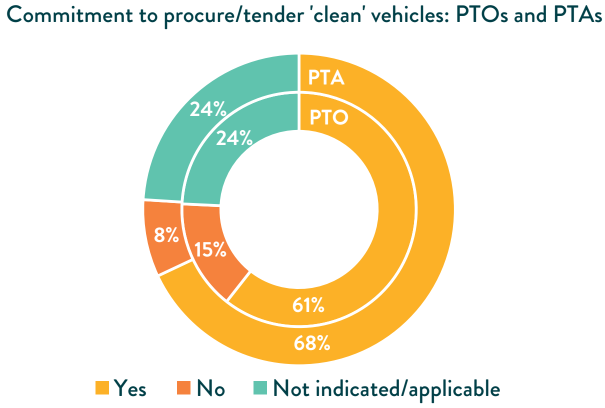
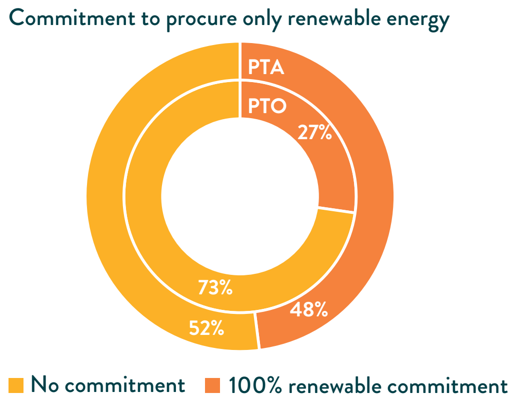
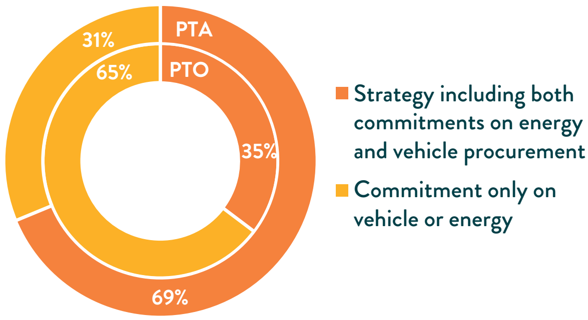


Figure 10: Commitment to procure renewable energy from PTOs and PTAs



Amongst respondents with a decarbonisation target, PTOs consider procurement of green vehicles more often than renewable energy provision. PTAs more often include both dimensions in their strategy (see figure 11).

Figure 11: PTOs and PTAs with a decarbonisation target: commitments on energy and vehicles procurement



Policy tools to energy transition in transport system: SUMP

The transition to a sustainable urban future requires policy tools that can modify the social and environmental costs generated by transport systems. Such costs are not limited to those related to GHGs but also factor in other externalities. These include time lost in traffic, safety risks from accidents, changes in property value, health impacts of local pollutants and noise and accessibility restrictions caused by separation of urban areas from infrastructure transport.[37]

Among these tools, Sustainable Urban Mobility Plans (SUMPs) in the EU are of particular importance. As known, the SUMPs are designed to satisfy the mobility needs of people and businesses in cities and their surroundings for a better quality of life. They build on existing planning practices and take due consideration of integration, participation and evaluation principles.[38]

The interconnection with Sustainable Energy and Climate Action Plans (SECAPs) is immediate (something also highlighted by recent literature on the topic).[39] These strategic tools, developed in the framework of the Covenant of Mayors - the initiative promoted by EU in 2008 to gather local government for the promotion of sustainability initiatives in cities - include several sectors when calculating energy consumption.

The following were mentioned:[40]

- **Buildings, equipment and facilities.** The category includes emissions mainly arising from final energy consumption in residential, commercial, production and municipal/institutional buildings and facilities.
- **Energy supply.** GHG emissions from the generation of grid-supplied energy within the local authority boundary, and GHG emissions from the generation of grid-supplied energy by facilities owned (fully or partially) by the local authority.
- **Transport.** All GHG emissions (direct emissions from fuel combustion and indirect emissions from consumption of grid-supplied energy) occurring for transport purposes within the local authority boundary.
- **Other non-energy related factors.** All non-energy related GHG emissions from the disposal and treatment of waste generated within the city boundary.

SUMPs, if correctly integrated in the policy design, can then contribute to a comprehensive improvement to the overall energy local plan.

An holistic approach to energy transition

Many public transport undertakings are accelerating their energy transition and should take a holistic approach to its implementation. When setting up their strategy, a few elements should be considered.

Define the aim of the strategy

There can be various reasons for an organisation to initiate its energy transition. It could be in response to the energy market situation, to help achieve the decarbonisation of the sector, improve air quality, improve the public transport and user experience, reduce street noise or a combination of factors. The organisation should define those reasons and be clear about the aim of the energy transition. It should be linked with the other strategies for the organisation and for the city, to understand how the energy transition can contribute to other strategic objectives in a local context.

A holistic approach across assets

Public transport consumes energy across a variety of asset classes, not only vehicles. When mapping energy consumption of the organisation, it should include depots, vehicles, stations, office buildings and all infrastructure deployed to ensure the functioning of public transport. This also allows synergies and ways of reducing energy consumption to be identified.

There are three key levers that should be included in an energy transition strategy.

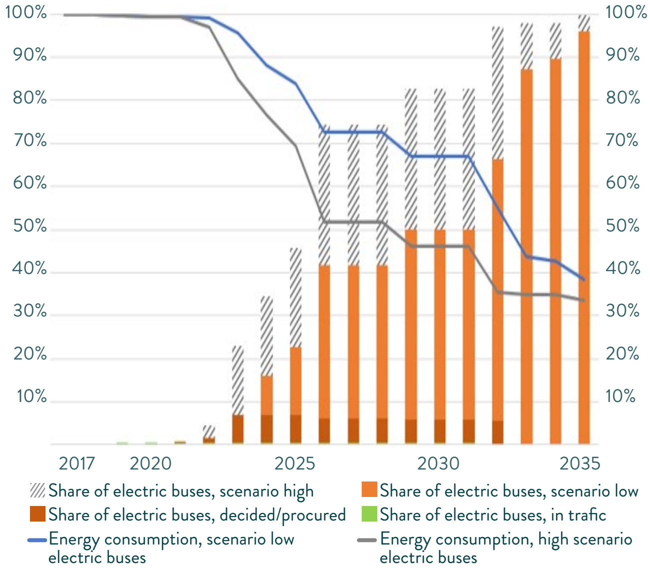
- Shifting the fuel demand of vehicles towards renewable sources of energy.
- Ensuring the provision of renewable energy to cover energy consumption.
- Reducing overall energy consumption.

SHIFT FROM BIOGAS AND BIOFUELS TO ELECTRIC VEHICLES: PUBLIC TRANSPORT ADMINISTRATION STOCKHOLM AND VÄSTTRAFIK

The examples of Västtrafik (Västra Götaland Region) and the Region of Stockholm (both in Sweden) and EMT Madrid in Spain illustrate the importance of maintaining flexibility in energy transition strategies.

Since the early 2000s in Sweden, the national public transport organisation has worked on a joint countrywide energy strategy for all public transport. This included a strategy and joint contract requirement to be used by PTAs in the country. As a result, 94% of public transport in Sweden now (2021) runs on renewable fuels. The original impetus was to switch away from fossil fuels in public transport operations, which led to the introduction of renewable fuels such as biomethane, HVO and RME. Thanks to this strategy, Västtrafik was able to reduce its CO_2 emissions by 60% (from 125,000 tonnes to 50,000 tonnes). The public transport administration in Stockholm has reduced its emissions by 67% by introducing buses running on HVO, FAME, ethanol, biogas and electricity (baseline 2011, when 56% of the fleet was running on biofuels).

However, with revised strategies of both authorities, a new ambition was set of reducing CO_2 emissions by 90% by 2035. The introduction of EVs running on renewables should support this objective, which cannot be achieved with the current biofuels fleet. Other appealing benefits of EVs identified for Stockholm were noise reduction, the attractiveness of the vehicles and cheaper procurement and maintenance costs. For Stockholm, the target is to have a 100% electric fleet by 2035, implemented through new traffic procurements. This should reduce their emissions by a further 60% (also relying on the evolution of the country's energy mix).



Stockholm plan for introduction of electric buses

Reduction of CO_2 emissions

The decarbonisation of public transport operations is essential – indeed, often central - to energy transition strategies. Any such strategy should state the target as reducing carbon emissions and should also define any particular technology to reach those needs (see case study below). The energy transition is usually part of wider strategic framework and can influence and be an essential component of reaching organisational objectives, particularly decarbonisation.

Flexibility

The implementation of new technologies requires dealing with uncertainties, as traction technologies evolve and charging infrastructure must be adapted. The current energy crisis has also highlighted the importance of including flexibility within the strategic choices of the organisation. Once implemented, the solution should fit the operational context and application. Taking account of uncertainties within the strategy is key to allowing flexibility in achieving strategic objectives while ensuring core objectives remain in place.

ASSESSING AVAILABLE OPTIONS AND TECHNOLOGIES

When evaluating different decarbonisation alternatives, multiple factors must considered. These relate not only to the operations themselves, but also to other environmental, economic and social factors. To do so, an evaluation methodology that contemplates each of these variables must be developed.

- Operation and characteristics requirements for the vehicles (such as operation time/range, vehicle size and frequency) must be taken into consideration. These factors will determine which type of energy supply and charging / refuelling infrastructure will be optimal for operations, and may exclude some alternatives due to their incompatibility.
- Local conditions such as climate conditions, topography, energy sources and infrastructure will also be determinants. For example, if there are steep slopes along the route, this will directly impact on energy demand. The requirements for electrification of rolling stock and creation of the necessary infrastructures should also be considered. For example, fuel cells and gas/liquid propulsion systems can be considered valid solutions for certain cities, as these have high autonomy. However, if the demand for primary energy is a determinant factor, the best solution could be BEVs, for which there are several charging options with differing features. However, in areas where power networks are not sufficiently developed, large investments (public or private) may be required to reach electrification targets.
- A Cost-Effectiveness Assessment (CEA) must be carried out. This is a type of analysis that calculates the value of energy saved in EUR/kWh, and is applied to energy efficiency investments.[41] Thus, the energy considered in this calculation is the one that has been saved thanks to the necessary energy efficiency investments. When undertaking this kind of study, it is not only the purchase price that should be compared; other factors, such as their operating range, whether they are fast- or slow-charging, battery weight or battery recycling; all these factors will influence the overall final energy savings. If an electric bus performance has an sizeable operating advantage in these fields through special batteries capacity and autonomy, it may be a more a cost-effective choice for authorities and operators.

Solar-powered ferry in Dubai, United Arab Emirates

- The **operational sustainability** must also be studied; not only the potential for reducing carbon emissions but also the available resources to maintain the solution in operation sustainably. It is important to consider the need to keep the system in operation as long as possible. In some cases - where access to funding is an issue, particularly in developing countries - a cheaper, lower-quality technology may be chosen based purely on upfront price criteria. Failure to think in the medium to long term is an error, as these cheaper technologies sometimes can only operate for a few years before having to be scrapped. It is important to consider what carbon reduction can be achieved according to the operator's financial means.

Last, it is essential to **understand the local energy market.** An important factor is how energy is produced and its carbon footprint, which varies between regions. Furthermore, the availability and reliability of the energy supply in the region must be studied. The nature of the city must be evaluated in order to make the most of the local situation, for example in cities or regions where there are locally available energy sources from the industrial sector or waste recycling. As an example, TMB in Barcelona decided to invest in hydrogen-powered vehicles, as they saw the opportunity to create a public plant for supplying green hydrogen in collaboration with the energy supplier Iberdrola. The price of the energy and stability of the source are also key elements in ensuring the durability of the system.

When considering the broad range of possible options for an energy transition, it is essential to recognise that there is never a one-size-fits-all solution. Each region will have to go through its own thorough assessment process in order to identify its particular characteristics and select the best technology for the situation.

FROM STRATEGY TO IMPLEMENTATION: DEPLOYMENT OF THE SOLUTION

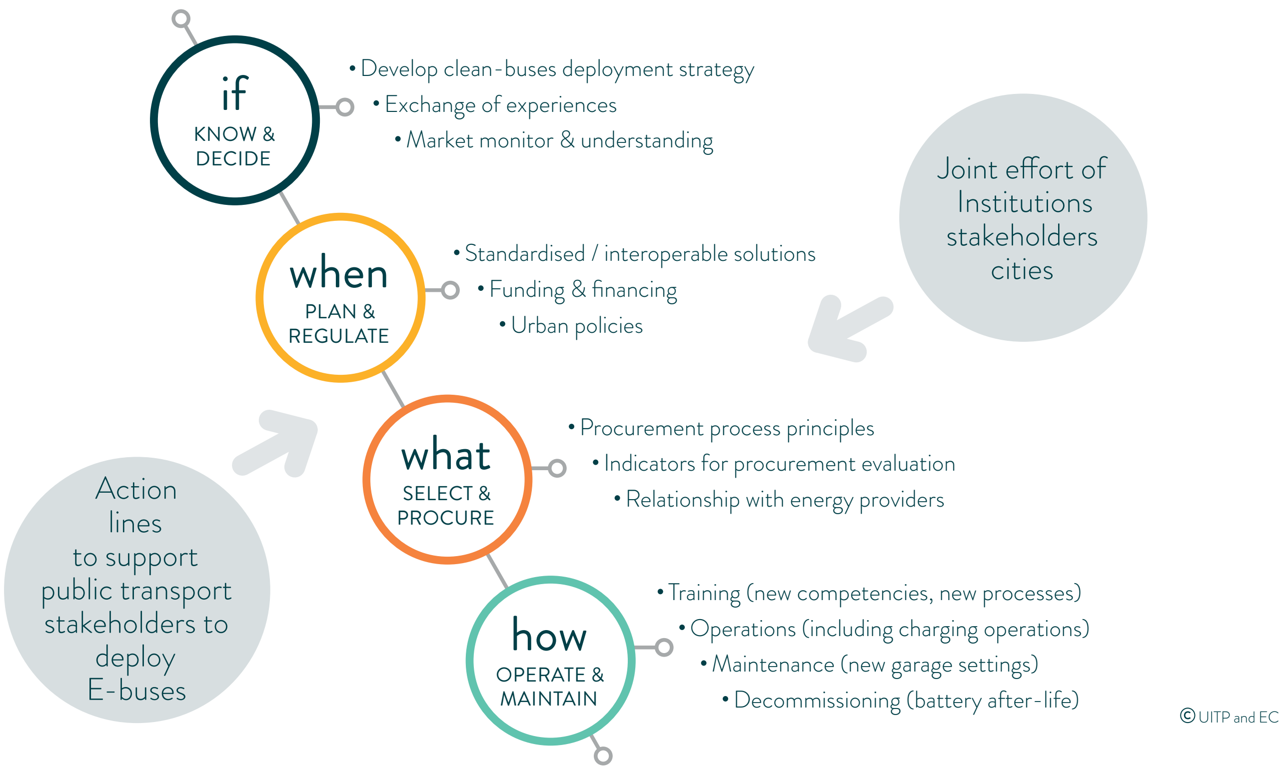
Once objectives are set and proper assessments have been undertaken of the technologies and local specificities, the deployment of the solution will be based rolled out in different phases.

Large-scale deployment of Electric Vehicles and alternative fuel technologies

A phased approach can be selected to the large-scale deployment of EVs and alternative fuel technologies. Deploying the energy transition is not simply about the vehicles; it is also about the deployment of a system.

The planning phase can represent an opportunity to identify synergies with energy consumption in other public transport assets. EVs can take advantage of metro and tram charging systems (where existing) thus reducing the cost of installation. Contractual conditions for energy provision between modes and assets should also be explored in the planning phase. Designing the infrastructures needed to deploy the solution is influenced by

Figure 12: Phased approach for ebus deployment, UITP & EC [42]



the technical specifications of the charging / refuelling equipment and whether those are brownfield (adaptation of an existing infrastructure) or greenfield projects (new infrastructure designed from scratch).

During the procurement phase, it is important to remember that EVs are not simply about vehicle renewal but also requires a 'system procurement' for developing the vehicle, the new infrastructure, civil engineering and other intelligent transport services. In terms of sustainability, the tender can also integrate 'innovation' aspects and lifecycle requirements.

Before entering into operations, the execution of the works is a critical step. This is particularly the case for brownfield-located projects, where infrastructure may be in operation during the duration of the works. Even before granting the construction permit, grid or gas network connection studies or environmental studies may be required before having the construction permit granted. From the environmental aspect, this may require conducting specific impact studies, compliance studies on the environmental code or legal environmental procedures, all of which may last more than two years. Planning the execution of works is complex, and involves many stakeholders and requires anticipation to provide supplies at the appropriate time in the implementation process.

Perform a pilot study with the solution before entering in operation is advisable, to support the management of risks and changes. To build the pilot, operators should liaise with industrial suppliers and monitor the data collected during the process to assess the potential and application of the technology in its planned operational context.

During operations, many processes - and the organisation itself - should integrate the changes brought about by the deployment of the new solutions. Maintenance models have to be reviewed, coordination with other services of the city should be ensured and monitoring of the solution is needed. The energy transition should be embraced by all staff involved in the operation, including maintenance and other organisational levels.

Deployment of biofuels in existing and new fleets

Biofuels procurement is essential for achieving the carbon objectives of the service operations. Two procurement options are available to public transport undertakings:

- Purchasing biofuels on the open market
- Local production, more specifically biogas from sewage water or organic waste.

An analysis of the market should be performed to assess the available biofuels. A joint procurement approach can also be considered to reduce costs or to contribute to establishing a production power plant.

The procurement should also include a series of criteria (technical, on sustainability and traceability) to ensure that carbon emissions objectives are being met.[43]

Biofuels procurement should also be considered for existing fleets of CNG or diesel vehicles. Using biofuels rather than fossil fuels can help reduce carbon emissions.

Pilots of hydrogen powered vehicles

In comparison to other technologies, hydrogen-powered vehicles are still at an early stage of development. Operators who chose to deploy those vehicles do so initially through pilots. This allows them to help manage risks and changes and confirm (or not) the potential of a technology by gathering and assessing local data in the frame of the project.

An increasing number of encouraging results are emerging from these pilots, but it is important to consider that the technology represents a step-change from diesel buses; securing support from the stakeholders involved and operational expertise will essential. An important element here is to collaborate with suppliers and the government to make the fuel cell bus system viable for a commercial enterprise.

From a government perspective, one of the challenges it is the ability to provide certainty for operators in the different frameworks: regulation and permit-wise. There is also the need to provide commercial certainty for operators by de-risking their investment (such as guaranteed demand for H2 or providing access to expertise). An important consideration is that increasing FCEVs operations could provide leverage for integrating hydrogen into the regional energy system.

CASE STUDIES

A TRANSITION TO E-BUSES: VÄSTTRAFIK, SWEDEN

Västtrafik's transition to ebuses that run on renewable electricity is a requirement for reaching the PTA's climate goals. All city traffic needs to be electrified by 2030. The shift began by testing new technology in a mutual learning exercise.

The first pilot started in 2011 with the testing of plug-in hybrids on an existing route in the centre of Gothenburg. It involved three plug-in hybrids, used outside the standard timetable, with two charging stations, one at each end of the route.

With the knowledge gained from the first pilot, Västtrafik continued with the project ElectriCity, which tested plug-in hybrids and fully electric buses on a separate route (line 55) during 2015. Again, two charging stations were used, one at each end of the route.

The ElectriCity project provided an platform for Västtrafik and partners to test different solutions connected to the Public Transport system. The customers have been pleased with the reduction of noise and that the buses are electric. Meanwhile, the drivers experienced a better working environment, with less noise and vibration.

Västtrafik continued implementing electric buses into some existing contracts together with the contracted partners in 2019. These were selected for differing conditions and differing geographical situations.

The pilots provided valuable insights and now all city traffic procurement is electric. It is important to define clear requirements in contracts and to give the various operators free rein to develop the traffic service to the local circumstances, as it is not just a change of bus technology but a whole new system.

It is also important to invite operators for a dialogue early in the process when preparing for the tender, to optimise delivery and implementation.

Summary

- An energy transition project is a complex process, one that can bring substantial change and involve decades of investment. The following aspects are important.
- Linking energy transition with other strategic frameworks and objectives in order to understand the role it has to play for the organisation.
- Identifying how to address those objectives through implementing new technologies and solutions.
- Assessing the potential of each solution to understand its possible operational role.
- Adopting a holistic approach to implementation, ensuring cooperation between assets (when possible).
- Reviewing operational and maintenance processes and assess the balance of risks between all stakeholders involved
- Monitoring the newly introduced technology, particularly certain critical and high-value equipment such as batteries, fuel tanks and fuel cells.

STRATEGIC APPROACH ON ENERGY TRANSITION: TMB, SPAIN

Energy transition is one of the key objectives of TMB's Strategic Plan. One of the main goals is a 6% reduction of energy consumption in the metro through applying technologies that allow braking energy to be recovered from trains.

Furthermore, TMB is working to progressively convert their bus fleet to make it more sustainable, starting with the purchase of hybrid vehicles and EVs. They will introduce 410 clean buses of varying types (46 hydrogen, 210 electric, 154 CNG-hybrid) and 120 EVs to renew the auxiliary fleet (cars, vans) before 2024.

Since 2016, all the low-voltage electricity purchased by TMB is derived from renewable sources. In addition, since 2018, all the high-voltage is also derived from renewable sources.

TMB is also creating synergies between buses and the metro: The chargers at two of the bus depots will be supplied with electricity from the receiving substations of two metro lines (9 and 10). Using of metro's electrical connections, which are currently only used during daytime hours, means that they can charge the buses at night, maximising the utilisation of the electrical infrastructure. This metro-bus interconnection solution will save approximately 30% on energy costs over traditional models.

TMB has realised clear benefits from its energy transition, including reducing carbon emissions, costs and increasing energy stability.

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Social acceptability of the energy transition

As a rule, renewable sources of energy receive strong approval. However, at a local level when the sources need to be installed, developers can encounter obstacles among residents of the designated neighbourhood (the 'not in my backyard' effect). This concerns not only citizens but also local administrations.

All aspects of the information issues surrounding the energy transition need to be addressed (such as social and economic impact, technical aspects and evaluation of the advantages and disadvantages).

In response to those obstacles, 'energy communities' allow the public to contribute to the clean energy transition. These communities are citizen-driven actions that help increase public acceptance of renewable energy projects and encourage private investments in the clean energy transition.

ASSESSING BENEFITS AND IMPACTS OF THE ENERGY TRANSITION

Transportation is subject to external costs arising from its operations, which are not usually borne by transport users themselves. External costs associated with transport include those arising from air pollution, congestion, accidents or noise. Public transport use offers a series of benefits and these have been promoted in a UITP campaign.[44] A modal shift towards public transport can achieve strong benefits for cities, as it allows a significant reduction in external costs compared to, for example, private cars. The internalisation of external effects by transport users should be central to their transport decision.

The public transport energy transition has the potential to amplify those benefits and make public transport an even more attractive option for users to reduce their external impacts of their travel.[45] The assessments of the impacts of the energy transition should therefore also factor in the wider general benefits that public transport already brings to cities.

Benefits from the operation of vehicles are manifold, from a perspective of the environment, economics, operations, on energy management and on city infrastructures, depending on the technologies and modes deployed. The impact of the energy transition should be assessed to showcase and monitor the impacts of the measures taken.

Providing renewable sources of energy to cover consumption needs also brings benefits in terms of decarbonisation but also for the organisation and the economy in general.

AN OVERVIEW OF THE BENEFITS OF CLEAN VEHICLE TECHNOLOGIES

Each technology brings potential benefits and impacts at different levels, according to its own specific characteristics. While clearly reliant on the local context, this assessment is meant to offer a global perspective on the potential of each technology to achieve a given benefit.

Environmental benefits apply to the improvement in environmental conditions in the local area and beyond.

Decarbonisation refers to the reduction of carbon emissions (Scopes 1 and 2).

Numerous frameworks and standards are available to track carbon emissions associated to operational emissions and from energy generation. To track carbon saved with the energy transition, the following assessments should be performed:

- Carbon emissions of the fossil fuel solution
- Carbon emissions of the new solution as claimed by manufacturer
- Carbon emissions of the new solution in operations.

To reflect the energy efficiency of public transport and other transport modes, those assessments should also be made according to CO_2 emissions per passenger kilometre.

As public transport mostly relies on public funding, it is important to have a system in place to check that decarbonisation initiatives are fit for purpose, work as intended and can be improved over time.

Air quality refers to improvements in air quality in the operational area such as reductions in NOx and particulate emissions. Attributing air quality improvements of the city to the energy transition of public transport can be difficult to prove, as improvements depends on a variety of factors. It is possible, however, to make a 'before-and after' comparison between NOx and particulates following the implementation. Models to calculate the benefits of modal shift to public transport should be updated to reflect the implementation of the energy transition.

Noise reduction refers to the decrease in noise emitted during the operation of a vehicle. Noise reduction for bus passengers can increase comfort levels and bring health benefits. This also applies for the impacts of external noise on a city's inhabitants.

Economic benefits for the operator for a specific solution.

The indicators are as follows:

CAPEX refers to capital expenditure to implement the solution.

OPEX refers to the operational expenditure to run the solution.

Price-shock risk refers to the stability of the energy market and crisis resilience of market prices.

Ex ante, a TCO analysis enables comparisons of different technologies. To best evaluate the most financially effective reduction technology, this should include purchase costs, operating costs, overheads, bus disposal and battery recycling cost and a price for carbon emissions.

Ex post, performing a life cycle cost analysis can provide a holistic view of the costs of the solution implemented from the infrastructures and operational aspects, including vehicles and infrastructures CAPEX, energy costs, bus as well as infrastructure maintenance costs.

Operational benefits of the solution for the public transport undertakings managing the lines.

Energy efficiency refers to the amount of output that can be produced with a given amount of energy, 'Well-to-wheel' (extraction / generation, transport, storage / compression and distribution).

The relative energy efficiency of each technology is regularly debated but rarely agreed upon, as they often depend on local operating conditions. Therefore, pilot studies or an example from a similar city can give a more precise guide to the real efficiency of the technology.

Technological risk refers to the potential for any technological failure to disrupt a business.

Operational flexibility refers to the flexibility for refuelling and charging the vehicles for operation, in terms of location, refuelling time, timing available to refuel. Flexibility and charging / refuelling methods influence the planning of lines and the operations of public transport. Alignments between the new and former operating conditions have to be performed to adapt to a new technology.

Energy management benefits to have a sustainable supply with low risks.

Security of supply refers to the ability of the market to cover the demand of public transport undertakings. An energy market analysis should be performed to understand how the market will provide the required amount of energy in a stable manner. According to the source and the local situation, this ability to provide a stable energy supply may fluctuate.

Transition risk refers to those risks associated with the shift to a new energy source. These include policy and legal, technological risks as well as market and reputational risks. A series of analyses should be performed to identify policy and legal risks locally, technological risks associated with the solution, reputational risks of the chosen technology. These should be performed early in the energy transition process.

City and public transport system benefits attributed to the introduction of an alternative fuel technology.

City infrastructures refers to the potential of the technology to provide benefits to other services in the city. The energy transition within public transport can also benefit other sectors. Consulting with other stakeholders and identifying the potential synergies in implementing the solution offers insights into the external benefits for the economy and other infrastructures managers.

Job creation refers to those created as a result of implementing a solution. Associated jobs created by the energy transition can be identified through a job market analysis.

Modernising customer offers refers to improvements to the comfort and offer of the public transport network. The energy transition improves the image of the service and the comfort of the vehicles. Customer satisfaction surveys should be performed following the implementation of the solutions to capture the benefits and further improve implementation.

These benefits should be monitored to ensure that the predetermined objectives of the energy transition are being achieved. Adaptation measures could be identified to achieve and maximise benefits

Benefits	Type of technology	Diesel	CNG	Biofuels	Biogas	BEV	FCEV
Environmental	Decarbonisation (whole life cycle)	Low	Low	Medium	Medium	Medium	Medium
	Local air quality (tailpipe emissions)	Low	Low	Medium	Medium	High	High
	Noise reduction	Low	Low	Low	Medium	High	High
Economic	CAPEX	High	High	High	High	Low	Low
	OPEX	Medium	Medium	Medium	Medium	High	Low
	Price-shock risk	Low	Low	Medium	Medium	Medium	Medium
Operational	Energy efficiency	Low	Low	Medium	Medium	High	Medium
	Operational flexibility (fuelling)	High	High	High	Medium	Medium	High
	Technological risk	High	High	High	High	High	Medium
Energy Management	Security of supply	Medium	Low	Medium	Medium	High	High
	Transition risk	Low	Low	Medium	Medium	Medium	Medium
City and public transport	City infrastructures	Low	Low	High	High	High	High
	Job creation	Low	Low	High	High	High	High
	Modernising customer offers	Low	Low	Medium	Medium	High	High

High: Strong potential of achieving this benefit

Medium: Possibility of achieving this benefit, according to local context, operational conditions and limits of the energy source

Low: The benefit is not applicable or does not work well for this technology.

AN OVERVIEW OF THE BENEFITS OF RENEWABLE ENERGY SUPPLIES

Procuring renewable energy for power public transport assets can deliver a range of benefits to an organisation compared to one that does not focus on its energy supply.

The table below lists, for each type of energy identified throughout the report (electricity, hydrogen and biofuels), the benefits for public transport of providing a renewable source compared to its non-renewable counterpart.

Type of renewable energies / Benefits	Renewable electricity	Hydrogen synthesised from renewable sources	Biofuels converted from waste and low Indirect Land-Use Change (ILUC) risk
Decarbonisation	Stronger if developing a new asset.	Stronger if developing a new asset.	Stronger benefits if biofuel originating from waste material.
Contribution of public transport to improving the renewable energy sector	Power Purchase Agreement: Deployment of new assets, either on or off site. Renewable energy certificates: Incentive to deploy new infrastructure, but less strong than PPAs.	If new renewable assets deployed. If not, potential risk of drawing renewable electricity produced to hydrogen production instead of grid supply.	Potential in the installation of biomethane production infrastructures in agricultural or waste collection sites.
Price stability	The greater the level of renewable in the mix, the more stable the price. Stable if a long-term contract (PPA).	Stable provision if produced locally and according to renewable electricity prices.	Depends on the origin (for example risks in case of food crisis for crop-based fuels). Generally tracks the price of fossil equivalent. Availability of biofuels is finite (land-use).
Financial	Stable price if long-term contract (PPA). Carbon offsetting potential for on-site assets.	Cost currently high, but expected to decrease with more investment in hydrogen economy.	Varies according to market and legal framework but generally similar price structure to fossil equivalent. Carbon offsetting potential for some biofuels.
Reputation of public transport	If certified and advertised.	If certified and advertised.	If certified and advertised.

CONCLUSION

The energy transition of our societies will be the major challenge to overcome in the coming years to achieve global climate objectives. While the transition towards alternative fuel technologies is ongoing in the public transport sector, renewable energy supplies are currently not yet as well developed in organisations' energy transition strategies. The energy supply for existing fleets and other public transport assets must not be ignored by any public transport stakeholders in striving for CO2 benefits.

Renewable energy supplies will differ from one context to another, which is why it is important to understand the legal context and local energy markets. Working in cooperation with an energy provider/developers, municipalities and other energy consumers facilitates the deployment of new renewable electricity assets and a supply of renewable fuels.

Switching to renewables may also require shifting fleets towards alternative fuel technologies. This can be a heavy process, which should be well prepared by:

- *Performing an assessment of available technologies*
- *Confirming the potential of a technology to achieve the objectives of the organisation*
- *Finding the appropriate financial schemes to cover the investments required to deploy the energy transition*

In addition to decarbonisation benefits, the energy transition and shift to renewable energy supplies have other strong added values in terms of operations, public transport users, citizens and cities. Emphasising this can be key to finance the energy transition, get public approbation and, ultimately, improve the image and strengthen the benefits of public transport within our societies.

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ATM - Azienda Trasporti Milanesi
Baku Transport Agency
Bangkok Expressway and Metro Public Company Limited
BKK Centre for Budapest Transport
Bureau du Taxi de Montreal
Bus Éireann
CCR S.A
City public transport company Belgrade
ComfortDelGro Corporation
De Lijn
East Japan Railway Company
EMT Madrid
Ferrocarrils de la Generalitat de Catalunya
FNM S.p.A.
Ruter
Hochbahn
HSL - Helsinki Region Transport
Île-de-France Mobilités
Intendencia de Montevideo
İzmir Metro A.Ş.
KeolisAmey Metrolink
Lagos metropolitan Area Transport Authority (LAMATA)
Land Transport Authority
Metro Bilbao S.A.
Metro do Porto
Metropolitano de Lisboa
Movia
MTA C&D
MTR Corporation Limited
Münchner Verkehrsgesellschaft
Nederlandse Spoorwegen (NS)
PostBus Ltd
Public Transport Authority in Warsaw (ZTM)
RATP Group
Roads And Transport Authority
Secretaría de Transporte del Estado de Jalisco
SRM - Societa' Reti e Mobilita' S.R.L.
Stadtwerke Augsburg Verkehrs-GmbH
Stadtwerke Osnabrueck
STIB-MIVB
STM
Stockholm Public Transport
Strætó
Thessaloniki Transport Authority
Tramvia Metropolità S.A.
Transdev
Translink
Transport for London
Transport Infrastructure Ireland
Transports Metropolitans de Barcelona (TMB)
Västtrafik AB
Wiener Linien
Metro de Medellín
Globalvia Inversiones
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This is an official Report of UITP, the International Association of Public Transport. UITP represents the interests of key players in the public transport sector. Its membership includes transport authorities, operators, both private and public, in all modes of collective passenger transport, and the industry. UITP addresses the economic, technical, organisation and management aspects of passenger transport, as well as the development of policy for mobility and public transport worldwide.

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