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Presentation on behalf of the 5GAA

Cost–benefit analysis on cellular vehicle to everything (C-V2X)

5 December 2017 • Janette Stewart (Analysys Mason) & Alain Dunoyer (SBD Automotive)

The purpose of the study was to assess the net benefits of C-V2X use in Europe

- Vehicle to everything (V2X) will enable communication between vehicles (V2V), and between vehicles and infrastructure (V2I):
  - potential to provide enhanced information, complementing on-board sensors, enabling operation over a longer range
- C-V2X is designed to deliver V2X, with two modes of communication:
  - a direct vehicle-to-vehicle mode (‘***PC5***’), for V2V/V2I
  - a network communications interface, for vehicle-to-network (V2N) communication via mobile networks (‘***Uu***’)
- An existing short-range technology, IEEE 802.11p, is also designed to offer V2V/V2I services
- We were asked to examine qualitative evidence, and perform quantitative analysis to compare the net benefits of C-V2X with those of IEEE 802.11p

There were three main elements to the study

1	Conduct primary research on C-V2X deployment	We interviewed 5GAA member companies, to gather evidence on planned C-V2X deployment, business models and cost assumptions
2	Consider qualitative evidence	We gathered published evidence about C-V2X deployment (and its evolution to 5G) in Europe, including trials, deployment plans, potential business cases and socio-economic benefits
3	Develop cost–benefit analysis	We developed scenarios and a cost–benefit model comparing C-V2X with IEEE 802.11p for V2V/I/N/P deployment in Europe

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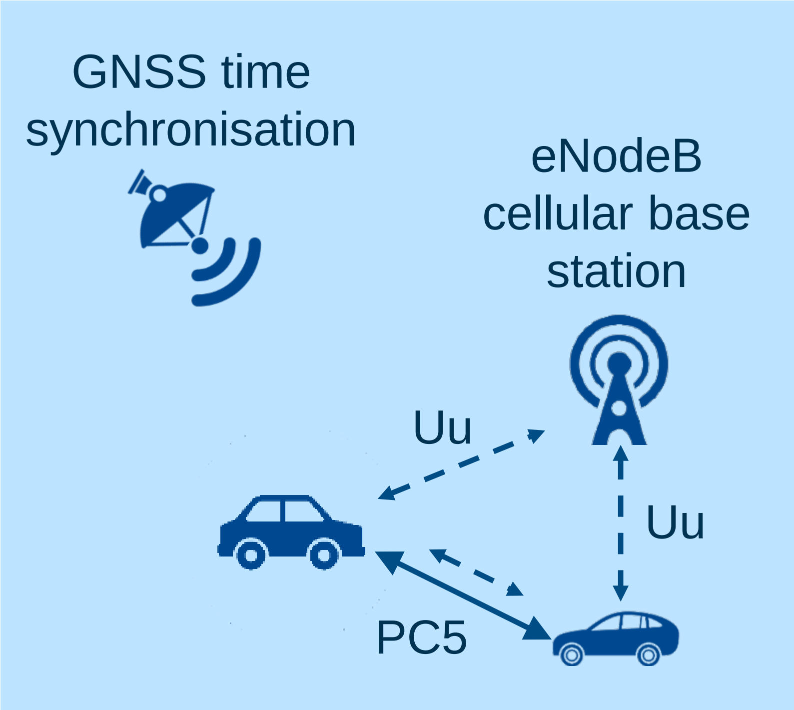
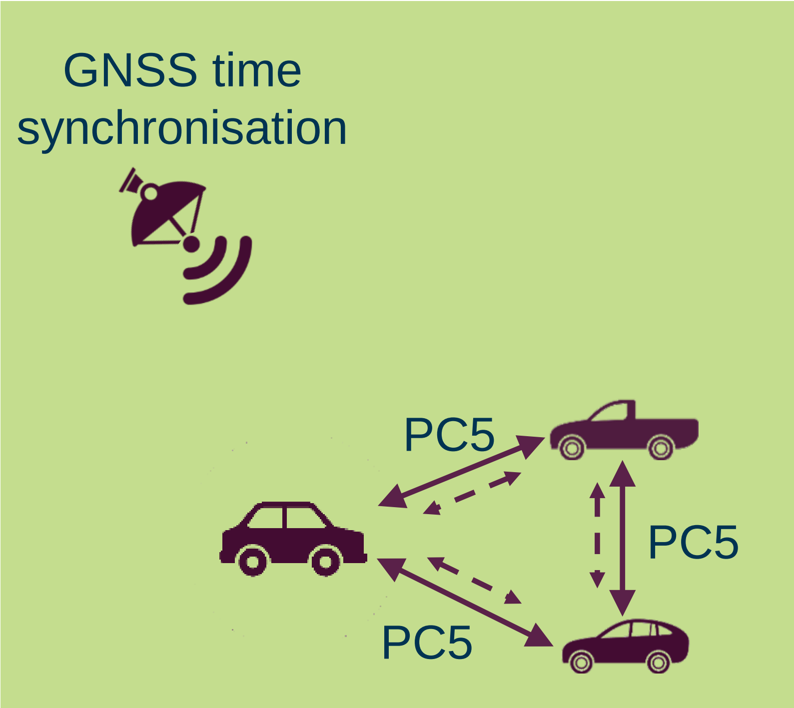
A key benefit of C-V2X is that it incorporates multiple modes of transmission

PC5 Mode 3:
Network-assisted radio resource management



PC5 Mode 4:
Distributed radio resource management

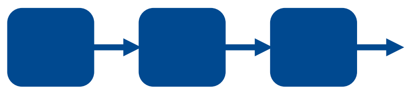


Communication for management of radio resource

Communication related to use cases

C-V2X benefits include its evolution path to 5G, and potential for rapid economies of scale [1]

Future-proof, providing a progression to 5G

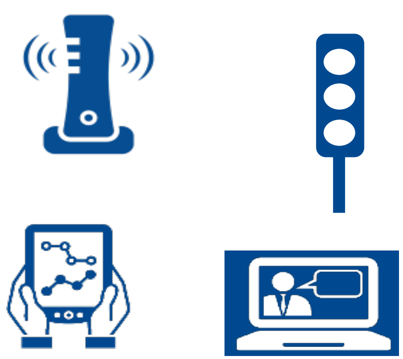


C-V2X will evolve to facilitate new capability in the 5G era. In the meantime, the dual modes of LTE C-V2X meet all the requirements of the automotive industry

Supports V2P communication

V2P may be needed for fully automated cars in urban areas. Although there are doubts that V2P can be achieved with IEEE 802.11p, V2P can be enabled using LTE smartphones (either via Uu, or PC5)

A wide range of business models are possible



Business models leveraging the multiple modes of C-V2X could include infotainment, traffic information, real-time mapping, telematics and data analytics. Network-based data analytics opportunities also exist (using data gathered via both Uu and PC5 interfaces)

C-V2X benefits include its evolution path to 5G, and potential for rapid economies of scale [2]

Economies of scale will develop more rapidly

Many automotive OEMs believe C-V2X will be less expensive to implement than IEEE 802.11p (and cheaper than a combination of IEEE 802.11p for V2V, plus cellular for V2N)

V2V and V2N modules **can be combined in a single C-V2X chipset**

This same integration between V2V and cellular is not expected for DSRC/ ITS-G5, which will need dual/multiple chipsets in vehicles compared to potential for a single C-V2X chipset

We identified that C-V2X commercialisation is imminent, with several trials underway [1]

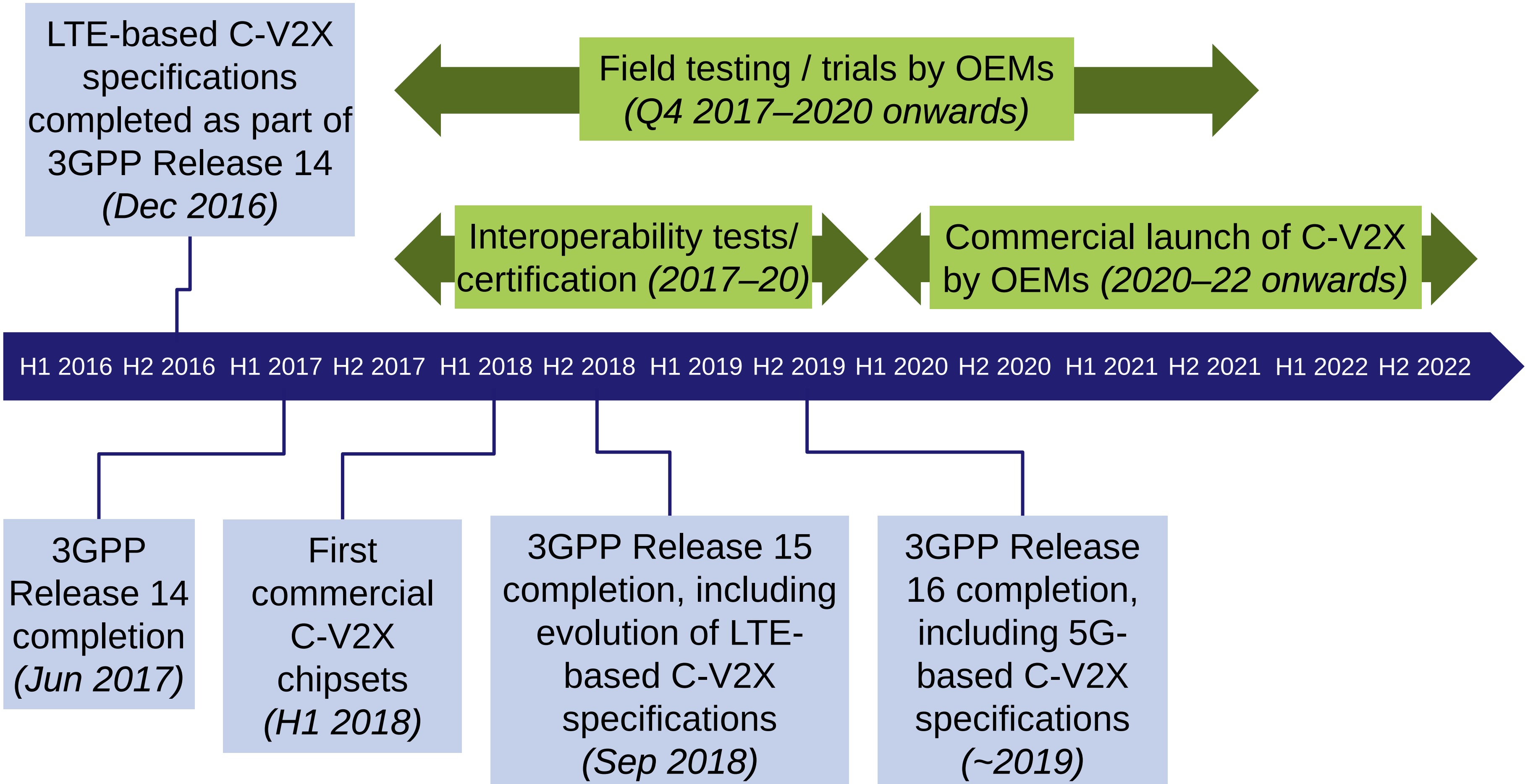
Deutsche Telekom (DT), Continental, Fraunhofer, Nokia Networks	Real-time V2N2V (<20ms latency)	Demonstrated on DT's LTE network with MEC technology (Nov-15); and Nokia Networks in China (Nov-16)
Audi, DT, Huawei, Toyota, other automotive OEMs	C-V2X	Technical LTE-based field trial (Jul-16)
Audi, Ericsson, Qualcomm, SWARCO Traffic Systems, University of Kaiserslautern	C-V2X	Formed Connected Vehicle to Everything of Tomorrow (ConVeX) consortium (Jan-17) to demonstrate C-V2X (3GPP Release 14)
Ericsson, BMW, Deutsche Bahn, DT, Telefónica Deutschland, Vodafone, TU Dresden 5G Lab Germany, Federal Highway Research Institute (BASt), Federal Regulatory Agency (BNetzA)	C-V2X	Formed 5G-Connected Mobility consortium (Nov-16) to develop real-world application environment for 5G-based C-V2X
Vodafone, Bosch, Huawei	C-V2X (direct V2V)	LTE-based trial (Feb-17); aims to demonstrate very low latency, and differences from IEEE802.11 solutions

We identified that C-V2X commercialisation is imminent, with several trials underway [2]

'Towards 5G' partnership (Ericsson, Orange, PSA Group, Qualcomm)	C-V2X	First phase (Feb-2017) tested use cases. Will demonstrate use of a network slice to isolate C-V2X from MBB and use cases for C-V2X/5G
UK Connected Intelligent Transport Environment (Vodafone, Jaguar LandRover)	C-V2X and IEEE 802.11p	Launched to provide a real-world testing environment for V2X (Feb-17)
National Intelligent Connected Vehicle Testing Demonstration Base, Shanghai (China Mobile Communications, SAIC Motor, Huawei)	C-V2X	Formed in 2016 to test connected cars, facilitate R&D, test and certify connected vehicle technology. Shanghai is planning a 100km^2 intelligent vehicle network
Michigan, USA (Ford Motor Company, Qualcomm)	C-V2X	Part of Connected Vehicle Safety Pilot. Has tested automated cars using LTE direct mode
5G showcase trials, South Korea (LG Electronics, Qualcomm)	C-V2X and IEEE 802.11p	Will trial connectivity solutions on Qualcomm's connected car platform in 1H 2018
San Diego, Regional Proving Ground (AT&T, Ford, Nokia, Qualcomm, supported by the San Diego Association of Governments)	C-V2X	Will demonstrate the cost efficiencies of C-V2X, and synergies between deployment of cellular base stations and RSUs

Our interviews suggest possible commercial launch of C-V2X from 2020/2021

Overview of C-V2X timeline



We modelled four scenarios, capturing different V2V/I technology choices

Scenario 1: Base case	▪ Automotive OEMs implement V2X in different timeframes, with some adopting IEEE 802.11p for V2V/I and others C-V2X ▪ With limited incentive to replace roadside infrastructure, V2I is delayed (but C-V2X uses V2N)
Scenario 2: 2020 EC mandate on V2V/V2I	▪ We assume that an EC mandate for C-ITS services to be supported in all new vehicle types from 2020 drives initial adoption of IEEE 802.11p ▪ V2I requires extensive roadside infrastructure upgrades
Scenario 3: 2023 EC mandate on V2V/V2I	▪ An EC mandate for support of C-ITS services in new vehicle types in 2023 rather than 2020 allows PC5 to develop, and automotive OEMs adopt this for V2V/V2I ▪ V2I requires roadside infrastructure upgrades, but synergies within C-V2X (Uu) are exploited
Scenario 4: Equitable 5.9GHz use	▪ Similar to Scenario 1 we assume automotive OEMs make different technology choices for V2V/I, but with higher PC5 adoption due to greater certainty on spectrum access

We estimated C-V2X benefits using inputs on vehicles sold, take-up and unitary V2X benefit

In-vehicle systems take-up

- % of vehicles sold addressable by V2X
- % of vehicles sold fitted with V2X systems
- Vehicles sold by vehicle bundle segment
- Vehicles sold by service bundle + technology

# of vehicles in use/sold in EU per year → # of vehicles sold addressable by V2X → # of vehicles sold with V2X systems → # of vehicles sold by V2X service bundle → # of vehicles sold/in use by service bundle by technology

Unitary benefits

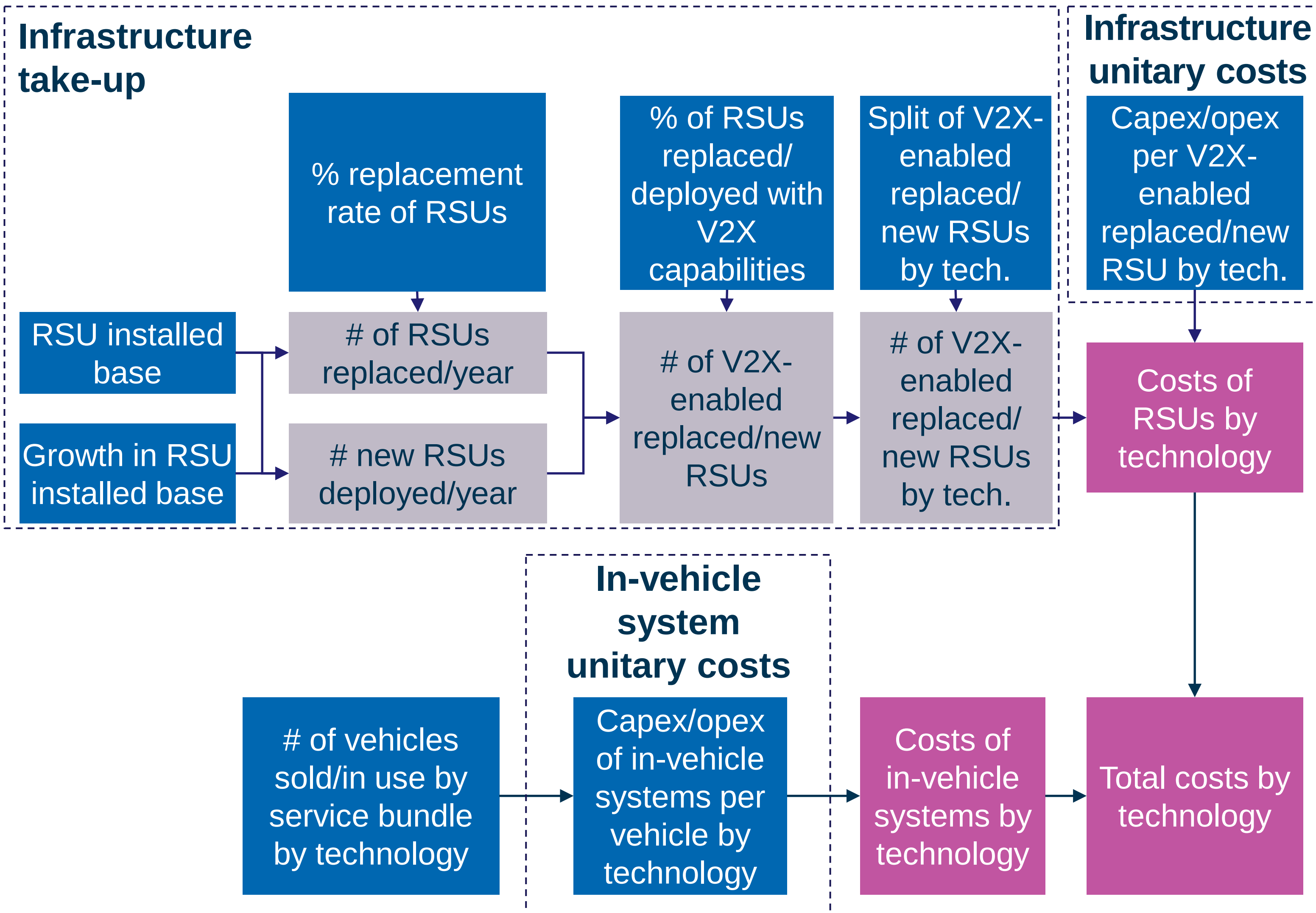
# of vehicles in use by service bundle by technology

% impact by service bundle per vehicle by category of benefits → Total impact by category of benefits by technology

Monetary value of impact by category of benefits → Total benefits by category of benefits by technology

Total benefits by technology

V2X costs by technology are based on unit costs & timetable for infrastructure/in-vehicle roll-out



Services represented in the model include warning, information and actuation/automation

V2V	*V2P*	*V2I/V2N*
Warning: Do not pass warning; Traffic jam ahead warning; Slow or stationary vehicle warning; Cooperative collision warning; Emergency brake light; Hazardous location notification	**Warning:** Vulnerable road user protection	**Information:** In-vehicle speed limits; In-vehicle signage; Probe vehicle data; Shockwave damping; Traffic signal priority requests; Green light optimal speed advisory (GLOSA); Traffic information for smarter junction management (e.g. signal violation, traffic management)
Actuation: CACC (cooperative adaptive cruise control); Active breaking		

By bunding services together we estimated vehicles sold by service bundle, per scenario

Share of vehicles sold with V2X systems by service bundle segment

Vehicle service bundle segment	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	2025	2035	2025	2035	2025	2035	2025	2035
Warning	0%	0%	75%	25%	85%	13%	0%	0%
Warning + information	81%	35%	25%	75%	14%	77%	79%	30%
Warning + information + actuation	19%	65%	0%	0%	1%	10%	21%	70%

We also varied the technology adoption assumptions (i.e. IEEE 802.11p or C-V2X) by scenario. Unitary cost assumptions (i.e. economies of scale) are linked to the forecast technology adoption

Assumptions on per-vehicle benefits of each C-ITS service were estimated from study inputs

Selected examples only (full service list and unitary assumptions are in the published report)

Service	Safety			Fuel consumption/ emissions			Traffic efficiency		
	Urban	*Rural*	*Motor-way*	*Urban*	*Rural*	*Motor-way*	*Urban*	*Rural*	*Motor-way*
Do not pass warning	–	3%	–	–	–	–	–	1%	–
Traffic jam ahead	1%	1%	1%	–	–	–	–	–	–
Slow/ stationary vehicle	7%	3%	3%	–	–	–	2%	2%	2%
GLOSA	–	–	–	1%	–	–	–	–	–

Category of impact

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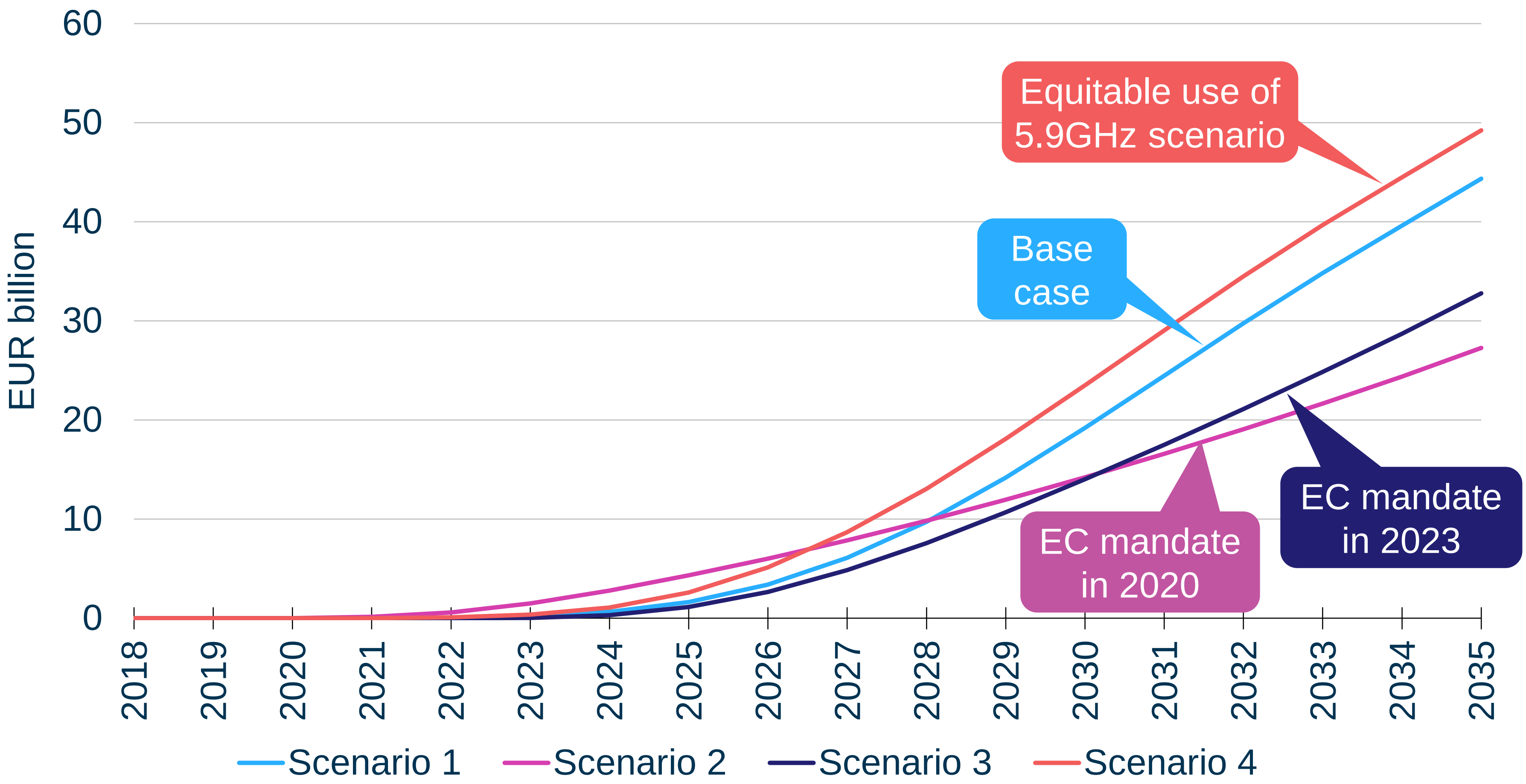
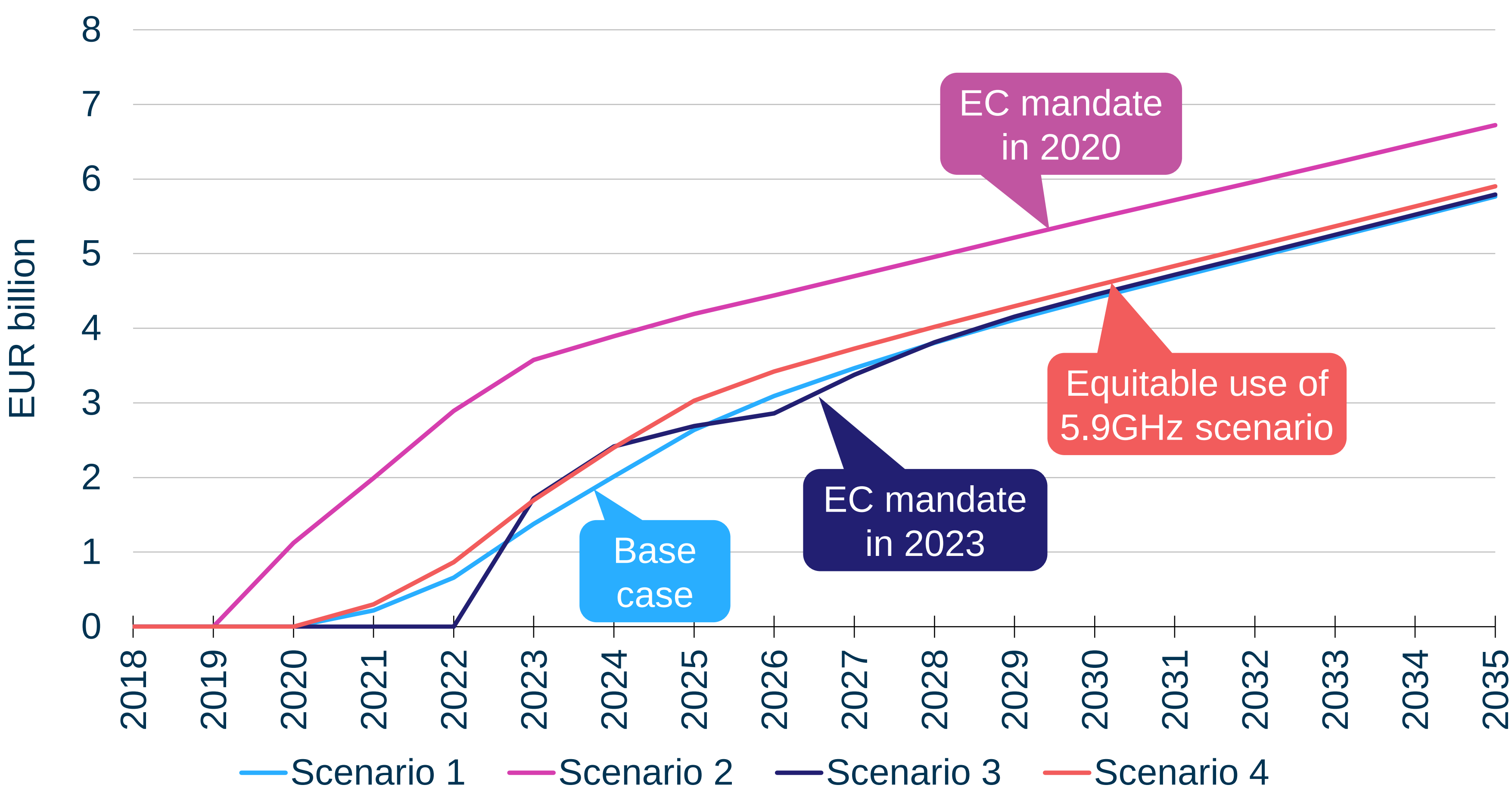
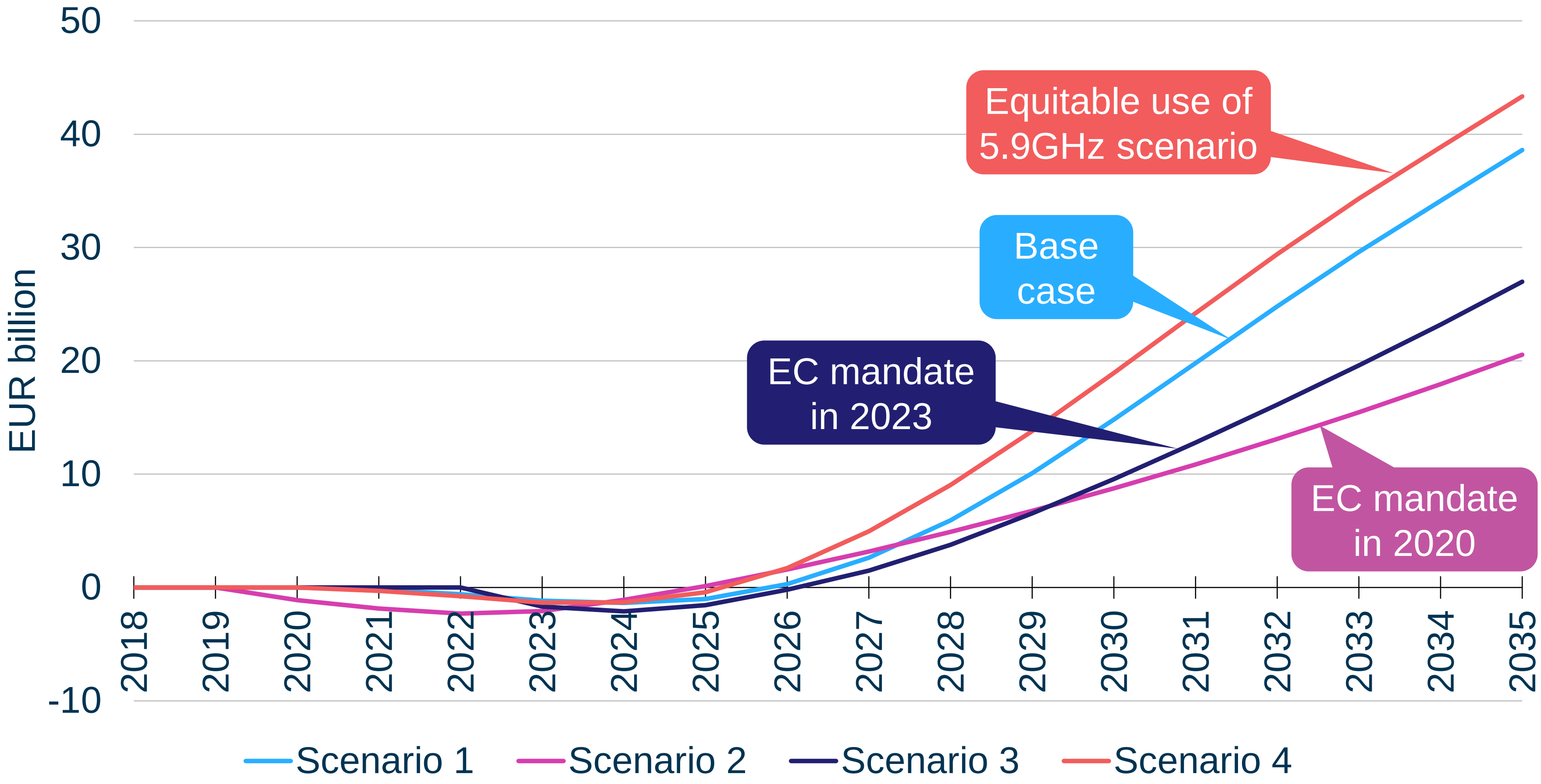
Benefits are highest in the equitable use scenario (4), due to V2V actuation + increased penetration



Costs are highest in Scenario 2, where the largest deployment of RSUs is envisaged



Net benefits* are highest in the equitable use scenario, using the multiple modes of C-V2X



** Net benefits = benefit – costs*

Other impacts were the positive effect of C-ITS on jobs, road fatality reduction and SMEs

Impact on jobs	▪ We estimate that up to an additional 220 000 jobs (direct and indirect) might be created in Europe by 2030 ▪ C-ITS could also have a positive impact on job quality
Reduction in road fatalities	▪ V2P specifically aims to protect pedestrians, cyclists and motorcyclists: C-V2X is well placed to deliver these services, leading to a reduction in fatalities among vulnerable road users
Impact on SMEs	▪ SMEs could play a role in C-ITS installation/operation, and could benefit from lower operating costs, higher traffic efficiency and improved fuel consumption

In summary, C-V2X benefits appear highest when its multiple usage modes are exploited

Multiple C-V2X modes offer flexibility and net benefit gains	▪ Roadside infrastructure upgrades can be avoided by using cellular networks for the C-V2X Uu connectivity mode
PC5 mode in smartphones will offer further benefits	▪ The ability for vehicles without an embedded V2V interface to use smartphone connectivity (PC5, or Uu) is a key benefit of C-V2X ▪ PC5 in smartphones will also enable V2P
C-V2X technology integration can make deployment less expensive	▪ C-V2X can reduce the cost of V2X/C-ITS deployment in Europe by offering cost efficiencies between its operating modes and exploiting synergies with mobile networks
Migration to 5G is also encouraged through C-V2X adoption	▪ The automotive sector is predicted to generate among the highest economic benefits for Europe from 5G use – adopting C-V2X will facilitate the evolution to 5G

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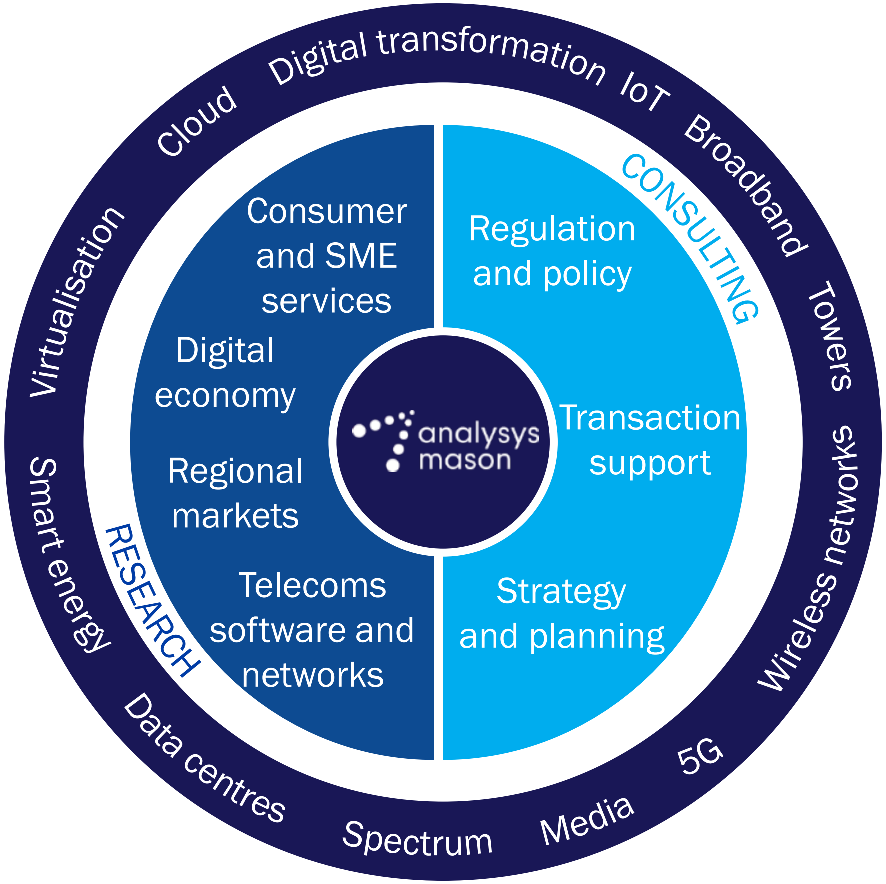

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