

Electrification of Madrid Fleet Public Transport Company (EMT-Madrid): Strategic Analysis and Implementation

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Abstract: Madrid Public Transport Company (EMT-Madrid) is a property of the Madrid City Council, and it provides the public buses service in the whole city. Madrid, as most of the big cities in the world, is facing problems related to high levels of urban pollution, which directly affects the health and life quality of their inhabitants. EMT, having a fleet of around 2000 buses, has an impact in the mentioned problem and in the global warming. With the Strategic Plan 2017-2020, many new buses will be acquired, resulting in a fleet of natural gas, hybrid and electric vehicles by the end of 2020. The present study has the goal of being the cornerstone of a future strategic plan of the company. To this end, both external and internal analyses of the company have been conducted, which support that the electrification of the whole fleet is the best option in the long term. Furthermore, a Benchmarking of the state of the public transport in other 25 cities and the technology used in them has been conducted. Last, a model that allows replicability of this strategic assessment is proposed, in order to help other Transport Companies and City Councils to decide which transport fleet is the best to implement in their cities depending on their necessities and resources.

Key words: Sustainable transport, Electric Buses, Air Quality, Emissions, Benchmarking.

1. Introduction

The presence of high concentrations of air pollutants in the city of Madrid has led to traffic restrictions in the city up to three days during December 2018 (Ayuntamiento de Madrid, 2019). This problem is not exclusive from Madrid, as many other large cities of the world are frequently exceeding the pollutants concentration level that the World Health Organization considers safe to breathe (World Health

Organization, 2005). The pollutants with the highest impact (due to its concentrations in the urban air and its harmfulness) are particulate matter (PM), nitrogen oxides (NO_x) and ozone (O₃). These compounds cause an increase in mortality and numerous cardiovascular and respiratory system diseases. There exists criticism both among the scientific community and public institutions on the attribution of pollutants solely to the exhaust of combustion engines. For instance, the German Federal Environmental Agency supports that brakes are responsible (in modern cars of Euro 6 type)

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for four times more particle emission pollutants than the combustion engine. Likewise, Grigoratos and Martini (2014) pose that brake wear can sum up to 21% of PM₁₀ traffic-related emissions. Airparif (2017) reports that, while PM_{2.5} can be attributed to exhaust emissions, PM₁₀ “particles include a significant fraction related to tire-wear, brake-wear, road abrasion and dust suspension”. Regardless of whether pollutants come from the engine exhausts or from other traffic sources, it is clear that private traffic is directly responsible for two of them, PM and NO_x, and indirectly responsible of O₃. Regarding the city of Madrid, reducing these emissions in the city is in the Air Quality Plan of the City (Ayuntamiento de Madrid, 2017).

Each kind of engines produces different pollutants. Diesel buses produces high quantities of CO₂, NO_x and PM. Natural Gas buses slightly increase the CO₂, reduce the NO_x and practically vanish the PM emissions. Electric and hydrogen powered buses have zero emissions.

In the field of electric buses, there are also different ways to charge them: A direct classic connector to the electric network in a charging station (which can be fast or slow depending on the power), a pantograph (automatic mechanical arm that connects with the bus from above) and magnetic induction (a magnetic field charges the battery from below). Also, trolleybuses can use the tram lines to charge their batteries.

EMT-Madrid (Empresa Municipal de Transportes de Madrid) is the public company that operates the whole public buses network in the city of Madrid, having a fleet of around 2000 units. The current strategic plan of the company for the period of 2017-2020 has the aim of replacing all their diesel buses for low emissions or zero emissions buses by the end of 2020 (Empresa Municipal de Transportes de Madrid, 2017). This eco-friendly or green fleet includes Compressed Natural Gas (CNG), hybrid and electric buses. EMT-Madrid currently has around 1000 diesel, 940 CNG, 40 hybrid and 20 electric buses.

By the end of 2020, EMT-Madrid will have acquired close to 80 new electric buses and 940 new CNG buses, achieving a full green fleet. The present study aims to be the seed of the future strategic plan of the company, on its way to the 0 emissions fleet. This procurement is well aligned with the proposal of Ocampo and Ocampo (2015), “Developing initiatives that simultaneously enhance customer satisfaction and community development by addressing environmental

concerns on toxic substance, GHG emissions and air emissions is fundamentally important to increase revenue and profit.”. Moreover, Vernadat (2014) states that successful management delves with making sure that the processes are executed in such a way that business objectives are achieved in an efficient, effective and economic way.

The three main goals of this research are:

- Strategic analysis of the company (internal and external), focusing in the fleet, infrastructure, human resources and everything related with the electrification.
- Benchmarking of the situation of the public transport in other cities and their plans and strategies.
- Creation of a model that can guide and support other Transport Companies and City Councils of the world to decide which transport fleet is the best to implement in their cities depending on their necessities and resources.

The rest of the article is organized as follows, similarly as in Ros-McDonnell *et al.*, (2018). Next section presents the theoretical framework, while section 3 presents the methodology used. Section 4 presents the results obtained in the Strategic Analysis and Benchmarking, which includes the strategic lines that the company should implement. In section 4, the Decision Tree is also presented, and finally, in the last section, conclusions, limitations and avenues for further research are gathered.

2. Theoretical framework

2.1. Global warming

Global warming is a huge problem that affects the whole planet and it is mainly caused by the greenhouse effect. This effect, according to Kyoto Protocol (1998), is produced by the greenhouse effect gases: Carbon dioxide (CO₂), Methane (CH₄), Nitrogen dioxide (NO₂), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF₆), emitted in sectors as Energy (including fuel consumption in transport), Industry, Agriculture and Waste (United Nations, 1998). These gases reflect part of the heat that the Earth emits to space, causing an increase of the average temperature of the planet.

According to the study “Long-term Climate Change: Projections, Commitments and Irreversibility”,

consequences of Global warming include more hot and cold extreme temperatures, changes in atmospheric circulation, in the ocean and in the water cycle, reduction of the Arctic ice extent and climate change (Cambridge University Press, 2013).

2.2. Urban growth and its consequences

Norman Foster in the “Future is Now Forum Madrid 2017” explained that society is migrating from rural to urban areas to an unprecedented level, and estimated that by 2050, 75% of the world population would live in large cities. In addition, the private car will be no longer used, and more sustainable and innovative transport systems will be implemented (Norman Foster, 2017).

Enrique Dans and Gildo Seisdedos, in their study “Upgrading urban mobility”, analyze the current situation of unsustainability in large cities. The solutions proposed so far, from restrictive measures to incentives for models based in sustainable transport systems have been, in most cases, insufficient. The alternatives available to the citizen are not enough to consider transport models not based on the use intensive private vehicle, even for the cities with the best public transport. It is estimated that 60% of the world population will live in cities in 2030. In that year, if the current trend continues, the world’s car fleet will double its amount from 1.2 to 2.4 billion cars. A change to a public and shared transport is needed (Dans and Seisdedos, 2016).

2.3. Emissions and their origin

The most important pollutants according to the World Health Organization are the following:

- Particulate Matter (PM): Pollution by particulate material occurs with the entry of suspended

particles into the atmosphere. The main difference between these particles in their way of affecting the organism is that PM₁₀ particles (diameter equal to or less than 10 µm) can penetrate to the lower respiratory tract, while PM_{2.5} (diameter equal to or less than 2.5 µm), being smaller, can be breathed, reaching the gas exchange zones of the lung. If the particles are ultrafine, that is, less than 100 nanometers, they can also get into the bloodstream (World Health Organization, 2005).

- Ozone (O₃): The polluting ozone is not the one found in the upper atmosphere, but it is the one that is produced by secondary reactions of other pollutants and is at ground level, so can be breathed by people. Due to its high oxidizing power over living materials and tissues, ozone can cause premature aging and deterioration of the lungs, as well as irritations in the respiratory system, cough, asthma, headaches and alterations of the immune system (World Health Organization, 2005).
- Nitrogen dioxide (NO₂): The effects of NO₂ on health are an important inflammation in the respiratory tract, decreased development of lung function and an increase in bronchitis symptoms in children with asthma (World Health Organization, 2005).
- Sulfur dioxide (SO₂): SO₂ affects the respiratory system and pulmonary functions, producing heart disease, cough, mucous secretion, asthma, chronic bronchitis and an increase in mortality, in addition to increasing the risk of contracting respiratory infections. SO₂ also causes eye irritation to exposed people (World Health Organization, 2005).

Table 1 shows a comparison between the maximum values allowed in Spain according to the Royal Decree in force with the values defined by the

Table 1. Comparison maximum concentration allowed by the EU and by the WHO.

Pollutant	Measurement period	WHO (2005)	2008/50/EC RD 102/2011	Times it can be exceeded RD 102/2011
PM _{2.5}	24 hours	25 µg/m ³	-	Cannot be exceed
	1 year	10 µg/m ³	20 µg/m ³	Cannot be exceed
PM ₁₀	24 hours	50 µg/m ³	50 µg/m ³	35 times/year
	1 year	20 µg/m ³	40 µg/m ³	Cannot be exceed
O ₃	8 hours	100 µg/m ³	120 µg/m ³	25 times/year
NO ₂	1 hour	200 µg/m ³	200 µg/m ³	18 times/year
	1 year	40 µg/m ³	40 µg/m ³	Cannot be exceed
SO ₂	10 minutes	500 µg/m ³	-	-
	1 hour	-	350 µg/m ³	24 times/year
	24 hours	20 µg/m ³	125 µg/m ³	3 times/year

European Union and the values defined by the World Health Organization (Boletín Oficial del Estado, 2011) (World Health Organization, 2005).

As can be seen in the Table 1, the European regulations are less restrictive than the maximum recommended values of the World Health Organization (WHO).

According to the Ministry of Energy, in Spain, transport is the sector with the higher emissions, having in 2016 a 42% of the energy demand of the country (Ministerio de Energía, Turismo y Agenda Digital. Gobierno de España, 2016).

2.4. Research Question

In light of the negative effects of air pollutants over the health of big cities inhabitants, public institutions have the responsibility of taking measures against the origin of these pollutants. In that vein, public transport policies are a powerful leverage to improve air quality.

In the authors' opinion, the strategic plan of EMT-Madrid can be taken as a brave initiative, and therefore suggests the following research question of this study: "What are the main recommendations that can be extracted from the strategic plan of EMT-Madrid in order to be followed in other cities facing similar problems?"

3. Methodology

In order to shed light on the abovementioned research question, a two-fold methodology is proposed.

3.1. Strategic Analysis

Firstly, the methods used for the strategic analysis of the company were the model of the competitive forces (Michael E. Porter, 1998) and the PESTEL Analysis (Political, Economic, Social, Technological, Ecological and Legal Factors) for the external part (effects from the environment). On the other hand analysis of the significant documents, interviews with the stakeholders and visits to the different

sections of the company for the internal part of the analysis. With these factors, a SWOT matrix (Strengths, Opportunities, Weaknesses and Threats) was created and used to decide the Strategic lines of Attack, Defence, Reorientation and Survival.

3.2. Benchmark and Decision Tree

The second method used is a benchmarking analysis (see the process followed in Figure 1), that aims at identifying the actions taken by other cities, to analyze those from EMT-Madrid under a new perspective. To that end, 25 cities were selected, with the criteria of (i) having similar characteristics with Madrid or (ii) being particularly innovative in the conception of their public transport. Next, the indicators for conducting the comparison were selected. Then, the cities were analyzed in light of all the available documentation. Finally, recommendations of measures to be implemented by EMT-Madrid are summarized.

The indicators in use for the benchmarking analysis focus on three streams. (i) the city, (ii) the inhabitants' characteristics and (iii) the city public transport system.

Regarding the first stream, the surface of these cities, the average traffic speed, the modal split and the average annual levels of pollutants in the air have been compared.

Secondly, the focus is made on the inhabitants, in which the number of inhabitants, population density, minimum and average salary, comparing it with the price of a bus ticket and the trips that are made per year in each means of transport have been examined.

That third stream deals with public transport systems, especially buses, the number of bus lines, the number of bus stops, the average speed of bus lines, the kilometers traveled by buses per year, the number of buses and the breakdown of the fleet according to the criteria of fuel or electrical technology and the kilometers of lines of each type of public transport in the city.



Figure 1. Methodology used for the Benchmarking.

The complete list of the cities used for the benchmarking analysis is listed in Table 2.

Lastly, a decision tree has been crafted upon the results obtained from the benchmarking, in order to allow for replicability of the strategic decisions of EMT-Madrid in other cities.

Table 2. List of the cities used for the benchmarking analysis.

1. Barcelona	14. Gothenburg
2. Valladolid	15. Genève
3. Bilbao	16. Amsterdam
4. San Sebastián	17. Tokyo
5. Berlin	18. Beijing
6. Bremen	19. Shanghai
7. Rome	20. Honk Kong
8. Milan	21. Sao Paulo
9. Brussels	22. Tel-Aviv
10. Paris	23. Chattanooga
11. Lyon	24. Nashville
12. London	25. San Francisco
13. Stockholm	

4. Results

4.1. Strategic Analysis

The result of the Strategic Analysis was a SWOT matrix that describes the most important internal and external factors of the company, focusing in the electric transition.

In Figure 2 the results of the Internal Analysis (Strengths and Weaknesses) are shown with the most important found points in documentation analysis, interviews and visits. The results of the External Analysis (Opportunities and Threats) are also shown in Figure 2 with the main PESTEL Factors.

With the SWOT analysis, 4 strategic lines have been defined: Attack (Take advantage of the Opportunities with the Strengths), Defence (Face the Threats with the Strengths), Reorientation (Correct Weaknesses with the Opportunities) and Survival (Face the Threats that affect the Weaknesses).



Figure 2. SWOT Analysis of the EMT.

4.2. Benchmark

The goal of the benchmarking analysis was to review the situation of the public transport in other cities of the world and their plans for the future and strategies to achieve them.

25 cities have been selected for this analysis, choosing with the criteria of similarities with Madrid (population, pollution, economy, fleet...) or innovation in the transport (special buses, new systems, alternative management solutions...).

A heat matrix has been created, showing graphically the different fleets that each city is using nowadays (diesel, gas, hybrid, electric and hydrogen), see Figure 3, and its associated legend.

CITIES	BUSES				
	HYDROGEN	ELECTRIC	HYBRID	GNC/GLP/ BIOGAS	DIESEL/ BIODIESEL
San Francisco	0	5	4	0	0
Amsterdam	0	5	0	0	5
London	1	3	5	0	5
Bilbao	0	2	3	0	5
San Sebastián	0	2	3	0	5
Hong Kong	0	2	3	0	5
Beijing	0	2	3	0	5
Madrid	0	2	2	5	5
Paris	0	2	0	5	5
Rome	0	2	0	0	5
Shanghai	0	2	0	0	5
Nashville	0	2	0	0	5
Barcelona	0	1	4	5	5
Berlin	1	1	0	0	5
Milano	1	1	0	0	5
Genève	0	1	2	0	5
Gothenburg	0	1	1	5	5
Sao Paulo	0	1	0	5	5
Tokyo	0	1	0	3	5
Tel-Aviv	0	1	0	0	5
Bremen	0	1	0	0	5
Lyon	0	1	0	0	5
Chattanooga	0	1	0	0	5
Valladolid	0	0	2	5	5
Stockholm	0	0	1	4	5
Brussels	0	0	0	0	5

0	1	2	3	4	5
0%	<0,5%	<5%	<15%	<35%	>35%

Figure 3. Heat map on the fleets used in each city.

Higher numbers (darker colors) represent higher percentages of the fleet. The order of the cities in the table can be read as higher or lower sustainable fleet, being those more sustainable located in the upper part of the table.

Another heat matrix (see Figure 4) has also been created to represent the opportunity electric chargers of each city (trolleybuses, magnetic induction and pantograph). The order of the cities in this table also shows those that are better equipped to leverage sustainable mobility, being the best those located in the upper part of the table.

CITIES	OPPORTUNITY CHARGERS		
	INDUCTION	PANTOGRAPH	TROLLEYBUSES
London	1	0	0
Madrid	1	0	0
Berlin	1	0	0
Stockholm	1	1	0
Amsterdam	0	2	0
Shanghai	0	2	0
Barcelona	0	1	0
Genève	0	1	5
Gothenburg	0	1	0
Tel-Aviv	0	1	0
San Francisco	0	0	5
Milano	0	0	3
Rome	0	0	2
Bilbao	0	0	0
San Sebastián	0	0	0
Hong Kong	0	0	0
Beijing	0	0	0
Paris	0	0	0
Nashville	0	0	0
Sao Paulo	0	0	0
Tokyo	0	0	0
Bremen	0	0	0
Lyon	0	0	0
Chattanooga	0	0	0
Valladolid	0	1	0
Brussels	0	0	0

0	1	2	3	4	5
0%	<0,5%	<5%	<15%	<35%	>35%

Figure 4. Heat map of electric infrastructure.

Most of the companies have the highest percent of their fleet formed by diesel vehicles, because it has

been the traditional fuel used by buses. But it exists a general tendency to electrify the fleets in the most relevant cities of the world to fight against the air quality problems.

Many actions and implementations in the public transport field have been found in this analysis, also similarities and correlations between cities. With this information, combined with the strategic analysis of the EMT-Madrid, the Decision Tree was made.

4.3. Decision Tree

The decision tree is a model that can guide and support other Transport Companies and City Councils of the world to decide which transport fleet is the best to implement in their cities depending on their necessities and resources.

The parameters that this model combines are buses, infrastructure, emissions and costs and investments.

Part of the outcome of the decision tree (zoom to the first questions) can be seen in Figure 5. The full tree is provided as an annex to the paper.

In this model, it has been considered that the objective of the cities is to obtain the least polluting

fleet within the economic possibilities of the city and trying to reuse the existing infrastructure. Also, that the priority of the cities is the reduction of NO_x and of the particles before CO_2 . With options of emissions and investments of the same order of magnitude, preference is given to the option with the simplest logistics.

In this model, hydrogen buses have been considered as the best option, since the logistics of their use is similar to diesel and natural gas buses, and hydrogen vehicles do not have any type of emissions. The problem of hydrogen is its difficult access for most cities, so the first question is if the city has the possibility of easy access to hydrogen at low cost.

The second best option is the trolleybuses, since they can work in electric mode for long periods of time, as they obtain electricity directly from the network that can charge their battery to operate when they need to travel in places without tram infrastructure. In the cases in which they must operate during very long periods of time outside the electric line, they should be hybrids, preferably of CNG. The main problem with trolleybuses is their infrastructure, since it goes through the surface of all or a large part of the line and has a very high cost and visual impact. For this reason, the second question is if the city already has

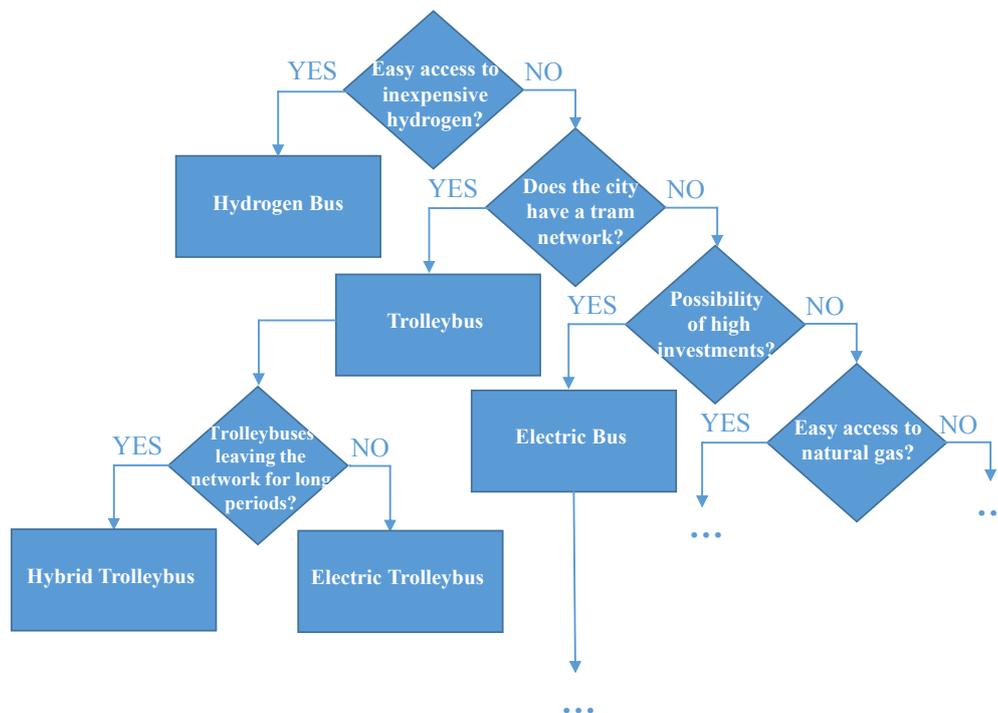


Figure 5. First questions of the Decision Tree.

the trams infrastructure, because, if not, it is not a good alternative. If this infrastructure already exists, its use should be prioritized.

Electric vehicles are the best option after hydrogen vehicles and trolleybuses, as they do not have emissions. For its proper functioning, a large investment must be made in the recharging infrastructure and buses so that they have long duration batteries. For this reason, the question is asked whether a high investment in vehicles and infrastructure can be made.

The next question, within the electric buses, is whether the necessary time of operation before returning to the Operational Centre to recharge is very long. If this time is longer than the duration of the batteries, opportunity charging systems are required in addition to the charge in the Operational Centre.

Within systems of opportunity charge there are Magnetic Induction and Pantograph. Magnetic Induction systems require a higher investment, but the infrastructure is more protected and generates less visual impact.

Inside the Pantographs, there are the exterior ones, placed in the tower that charge the bus or pantographs placed in the bus that are connected to the charging tower. Those placed in the tower have a higher infrastructure cost, while those placed in buses have a higher cost of the vehicle.

The same happens in the Operational Centers, where Pantographs or Plug Chargers can be placed, depending on the charging time that the bus needs before starting the service.

If it is not possible to invest in electric buses, the solution to reduce local emissions is Compressed Natural Gas buses. If the city can also have electric chargers, the best option is the GNC Plug-in Hybrid buses.

If it is possible to invest in CNG vehicles, but not in electrical infrastructure, the least polluting vehicles are the GNC Non-Pluggable Hybrid vehicles, although they cost more than CNG vehicles.

If the city cannot invest in CNG vehicles, but in electric chargers, the best option would be the Hybrid Diesel Plug-in buses, because of their possibility of operating in electric mode recharging their batteries.

If the city cannot make any type of investment in infrastructure, the best option is the Hybrid Diesel Non-Plug buses, since they have less consumption and emissions.

5. Conclusions

5.1. Implications for public institutions

The result of the analysis supports the proposal of switching to a 100% electric fleet at EMT-Madrid. However, the large investments and change costs required call for a gradual implementation. To this end, new Operational Centers need to be built. Alternatively, adaptation of the existing ones and, in some cases, implementing opportunity charging structures, such as pantographs and magnetic induction chargers on the bus lines, will be needed. The employees of the company should be trained to work with this new electrical technology, especially the mechanics, since electric engines and batteries are completely different to diesel and natural gas engines. These needs have been detected for the city of Madrid, but can however, be of use for other cities facing similar problems.

Moreover, a decision tree that can guide and support other Transport Companies and City Councils of the world to decide which transport fleet is the best to implement in their cities depending on their necessities and resources has been created.

This study is the detonator of a process that will reshape the emission of pollutants within the city of Madrid. Insights for the development of a new strategic plan have been given, which conclude with the need of creating a 0 emissions fleet for the company in the near future. This will influence private users, which will move to this type of mobility as well.

To this end, attention should be paid to the three key points to focus in the implementation of the electric buses, namely the fleet, the infrastructure and the human resources. They should be perfectly coordinated during all the transition to ensure a proper change.

Investing in sustainable mobility is investing in the future, improving health and life quality of the citizens, and building a better city and a better world for future generations.

5.2. Limitations and avenues for further research

This study is not without limitations. First, the final recommendations are extracted from a limited number of observations. Second, it is not a longitudinal study, and for this reason, the analyses have been made for a particular moment in time. Third, the cost analysis has not been included.

These limitations open, in fact, possibilities for further research. For instance, an economic study of each type of electric fleet and associated infrastructure could be conducted, with particular emphasis on investment requirements and cost of operations, maintenance and training of workers. Likewise, an implementation plan for the electric fleet in Madrid, with simulation of different scenarios could be performed, with the aim of assessing which bus lines should be prioritized for the use of new electric buses.

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Annex

Complete version of the decision tree

