Closing the infrastructure gap through innovative and sustainable solutions

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Executive summary: This strategy paper explains transition of existing infrastructure into truly sustainable form with ET3^{tm} (Evacuated Tube Transport Technologies) while: closing the investment gap, boosting economies, GDP growth, trade, transport of: passengers, goods, energy, communications, water, waste; addressing "the need for speed" and providing quantum leap in quality of life. Relevant stakeholders are invited to take part; the market opportunity exceeds US$75 trillion.

1 Introduction

1.1 Infrastructure investment In the "business as usual" scenario, to keep up with the projected global GDP growth (3%/year) and to control climate change, global infrastructure investment demands [1] US$93T (trillion) in the years 2015 to 2030. This is shared as 43%, 29%, 21% and 7% respectively by energy, transport, water & waste and telecommunications. On average US$6.2T per year is currently needed, but only US$2.5T is invested leaving an investment gap of US$3.7T per year. To compare, the year 2015 global GDP was US$75T, so the annual demand is 8% of that. With the same trends continued, in the year 2050 annual GDP will be US$147T; the cumulative investment for infrastructure: US$217T (needed), US$87T (invested) and US$130T (the gap). Meanwhile, the gap widens with time [1], making it clear that traditional "proven and reliable" solutions cannot cope and there is a clear need for innovation. In our view, the traditional approach could only bridge the gap by asking for more funds. In contrast, truly innovative technologies applied to infrastructure will allow boosting of: trade, transport, communications and quality of life, while closing the gap, see figure 1 and explained below.

1.2 The issue and the timing The transition to sustainability already causes a wave of innovative attempts, however not all of them make life more comfortable, convenient and affordable. In fact, major innovations that truly add value, often meet more resistance and disregard than support and acceptance. Meanwhile, we are exhausting natural resources at an alarming rate: the 23 COP meetings confirm the inefficiency of the traditional approach (with the USA - the 2nd largest polluter - staying out of the Paris agreement and in contrast with reports of how other nations are meeting climate targets). So the Earth's surface temperature rise continues with the five warmest years on record being after 2010 and year 2017 being one of the warmest since 1880 [2]. Additionally, urbanisation together with noisy, polluted air and other spoiled resources; congested, aging infrastructure; lack of trust in global finance, a stagnant economy (with 10 years of slow growth following the global financial crisis), scarcity of long-term investments, inequality; poor mobility and connectivity; mounting waste problem; and lack of clean water and food for many [2]. This calls for a paradigm shift. We find that the root of these inefficiencies lies in the illusion that we all will be fine with minor innovations of current technologies (smart urbanisation, renewables, electric vehicles, self-driving cars, etc.) as well as in the fear of losing the return on existing infrastructure investments that would be displaced by major innovation. Altogether this results in negligence of and resistance to true innovation, lack of vision and responsibility that lead to such wan present and future. For example [1] focuses on how to mobilise finance to make existing marginal infrastructure environmentally sustainable, while the way to make it adequate, sustainable, with lower investment is long known [3].

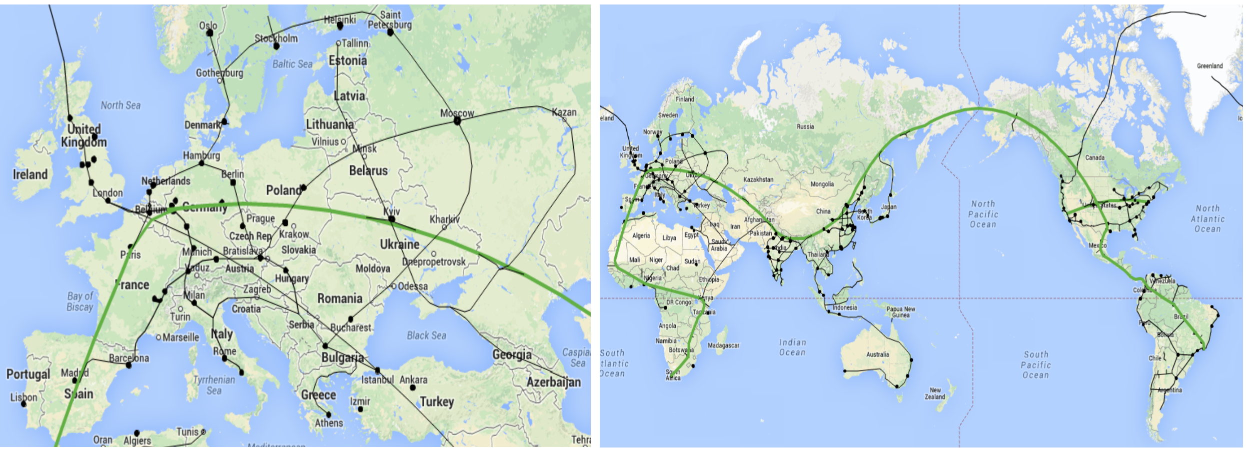

Figure 1 The world can certainly close its infrastructure gap in year 2050 by using ET3: examples of the proposed priority routes for Europe (left) and World (right) [6]; the black and the green lines are $ET3_{nl}$ and $ET3_{gl}$ respectively

We are confident that tangible results can be achieved before the year 2030 with the right approach. In the year 2050 we expect much of the existing infrastructure be transformed into unified, standardised, automated, clear and easy-to-manage system transporting goods, passengers and services with outstanding comfort, safety, speed and capacity [3]. This innovation will be highly profitable and it will speed up global GDP growth. The purpose of this paper is in explaining our strategy offering ET3 as the solution and inviting interested stakeholders and investors to take part in the upcoming change.

2 Closing the gap, impact of innovative transport on the infrastructure

2.1 Transport of freight and passengers The global demand and the investment available are US$1.8T/year and US$0.7T/year. The year 2050 EU transport targets are: 1) total emissions (↓60%); 2) a shift (↑50%) of medium length journeys from road to rail 3) carbon emissions (↓40% for air and water) [4]. To rephrase, following EU plans in 2050 we will still mainly use conventional (rail, road, air and water) transport known to all as slow, expensive, or both. With this plan carved in R&D program, transport will be more expensive as the intended shift from road to rail proves (e.g., in Germany currently rail transports 10% of passengers and 24% of freight at a cost per km five times that of road [5]). Moreover, "*the need for speed*" is not addressed: present trends indicate that customers of the 3rd millennium expect their (e-commerce) deliveries within minutes or hours, not days or months.

We think the reasons for such transportation plan are lack of: vision, responsibility and innovation. Today it is common to plan huge investments in road, rail, air and water transport. On the other hand, it is already long known [3] that every euro invested in ET3 will reduce transport emissions >10 times, ET3 could save 60% of the planned EU transport investment while providing more traffic volume at 5 times faster speeds, ET3 eliminates >10 times more CO_2 and reduces the energy costs >50 times (see also Table 1), thereby addressing all transport targets far more effectively. If only 20% of the planned investment were to be redirected into an ET3 network, ambitious climate targets could be achieved twice as fast. In other words, this step allows meeting all climate goals with far less investment and at the same time building up to 30 thousand km/year of the ET3 network; yet to spend €0.35T/year on keeping the obsolete technologies operational, adjusting to the change, providing smooth transition (thus respecting the right for return of those who already invested in conventional transport) and to finally close the transport infrastructure gap ($1.1T/year) entirely. Moreover, all the global environmental targets can be met 10 years earlier. Clearly this approach can be applied anywhere (primarily along the foreseen ET3 routes, figure 1 and [6]). Dialogues and systematic studies with interested stakeholders are welcome.

Below we illustrate the potential impact of ET3 on the existing connection Berlin to Hamburg (B-H) in Germany. Because of the relatively short distance (289 km) travel by road and rail currently dominates, option T0, Table 1, see section 8.1 for further details. The situation will qualitatively remain the same in year 2030 (freight and passengers growth of 38 and 12% respectively [5]), so in the "business as usual" scenario with modest upgrade the infrastructure gap will widen. Moreover, "*the need for speed*" remains unanswered as none of the shippers offer fast delivery at attractive price (e.g., typical delivery times for any sizeable cargo by road or rail are at least 12 hours for the B-H connection, meaning that the average speed of such a delivery is <25 km/h).

This situation can be drastically improved with an ET3 connection built parallel to the existing one, see option T1, Table 1. According to the ET3 routes [6], the national level $ET3_{nl}$ would be sufficient, figure 1, left: the maximum speed is 1.3 to 2 thousand km/h. The network includes freight and passenger handling hubs, capsules, interchanges, etc. all matching the capacities of option T0 for freight and passengers, Table 1. The resulting costs are listed in Table 1, see e.g., [3, 7] for more details. At the modest investment and the total load (utilisation) factor of 0.4 option T1 (€4B) will fully match the freight and the passenger capacities of option T0 (€10B) with excellent economics: the 6 €cent/ton/km and 27 € per one-way ticket, 1st class allow the RoI of 10 years (at RoI of 40 years the cost-prices are 4 times less). The delivery time decreases to 18 minutes (e.g., a freight of 500 ton, on pallets, figure 2, left), while passenger travel time will be 12 minutes (figure 2, right at the average speeds of 578 and 693 km/h respectively). On demand, the passenger capacity can increase many times as the load factor is only 0.012. On a medium (longer) term, the capsule speed can go to 2 (10) thousand km/h for elevated tube sections (underground tubes) and the travel time to 10 (3) minutes. These latter performance milestones can be met and funded by ET3 itself. Moreover, option T1 in parallel to option T0 can take initially as little as ¼ of the

Table 1. Options to strengthen the connection Berlin-Hamburg: transport of freight and passengers

		Freight				Passengers					
Option	Connection Berlin-Hamburg	Investment cost, B€	Capacity Mt/yr	Return cost €ct/tkm	Load factor	Investment cost, B€	Capacity Mp/yr	Travel time minutes	1-way ticket cost, €	Load factor	Max. speed km/hour
T0	Existing (road + rail)	5	121	5 to 2.3	0.3	5	74	180 to 90	10 to 80	0.5	150 to 230
T1	**ET3 as proposed in years 1997-2017**	**2**	**121**	**5.7**	**0.4**	**2**	**74**	**12 to 10**	**27**	**0.012**	**1300 to 2000**
T2	Hyperloop, as proposed in 2017-2018	12	3	313	0.8	12	3.2	20	951	0.8	1080

Legend: B€= € billion; Mt/yr = million ton/year; €ct/tkm=€ cent/ton/km; Mp/yr = million passengers/year. For T0 , T1 , T2 the time to investment return (RoI) is 40, 10, 40 years of operation respectively. For T1, T2 we assume 10% of the revenue is used for RoI. The load (utilisation) factor is the ratio of the time connection is in use at full capacity to the total available time.

flow (Table 1), still have competitive RoI at the same (or slightly higher) prices, with "*the need for speed*" fully addressed (while less use of road and rail will also result in their longer lifetime, necessary for transporting freight not compatible with ET3, which is <6% of the total [3]). Therefore, it will provide a smooth transition (e.g., of 30 years) into a brighter future with redundant and resilient hybrid operation of the connection without any congestion or capacity reduction in cases such as peak hours, bad weather, need for repair, etc. Such an ET3 connection can be built in 2 years with just one thousand skilled workers [7]. After some years of operation, option T1 will allow to proceed with step by step expansion of ET3 network while generating sufficient means for maintaining and transforming the aging conventional infrastructure (road, rail, air, water, pipeline, cable, etc.) first nationally and then globally [3, 6] as addressed in section 3. Put simply, ET3 connecting Germany's two largest cities with a travel time of just 10 minutes will effectively merge the cities (and the connection areas) into one, thus Germany's largest port becoming an integral part of the capital.

Yet another example of ET3 capability is shown in figure 3. The importance of ET3 for long distance transportation (e.g., "the new silk road" [3] and figure 1, right) is clear from that ET3-compatible freight between Hamburg and Beijing can be delivered in 2 hours (compared to 30 days by ship, 10-15 days by train) at the same price and capacity as by train or by ship.

In addition, option T2 [18] is evaluated by extrapolating the recent data. Namely, the system described in [19] costs €2.4B, has only two stations spaced by 57 km, aims to transport only passengers at capacity of 3.2 Mp/year and similar more recent data for the 140 km-long Abu Dhabi-Dubai connection: €4.8B for 140 km long connection, 19 passengers or 20 tons freight per pod. To arrive at listed in Table 1 data for option T2, we assumed that the 289 km-long system has 6 stations (spaced by 58 km), the same passenger capacity, and works at the headway time of 99 seconds. Shorter headway times of 10 to 20 sec are mentioned [19], but are excluded here as they need more airlocks in parallel and drive up the costs rapidly. The comparative differences of options T1 and T2 are listed in [17]. At the highest investment, option T2 (€24B) is capable to match only 2.5 and 4% of respectively the connection's freight and passenger capacities, Table 1 (thus being competitive only in passenger capacity of only rail and not of road) and fails completely to match the freight capacity of either rail or road). In our view, option T2 is not competitive, economically unsustainable and clearly it has no added value as compared to option T1, see also [17]. It is unjustifiably expensive, though relatively fast.

To summarise, the **ET3** connection (the **fastest, affordable and with sufficient capacity**) easily competes in all key parameters with road, rail and Hyperloop (HL). Moreover, the **HL** connection (**fast, the most expensive and lacking the capacity**) fails to compete with road (except for shorter delivery and travel times), or rail (in the investments costs for both freight and passengers, in the freight capacity and the cost per ton·km, in the one-way ticket price). Both road and rail are slow as compared to ET3. Even though we do not compare it here to air transport, it is clear from Table 1 that HL while being potentially as fast as an airplane, fails to compete in the two-way ticket price of €210 for B-H connection. When used, HL will widen the infrastructure gap instead of tightening it. We therefore exclude option T2 from further consideration.

2.2 Energy transport The global demand (the investment available) is \$2.6(1.1)T/year [1]. The year 2030 EU targets are [4]: 1) emissions of green house gases (↓40%); 2) renewables & grid (↑27%); 3) energy efficiency (↑27%). In our opinion, the reasons for such plan are lack of vision, responsibility and of innovation. Indeed, it is common approach to address the renewables target by investing in wind, solar, bio-, etc. However, every euro invested in ET3 (instead of wind) eliminates >12 times more CO_2, returns >7 times more clean energy (by reducing the need for it) as the example from the Netherlands shows [8] and it provides much more energy efficiency (instead of building a wind park, that has energy efficiency comparable to that of a power plant, for the same money ET3 network is built replacing 50 times less energy efficient transport and thus resulting in respective savings) [8] thereby addressing all targets far more effectively. When >10% of the above investment is redirected into an ET3 network, more ambitious climate targets are achieved. This step allows to meet all climate goals with far less investment and at the same time to build over 40 thousand km/year of the ET3 network, to spend €0.5T/year on renewables and keeping the obsolete technologies operational, adjusting to the change and to eliminate the energy infrastructure gap (\$1.5T/year) entirely. Moreover, transporting energy-rich substances (such as LNG) with ET3 [9] and electricity with high temperature superconductor cables [10] adds most of the value. For instance, under-grounding of the 5 x 2 GW SuedLinks in Germany with such cables saves up to €27B, enough for bringing ET3 to commercial deployment in the country and it provides plenty of land for building ET3 networks.

Figure 2. Examples of freight arrangement (left) and passenger experience (right) inside ET3 capsule [6]

Figure 3: Examples of the two-way transport connection (with the same capacity, 1 million passengers/day) comprised of: conventional 18-lane freeway for 100 km/h that is 72 m-wide (left, [https://commons.wikimedia.org/wiki/File:Highway_401.png]) and operated at load factor of 0.5; a pair of ET3 vacuum tubes for 600 km/h operated at load factor of 0.16 (right, the elevated by 6 m tubes have diameter of 1.5 m each and the overall footprint of 1x1 m^2 every 25 m). Such ET3 connection costs less than 1/4 of the freeway connection and fits in one lane. Notably, the same ET3 connection operated at full load is close in capacity to a 100-lane freeway, such as the 400-m wide Beijing-Hong Kong-Macau Expressway (not shown).

2.3 Water and waste The global demand (and the investment available) is $1.3(0.5)T/year [1]. Impact of ET3 on water transport was explained in [3], here we only demonstrate the potential impact of ET3 on waste management. A removal of waste by truck costs today 1 €/m^{3}km (30 €/m^3 or 11 €/month per household, which gives the same 30 €/m^3 assuming 4 m^3 of waste per household per year). For instance, instead of using a truck an automated waste removal vehicle connecting waste sources to the nearest ET3 hub (1.5 km) and the ET3 network for waste transport over the same distance of 30 km will result in the total cost of 3 €/m^3, the investment into waste removal can be reduced proportionally. Alternatively, for the price of 30 €/m^3 the distance of 500 km for waste removal can be achieved with ET3. By using RoI of 40 years (Table 1), utilising the excessive capacity and making use of the periods of low demand for traffic (e.g., at night) ET3 can transport waste and water at even lower prices. The added value of ET3 to solving this problem is clear. We hereby invite interested communities, municipalities and authorities to explore this possibility together. Assuming that 20% of the investment available for waste will be redirected to ET3, 8750 km/year of ET3 network can be built. This would dramatically increase quality of waste removal while keeping the obsolete technologies operational, adjusting to the change and finally to close the infrastructure gap ($0.4T/year) entirely.

2.4 Telecom and digital services The global demand (and the investment available) is $0.42(0.18)T/year [1]. Following Amazon's way to move huge amounts of data (e.g., 100 Petabyte per AWS Snowmobile, a truck with a 45 –foot shipping container), our company enjoys being the first in offering ET3 for the same purpose [6]. The advantages are clear from Table 1: reduced shipping times (e.g., from 12 hours to 12 minutes) at the same capacity mean the internet speed reaching 1 Petabyte/s in combination with lower price, higher reliability, independence of weather, flexibility, etc. Use of ET3 powered telecom will strengthen and largely relieve existing congested digital networks: e.g., Germany today remains a "land of woefully slow internet". Assuming that 40% of the available investment will be directed to ET3, 5800 km/year of ET3 network can be built to dramatically increase quality, speed and volume of telecom, internet and digital services while keeping the obsolete technologies operational, adjusting to the change and finally to eliminate the telecom infrastructure gap ($0.25T/year) entirely. We hereby invite interested telecom leaders, communities and authorities to explore this possibility together.

3. Future global infrastructure strengthened by ET3, the proposed scenario

3.1 ET3 networks at national level (1.3 to 2 thousand km/h, ET3$_{nl}$) We propose in overlap with the initial preparation and demonstration phase (starting now), the phase of creating ET3$_{nl}$ network at national levels starting everywhere in year 2020-2023 (preferably along the ET3 routes [6]) and proceeding so that on average 172 thousand km is added each year, see figure 4, left. Thus by the year 2050, 6 million km of ET3 network will be added. The total investment of US$75T is in line with the elaborated in sections 1-2 and it will be returned in year 2046. The average required investment of US$2.5T/year can be fully or partly taken from the demanded or available ones (for "business as usual", see sections 1, 2), since implementing ET3 provides a huge saving of the conventional infrastructure investment (US$21M/km as clear from Table 1, or US$126T for 6 million km, that is US$4.1T/year). Moreover, additional funds will be available through re-investing (part of) the return (US$107T by year 2050, figure 4, left). As the total length of paved roads (railways) in the world today is around 30 (1.05) million km, we assume that the ET3$_{nl}$ networks will be utilised as much as in Table 1 and based on that the return is calculated, figure 4, left (the horizontal dotted line indicates that by year 2041 the return is equal to the invested US$46T in built 3.7 million km, while in year 2050 the return is US$107T). In this basic scenario (NL1), by year 2050, 0.1 billion jobs will be created, 20% of existing paved road connections will be bypassed with ET3 and over 60% of total road emissions eliminated. In the five times more ambitious scenario (NL2) it will be possible to bypass nearly all paved roads, creating 0.5 billion jobs. This scenario demands up to US$375T and would save up to US$315T, see section 8.2.1. More details are presented in Annex 2.

3.2 ET3 networks at international level (6.5 to 10 thousand km/h, ET3$_{gl}$) We propose after the preparation, the phase of creating ET3$_{gl}$ network starting everywhere in year 2030 (along the ET3 route [6]) and proceeding so that on average 4.3 thousand km is added each year, see figure 4, right. Therefore at the end of this phase (in year 2045) 60 thousand km of the ET3$_{gl}$ network is added. The total investment of US$1.45T in line with [3, 16] is a small fraction (on average US$0.1T/year) of that available (sections 1-2) and it will be returned in year 2044 (as the total length of motorways in the world is currently <0.3 million km, we assume that ET3$_{gl}$ networks will be utilised as much and based on that the return is calculated at the speed of 6.5 thousand km/h, see figure 4, right).

These proposed steps are challenging and require commitment of nations and countries (authorities, businesses) to work together towards this goal. But the rewards by far exceed the risks at the same time offering the escape route for obsolete technologies through the transition period of 30 years. In section 8 we briefly review relevant key concepts and technologies. With this much reward in mind, a one-time spending of total €1.1B (<0.44 ppm of the foreseen annual investment) on the full-scale ET3 pilot system (section 8.2.1), is a risk worth taking (the reward/risk ratio $>10^6$). Transport at speeds 1.3 to 2 thousand km/h requires relatively long test tracks and large radii [3], which justifies this investment magnitude. Taking the four-step approach (elaborated in section 8.2.3) further mitigates the risk. Moreover, proper annual budget (€25B) for CERTS (including regional offices, see section 8.2.3; 10 parts per million, ppm, of the investment) seems fully justified.

4 Closing the infrastructure gap with ET3

With the current trends continued, in year 2050 annual GDP will be US$147T accompanied with the following infrastructure investment landscape (cumulative over the 35 year period): US$87T (invested), US$217T (needed), and US$130T (the gap). When in parallel the proposed scenario NL1 is realised (section 3), the infrastructure investment savings of US$126T caused by the ET3 implementation together with the returned investment (US $107T, figure 4, left) provide enough resources to close the infrastructure gap (<US$130T, demanded by the remaining conventional infrastructure) entirely and with full confidence. Thereby, our approach opens up market opportunity for ET3 exceeding US$75T.

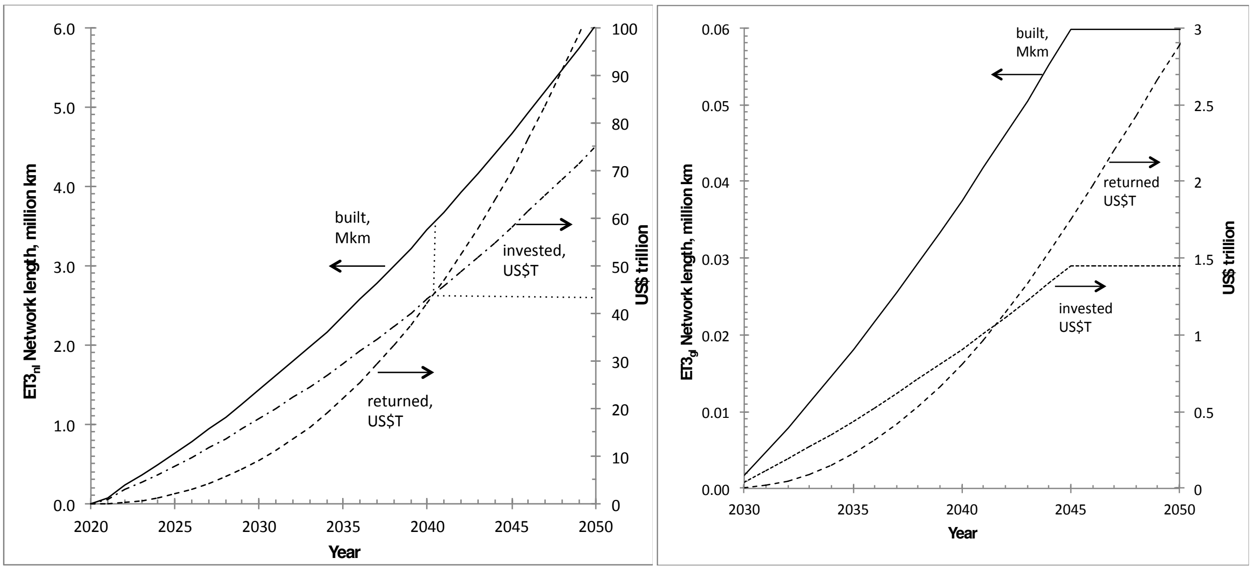

Figure 4. Examples of the proposed evolution for the ET3 networks in years 2020-2050: at the national levels ET3$_{nl}$ (left) and at the international level ET3$_{gl}$ (right)

5 Conclusions

1 Closing the infrastructure gap before the year 2050 by strengthening existing infrastructure with ET3 is entirely feasible and it can be achieved in three coordinated phases: 1) bringing ET3 to maturity, including full scale commercial deployment (2-5 years); 2) expanding ET3 networks around the globe at national levels (30 years); 3) connecting national ET3 networks into the international network (15 years) and creating one city called Earth.

2 Proposed scenario (NL1) allows in the year 2050 to reverse the trend for cumulative infrastructure investment (from current costly: -US$87T) to future profitable: +US39$T (calculated as: -US$87T +US$126T), return (US $107T) more than invested (US75$T), create an income of US8$T, over 0.1 billion jobs and at the same time it offers the escape route for obsolete technologies with the transition period of 30 years. So far we did not include the effect on humans and economies of transport becoming faster, safer, more comfortable, sustainable and affordable, of changes in value of land, etc. With these included, ET3 combines huge investment savings with the rapid returns and: greatly improved quality of life (healthcare, real estate, tourism blooming); flexible industries, cheaper products, better economics, efficiency and ecology with more capacity, safety, reliability for transport of passengers, goods, energy, etc. altogether resulting in the GDP increase of over 10%.

3 When compared to ET3 in competitiveness, economic viability, volume and return of investment, speed, capacity, energy efficiency, sustainability, etc., the alternatives: conventional modes (road, rail) lose and HL fails, similar (somewhat better) result is expected for T Flight. Moreover, these three versions of evacuated tube transport are not compatible with each other. We therefore urge end users of infrastructure, general public to encourage their states, the policy and decision makers, authorities, business, country leaders and governments join the efforts and together create with ET3 the 3rd millennium infrastructure. We invite all progressive and rationally thinking leaders, multinational conglomerates, corporations, financial institutions, funds, decision makers, governments, authorities, nations, communities, general public and individuals to accept this innovative strategy and together make our world a better place by strengthening the existing infrastructure with ET3.

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This study is funded internally and all rights belong to the authors, PBD Industries, Inc. and ET3 GA. Investors and stakeholders interested to apply ET3, contact us at: et3@et3.eu; et3@et3.com .

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Annex 1

Larger companies are entering a stakeholder race [16, 22], currently in ways rather irrational and empirical, by trial and error: for example HL and T Flight networks are not compatible with each other or with ET3. As the case with HL shows, the difference in the key performances of the less-so and optimal solutions can be striking (Table 1) and that namely the end users are to pay for these differences, while ET3 is much more attractive, section 3. These end users are most of us, creators of Gross Domestic Product, GDP.

8 Key concepts and technologies

8.1 Conventional transport Conventional transport by road, rail, water remain relatively slow and affordable, while by air may be faster but usually more expensive. Road transport stands out almost in every country keeping up to 95% of the share and offering most attractive combination of capacity, delivery/travel time at reasonable price. All four conventional modes are environmentally unsustainable and polluting (noise, fine particles, heat, chemicals, etc.; except rail all use fossil fuels, etc.) They still will be polluting after switching from fossil to electrical energy. For the B-H connection (section 2.1) the total investment costs for 4-lane road of 6 M€/km and 2-track rail of 29 M€/km are assumed. The resulting freight costs are 5 to 2 €cents/km/ton and the delivery times are 5-13 hours; for a passenger one-way ticket price is 10-80 € with travel time of 1.5-3 hours. In this example we assume the annual rail traffic of 45 Mton of freight (close to that of the Betuwelijn, NL) and of 3.6 million passengers (Deutsche Bahn data), the others are transported by road, for which a traffic mix is assumed of 14% of 30-ton trucks and 86% of 3 passenger cars.

8.2 The 5th transportation mode: Evacuated Tube Transport (ETT) In brief (we quote here the abstract from ref. 10 in [3], year 1997): "An evacuated tube transport (ETT) system comprises: evacuated tubes along a travel route for both directions; capsules to transport occupants or cargo within the tubes; equipment providing continuous transfer to tube while preserving vacuum; capsule suspension that substantially eliminates drag; coordinated acceleration device; energy recovery braking; vibration control structures; tube alignment devices; automatic capsule switch and synchronisation; automated operation, inspection, and maintenance; methods of construction; redundant data, safety and security systems. Low and high technology embodiments are comprehensively disclosed. Possibilities include replacement or augmentation of: vehicles, power lines, energy storage devices, power plants, heaters, air conditioning, water and sewer pipes, and communication cables and satellites. ETT provides continuous, environmentally benign, sustainable, local and international travel. Aerodynamic limitations, weather exposure, and obstacles are essentially eliminated; the system enables a quantum improvement in safety, speed and efficiency"; we also refer specifically to [13] (both are open access references published in year 2011): "the ETT vacuum chamber will be a circular tube with an inside diameter of about 2–5 m", to figures 1-4 and Table 1 [13], to "ETT vehicles will run in a vacuum environment …1013–10.13 Pa {10 to 0.1 mbar}" in section 6 [13], etc. ETT offers many ways for non-optimal market entry resulting in being fast, but rather expensive (Swissmetro, HL, T-flight) and therefore hardly competitive and economically viable only on demand. We knew from the start that ET3 (section 8.2.1) will be faster (0.6 to 10 thousand km/h limited by the Earth's escape velocity of 11 km/s) [3]) and that the larger diameter versions of ETT ([13, 22]), especially those using low vacuum quality (pressure e.g., 1 mbar) will be rather expensive and less fast. Moreover, Institute of Evacuated Tube Transportation (ET3 licensee) of Xijing University originating from year 2002 [3, 13] and Applied Superconductivity Lab of Southwest Jiaotong University in China, e.g., ref. 3 in [20]) are long known as ETT and ET3 supporters and promoters. Part of ETT optimised for smooth market entry is ET3.

8.2.1 Fastest ETT with competitive price and sufficient capacity for freight and passengers

Evacuated Tube Transport Technologies, ET3^{tm} (option T1, Table 1) Daryl Oster founded the ET3.COM, Inc. in year 1997 [11, 12]. The current ET3 concept is optimised for maximum value competitiveness and for smooth market entrance (tube diameter of 1.5 m, high vacuum quality inside: pressure around 1µbar, like in a thermos bottle; the concept: a car instead of train, truck or bus [3]), as Table 1 clearly illustrates. Capsules move frictionless through pairs of bidirectional ET3 tubes (mainly elevated on pylons for ET3$_{nl}$ and mainly placed in underground tunnels for ET3gl) that are connected into networks. ET3 uses coordinated linear ac/decelerators to speed up and slow down capsules e.g., near access portals (terminals). The passive switching, the interchanges are conceptually similar to those of highways, more details e.g., in [6, 7]. As a result, ET3 network connection is the fastest (1.3 to 10 thousand km/h), the cheapest (assuming 40 years for RoI) offers the highest capacity, see Table 1 and other advantages e.g., in [3, 6-9, 16]. "ET3 can use any type of maglev" [3, 6-15]. Hundreds of ET3 documents (many published well before year 2013) provide compelling evidence of authenticity and originality of ET3 and leave little room for successful imitations. Moreover, ET3 has never publicly abandoned any of the above, always understanding that the larger diameter ETT networks are available on demand, but not optimal for the market entry ([3], Table 1). ET3 has no intention to give its intellectual property away for free, instead it offers affordable for most participation and licensing conditions. ET3 per kilometre investment costs (€13.8M/km at this capacity, Table 1) are higher that of road transport (€6M/km, section 8.1), nevertheless in order to keep our approach simple and uniform, by means of the following calculation we justify that implementing ET3 instead of road offers the same savings (€21M/km, used in section 3.1) as in Table 1. Indeed, assuming that average car (truck) consumes 15 (67) litres of fuel for 289 km (B-H connection) worth €20 (90), it is easy to see from Table 1 that over the lifetime of 40 years with 23.5 million cars and 2.5 million trucks passing each year total spending on fuel only will exceed €27B (that is €96M/km of fuel costs). Therefore, in cases when there is no railway in parallel to road (as in Table 1), ET3 can directly compete with road (with the same savings as in Table 1: (€21M/km) by offering e.g., 25% lower prices per tkm and per passenger (than that for road). The corresponding ET3 price reduction can be achieved by using 20% of revenue instead of the assumed 10% (Table 1), by increasing RoI (e.g., from 10 years to 20), by changing the speed, capacity, etc. Clearly, this approach is (linearly) less effective where traffic demand is low, e.g.: "last mile" 1-lane road to a house. Our study shows that in many cases nearest ET3 access portal can be within 1-2 km range (next to ET3 routes, figure 1). That "last mile" can be covered by other means (autonomous vehicle, PRT, bicycle, walking, etc.). From Table 1 it follows that any individual or household within a community of 400 persons (2.2 persons per household) living on 1 km^2 anywhere along the B-H route by agreement can own (collectively) e.g., 1 km of ET3 tube with an access portal for a fee of €160, while the revenue is €6.3 thousand, both calculated per household, per month. Even at 1/30 of the traffic, it remains profitable and attractive to be such owner.

8.2.2 ET3 Global Alliance (ET3 GA) founded in 2012 by Daryl Oster [11] through all forms of intellectual property (IP, such as multiple patents, publications, talks, videos) enjoys being first in the world in developing a revolutionary concept and pilots of ET3, e.g., [3, 6-15]. The only way that removes the unnecessary costs and other multiple barriers (e.g., compatibility issues), brings order in the implementation process (section 3) and the one we promote here is by cooperating with ET3 GA. This is especially relevant in cases when public funds are getting involved. Rather than building ET3 networks itself, in return for royalties ET3 GA provides a framework and platform with superior knowledge, know-how, advice, guidance, coordination and leadership to consortia focused on owning, building and operating ET3 networks. In this respect ET3 GA offers its support through licensing and compensatory shares to anyone eligible entering into a contract (and when such participation results in any valuable ET3 implementation). In simple words, almost any natural or legal person or entity interested and capable in owning, creating and operating (parts of) ET3 networks anywhere, can count on the support of ET3 GA [14]. ET3 GA enjoys being the first and has nothing to hide: the concept and the expected cost details are long time in public domain e.g., [3, 6-9, 11-13], the open consortium has transparent and traceable history; everyone interested in the technology can get an access and contribute to implementation by becoming a licensee ([14] or consult the ET3 interactive page, the last one of the "Links" in [15]). ET3 GA has all evidence needed to convince any interested stakeholder to invest in the (pilot) project and rank them on the best added value and first come-first served bases.

8.2.3 Bringing ET3 to maturity As mentioned in sections 1-2, there is only one way to address doubts and questions on this innovative technology: by demonstrating its capabilities in pilot projects. Transport at speeds 1.3 to 10 thousand km/h requires relatively long test tracks and large radii [3] fully justifying the investment magnitude. The risk of the one-time investment in such demonstrator (€1.1B) bringing ET3 to the full-scale commercial deployment (TRL 9) is mitigated by taking the four step approach: 1) €1M for the feasibility and capsule demo, 2) €10M for a demo of ET3 main components: freight and passenger capsule, vacuum tube, airlocks, propulsion, etc., 3) €0.1B for a demo of ET3 fully operational main systems: of capsules in tubes, levitation, propulsion, guidance, emergency stops, control, interchanges, switching, speed, capacity, safety reliability, etc., 4) €1B for fully operational, economically sustainable commercial prototype. The steps are linked by the condition: next step is financed when targets of the previous one are met. ET3 can be seen as a new kind of accelerator transporting through a network of tubes from origin to destination "macro-particles" (capsules of 0.5 ton, 5 m long, 1.3 m in diameter, at max. speed 3 km/s, kinetic energy 3.9 GJ) and fully avoiding collisions by automated control and coherent motion, whereas e.g., LHC at CERN namely collides much smaller particles at higher speed and energy of 14 TeV, 15 orders of magnitude below 3.9 GJ. While CERN makes nations smarter (WWW is an example), ET3 will make nations smarter and economies faster, more competitive, sustainable and better connected. Considering the added value of ET3, it therefore makes sense to create for this purpose similar to (and perhaps next to) CERN international organisation (e.g.: CERTS, Conceil Européen de la Recherche pour le Transport Superfluide terrestre, or: European Organisation for Superfluid ground Transport, Research and implementation) studying ET3, "space travel on Earth" and developing ET3 pilots, promoting both, educating, ensuring that all parts of the national and global ET3 networks are compatible, tested, conform, accredited and to the same standard, coordinating activities, etc. and to provide it with the proportionate budget.

8.2.4 Fast, more costly ETT with sufficient capacity for freight and passengers

Quantum Train (**QT**): Quantum Train Intl. founded in 2013 [15] supports ET3 implementation primarily in the Netherlands and Europe. On demand, the company also promotes ETT with the larger tube diameter (3 m, the concept: a train instead of a car), magnetic levitation, use of linear motors/generators at stations and along the tracks to ac/decelerate trains, similar to **T-flight**. **T flight** announced in August 2017 by CASIC [22], is a larger than ET3 tube diameter ETT (3 m, the concept: a train, a bus, a truck instead of a car; the pod length and diameter are 36 and 2.2 m respectively, 20 tons, 16 passengers per pod, speeds up to 4000 km/h only possible in the high quality vacuum, headway time of 189 s are mentioned). The QT, T flight (and ET3) are sharing the same philosophy resulting in much higher capacity than that of HL, see Table 1 and [17].

8.2.5 Less fast, the most expensive ETT with insufficient capacity for freight and passengers

In this paper we call **Hyperloop** (**HL**) a group of companies involved in this activity: Space*X*-Hyperloop announced in August 2013, Virgin Hyperloop One founded in June 2014, Hyperloop Transportation Technologies founded in November 2013, etc. [18-21]. ET3 would rather see HL as our colleague working towards the same goal rather than a competitor, Table 1. In our view, current HL adds little value to ETT and ET3 concepts by repeating and copying them. The HL alpha [21] concept is a copy of ETT version described e.g., in [13], the differences (e.g., pneumatic instead of magnetic suspension) are largely abandoned by HL itself as impractical, therefore current concept of HL is even more a copy of [13]. As a result of this imitation process, marketing and engineering successes of HL in fact prove the correctness of our approach. The key problem of HL is that it is not optimised for broad market entry and therefore is not competitive or economically viable (Table 1, [17, 20]) and we think it never will be: this place is already taken by ET3 [3], the history of ETT is written [12] and the only way now is in productive cooperation e.g., through licensing [14]. Why to invest in the fast connection (with option T2, Table 1) 6 times more, for a passenger to pay >35 times more, for freight transport >55 times more than it is really needed (option T1)? Why should any rationally thinking taxpayer, investor, passenger or shipper pay so much more for HL, when there is ET3 [3, 6, 7, 11, 19]? Notably, all relevant parameters of ET3 used in Table 1 are published long ago [3, 6, 15, 16], moreover the lack of economic viability, of capacity, etc. for HL when compared to ET3 was addressed in May 2016 [17]. It would be beneficial for all to accept the reality, continue the dialogue [16], to stop imitating and wasting resources. Best results are where knowledge and business meet. As clear from Table 1, HL currently fails in its main goal: it ends up being *relatively fast and most expensive* instead of cooperating with ET3 GA and becoming *the fastest and affordable*. Thereby, it puts at risk reputation of investors, business and country leaders, other entities, groups and individuals supporting it. This situation is in part caused by media frenzy and scarcity of ETT experts. It delays implementation of the true innovation and the only beneficiary is conventional infrastructure.

Annex 2

9 Examples of evolutions of the ET3 networks in years 2020-2050 for selected economies

9.1 Evolution of ET3 networks in selected regions in figures A2.1-3 examples of the proposed evolution in years 2020-2050 of the ET3 networks at the national level are given for the World's six largest economies (representing 79% of the global GDP and 51% of the expected $ET3_{nl}$ network length) using the same approach as described in the paper and available statistics for regional GDP, population, geographic area, road and railways lengths, passenger and freight traffic volumes, etc. The proposed in section 3.1 phase of creating $ET3_{nl}$ network at national levels in USA, Europe, China, Japan, Germany and France will start n year 2020 and proceed so that on average respectively 103 (33, 33, 19, 7, 4 and 7) thousand km are added each year, see figures A2.1-3 respectively. Thus by the year 2050, 3 million km of ET3 network will be added in these regions. The total investment of US$39T is in line with that elaborated in sections 1-3 and it will be returned in year 2046. Moreover, additional funds will be available through re-investing (part of) the return: US$55T by year 2050.

9.2 Saving of travel times with ET3 and the impact on GDP here we only illustrate the impact of ET3 on GDP in selected regions from saving travel times of passengers, see Tables 1 and 2. The added value is calculable and varies from country to country. For example, using Tables 1-2, Figures A2.1-3 and relevant statistical data one finds for: World, USA, EU, China, Japan, Germany and France the monetary value of the saved travel times (passengers only) in the year 2050 will add to the GDP of the same year at least: 8, 28, 21, 6, 23, 17 and 36%. The estimate uses a conservative assumption that each passenger's annual income equals to the local GDP per capita, resulting in the following monetary values (in the year 2050): 3, 14, 10, 4, 13, 12 and 11 US$/hour respectively. Contact us when you are interested to receive similar estimates for your country.

9.3 Well-known transport wisdom is: to travel through space (to cover a distance), one spends time and money expecting certain levels of comfort, safety, security and certainty, see Table 2. ET3 solves this by being the fastest, affordable, comfortable, safest, secure and most certain. Examples of the wisdom resolved with existing (bus, car, train, airplane) and future (ET3) transportation modes are presented in Table 2. Would you rather travel using option 1a or 0a,b,c; 1c or 1b; 1c or 2a; 1d or 2b? When your answer is "option 1a-d", read the paper, act and support ET3 development.

Table 2. Examples of the transport wisdom resolved with existing (car, airplane) and future (ET3) transportation modes

Option	Mode	Distance, km	Time	Price, €	Comfort class	Safety level[#]
0a	Bus	289	190 minutes	18	2nd	4
0b	Car	289	180 minutes	27	2nd[◆]	4
0c	Train	289	102 minutes	70/76	2nd / 1st	2
1a	**$ET3_{nl}$**	**289**	**10 minutes**	**27**	**1st**	**1**
1b	**$ET3_{nl}$**	**1156**	**40 minutes**	**40**	**1st**	**1**
1c	**$ET3_{gl}$**	**1156**	**12 minutes**	**220**	**1st**	**1**
1d	**$ET3_{gl}$**	**8212**	**1 hour**	**780**	**1st**	**1**
2a	Air	1156	4 to 6 hours	195/390[*]	2nd/1st	3
2b	air	8212	13 hours	609/7090[**]	2nd/1st	3

#safety levels: 1, 2, 3, 4 - highest (ET3), high 1 (train), high 2 (air), lowest (road)

[*] such as the flight Amsterdam-Vienna, 1146 km (this price is with one week advance)

[**] such as the flight Paris-Beijing, 8212 km (this price is with one week advance)

[◆] and you drive

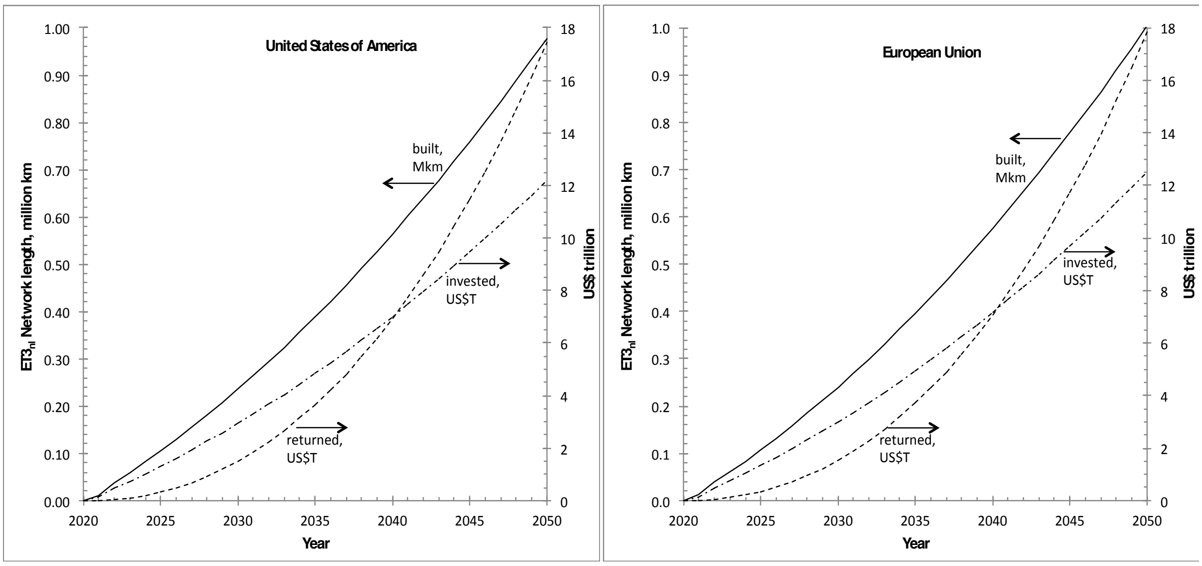

Figure A2.1. Examples of the proposed evolution in years 2020-2050 for the ET3 networks at the national levels ET3$_{nl}$: (USA, left) and (EU right)

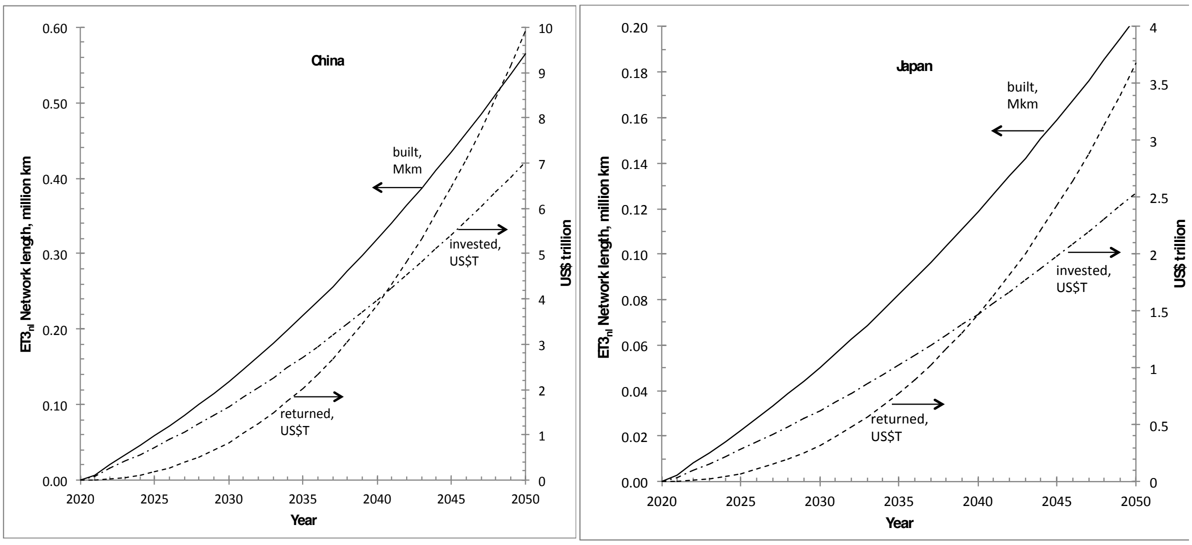

Figure A2.2. Examples of the proposed evolution in years 2020-2050 for the ET3 networks at the national levels ET3$_{nl}$: (China, left) and (Japan, right)

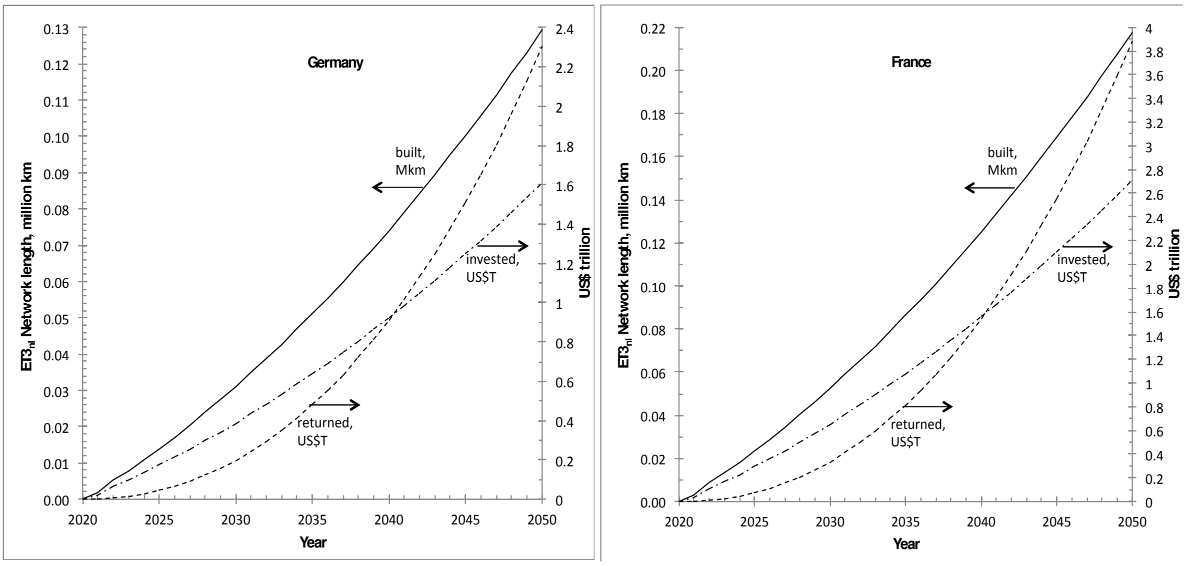

Figure A2.3. Examples of the proposed evolution in years 2020-2050 for the ET3 networks at the national levels ET3$_{nl}$: (Germany, left) and (France, right)

Annex 3

10 Economy of the mobility transition from a car to ET3

10.1 Executive summary The transition from a car to ET3 offers the most attractive combination of improved: economy (the total cost down to 3-4 US¢/km), speed (up to 2 and 10 thousand km/h for ET3$_{nl}$ and ET3$_{gl}$ respectively), range (>6 thousand km), ecology (all emissions reduced), safety (10 times safer than an airplane), privacy (better than that of individually owned car), comfort (1st class), simplicity (e.g., much easier to achieve full automation), etc. The transition from individual- to company-owned cars (fleet, mobility as a service) offers a reduction of the total cost (down to 39 to 34 US¢/km, further reduction limited by the costs of travel time and cleaning), but demands a full self-driving functionality (the safety is a challenge). The transition from internal combustion engine car to electric car offers only a reduction of CO$_2$ emissions along with: reduced range, comparable: speed, economy, safety, privacy; increased vehicle mass, longer refuel times, etc. The current total cost of owning and operating a mid-size car (internal combustion or electric) are at present relatively high (62 to 70 US¢/km respectively, including the often ignored costs of travel time, cleaning and parking) and ET3 is the only option offering their substantial reduction.

10.2 Road mobility as a service (rMaaS) When rMaaS is provided (e.g., a taxi), certain levels of comfort, safety, security and certainty come together with a price. Today, 65-80% of all passengers and freight are moved by road almost in any country. In this Annex we focus on the passenger transport by road and explain why we think that the smart urbanisation, renewables, electric vehicles, self-driving cars, etc. (section 1.2) are largely illusions.

10.2.1 Introduction Published at the time when regular horse-drawn vehicle (rHV) dominated, but first internal-combustion-drawn vehicles (iCV) were already built (though not yet mass-produced), Frank Reade's story goes [31]: "… the wooden skeleton of a horse had been completely enclosed by plates of …steel… shaped so as to conform to the outline of a well-formed horse. The upper edge of each plate was tucked up under the lower edge of the plate above it, and ingeniously riveted together, and by the joining together of many plates, the horse was formed. Then the … skeleton was removed from the interior. The horse was a giant in stature, and Bob could walk right under his belly without scraping his head even if he stood on tip-toes. In the horse's belly was an iron … door, which, on touching a hidden spring, dropped down, leaving a sort of door up through which a person could climb into the interior of the body. Two powerful electric batteries, connected to wires, and magnets powered the Electric Horse." Even though rHV were bound to find their new niche rather quickly, the attempts "to keep a habitual vehicle of some kind" (a horse that is) were multiple, classical examples are: "where is a place in this automobile for my horse?", "automobile is not allowed in our streets as it disturbs horses". Anyway, a travel by a rHV over a distance of 289 km (such as that for B-H connection, Table 1) would take two days (24 hours of transit at speed of 12 km/h, in practice resulting in 6 meals, 1 overnight stay and summing up to 10 and to 5 €/km for 3 passengers at today's prices with and without coachman respectively). By year 1905, a price of ten (regular) horses was close to that of a mass-produced iCV (Ford model A). Today, a B-H taxi ride sums up to just 1.5 €/km (for 3 passengers the cost is €430). And, most of the added monetary value of iCV (automobile) as compared to rHV (horse) was and still is in converting a two-day-long travel (by horse) into a three hours-long drive (resulting in at most one light meal/drink, summing up to 0.65 €/km for iCV with 3 passengers at today's prices, Table 3 and assuming that one of the passengers is a driver).

10.2.2 Costs of owning and operating a vehicle Our study uses realistic assumptions and draws realistic conclusions that respect value and provide a sound base for further analysis of and comparisons with ET3. Our conclusions are different from that of [32] (even though some of them may look similar) and detailed comparison of two studies goes beyond the scope of this paper. In Table 3 we compare the total costs per vehicle in US¢/km for iCV (option 1), aiCV (1a), EV (2), aEV (2a), and ET3 (3): at the time of writing €/US$=1.16. Some of the assumptions (e.g., all for ET3) in this Annex are our own, we use those of [32-34] where agreeable and our own findings where not. As a result, our study is different from [32] in that e.g., five options are compared (four in [32]); the costs are included of travel time (section 9.2), of parking and of cleaning (these are not considered in [32]). Furthermore, we assume the maintenance cost for EV is only 20% less than that for iCV [35] (and not 90% less [32]). In order to compare things that are comparable and to follow the available statistics, we assume below that on average each vehicle is occupied by 1.6 persons (for options 1a, 2a: one of them is a driver, for options 1b, 2b and 3: all are passengers), used at 82 and 1110 km/h (options 1a-2b and 3 respectively), persons use vehicles 48 and 3 minutes/day (options 1a-2b and 3 respectively) and make 55 km/day (any option). The guideway costs (road or tube, exits, parking spaces, etc.) are accounted for in f1, but not shown in Table 3 as a separate line because they are low (1 US¢/km for cars and for ET3). The relevant cost components are calculated over the lifetime (in years) and divided by the total amount of km over the vehicle lifetime. Naturally where applicable, some of the cost in Table 3 can be reduced (e.g., when driver cleans individually owned iCV), we assume however the cleaning and parking costs are present for company-owned vehicles. For ET3 the cleaning cost is greatly reduced by the proprietary solutions.

10.2.3 Conventional vehicle with internal combustion engine (**iCV,** options 1a and 1b in Table 3) In our study, for an <u>individually owned</u> iCV the total cost per vehicle (**70 US¢/km** in Table 3, option 1) is comprised of the: fixed (44 US¢/km) and variable (26 US¢/km) costs. The fixed cost consists of f1 (26 US¢/km with all sub-components agreeing with [33]) and additional to [32-35] cost f2 (17 US¢/km as the travel time cost for USA, 0 as cost of CO$_2$-tax in USA. To compare, in countries like the Netherlands this tax is 23 US¢/km, this value is not included in Table 3.

Table 3. RMaaS: the costs of owning and operating vehicle (and guideway, all in US¢/km per vehicle)

Cost breakdown \ Option nr. (type of vehicle)	1 (iCV)	1a (aiCV)	2 (EV)	2a (aEV)	3 (ET3V)
Total(=Fixed + Variable), all costs are per vehicle	**70**	**39**	**62**	**34**	**3.5**
Fixed = f1 + f2:	**43.8**	**22.8**	**40.1**	**21.4**	**2.8**
f1: insurance, financing, depreciation, licences, fines, taxes, guideways, etc.	26.3	8.9	22.7	7.6	0.9
f2: all additional to f1 fixed costs:	17.4	13.9	17.4	13.9	1.9
- travel time	17.4	11.9	17.4	11.9	0.9
- carbon tax	0.0	0.0	0.0	0.0	0.0E+0
-(software) platform and updates (Rethink, fig. 3 for options 1-2a)	0.0	2.0	0.0	2.0	1.0
Variable= fuel + maintenance + parking + cleaning + tires:	**26.2**	**15.7**	**21.4**	**12.6**	**0.7**
fuel	5.3	3.2	1.14	0.69	0.2
maintenance (vehicle and road/gudeway: repairs, airco, etc.)	3.6	3.6	3.0	3.0	0.4
parking	8.8	0.46	8.8	0.46	1.6E-3
cleaning (outside & inside):	7.9	7.9	7.9	7.9	2.7E-2
-inside (interior vacuuming, shampooing, wiping windows, etc.)	5.7	5.7	5.7	5.7	2.2E-2
-outside (washes, waxes, etc.)	2.2	2.2	2.2	2.2	5.4E-3
tires or levitation system	0.6	0.6	0.6	0.6	1.9E-3

The platform cost [32] is set to 0). The variable cost in addition to the usual components (fuel, maintenance, tires [33, 34]), in our study includes parking (9 US¢/km) and cleaning (8 US¢/km). To arrive at the above data, we assume that a mid-size car (average of three current models [33] with internal combustion engine, mechanical drivetrain) is occupied with 1.6 persons, has physical lifetime of 16 years, costs US$22.5 thousand, requires a human driver that drives 24 thousand km/yr at 82.3 km/h, 66 km/day and 293 hours/year, the travel time costs 11 and 6 US$/hour for driver and passenger respectively (USA today, see section 9.2 for the values per country in year 2050), the car is parked for 97% of the time (25 US¢/hour), cleaning of interior (exterior) is every 2 weeks (2 months), etc.

For a company owned autonomous iCV (aiCV e.g., offered as part of rMaaS), the total cost per vehicle (**39 US¢/km** in Table 3, option 1a) is comprised of: the fixed (23 US¢/km) and variable (16 US¢/km) costs. The fixed cost consists of f1 (9 US¢/km with all sub-components agreeing with [32]) and of the additional cost f2 (14 US¢/km as the travel time cost for USA and 0 as cost of CO_2-tax in USA. To compare, in countries like the Netherlands this tax is 23.4 US¢/km currently, the latter value is not included in Table 3. The platform cost [32] is 2 US¢/km). The variable cost in addition to the usual components (fuel. maintenance, tires [32]), in our study includes parking: 0.46 US¢/km greatly reduced as compared to option 1 due to more use) and cleaning: 8 US¢/km. As compared to option 1, the fuel cost is reduced by 40% accounting an advantage of company over individual price bargains. To arrive at the above data, we assume that a mid-size car (average of three current models [32] with internal combustion engine, mechanical drivetrain) is occupied with 1.6 persons, has physical lifetime of 1.1 years, costs US$22.5 thousand, requires no human driver, drives 288 thousand km/yr at 82.3 km/h, 1975 km/day and 3504 hours/year, the cost of time lost on travel is 6 US$/hour for passenger (USA today), see section 9.2 for the values per country in year 2050, vehicle is parked for 10% of the time (0.25 US$/hour), cleaning of interior (and exterior) is 12 times more frequent as compared to option 1, etc. The aiCV lifetime can be shortened to 0.6 years, in this case the total cost changes only slightly to: 37 US¢/km making possible utilizing of many iCVs that may become redundant (as expected e.g., in [32]).

Conclusions from section 10.2.3 of our study: 1) transition from option 1 to 1a (both using iCV) has advantages, namely it keeps iCV competitive with EV (section 10.2), for the same service delivered (same number of km travelled by each client per year and same total CO_2 emission) the total number of vehicles and their lifetime duration are greatly reduced (each by 12 times in Table 3), the total cost per vehicle goes down from 70 to 39 US¢/km (by 44%) and from 93 to 40 US¢/km (by 57%) for the cases when carbon tax is zero and 23 US¢/km respectively, but overall reduction of carbon emissions is limited and no progress is expected in addressing “the need for speed”; 2) the total cost for option 1a (39 US¢/km) depends only slightly (<5%) on CO_2-tax and substantial parts of the cost (31; 20 and 10% in our study) are due the cost of: travel time, cleaning and fuel respectively; 3) the short vehicle lifetime (can be as short as 0.6 years, in this case the total cost is: 39 US¢/km) allows utilizing of many iCVs when needed; 4) the transition from option 1 to 1a (anticipated e.g., in [32]) results in saving of 7.6 thousand US$/year for a consumer.

10.2.4 Electric vehicle (EV, option 2 in Table 3) In our study, the total cost for an individually owned EV (**62 US¢/km**) is comprised of: the fixed (40 US¢/km) and variable (21 US¢/km) costs. The fixed cost consists of f1 (23 US¢/km with all sub-components agreeing with [32, 33]) and of the additional cost f2 (17 US¢/km as travel time cost for USA and 0 as the cost of CO_2-tax in USA. To compare, in countries like the Netherlands this tax is 4 US¢/km, the latter value is not included in Table 3. The platform cost [32] is zero). The variable cost in addition to the usual components (fuel. maintenance, tires [33]), in our study includes parking: 9 US¢/km and cleaning: 8 US¢/km. To arrive at the above data, we assume that a mid-size car (a current model with electrical engine, battery and mechanical drivetrain) is occupied with 1.6 persons, has physical lifetime of 33 years, costs US$22.5 thousand, requires a human driver, drives 24 thousand km/yr at 82.3 km/h, 66 km/day and 293 hours/year, the travel time costs 11 and 6 US$/hour for a driver and passenger respectively (USA today, see section 9.2 for the values per country in year 2050), the car is parked for 97% of the time (25 US¢/hour), cleaning of interior (and exterior) is every 2 weeks (and 2 months), fuelled regularly (0.21 US$/kWh), etc. Moreover, our study accounts that according to AAA, the maintenance cost per year of EV is 20% lower than that of iCV [35].

For a company-owned (e.g., offered as part of rMaaS) autonomous EV (aEV), the total cost (**36 US¢/km** in Table 3, option 2a) is comprised of the: fixed (21 US¢/km) and variable (14 US¢/km) costs. The fixed cost consists of f1 (8 US¢/km) with all sub-components agreeing with [32]) and of the additional cost f2 (14 US¢/km as travel time cost for USA and 0 as the cost of CO_2-tax in USA. The platform cost is 2 US¢/km [32]). The variable cost in addition to the usual components (fuel, maintenance, tires [33]), in our study includes parking (0.46 US¢/km greatly reduced as compared to option 2 due to less idle time) and cleaning (8 US¢/km). As compared to option 2, the fuel cost is reduced by 40% accounting an advantage of company over individual price bargains. To arrive at the above data, we assume that a mid-size car (current model with electrical engine, battery and mechanical drivetrain) is occupied with 1.6 persons, has physical lifetime of 2.8 years, costs US$22.5 thousand, requires no human driver, drives 288 thousand km/yr at 82.3 km/h, 1975 km/day and 3504 hours/year, the cost of time lost on travel is 6 US$/hour for passenger (USA today. Inside an aEV, the choices are limited, as much as e.g., in a taxi today. So the quality of travel time is valued with the factor of 0.6), see section 9.2 for the values per country in year 2050, vehicle is parked for 60% of the time (25 US¢/km), cleaning of interior (exterior) is 12 times more frequent compared to option 2, etc. Due to the increased utilization (40% for aEV instead of 4% for EV), the total number of vehicles serving the same amount of customers can be proportionally smaller [32], however swapping of batteries may be needed every 3 hours, and the total number of car batteries increases. Our study supports qualitatively the conclusions of [32] with respect to the reduced maintenance and insurance costs, Table 3, options 3 and 2, the smaller changes are due to the different assumptions in our study. In contrast to [32] we assume in this case the bulk of the maintenance cost over the lifetime in years (parking, tires, washes, waxes to name a few) is the same as for EV and the corresponding cost reduction per km is due to the more km covered during the lifetime, while the reduction of the parking cost is due to the shorter (longer) lifetimes in years (in km). Furthermore, an assumption that all EVs (aEVs) will be charged from a network (respectively 0.21 and 0.33 US$/kWh in USA and in Germany in the year 2017) will increase the total costs by only 2 US¢/km as compared to those in Table 3 (options 2 and 2a) and will affect only slightly the conclusions of our study. It is clear from Table 3 that at zero carbon tax (USA), the total costs of iCV and of EV are comparable (70 and 64 US¢/km respectively even under the assumption that the upfront costs of both vehicles are the same).

Conclusions of our study for options 1 and 2: 1) main advantage of EV over iCV is in ecology (CO_2 emissions); 2) under the assumption that the upfront costs of both (individually owned) vehicles are the same, the total costs of EV and of iCV are comparable (62 and 70 US¢/km respectively) at zero carbon tax (e.g., USA); 2) EV is cheaper than iCV where CO_2-tax is substantial (e.g.: 68 and 94 US¢/km respectively at CO_2-tax such as currently in the Netherlands even when to account for the higher price of EV compared to iCV: US$48 and 22.5 thousands respectively); 3) without the CO_2-tax, the current advantages of EV over iCV are hardly sufficient for switching to EV: the transition from option 1 to 2 results in saving of less than 2 thousand US$/year for a customer, the carrot politics does not really work, as currently the carrot is too small (think of: range, speed, economy, ecology, etc.).

Conclusions of our study for options 1a and 2a: 1) rMaaS format is attractive for both aEV and aiCV as it reduces the required fleet of vehicles substantially and makes mobility cheaper [32], for instance a transition from option 1 to option 1a (2a) results in saving of 7.6 (8.6) thousand US$/year for a customer; 2) the total costs per vehicle for rMaaS aEV and aiCV are comparable, for aEV the total cost (34 US¢/km) is largely limited by the: travel time (35%), cleaning and maintenance (32%) and f1 (22%, mainly depreciation); for aiCV the total cost (39 US¢/km) is limited by the: travel time (31%), cleaning and maintenance (30%), f1 (23%, mainly depreciation) and fuel (8%); 5) the lifetime of both aEV and aiCV in the rMaaS format is short, e.g., for aiCV it can be 0.6 years, so this way redundant iCVs can be utilised.

10.2.5 Main conclusions of our study so far, sections 10.2.3 and 10.2.4: 1) our findings support the conclusion [32]: transition from individual ownership to rMaaS delivers most of the value, for instance a transition from option 1 to option 1a (2a) results in saving of 7.6 (8.6) thousand US$/year for a customer, but the impact is limited to 51% reduction of the total costs at most and it requires challenging full self-driving function of vehicles (as only in this case a privacy of individually owned vehicle is preserved); 2) on the other hand, a transition from iCV to EV (at zero CO_2-tax) has less effect, for instance from option 1 (1a) to 2 (2a) results in saving of 2 (1) thousand US$/year for a customer, it barely addresses the issues (section 1.2), the advantages in terms of speed, range, economy, ecology, etc. are not convincing and such transition is largely an illusion of the action really needed. Thus our study basically supports the conclusion of [32, fig. 2]: the switch from an individually owned iCV to EV is environmentally beneficial (CO_2 emissions are 0), but it leaves substantial economical burden (62 US¢/km), “the need for speed” is addressed at the same level; congestions, traffic jams, dependence on weather, other pollutions (noise, fine particles, heat, etc.) will stay, see section 1.2 for more. It is easy to imagine the future scenario with EV by replacing in your head every iCV you see today with EV and in our opinion, such future is less bright than that painted in [32].

10.3 ET3 mobility, network and capsules (aET3V, option 3 in Table 3)

In this section we show the potential of ET3 for “clean disruption” as compared to that of iCV or EV of any kind. ET3 network provides naturally the MaaS format with all the advantages of company-owned vehicles (sections 10.1-2) and more. That is, a typical vehicle average speed is 1110 km/h (higher 13 times of that for any iCv or for EV); the typical range is >6 thousand km (>6 times that of iCV), the total cost (3 US¢/km, is lower >10 times than that of aiCV or of aEV), zero CO_2 emissions (e.g., all consumed energy is green) and all other emissions (noise, fine particles, vibrations, heat, etc.), far greater capacity and redundancy, vehicle and guideway simplicity, hence higher reliability, immune to weather, etc. In our study, the aET3V total cost (**3.5 US¢/km** in Table 3) is comprised of the: fixed (2.8 US¢/km) and variable (0.7 US¢/km) costs. The fixed cost consists of f1 (0.9 US¢/km: financing, insurance, depreciation, registration renewals, driving license, taxes, fines, etc.) and of the additional cost f2 (1.9 US¢/km as travel time cost for USA: 0.9 US¢/km, the difference is due to the higher average speed; 0 as the cost of CO_2-tax and the smart platform cost: 1 US¢/km). The variable cost (0.7 US¢/km) includes fuel (0.2 US¢/km: energy to sustain vacuum, cooling, ac-and decelerate vehicles, operate airlocks, portals, computers, etc.), maintenance (0.4 US¢/km: preserving vacuum systems, levitation - magnets, cooling and cryostats, life support, repairs, cleaning; linear motors/generators, converters, solar panels;

tubes, joints, alignment mechanisms, sensors, automation system, etc.), parking (<0.01 US¢/km) and cleaning (<0.03 US¢/km). To arrive at the above data, we assume that an ET3 capsule (see example in figure 2 and section 8.2.3) is occupied with 1.6 persons on average, has physical lifetime of 20 years, costs US$22500, requires no human driver (fully automated by computer control), drives 8.9 million km/yr, each passenger makes 55 km/day and spends 18 hours/year on travel, the travel time costs 6 US$/hour, a capsule is parked for 34% of the time (25 US¢/hour, e.g., in airlocks), serviced and interior cleaned after every trip (10 US$), etc. The assumed average (maximum) speed of aET3$_{nl}$V is 1110 (1650) km/h. The coherent motion of the ET3$_{nl}$ capsules (all cruising at the same speed of 1300 to 2000 km/h, section 8.2.3, ac- and decelerating in the same ways) is provided by their automated control. To compare, a Hyperloop ride in the MaaS format would cost 330 US¢/km (Table 1).

The data in Table 3 show that: 1) transition between iCV, EV, aEV does not change vehicle speed and therefore has no substantial effect on the travel time; 2) switching from iCV to EV is economically neutral with regard to the total costs (economical burden remains the same) and likely to happen only with carbon tax incentives; 3) switching from iCV to aEV will lead to the mere 51% reduction in the total cost; 4) switching from iCV, EV or aEV to ET3 results in over 10-fold reduction of the total cost (e.g., respectively from 70, 62, 34 to 3.5 US¢/km) including 12-fold saving of travel time, and is the only alternative resulting in the "win-win-win" situation (citizen, company and government win) that should be offered by adequate governments as the solution timely addressing the issues in section 1.2.

Let us give two more detailed examples. For a typical trip: 1) from A (e.g., home, office, shop) to A1 (ET3 portal) separated by 2 km (with aEV: total time of 1.8 minutes, the cost of 0.7 US$); from A1 to B1 (ET3 portals) separated by 289 km (with ET3: total time of 12 minutes, the cost of 14.5 US$); from B1 (ET3 portal) to B (e.g., office, shop, home) separated by 2 km (with aEV: total time of 1.8 minutes, the cost of 0.7 US$) the total travel time is 16 minutes at the total cost of 16 US$ (the average speed is 1121 km/h and the cost is 10 US¢/km per vehicle, 6.25 US¢/km per passenger). Similarly, for the distance between A1 and B1 of 2 km: the total time and cost are 4 minutes and 1.6 US$ respectively (and since the average speed is 97 km/h, the cost is 26 US¢/km, option 3 makes more sense in this case than any other option, including 2a, Table 3). To compare, a trip with aEV over a distance 293 km (6 km) will cost 99.6 US$ (2.04 US$), 3.6 hours (4.4 minutes) at the average speed of 82 km/h (and cost of 34 US¢/km). It is clear from the examples that a trip with ET3 at the total distance of >6 km is beneficial as compared to that by car in terms of economy, travel time, ecology (fine particles, noise, heat waste, etc.), safety, privacy, comfort, etc., which limits the future niche for CV and EV by the range of perhaps <50 km/day. In turn, such range greatly simplifies achieving of the self-driving function, calls for cheaper, more elegant and light EV with a battery of 20 kWh (e.g.: US$ 3-4 thousand, 100 kg), acknowledges technological development of EVs as being already at sufficient level, etc. Similarly, as compared to aiCV, aET3V has advantages in: range (1 and 16 thousand km respectively), speed (82 and 1110 km/h), economy (40 and 3.5 US¢/km), ecology (for ET3: zero fine particle emission, less noise, vibration, heat, waste, etc.), capacity, reliability, simplicity (e.g., in achieving self-driving functionality), energy efficiency, etc.

In this paper we only present a brief comparison with travel by an airplane. It is easy to derive from the real-life examples of Table 2 that travel by plane over a distance 1156 km (8212 km) results in the total cost per passenger (airplane-mobility-as-a-service, including travel time cost) of: 20 to 40 US¢/km (8 to 87 US¢/km the costs are per passenger, as vehicle is often shared with >100 strangers; respectively ranging from the "second-", "economy" [36] to "first-", "suite" - offering true privacy and being better than "business"-, travel classes as defined by airlines) at the average speed of: 193 to 289 km/h (631 km/h). Therefore, a travel by an airplane when compared to that by an automobile at distances >1000 km offers clear advantages in: range, speed, safety and at comparable economy it fails to compete with EV in ecology, comfort and privacy. Similarly, (Tables 3 and 2, section 2.1), a travel by ET3 over a distance of 289; 1156 km (8212 km) results in the total cost per passenger, not per vehicle, of: 4 US¢/km (ET3$_{nl}$); 2.4 to 12 US¢/km for ET3$_{nl}$ and ET3$_{gl}$ respectively (6 US¢/km) at the average speed of: 1445 km/h; 1734 to 5780 km/h (8212 km/h). For example, an ET3$_{gl}$ capsule travelling 4 hours non-stop has range of up to 40 thousand km, section 3.2 (compared to e.g., 23 and 18 hours, 21.6 and 15.7 thousand km for Boeing 777 200LR and Airbus A380 respectively). Therefore, a travel by ET3 as compared to that by an airplane at any distance offers clear advantages in: range, speed, economy, ecology, safety, comfort (1st class for ET3), privacy, energy efficiency, etc. This is why we are confident that the "clean disruption" [32] of existing transport will indeed happen, but the real change is much more likely to come from the transition to ET3 (and much less so from the transition to EV): with regard to the economy for instance, as the reduction of the total cost per passenger from 44 US¢/km for iCV and from 40…87 US¢/km for an airplane to 2.4…4.4 US¢/km for ET3$_{nl}$ at distances ranging from 2 to 300 km and to 2.4…13 US¢/km for ET3$_{gl}$ at distances over 300 km (as compared to the reduction of the total cost per passenger from 44 to 39 US¢/km for EV to 21 US¢/km for aEV, Table 3).

We know from the history of EVs that their mass production declined around the year 1910 as iCVs gained the advantages over EVs in: range, speed, economy, etc. (at the time, with far less vehicles in use, ecology was overlooked). A good question therefore if an EV (offering at present: reduced CO_2 emission along with 1/3 of the range, larger vehicle mass; longer refuel times, comparable speed and economy to those of iCV) is really the best future transport solution for the issues we are facing, section 1.2? We find that in the rMaaS format aiCVs are competitive to aEVs regardless if CO_2-tax present or not (23 and 2 US$/km for iCV and aiCV respectively). What one sees depends on what he knows and with the existing knowledge on ET3 we are certain that namely the advantages of aET3Vs will limit use of iCVs and of EVs of any kind to the niche defined above. It is therefore clear that focussing on spending time and resources on further development of EVs is an illusion of required action (section 1.2), since more rational solution exists. In our opinion, it reminds an attempt of bringing the "Electric Horse" into mass production.

We therefore conclude the study in this annex with two quotes: 1) "*Life is not complex, we are complex. Life is simple, and the simple thing is the right thing*"; 2) "*Any intelligent fool can make things bigger, more complex, and more violent. It takes a touch of genius—and a lot of courage —to move in the right direction*".

10.4 Concluding remarks

10.4.1 Main conclusions of Annex 3 The transition from a car to ET3 offers the most attractive combination of improved: economy (the total cost down to 3-4 US¢/km), speed (up to 2 and 10 thousand km/h for ET3nl and ET3gl respectively), range (>6 thousand km), ecology (all emissions reduced), safety (10 times safer than an airplane), privacy (better than that of individually owned car), comfort (1st class), simplicity (e.g., much easier to achieve full automation), etc. The transition from individual- to company-owned cars (fleet, mobility as a service) offers a reduction of the total cost (down to 39 to 34 US¢/km, further reduction limited by the costs of travel time and cleaning), but demands a full self-driving functionality (the safety is a challenge). The transition from internal combustion engine car to electric car offers only a reduction of CO_2 emissions along with: reduced range, comparable: speed, economy, safety, privacy; increased vehicle mass, longer refuel times, etc.

10.4.2 Business supporting road transport of passengers In section 9.2 the estimates are presented for the travel time cost. Let us now illustrate the magnitude of annual turnover of the business directly supporting road transport of passengers, Table 3. Passenger traffic (in pkm) in year 2010 in USA, EU and World was: 7.4T, 5.4T and 39T respectively and assuming 86% of that (section 9.1) was by individually owned passenger cars (iCVs, option 1, Table 3) it is easy to estimate that turnover of the business (directly supporting road transport of passengers) accounted respectively for 14%, 15% and 15% of the GDPs in the same year. Similarly, assuming that in year 2050 15% of the World GDP (of that year) will be representative for the turnover using option 1 (scenario: business as usual), it is easy to extrapolate from there that the turnover using only option 2a (scenario: company owned aEVs dominate) will be: 9% of the GDP, and using only option 3 (scenario: ET3 networks dominate): 0.8% of the GDP. We therefore can expand conclusion 2 (of section 5) as follows: "…. altogether resulting in the GDP increase of over 10%: in particular, passenger transport alone when performed mainly by ET3 instead of car, has potential to boost GDP by 8 to 15%".

10.4.3 Policy change and strategy innovation It is clear from sections 2.1-2.2 and Table 3 that e.g., European Commission (EC, being ultimately responsible for managing EU budget and setting strategic priorities including "Energy union and climate" and "clean mobility") requires an update of its current policy [37, 4] in the transport sector, as currently it looks like a victory of existing transport providers in preserving their market share, as EC: fails "to think European" and to select and agree with the providers what is best for Europeans; ignores rational solutions: ET3 was invented in the year 1997, but so far receives ignorance and no support of EC; serves primarily interests of large stakeholders (road, rail, etc.), perhaps assuming they will serve the citizens, however reality is often very different [36]: they serve their own interests and as a result, in the current EC framework the citizens are offered no other choice but to carry the economic burden and to pay for the policy mistakes until year 2050, see Table 3, options 1-2a.

10.4.4 Roles of the MaaS stakeholders The stakeholders form the ABC-triad: authorities, businesses and citizens, see [38] for more details; the relevant scenarios are: <u>1 or 1a</u>) vehicles with internal combustion engines dominate in providing rMaaS, the economic burden ranges from 70 to 40 US¢/km depending respectively on the option 1a or 1 in Table 3, the society faces problems described in section 1.2, the infrastructure gap widens with time; <u>2 or 2a</u>) electric vehicles dominate in providing rMaaS, the economic burden ranges from 64 to 32 US¢/km depending respectively on the option 2 or 2a in Table 3, the society faces problems described in section 1.2, the infrastructure gap widens with time; <u>3</u>) ET3 networks and vehicles dominate in providing MaaS, the economic burden is 4 US¢/km for option 3 in Table 3, the society solves problems (section 1.2), the infrastructure gap closes with time as described in this paper.

<u>rMaaS stakeholders in a non-sustainable society</u><u>, Table 4</u>

Authorities play passive roles: R1.1, R2.1 – by assuming that business will take entirely care of citizens; delegate to business providers the responsibility of making sure that offered MaaS meets interests of the Users (part of the ABC-triad), the resulting policy and strategy (see examples in sections 2.1, 2.2) are in the interest of rMaaS providers and less so of consumers (only those with funds are heard, power without knowledge is common); the consumers: R1.2, R2.2 are offered no other choice, but to use available rMaaS options and to carry the respective economic burdens, scenarios <u>1 or 1a</u>, <u>2 or 2a</u>.

Business providers play active roles: R1.3, R2.3 – by convincing rMaaS users that the options 1, 1a, 2, 2a are the best available on the market (until at least year 2050) and by ignoring option 3, Table 3. The reasons are clear: the existing road business (section 10.4) makes profits, the scenarios 1, 2 preserve the profit (it does not really matter if the profit comes from cars with internal combustion or with electric motors as long as the economic burden remains), scenario 3 disrupts this business, therefore it is a threat and the best way is to ignore it for as long as possible; the consumers are offered no other choice, but to use the available rMaaS options (1, 1a and 2, 2a in Table 3) and to carry the respective economic burdens: R1.4, R2.4, some of them are interested in option 3, but not ready to take a risk of its development and implementation, section 8.2.3.

Citizens play different roles: some providers (R1.5, R2.5) invest in electric or flying cars, in hyperloops, in anything that supports an illusion that scenarios 1, 2 are the best in the market (see above) and ignore firmly option 3; for the reasons explained above, all consumers are offered no other choice, but to use available rMaaS options (R1.6, R2.6), most of the consumers are not aware, or have no sufficient knowledge of scenario 3, or want to see ET3 fully operational first, etc. The available resources are spent irrationally, the infrastructure gap widens and the society is non-sustainable.

Table 4. Roles of the MaaS stakeholders in each of the three main scenarios: 1, 2 or 3

	Society type->	Non-sustainable, irrational		Sustainable, rational
Stakeholder type		Scenario 1 or 1a	Scenario 2 or 2a	Scenario 3
Authorities (A)	providers	R1.1	R2.1	R3.1
	consumers	R1.2	R2.2	R3.2
Businesses (B)	providers	R1.3	R2.3	R3.3
	consumers	R1.4	R2.4	R3.4
Citizens (C)	providers	R1.5	R2.5	R3.5
	consumers	R1.6	R2.6	R3.6

rMaaS stakeholders in a sustainable society, Table 4.

Authorities recognise that with the invent of ET3 options 1, 1a and 2, 2a in Table 3 have limited future and becoming obsolete, they develop and implement adequate strategy and policy, initiate and supervise the process of the infrastructure gap closing locally, regionally and globally, they recognise that existing rMaaS providers will not give up their positions voluntarily, R3.1 – by motivating the MaaS providers to add option 3, creating a regulatory framework for its implementation and this way making sure that interests of all consumers (of ABC-triad) are satisfied and relevant actions are supported, that their choice includes ET3 option; R3.2 – by demanding from MaaS providers to close the infrastructure gap (e.g., by using ET3 as described in this paper) and by making ABC-triad aware of the benefits, by creating conditions for accelerated ET3 development and implementation, section 8.2.3, etc.

Businesses recognise that with the invent of ET3 options 1, 1a and 2, 2a in Table 3 have limited future and becoming obsolete, they actively support the authorities and the citizens in the process of the infrastructure gap closing, as well as in the ET3 implementation and maturation, R3.3; by demanding from the MaaS providers to close the infrastructure gap using ET3, R3.4.

Citizens play active roles: the providers invest in ET3 and in closing the infrastructure gap with ET3, R3.5; the consumers urge the ABC-providers to close the infrastructure gap using ET3, they become aware of the benefits and support the ET3 development by all suitable means (R3.6).

As a result, the available resources are spent wisely, the infrastructure gap closes and the society is sustainable.

10.5 References

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